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Transformations of Middle Eastern Natural Environments: Legacies and Lessons

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JANE COPPOCK AND JOSEPH A. MILLER, BULLETIN SERIES EDITORS

JEFF ALBERT, MAGNUS BERNHARDSSON, AND ROGER KENNA, VOLUME EDITORS

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IN MEMORY OF

JOSEPH A. MILLER
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Preface

Abbas Amanat
Yale University

This volume of the Yale School of Forestry and Environmental Studies *Bulletin Series*, entitled *Transformations of Middle Eastern Natural Environments: Legacies and Lessons,* is based on an international interdisciplinary conference by the same name organized by Yale's Council on Middle East Studies. The conference, which was held October 30-November 1, 1997 at the Yale Center for International and Area Studies, brought together an array of scholars, practitioners, and journalists interested in and concerned with the natural environments of the Middle East.

The interdisciplinary nature of the conference and this volume are significant. It is our belief that just as environmental problems transcend national boundaries and present widespread concerns throughout society, issues of the environment should not be discussed solely by people of the same discipline or profession. Given the complexity and diversity of environmental degradation in the Middle East, a comprehensive approach which takes into account historical and societal, as well as ecological and technical aspects, is the most congenial approach to a broad understanding of the problems in question. This present undertaking is but one step toward such an understanding. It is our hope that the following essays will represent the state of today's scholarship, illuminate what we can learn about the past, and suggest what the future may entail. We hope furthermore that this volume may not only be useful for those scholars and practitioners currently working in the field, but also to students and others who wish to know more about the Middle East and its environments.

The conference and this publication would not have been possible without generous financial support from Yale's Kempf Memorial Fund at the Provost's Office, the Yale Center for International and Area Studies, and Yale's School of Forestry and Environmental Studies. My thanks are due to Arline McCord, Associate Provost, Professor Gustav Ranis, Director of the Yale Center for International and Area Studies, and Jared Cohon, the former Dean of the Yale School of Forestry and Environmental Studies. My special gratitude is also due to three Ph.D candidates, Jeff Albert, Magnus Bernhardsson and Roger Kenna, whose contributions were crucial to the organization of the conference and the editing of this stimulating volume. The quality of the papers presented and the overall format of the conference and of this volume testify to their dedication and diligence. Professors Frank Hole, J. A. Allan, and Harvey Weiss provided sound advice and helped with identifying which key areas should be covered. They also helped organize three significant panels in their area of interest. Furthermore, Jane Coppock, *Bulletin Series* Co-editor and Assistant Dean at Yale's School of Forestry and Environmental Studies, was critical in the publication process. Without her energy and enthusiasm this volume would never have reached its present shape. I would also like to express my appreciation for the work *Bulletin Series* Co-editor Joseph Miller was able to contribute to this project before his death in July of this year after a long illness.

I would also like to thank all the participants in the conference, many of whom traveled great distances to come to New Haven. A conference is only as good as the quality of its participants. And in our case, we were especially fortunate, as the conference was characterized by high academic and professional standards, reflected both in the following essays and in presentations, observations, and conversations which enriched the conference but by their ephemeral nature cannot be incorporated into a written volume.

I hope that the dialogue initiated at our conference and continued in this volume will bring the issue of Middle Eastern environments the attention it deserves.

ABBAS AMANAT is Professor of History at Yale University and the Chair of Yale's Council on Middle East Studies. A graduate of Oxford University, he specializes in modern Middle Eastern history, in particular the modern history of Iran. He is the author of numerous publications including *Pivot of the universe: Nasir al-din Shah and the Iranian monarchy* (1997) and *Resurrection and renewal: the making of the Babi movement* (1989).

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Acknowledgements

Jeff Albert, Magnus Bernhardsson, and Roger Kenna
Volume Editors

We are grateful to Abbas Amanat, Chair of the Council on Middle East Studies (CMES) for his intellectual generosity. He put at our disposal both the resources and the mechanisms to facilitate the production of this volume. He was relentless in his enthusiasm and seemingly unlimited faith and support.

Similarly, our utmost thanks are due to Jane Coppock, Assistant Dean of the Yale School of Forestry and Environmental Studies (F&ES) and Co-editor of the F&ES *Bulletin Series.* This book owes its quality in large part to her attention to detail, ambitious vision, and invigorating determination. We are thankful for her congeniality and her faith in us and this project.

J. A. Allan offered invaluable guidance during the planning of the conference which led to this volume. The photographer Luke Powell was generous with his powerful work in the support of both this book and the conference which inspired it.

Design and production were handled in the most professional manner by Peggy Sullivan of Sullivan Graphic Design, and Joseph Cinquino, Russell Shaddox, Karen Aiken, and Patricia Smith of Yale's Reprographic and Imaging Services (RIS). We also thank Barbara Papacoda of CMES and Peter Cook of F&ES for their assistance.

Lastly we are grateful to the participants of the "Transformations" conference, who in their professionalism and patience ensured that the editorial process was a stimulating one.

Introduction

Jeff Albert, Magnus Bernhardsson, and Roger Kenna
Yale University

Scholars recognize at least two profoundly important characteristics that have combined to give the Middle East its enduring importance in world history. First, the region has been a wellspring of major civilizations and religions, and second, it is located at the junction of Asia, Europe and Africa, and has long contributed to important exchanges of goods and ideas. A less discussed, but crucial thread woven into the tapestry of Middle Eastern history is the long and complex relationship between the region's natural environments and its human inhabitants.

If one conceives of "the environment" as the physical, chemical, and biological integrity of natural ecosystems, the contemporary Middle East can certainly be thought of as a place in crisis. Burgeoning human populations and rising standards of living are testing the limits of plant, water, and air resources, while sensitive territories are placed increasingly at risk. At the same time, pastoral lifestyles which have survived for centuries are now threatened, and international tensions are compounded by pressing environmental issues such as water scarcity and pollution.

Notwithstanding the serious environmental threats currently facing the region, however, it can be argued that Middle Eastern peoples, in fact, were among the first to become privy to the sensitivity of natural environments.

There are clear historical examples of the consideration paid by the region's pre-modern residents to the fragility of nature, and the lessons that that fragility has taught. The Fertile Crescent was home to one of the original departures from hunting and gathering to sedentary cultivation, and it has been posited that soil salinization from irrigation played a central role in the demise of Sumer in the second millenium BCE (Jacobsen and Adams 1958). But as Paul Ward English points out in these pages, groundwater has also been sustainably extracted for centuries with the use of self-regulating chain wells, known as *qanats*. Indeed, the venerable age of the civilizations of the Middle East requires that the notion of "environment" be defined in ways very different from how it has been presented in the modern West. Sharif Elmusa, a contributor to this volume who grew up in the region, once remarked that the first thing that comes to mind when he thinks of "nature" is a plowed field, not a tract of wilderness.

Early 20th century scientific models of human-environment interactions focused on disturbance and recovery, as though the environment were a passive receiver of human action. Later formulations conceived of an interface of natural systems and social systems, a partial intersection of two sets (Bormann *et al.* 1993). Others have gone farther still, disputing that any portion of the natural system is isolated from human influences, asserting that even apparently "virgin" environments show evidence of human impact (Vogt *et al.* 1997). They place emphasis on ecosystem "legacies," signs of the momentum of a natural system, which have been imparted to it by the history of its interaction with humans. Middle Eastern history, many would claim, supports this view.

Despite such a long history of human-environment interaction, the Middle East is an area of surprising biological diversity. Although the stereotype of the Middle East as a barren landscape is predominant, the reality is quite different. The area that was Mandate Palestine, for example, is host to nearly 90 plant species/1000 km^2 (more than double that of the United States). Located at the juncture of several major terrestrial ecosystems (including the temperate grasslands of Mesopotamia, the Mediterranean semi-desert and arid grasslands, the schlerophyllous woodlands and shrublands of the Lebanese and Turkish coasts, and the deserts of Sinai and Arabia), the region hosts over 500 species of migrating, wintering and resident birds (well above 15 species/1000 km^2, an order of magnitude greater than most of Europe) (Leshem 1996).

A desire to better understand the relationship between humans and nature in an area which has been continuously settled for millenia inspired us to convene "Transformations of Middle Eastern Natural Environments: Legacies and Lessons," a conference which took place between October 30 and November 1, 1997, at Yale University, sponsored by the Council on Middle East Studies at the Yale Center for International and Area Studies. The event included well over 70 participants from the Middle East, Europe, and North America (a list of panels and participants can be found at the end of the volume). In organizing this conference, we sought to focus attention on the following questions:

- What are the key elements that define Middle Eastern natural environments?
- What are the core issues of environmental change in the Middle East as the 21st century approaches?
- How have the human inhabitants of the Middle East interacted with these environments and how have both sides changed in the process?
- How can perceptions of the value of natural resources, as well as the belief systems reflecting these values, be characterized?
- Do our assessments of environmental legacies enable us to propose lessons to guide future policies? If so, what lessons can we offer?

The event's earnest attempt to answer these questions spawned the volume you hold in your hands.

Our endeavor first required a definition of the region in question. What is the "Middle East?" We opted for an exceedingly broad and inclusive operational definition of the term. The geographic bounds, which are indicated in Figure 1, encompasses peoples who are linked by physiography, climate and culture.

The breadth of the central questions articulated above was such that only an extremely diverse collection of scholars and practitioners could be hoped to make progress toward answers. By consequence, the conference and the volume drew from a wide spectrum of disciplines, ranging from climatology and marine ecology on the one end to cultural studies and art history on the other, with plant genetics, agronomy, fisheries management, regional planning, geography, climate change, remote sensing technology, international

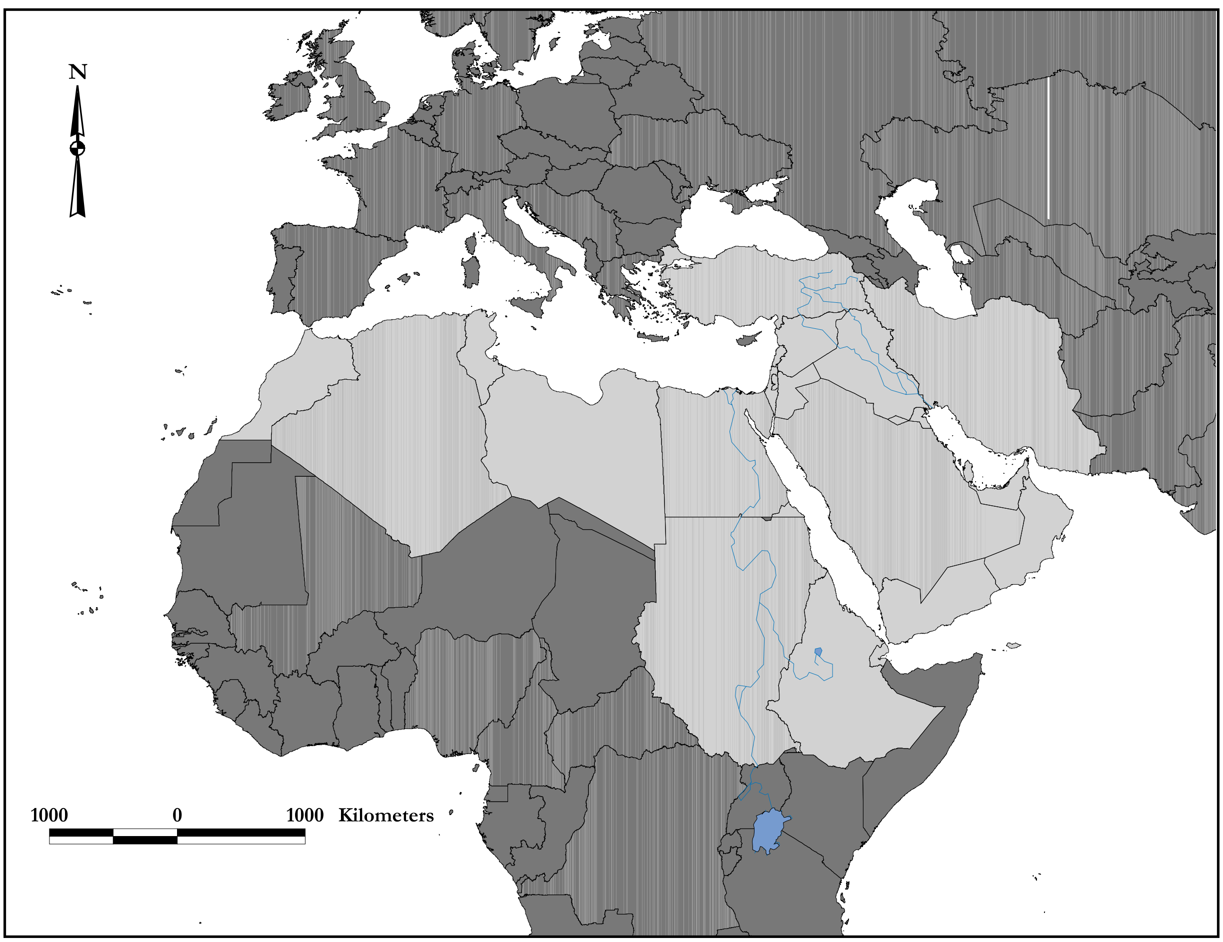

Figure 1

relations, political science, human ecology, history, demography, and anthropology all falling somewhere between.[1]

In this volume, to answer the first question about what key elements define the environment of the Middle East, Michael Mann and Raymond Bradley, co-authors of an important recent study performing historic global climate reconstructions (Mann *et al.* 1998), provide an assessment of the global climate patterns which are best correlated with mesoscale variations in the Middle East. They emphasize (implicitly) that one major element of the environment of the Middle East is the variability of temperature and rainfall.

Variability of the biotic factors (as opposed to abiotic climate factors) is also investigated in these pages. Keith Cressman, in his essay, considers modern efforts to understand and defend against one biotic factor in particular, the plague of biblical antiquity, the desert locust. Amir Afkhami evaluates a different plague—cholera in Iran—and demonstrates how its transmission was facilitated, ironically, by the *qanat* system, an otherwise efficient and environmentally benign hydraulic technology.

Additional important elements of the Middle Eastern environment are water scarcity, and as a partial result, conflict. John Waterbury and Dale Whittington investigate both questions in their assessment of a resource once deemed so vast as to be infinite: the River Nile. Growing populations make the status quo arrangement, Egyptian dominance, a far less certain question than in decades past.

Another river basin, the Jordan, is the subject of another set of studies which focus on the elements of scarcity and conflict. Uri Shamir provides reflections on recent water agreements between the Israelis and the Palestinians and Jordanians, respectively, while Aaron Wolf presents the historical context for Arab and Israeli hydrostrategies, as well as a proposed refutation of the "hydraulic imperative" hypothesis. Sharif Elmusa targets his essay on a specific proposal for regional accommodation, the fabled "Johnston Plan," and in investigating its evolution, makes an argument for its modern application.

Several core issues of environmental change—our second central question—emerge from the papers in the volume. Onn Winckler surveys population trends and government responses, with a focus on the Arab countries of the region. His assessment is a sobering one. Prominent among the core issues in the region are food production and the ability to meet the demands of rising populations. A. A. Jaradat, on the other hand, offers an overview of the historic role the Fertile Crescent has played in modern agriculture worldwide, as well as the opportunities associated with agricultural transformations and the reduction of genetic biodiversity.

[1] Due to the multiple disciplines represented and their often distinct jargons, we decided to allow for a variety of terms in describing the area we define as the Middle East. The reader will therefore encounter several terms, such as Middle East and North Africa (MENA), Near East, or West Asia North Africa (WANA). Those terms were the choice of the authors.

Kouchoukos *et al.*, in describing the tools available for monitoring land use and land cover change, provide additional insights into agricultural change—principally irrigation and the expansion of cultivation into marginal areas. These changes are sufficiently widespread and dramatic that they can be understood using images resolved from satellite platforms. J. A. Allan, in his work on the political economy of water, considers the water/food nexus and the role of international trade in the avoidance of violent conflict over water.

Also noteworthy among the core issues in the region is the integrity of the marine environment. Pearson *et al.* present a case study of oil pollution in the Gulf of Oman, highlighting the sensitivity of marine resources and the ease with which they can be impaired. Menakhem Ben-Yami and Izzat Feidi offer discussions of a particular marine resource, the fishery, Ben-Yami focusing on the eastern Mediterranean and Feidi on the development challenges fisheries pose to communities throughout the Arab world.

The interaction of humans and nature is the central theme of many of the papers presented in the volume. Peter Christensen investigates the history of irrigated agriculture with a critical eye on its limitations and the damages it wreaks on both human and natural systems. Peter Beaumont considers the massive hydrologic and agricultural implications of the Turkish Southeast Anatolia Project (GAP) for Syria and Iraq, the downstream riparians on the Tigris and Euphrates Rivers. Lois Beck and Susanne Steinmann provide case studies of nomadic peoples. Beck offers an overview of her extensive anthropological research among the Qashqa'i in Iran and their changing relation with the natural environment during momentous political changes in recent decades. Her discussion reminds us not to overlook people in any environmental analysis. Steinmann presents a critical analysis of gender-specific behaviors among the Beni Guil pastoralists in Morocco and shows how gendered resource exploitation is changed through sedentarization and urbanization. Behrooz Morvaridi considers the case of contract farming in Turkey to examine the disconnect between centralized agricultural planning and local conditions, hypothesizing that damage to land resources is attributable to the nature of the relationship between farmers and their government clients. Finally, in an examination of a profound human interference with a natural system, Daniel Golani surveys the impacts of the creation of the Suez Canal, and the subsequent interlinking of the Mediterranean and Red Seas, on fish population dynamics.

Four contributions on nature and culture offer insights into the interplay between cultural norms and the environment, with particular emphasis on the idea of the garden. Karen Polinger Foster focuses on exotic flora and fauna in ancient times and how they served as integral components of the idea of the garden. Attilio Petruccioli examines the idea of the Islamic garden and raises important theoretical and methodological issues which will serve as useful paradigms in future research. Heidi Walcher's contribution is a useful companion to Petruciolli's, since her work explores several of his themes within the context of the city of Isfahan in Iran. Finally, environmental scientist Daniel Hillel utilizes his extensive knowledge of the natural environments of the Middle East to hypothesize about the advent of monotheism in the ancient Middle East. His hypothesis is one intriguing answer to our question about how perceptions of nature, and belief systems reflecting those values, can be characterized.

Finally, there is the question of legacies and lessons. Perhaps the strongest belief guiding both the conference and the volume is that good information and good communication, even across enduringly difficult political and cultural boundaries, will do more to focus attention on, and move toward solution of, environmental issues of critical importance to all inhabitants of the region than any other factors. It is toward that end, and in that spirit, that our endeavors are undertaken.

We ended our conference after three days of lectures and presentations with an open discussion, from which two wonderful memories emerged. First, Youssef Barkoudah elected not to deliver an academic address, but instead to present a heartfelt account of the landscape changes he has witnessed in the Syrian village of his childhood. His description of "the day the *qanat* dried up" as a result of the construction of mechanized deep wells miles away was both powerful and moving, and placed much of what was discussed during the prior three days in a very human context. Second, Daniel Hillel ended the conference with an inspiring etymological discourse on the expressions describing the natural world, inspiring shouts in Arabic, Persian, Hebrew, and English from participants in the audience. Although Yale anthropologist Frank Hole pronounced Professor Hillel's address to have provided "closure" to our event, we are hopeful that this volume instead will open readers' minds to the complex and varied environmental changes which have characterized the Middle East since antiquity and the importance of continuing to work in cooperation toward successfully functioning human *and* natural environments in the region.

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Section I: Agriculture and Pastoralism

Middle Eastern Irrigation: Legacies and Lessons

Peter Christensen
University of Copenhagen

ABSTRACT
This article argues that the pre-modern Middle East suffered a long period of political and economic decline after achieving a remarkable fluorescence centered on the Sassanian Empire (ca. 500 CE). Building on the works of various predecessors, the Sassanians managed to construct irrigation works on the Mesopotamian floodplain which provided them with an immensely wealthy material base. This base, however, had been built in a natural environment that was relatively fragile and susceptible to disruption. When new and properly maintained, Sassanian dams and canals enabled their owners to attain great riches. With time, however, thorough upkeep of these systems exceeded the ability of the Sassanians and their Muslim successors. Canals silted up and agricultural lands without adequate drainage suffered from salination. By themselves, these problems contributed to the decline of the region's agro-ecological productivity. Other factors, however, exacerbated the decline. Epidemic disease, especially plague, and wars prevented the region's inhabitants from remedying problems such as siltation and salination. The result of this combination of systemic fragility and regular visitations by war and disease was the decline that had become so evident by the early nineteenth century. Beginning in the nineteenth century, under the influence of European technological advances, a movement began which proposed to reverse the environmental (and therefore political-economic) decline of the Middle East through the application of modern irrigation technologies. Although the final outcome of this attempted revitalization remains to be determined, the author argues that preliminary indications thus far do not provide much hope for long-term productivity and sustainability.

In 1471, the Venetian merchant Josafat Barbaro, traveling with his companions along the road to Isfahan, marveled at how people had managed to cultivate this arid and stony land by means of underground canals, i.e., *qanats*. Without these, he said, "there could be no dwelling there" (Barbaro 1873). Almost two thousand years earlier, Greek invaders of the Iranian plateau had admired these same ingenious devices (Polybios 1922 edition). Indeed, *qanats* have played a crucial role over the millennia in the resilience of the small oases of the Iranian plateau.

Of course, some settlements on the plateau declined or were even abandoned. The famous cities of Ray and Nishapur are perhaps the most striking examples of decline. The small Parthian and Sassanian-era towns of southern Fars had comparable histories. Nevertheless, in most cases, derelict and abandoned settlements were replaced by successor settlements (e.g., Mashhad took the place of Nishapur). In the long-term perspective, the resiliency of human habitation on the plateau, linked to the use of *qanats*, is remarkable.

Other irrigated settlements in the Middle East have, however, proven to be less stable. At the beginning of the early modern period, when Barbaro visited Isfahan, desertification and recession had already occurred on a large scale, perhaps most notably in the alluvial plains of Mesopotamia (including Khuzistan), which in antiquity and the early Middle Ages had held the largest population cluster in Southwest Asia, and had formed the basis of successive empires. In this region settled agriculture and urbanization had declined steeply after the early Middle Ages. A comparable decline had overtaken the Sistan Basin and the delta of the Murghab, where the great Marv oasis was largely abandoned by 1400. Further east, in the country of the *Yeti-su*, "The Land of the Seven Streams" (or *Semirechie)*, a marked contraction of settlement and urban life had also occurred by the 14th and 15th centuries. Even Egypt, where irrigation was practiced under more favourable conditions than in most other places, suffered decline, though certainly on a less severe scale.[1]

Long-term fluctuations in population size, settlement numbers, cultivated area, economic diversity, and trade volume, can, of course, be seen in all societies, including Europe. Moreover, many irrigated settlements in the Middle East and Central Asia have proved remarkably resilient, in particular the oases of the Iranian plateau and of Transoxania (the Zarafshan Valley). But even allowing for these fluctuations, and for the fact that ruins sometimes represent successive settlements, and thus may not be evidence of decline, and allowing finally for the fact that our image of vanished centers of civilization may be unduly exaggerated, it remains indisputable that the Middle East as a whole suffered marked, cumulative decline in pre-industrial times.[2]

Western scholars have suggested a number of explanations for this decline. Some argue that the need for irrigation and flood control caused the rise of *Oriental Despotism*, regarded as a particularly nasty form of centralized government that eventually stifled society (Wittfogel 1960). Others point to the wartime destruction caused by the *barbarian invasions* of the Middle Ages, in particular the Mongols (13th century) and Timur-é Lenk/Tamerlane (14th century). This explanation largely paraphrases medieval chroniclers' horror stories and rests more or less explicitly on the assumption that the nomadism of the invaders and the settled agriculture of the invaded were antagonistic methods of subsistence.

For a variety of reasons, these two explanations are unsatisfactory. The concept of *Oriental Despotism* was more or less discredited in the course of the debate on Karl Wittfogel's thesis; today "the Oriental Despot reigns with foremost authority in the realms of fiction" (Steadman 1969). The chronology of the barbarian invasions, on the other hand, does not correspond to the process of decline. There are, fortunately, more creditable explanations.

[1] It would seem that in 1800 the population was between 3 and 3.5 million. Before that we have no reliable figures, so the decline cannot be quantified in any way. Suggestions that the population at the time of the Persian conquest, i.e., 525 B.C., had been above 20 million and had reached more than 30 million by late Roman times, the same as in 1966, may be dismissed as wildly inflated: (Issawi 1970) and (Hollingsworth 1969). The first reliable census recorded a population of almost 10 million in 1897.

[2] The rise of the Ottoman Empire as a great power in the 14th and 15th centuries would seem to go against this view, but the resource base of this empire lay primarily *outside* the irrigated enclaves of the Middle East.

More recently, scholars have begun to investigate the inherent *environmental constraints*, such as salination, destructive flooding, and drifting sands, that typify the Middle East. According to the hypothesis suggested by Thorkild Jacobsen and other participants in the Diyala Basin Project, Mesopotamia in particular was predisposed to these dangers owing to high water-tables and poor natural drainage: the salination of once-fertile soils and siltation of crucial watercourses made irrigation unsustainable over the long run.[3]

Although the idea of environmental limits, with its obvious links to present-day concerns (i.e., modern environmentalism), is in many ways a convincing explanation for the decline of the Middle East, it nevertheless has inherent problems. Based as it is on such concepts and models as the *ecosystem*, the idea tends to become overly functionalist and reductionist: in the final analysis, Middle Eastern decline is simply the outcome of humankind's misreading of the environment's limits. Although the notion of environmental limits offers a powerful tool for understanding Middle Eastern decline, it does not tell the whole story. Indeed, it conveys a false sense of inevitability. The idea of environmental limits may suggest a way of looking at the larger patterns in history, but historical explanation is also about *contingency*: no universal agent or condition can give an adequate causal explanation of historical change in the oases and irrigated regions of the Middle East.

The idea of environmental limits may suggest a way of looking at the larger patterns in history, but historical explanation is also about contingency*: no universal agent or condition can give an adequate causal explanation of historical change in the oases and irrigated regions of the Middle East.*

MESOPOTAMIA

Irrigation in the Mesopotamian floodplain goes back at least to 5,000 BCE.[4] For the first several thousand years, the region's inhabitants diverted irrigation waters via canals that roughly paralleled the course of the Euphrates. Settlement and cultivation was therefore concentrated in narrow strips along the river and canals. Beginning around the middle of the first millennium BCE, new irrigation practices were adopted in Mesopotamia that drastically manipulated and coerced the floodplain's environment. Key elements in the new large-scale irrigation system included, first, the construction of five huge feeder canals diverting the waters of the Euphrates *across* the central floodplain into the Tigris; and second, the tapping of the Tigris as a major source of irrigation water by the construction of two huge, interconnected parallel diversions known as the *Katul al-Kisrawi* and the *Nahrawan Canal*. In the process, the political and economic center of the floodplain moved from ancient Babylon on the Euphrates to successive metropolitan complexes on the Tigris: Seleucia, Ctesiphon, and Baghdad.

Precisely when the various components of the new system were constructed is difficult to say. It is fairly certain, however, that a

[3] This explanation has gained wide acceptance, cf. C. Ponting, *A green history of the world* (London 1991).

[4] The sections that follow are based on research by the author. See Christensen 1993.

major reshaping of the floodplain occurred under Persian rule, especially in Parthian and Sassanian times (2nd century BCE to CE 651). According to the traditions recorded by Muslim historians of the ninth and tenth centuries, the Sassanian kings in particular made a spectacular effort to extend settlement and cultivation between 226 and 651 CE. Although the Muslim historians were paraphrasing official and highly tendentious histories composed by the Sassanians themselves for legitimating purposes, the account of the great colonizing drive is essentially credible. Independent sources confirm this. The Sassanian kings established numerous cities and settlements, forcibly transplanted thousands of prisoners from Roman territory to Mesopotamia (and other places), and constructed great irrigation and flood control works such as the Nahrawan complex. Moreover, their efforts were not confined to Mesopotamia. In the adjacent plain of Khuzistan, watered by the Karun River and its tributaries, the Sassanians constructed similar works, including five large dams combined with canal systems. Their settlements and irrigation works also spread out over large parts of the Iranian plateau. It would seem that by the late Sassanian times irrigation, settlement, and cultivation in the Mesopotamian floodplain and Khuzistan had reached their pre-industrial maximum extent. All available water resources had been exploited in an effort to extend as well as to intensify agricultural production. Thus summer cultivation involving various exotic plants (rice, sugar, cotton) had probably become widespread by this time.

It would seem that by the late Sassanian times irrigation, settlement, and cultivation in the Mesopotamian floodplain and Khuzistan had reached their pre-industrial maximum extent. All available water resources had been exploited in an effort to extend as well as to intensify agricultural production….We know few details about how this impressive reshaping of the Mesopotamian landscape was achieved.

We know few details about how this impressive reshaping of the Mesopotamian landscape was achieved. The kings employed corps of engineers as well as groups of specialist workers. Later in the Muslim period the army was occasionally used for emergency repairs. But, as very scattered references indicate, the hard and exhausting work involved in the construction and maintenance of the great feeder canals must largely have been performed by *corvée* labour. But how the work force was mobilized and organized is not known. It seems that the digging and upkeep of the smaller canals that actually brought water to the fields was often done on a local, communal basis. In any case, the purpose of the whole enterprise seems clear enough: it was to enlarge the tax base. As the Mesopotamian floodplain constituted the largest potentially irrigable spot in southwest Asia, it was of crucial importance to the successive empires of that region; consequently, the kings determinedly attempted to maximize its agricultural and fiscal potential. There is no reason to believe that some sort of population pressure constituted the real "prime mover." Population certainly increased in the process, but that was more likely a consequence than a cause of the expansion.

By the late Sassanian period (sixth century CE), when the Mesopotamia-centered empire really was a great power, the floodplain contributed more than half of the imperial income from the land tax (which was by far the most important source of revenue). Understandably, the Sassanian kings used to refer to the floodplain as "the heart" of their dominions *(Dil-Iranshahr)*.

For all its great size and impressive engineering, however, the system created by the Sassanians and their predecessors proved short-lived. As early as the sixth and seventh centuries, the low-lying south was ravaged by recurrent flooding and hydrological changes. By the end of the ninth century the whole system was clearly in decay. By mid-twelfth century the great Nahrawan complex had definitively broken down, and sometime between 1350 and 1550 the last of the transverse canals stopped working. In part, this was a result of coercing a fragile environment: the cutting of the natural drainage pattern and the introduction of summer cultivation must have increased soil salinity (this we may confidently infer from modern attempts to intensify agricultural production); and the increasing diversions from the rivers certainly caused an increase in the rate of siltation. In the south the riverbeds became unstable until the Tigris in the early seventh century broke through all embankments, seeking a new channel. In the process some agricultural lands were literally drowned while others were left without adequate water supplies. Further north, siltation threatened to choke the canals, weirs, and floodgates unless these were regularly cleaned and dredged.

For all its great size and impressive engineering, however, the system created by the Sassanians and their predecessors proved short-lived…in this case, political impotence, continuous internal fighting , and excessive taxation may have been the direct causes…. Factors such as plague (and epidemic disease in general) and political unrest are, I also believe, the direct causes of the destruction of Mesopotamian irrigation. Yet their impact can only be understood in the context of environmental instability.

Changes in the micro-environment were equally important. For two hundred years, from 542 CE to the late eighth century, the floodplain was ravaged by recurrent outbreaks of plague. By all accounts the mortality was staggering (as it was in the Mediterranean Basin), and a conservative estimate would be that Mesopotamia cumulatively lost 40 to 50% of its population. An inevitable consequence of this demographic crash was that irrigation works fell into disrepair and agriculture contracted. The labour force necessary for maintaining and operating the system no longer existed.The successors of the Sassanians made only limited attempts at repairing the damage and were quite unable to restore the system.

Plague can be seen, therefore, as a key factor in the decline of the early Middle Ages. But it cannot be an exhaustive explanation for the entire period up to the 19th century. As already stated, the great Nahrawan system that supplied the east bank of the Tigris definitively stopped working around 1150 CE when there was no plague. In this case, political impotence, continuous internal fighting, and excessive taxation may have been the direct causes. The last element of the large-scale system, the transverse canals of the central plain, stopped operating between 1350 and 1550, the chronology suggesting that plague may again have been decisive (the Black Death struck Baghdad in 1347, and plague kept recurring until 1840).

Factors such as plague (and epidemic disease in general) and political unrest are, I also believe, the direct causes of the destruction of Mesopotamian irrigation. Yet their impact can only be understood in the context of environmental instability: expansion under Persian rule had created an irrigation system that was, if not self-destructive, then at least extremely vulnerable to even small disturbances. In Europe the consequences of the plague epidemics were very different, partly owing to the resiliency of the European cultural landscape. Economic activity in Europe rebounded (and, of course, grew) in a way that the economy of the Middle East could not.

SISTAN

A similar cycle of expansion and recession occurred in the Sistan basin on the far eastern fringe of the Middle East. Sistan, which is today divided between Iran and Afghanistan, comprised the land bordering the lower course of the Hilmand River and the inland delta of the river. The Hilmand drains the Western Hindu Kush range. Running for a thousand kilometers across the arid steppes of Western Afghanistan, it finally empties into a closed basin identical to the barren *kavirs* of Iran. However, owing to the large quantities of water carried by the river, the center of the Sistan basin is covered by extensive, shallow sweet water lakes (the *Hamun-i Hilmand*) for most of the year. The extent of the lakes, of course, fluctuates with the variability of precipitation in the Hindu Kush.

Historical inquiry clearly shows that the belief that Third World societies formerly operated sustainable agricultural systems (until disturbed by imperialism and excessive population growth) is quite unwarranted. Technological pessimism should not make us romanticize ancient practices.

Written sources and archaeological material show that Sistan was populous and intensively irrigated and cultivated. The medieval Muslim geographers and travellers extolled the fertility of the land and the prosperity of the inhabitants. The local urban center, *Zarandj*, was regarded as one of the great cities of the East, famous for its textiles and centers of learning. By the 19th century, Sistan had been reduced to a sparsely settled maze of ruins and windblown dunes. According to conventional wisdom—which bases itself on the horror stories of the medieval chroniclers—this transformation was precipitated by the invasion of Timur in 1383. Not satisfied with razing Zarandj and massacring the inhabitants, the conqueror is said to have destroyed a vital dam on the Hilmand, thus willfully ruining the elaborate irrigation system. Other sources point to Shah Rukh, the son and successor of Timur, as destroyer of the dam. Who did it, however, is not important for the present argument.

There can be little doubt that Sistan suffered much destruction in the course of the protracted Timurid wars. A careful analysis of the available data shows, however, that the recession of cultivation and settlement was a much more complex process. In the first place, it is clear that recession had started long before the advent of the Timurid armies. Irrigated agriculture, based on diversions from the Hilmand, had been practiced in the Sistan Basin at least since the beginning of the third millennium BCE. We need not follow the early settlements and the fluctuations caused by siltation and changes in the course of the river. Many phases of Sistani history remain obscure in any case.

A remarkable expansion of settlement and cultivation began in Parthian and Sassanian times, however, culminating in the early Muslim epoch (i.e., in the 9th and 10th centuries). It is evident that the expansion was based on a vast extension of the diversions from the Hilmand River. On the east bank the cornerstone was a great dam across the Hilmand located one day's march south of the capital city of Zarandj. This is the dam supposedly destroyed by Timur. The dam diverted water into a huge system of feeder canals reaching almost 150 kilometers northwards. The system was completed in the early eighth century, but, as stated above, had been partially constructed in the preceding centuries.

Constraints, however, only become constraints in specific historical contexts (which, of course, is true of assets as well). Low gradients, high groundwater tables and soil salinity are not major constraints unless large-scale (and fairly intensive) irrigation is practiced. Extraneous events, such as recurrent civil wars, invasions, and, possibly, the outbreaks of epidemic disease are key catalysts for the onset of marked decline. So are the actual means available for coercing and manipulating the physical world, i.e. technology and energy resources. In the last 100 to 150 years, these variables in particular have been seen by many as the key elements in reversing the decline of the Middle East.

As was the case in Mesopotamia, the construction and maintenance of the irrigation system required large expense and a huge labour effort. Moreover, the shifting sands, perpetually kept in motion by the "wind of a 120 days"(a strong northwester blowing constantly from May to October), constituted a particular danger that had to be kept under control by groups of expert sandfighters. Also, the elaborate network of canals was frequently damaged by the unpredictable floods of the Hilmand. The cleaning of canals added to the windblown material and, finally, there are fairly clear indications that the increased irrigation caused salinity problems. For all the efforts expended in maintenance, the first signs of deterioration followed immediately upon the maximum extent of cultivation. By the late tenth century, the shifting sands had even temporarily broken into Zarandj itself and declining productivity was observed in several places. A century later, areas in the northern end of the great feeder system had been abandoned. Although attempts at repair and recolonization are recorded, chiefly at the end of the 13th century, the overall picture is one of irreversible recession. By the early nineteenth century, settled and irrigated agriculture had contracted to a small area in the northwestern part of the delta. Yet the Sistanis, despite demographic decline and political decentralization, still commanded the technology to construct quite serviceable weirs across the Hilmand. The British border commission, in 1870, saw how this was done:

> The dimensions of the 'Band' are as follows:
> entire length, 720 feet; length across original bed of river, 520 feet; breadth at broadest part, 110 feet; depth 18 feet on the river side. It is formed of fascines of tamarisk branches closely interwoven together with stakes driven into them at intervals: the branches used for this purposes are green and fresh, but of no great size, while the interlacing of them is very close. The present 'Band' was constructed by 2000 men in three months, all classes in Sistan giving their aid to a work on which their own prosperity was so much dependent. The great part of the labour was in bringing from a distance the enormous quantity of tamarisk required; but it is said that once the branches were collected, the actual construction was performed in a short time by one man, a native of Banjár, the sole possessor of this art, and who refuses to impart his knowledge to any one but his own son. The 'Band' still requires a small yearly repair when the spring floods are over, and its face towards the river is annually increased by a yard or more, but these repairs are now easily accomplished by fifty or sixty men.[5]

[In India] The British eventually developed the basic hydraulic technologies of modern large-scale irrigation and water management. Among the important technological innovations were masonry headworks, drainage networks, the elimination of erosion and silting by calculating optimal gradients, and, of course, barrages or weirs making perennial irrigation possible. In the process, the British, persistent critics of the kind of oriental despotism and Eastern centralization that supposedly accompanied hydraulic societies, ended up as the greatest irrigation system builders of all.

Tate, who witnessed the rebuilding of the weir in 1904, says that the work began in the middle of August (i.e., between harvest and sowing), lasted a month and involved 40,000 people in all. For the construction itself, no less than 450,000 fascines of tamarisk branches were used (Tate 1909). But the cultivated area had contracted drastically and instead extensive subsistence—herding and shifting slash-and-burn agriculture—had become widespread.

In Sistan, as in Mesopotamia, the decline of large-scale irrigation clearly was conditioned by environmental constraints such as climate, topography, soil composition, and hydrology. Constraints, however, only become constraints in specific historical contexts (which, of course, is true of assets as well). Low gradients, high groundwater tables and soil salinity are not major constraints unless large-scale (and fairly intensive) irrigation is practiced. Extraneous events, such as recurrent civil wars, invasions, and, possibly, the outbreaks of epidemic disease are key catalysts for the onset of marked decline.[6] So are the actual means available for coercing and manipulating the physical world, i.e. technology and energy resources. In the last 100 to 150 years, these variables in particular have been seen by many as the key elements in reversing the decline of the Middle East.

[5] Goldsmid 1876: 281f. Bandjar was a village situated a few kilometers northeast of Zabul. See also Christensen 1993: 52–56, 107–112, 166–168.

[6] In Sistan (and on most of the Iranian Plateau) the course of the second plague pandemic, beginning in the mid-14th century, remains an enigma. Nearby Herat suffered several outbreaks, but there is no evidence of the disease ever reaching Sistan. Very likely, this simply reflects the dearth of sources. It is, after all, hard to believe that the highly contagious infection simply bypassed Sistan. In the early 20th century plague did in fact reach the country. But plague was erratic, and positive evidence is necessary if massive supermortality is to be considered a factor in the decline of Sistan.

THE MAGIC WAND

European engineers arriving in the Middle East in the 19th and early 20th centuries suggested that technological limitations lay at the root of the region's decline: in the past, in their view, irrigation had failed because of restricted engineering capabilities and unsound agricultural practices; the engineers of the past had been unable to construct permanent headworks and, lacking mathematical skills, had not calculated gradients properly. This view was largely based on observations made by British engineers surveying remnants of Mughul canals in northern India in the early 19th century. These canals had served only for limited time partly owing to technological deficiencies of the sort just mentioned: little use had been made of masonry structures, and the canals were just contour canals, i.e., they tended to avoid high ground and follow the river courses. Thus they were vulnerable to floods and silt deposits. (Stone 1984; CEHI 1 1982)

The British then proceeded to repair and improve the old canals and construct new ones all over the Punjab and in the Gangetic Plains. Gathering experience by trial and error, they eventually developed the basic hydraulic technologies of modern large-scale irrigation and water management. Among the important technological innovations were masonry headworks, drainage networks, the elimination of erosion and silting by calculating optimal gradients, and, of course, barrages or weirs making perennial irrigation possible.[7] In the process, the British, persistent critics of the kind of oriental despotism and Eastern centralization that supposedly accompanied hydraulic societies, ended up as the greatest irrigation system builders of all.

Together with a robust technological optimism, the British later brought their hydraulic skills to the Middle East. Thus William Willcocks, in 1894, suggested the construction of a storage dam across the main channel of the Nile at Aswan. A dam this far up the river would prove a much more efficient way of raising water and extending perennial irrigation in Upper Egypt.[8] A few years later, Willcocks, along with other British engineers serving as advisers to the Ottoman Empire, surveyed the dreary plains of ancient Mesopotamia, and confidently predicted the reclamation of the whole country through British efforts: "Modern science," he wrote, "will touch this region with her magic wand, and the waste places shall again become inhabited, and the desert shall blossom as a rose."[9]

When the Russians conquered the ancient irrigated enclaves of Turkestan in Central Asia, they viewed local technology with great disdain. In 1819, Captain Nicolai Muraviev, the Russian spy, arrived in Khiva and reported that the inhabitants were cruel, backward,

[7] Weir-control was first developed during repairs of an ancient, silted weir, the Grand Anicut, on the Cauvery River in the south. Reinforced concrete and labour-saving machinery were not widely used until the1920s, however (Headrick 1988).

[8] In fact, a storage dam at Aswan had already been suggested by British engineers in 1876 (Collins 1990).

[9] Willcocks (1903). Willcocks was fond of this metaphor, cf. his plans for development of the Sudd regions on the White Nile (cited in Collins 1990).

and superstitious. He grudgingly admired the flourishing agriculture, but added disparagingly that their irrigation was "unscientific."[10] Later official Russian reports convey the same picture:

> The construction of canals in the Zerafshan province, though not without some boldness both in design and execution, is generally defective; the canals are tortuous, too numerous, and liable to burst and overflow. The intakes of the canals are simply cuttings in the banks, dammed up occasionally by very unsubstantial weirs of any fragile material near at hand. The cleaning and the general maintenance of the canals is most unsatisfactory, as they are allowed to be obstructed by rubbish of every kind. The whole system of irrigation is a very primitive one; all the constructions to raise, dam, let out, carry, distribute, and gauge the water are of the most simple description, and are built of materials close at hand, such as earth, fascines, stakes, branches, sand, gravel, and sometimes rough stones (Curzon 1889).

A few Russians were genuinely impressed by the sophisticated irrigation networks around Samarkand in 1870 and thought that these could not be much improved upon by Russian engineers in spite of their superior scientific skills (Radlov 1868). Generally, however, Russians, whether Czarist or later Soviet, believed that they had a great civilizing task to perform in Turkestan, where they believed that chronic raiding, slavery, and religious fanaticism marked a society long sunk in decay and barbarism. The Russians believed that the chief means to achieve progress in Central Asia would be scientific irrigation and enlightened rule. The Russians managed to combine this outlook with an unabashedly predatory approach that sprang from historically conditioned attitudes to Islam; they consequently treated *Turkestanis* as third-rate citizens.

Following the conquest, Russian engineers and officials regularly advanced more or less fantastic schemes for extending the area under irrigation. Among the more spectacular ideas were schemes for diverting the waters of the Amu Darya into the Karakum Desert. Even the transfer of extra water from the Siberian rivers was suggested (Micklin 1986). Yet under Czarist rule little was actually achieved as the Russians lacked both capital and, equally important, the engineering skills (Pahlen 1908). In fact, Russians in Turkestan were painfully aware of how much more successful were their British adversaries in India in this respect.[11]

Yet to many Europeans sharing the Russian view of moribund Turkestan, even the modest efforts of Czarist Russia seemed a great

[10] Murav'yov (1820). Incidentally, Muraviev realized that the numerous ruins around Khiva were in fact the remains of successive settlements that had shifted with hydrological changes.

[11] Pierce (1960). In consequence, engineers were sent abroad to study Western irrigation technology (Pahlen 1908).

step forward on the path of civilization. Curzon, who had travelled through Transcaspia in 1888, admitted that "Russia has conferred great and substantial advantages upon the Central Asian regions," although drunkenness, gambling and prostitution as always followed the Russians.[12] Some modest irrigation works were undertaken, for instance around Tashkent where the Romanov Canal was dug (until construction was stopped by the first World War). Some new concrete dams with iron sluice gates were constructed on the Zarafshan River (Pahlen 1908). On the whole, however, results were disappointing. A sustained attempt at transforming Turkestan through modern irrigation technology had to await the establishment of Soviet rule. What the Soviet engineers brought to *Turkestani* irrigation was, above all, an increase in scale. Command of energy, of earth-moving machinery and reinforced concrete, combined with political command of entire drainage basins led to gigantic (and destructive) projects such as the Karakum Canal.

LESSONS?

The idea that poverty and other characteristics of "underdevelopment" can eventually be overcome, in part at least, by education and transfer of western science and technology remains a key element in all developmental theorizing. To promote agricultural production in the arid zone, FAO and UNESCO in the 1950s and 1960s organized several international symposia and conferences and published papers analyzing the water resources of the arid zone and their development potential.[13] Reading through these papers as well as the conference reports, one is struck by the pervading optimism. Of course, the experts were aware that in the past, irrigation societies had faced severe environmental problems and that present conditions were somehow rooted in these problems. But their understanding of what had occurred in the past was incomplete and colored by stereotyped ideas about the rise and decline of civilizations. Indeed, little factual knowledge was readily available.[14]

Because of the obvious and well-known hazards of large-scale irrigation, chiefly in the shape of salinity build-up, one would think that irrigation experts had to consider their schemes in an environmental context, perhaps even in terms of sustainability (however this may be defined). Yet most experts firmly believed that whatever problems might arise from expanding irrigation could be solved by improved technology including fertilizers, mechanization, new crop rotating patterns and new crop varieties, i.e., by transfer of advanced western technologies. More economical approaches and equitable social arrangements would further advance productivity and thus living conditions in the arid lands. Similar attitudes may be found

[12] Curzon (1889). Of course, Curzon would not accept Russia as a true representative of European civilization, but rather as a backward nation that appeared advanced in even more backward Turkestan.

[13] E.g., in Tehran (1961), Heraklion (1962), Paris (1962).

[14] Iraq was an exception. The preliminary results and hypotheses of the Diyala Basin archaeological project had just been published.

later in *The Report of the World Commission on Environment and Development* (WCED, the so-called Brundtland Report) and diverse FAO and World Bank reports.

Soviet experts in particular showed great faith in their ability to overcome salinity and other environmental problems. Thanks to modern technology, the deserts and steppes of stagnant Turkestan would be conquered and millions of square kilometers brought under irrigated cultivation. At the Arid Zone Conferences they even presented a scheme for turning to the great Siberian rivers to provide extra water for arid Turkestan as if no environmental risks were involved (Korda 1961). In retrospect this seems extremely naive, considering how Soviet development projects have brought ecological disaster to Turkestan.

At the time of these United Nations conferences (in the early 1960s) the transfer of advanced western technologies, including irrigation technology, to the underdeveloped regions of the world had in fact been going on for a long time, and modern development experts and engineers might have drawn some basic lessons from this process. But they didn't. And they still don't. Although debates about appropriate technologies have been underway since the 1970s, as the environmental constraints become ever more obvious,[15] the prevailing attitude remains that modern technologies offer a wider range of options which, combined with effective policies and institutions, can make economic growth compatible with improved environment.

Technological optimism, so deeply rooted in the European world-view, has always overruled historical evidence.

Therefore, the World Bank and the WCED can confidently claim that development is not antithetical to the environment. "Economic development and sound environmental management are complementary aspects of the same agenda" (World Development Report 1992). Technological optimism, so deeply rooted in the European world view, has always overruled historical evidence.

Over the last 150 years or so, systematic attempts have been made to increase productivity and material welfare in the Middle East by introducing western hydraulic technologies. This transfer has achieved an impressive expansion of irrigated agriculture: ancient oases have been expanded, water has been brought to new areas, and productivity as well as safety have been increased by extending perennial irrigation. At the same time, production has been restructured: the traditional subsistence agriculture of the ancient enclaves and oases has been largely replaced by market-oriented cash crops. In quantitative terms, the decades following World War II saw the maximum extent of expansion, when mechanization, chemical fertilizers, pesticides, high-yielding crop varieties, and additional sources of energy were applied on an ever-increasing scale.

[15] Cf. M. Taghi Farvar and J. P. Milton, eds.: *The careless technology: ecology and international development* (Garden City 1972).

Yet, in the broader perspective, results are disappointing. Western technology has brought neither economic nor environmental stability. On the contrary, per capita availability of water has decreased, while environmental degradation has escalated. It is not that modern irrigation should bear the blame exclusively. After all, western technologies were imported into areas already severely degraded by centuries of indigenous large-scale irrigation. Surveyed in the long term, large-scale irrigation systems appear to have limited life-expectancy, i.e. they have not been sustainable. There are exceptions, of course, but they are few.[16] No single reason will account for this. The rise and fall of irrigation systems are historical processes that involve many specific variables, ranging from political upheaval to climatic fluctuations. Yet in the arid lands, limiting environmental conditions have been a decisive obstacle. However defined, the concept of *sustainability* essentially refers to maintenance, durability, and resiliency in *the long term.* Western hydraulic technologies have brought *short-term* increases, but at the price of long-term degradation. The Soviet destruction of Turkestan may be an extreme example, but at present most arid lands are operating unsustainable agricultural systems which cause rapid resource depletion and environmental destruction.

[16] In parts of India the expansion of large-scale irrigation has achieved impressive and apparently sustainable increases, although the wider environmental consequences remain to be assessed.

Yet, in the broader perspective, results are disappointing. Western technology has brought neither economic nor environmental stability. On the contrary, per capita availability of water has decreased, while environmental degradation has escalated. It is not that modern irrigation should bear the blame exclusively. After all, western technologies were imported into areas already severely degraded by centuries of indigenous large-scale irrigation.

If present technologies are inappropriate, what are the alternatives? If the results of technology transfer have been disappointing, could it be that it was not the right kind of technology? Or, as in the case of the "Green Revolution," that the implications have not been thought out properly? It is widely argued, e.g., in the report of the WCED and by FAO, the World Bank, and other such agencies, that, given the proper technology, conditions may still be improved. This view cannot be dismissed by saying that western technology is inherently self-destructive. Throughout history humans (and extinct hominids as well) have relied on technology for survival and we certainly must go on doing so. The question is: what are the appropriate technologies in the fragile environments of the arid lands?

In the past, knowledge of the physical processes causing salination, desertification, etc., was limited if not completely absent, making the negative consequences of human manipulation of nature inevitable for all practical purposes. Today we have greater insight into the way natural forces work and on this basis we should be able to take more sustainable courses of action. No doubt there is room, for instance, for considerable improvement of existing irrigation systems by tranferring of super-modern technologies. The predominant gravity-flow canal irrigation loses at least 50% of the water through evaporation and seepage. These losses may be drastically cut by lining canals with plastics, concrete or tile or by adopting new technologies such as sprinkler-, drip-, or trickle irrigation, and even have these computer-controlled so that water is only released when necessary. Such highly mechanized and highly specialized irrigation technologies are employed on a large scale in the arid southwest of the United States, especially in California, and have served as models for creating modern, efficient irrigation in, for instance, Israel and Australia.[17] But for most Third World countries these technologies do not present a realistic option. Their demand for expertise, energy, and capital place them beyond the reach of ordinary peasants. Moreover, they are only feasible for high-profit cash crops and can hardly solve the problem of providing basic crops. For political reasons, moving away from cereal production seems unacceptable, anyway. Also, the historical record of irrigated agriculture in developed, industrialized societies is not altogether comforting: sophisticated, advanced technologies have brought serious (and steadily increasing) environmental degradation in the United States, Australia and Israel.[18]

In current debates on development strategies it is frequently asserted that traditional technologies—displaced by modern western technology—were in fact much more sustainable and that we should rediscover these, e.g., the terracing techniques of the ancient Andean farmers. The failure or, at least, dubious benefits of modern irrigation technology is not an argument in favour of "indigenious" (or "traditional") technologies, however. Historical inquiry clearly shows that the belief that Third World societies formerly operated sustainable agricultural systems (until disturbed by imperialism and excessive population growth) is quite unwarranted. Technological pessimism should not make us romanticize ancient practices. The small-scale *qanat* of the Iranian highlands was an ingenious and environmentally fairly neutral device, but large-scale systems, represented by engineering feats such as the Nahrawan Canal in pre-Islamic Iraq, were usually harmful to the environment and unsustainable (Christensen 1993). So were the formerly much-admired agricultural systems of China.

The realization that large-scale irrigation, even when involving modern technology and massive inputs of energy, is a hazardous undertaking has brought small-scale, low-cost irrigation technologies in focus (Stern 1982). No doubt these have longer life expectancies and are more easily available to ordinary farmers, but it is hard to see what kind of small-scale technology will help solve the problems of Egypt, for instance. The fact remains that the societies living in arid lands are, for historical reasons, dependent on large-scale irrigation systems and these constitute a key factor in the processes of land degradation. At present no readily available technology can

[17] Irrigation was brought to California by Spanish settlers (no indigenous irrigation agriculture existed), but remained of little importance until the late 19th century when growing markets in the east promoted heavily irrigated and very efficient garden agriculture.

[18] E.g., Hays (1982); Worster (1985); D. Worster, "Thinking like a river," in W. Jackson, et al. (eds.): *Meeting the expectations of the land* : 56-67 (San Francisco, 1984).

overcome this fact and the systems, therefore, have an inherently limited life expectancy. Thus the prospect of achieving further agricultural growth without very serious environmental degradation appears so slim as to be nonexistent.

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Biodiversity and Sustainable Agriculture in the Fertile Crescent

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ABSTRACT
The Fertile Crescent is a high biodiversity region where most temperate-zone agricultural species originated and were first domesticated. A favorable environment, a special plant community, and an adaptive population combined to initiate the Neolithic—the New Stone Age—in the Fertile Crescent. However, over time, valuable plant genetic resources of the region are being eroded through degradation of natural habitats, intensification of the cultivation of arable lands, expansion of cultivation into marginal areas, replacement of diverse and widely adapted landraces by new cultivars based on a narrow genetic base, and over-exploitation of natural pastures and grazing lands. There is a grave risk that much of the inherent biodiversity of the Fertile Crescent will be lost unless a holistic approach to the management of ecosystems, based on sustainable agriculture and sustainable development, is implemented. Components of the holistic approach are presented and discussed under the following five themes: (i) assessment of problems, obstacles and needs (ii) land use management, including soils, water and vegetation (iii) the conservation of agricultural biodiversity and its utilization in agricultural production systems (iv) social, political and economic factors, including indigenous knowledge and (v) human resources. It is hypothesized that food security for future generations in the Fertile Crescent will be strengthened by the conservation and utilization of agricultural biodiversity. This can be achieved through the development of productive and sustainable resource management strategies in the agroecosystems of the region.

INTRODUCTION

The modern territories Iraq, Jordan, Lebanon, Israel, Palestine, Syria, western Iran, and southeast Turkey encompass the region often referred to as the Fertile Crescent. Here, many of the species of temperate-zone agriculture originated and were first domesticated. Their wild relatives and landraces are still found in the region (Harlan 1992; Zohary and Hopf 1993). It is an area of megadiversity of important food, feed, medicinal, horticultural crops, spices, pasture and rangeland species. However, the area under arable, annual and perennial crops and forests is small, leaving the bulk of the land as steppe, desert, or semi-desert. Much of the land has steep slopes and/or shallow, or saline, soils that are unsuitable for cultivation without extensive and expensive reclamation work. The land resource is fragile and the conservation and maintenance of its biodiversity and productivity are of crucial concern (Held 1994).

THE FERTILE CRESCENT: CENTER OF ORIGIN AND CENTER OF DIVERSITY

The Fertile Crescent is at the core of the West Asia and North Africa (WANA) region (see Kouchoukos *et al.*, this volume). The WANA region straddles three important centers of biological diversity: the Near Eastern, the Mediterranean and the Central Asian. Many major crops, including cereals, pulses, spices, oil crops, fiber plants, pasture and forage species, and fruit and nut trees trace their origins to different parts of WANA (Harlan 1975, 1992).

The region is characterized by several major land forms (Zohary 1973). The Afro-Arabian tableland borders the area to the south and is today largely desert. The Irano-Anatolian folded zone, which includes the Zagros, Taurus, and Syro-Palestine ranges, forms a mountainous arc where most of the arboreal vegetation now grows. Between these two zones is a region of rolling terrain and alluvial plains. The tremendous variability in topography has a strong influence on climate and vegetation. The coastal regions in the west are characterized by a Mediterranean regime of hot, dry summers and cool, wet winters. A lowland area known as the "Syrian Saddle," which separates the Anti-Taurus from the Syro-Palestine ranges, allows the Mediterranean influence to extend inland. The inland regions, however, have a more continental climate.

Despite a scarcity of water and cultivable land, the Fertile Crescent was one of the major food-producing regions of the old world for many centuries (Harlan 1992; Zohary and Hopf 1993), having once been termed the granary of the Roman Empire (Held 1994). Today, it supports a rapidly growing (3-3.6% per annum) population of some 70 million people. It has become the largest food-importing region in the developing world due to this rapidly growing population (and, in some countries, rising income) at a time of sluggish growth in its agricultural production (FAO 1996a).

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THE FIRST GREEN REVOLUTION

Favorable climatic conditions after 9,000 BCE brought steady improvements in the Fertile Crescent environment, which encouraged the growth and spread of wild plants and animals that constituted food supply for an increasing human population (Miller 1992). Grasslands with scattered trees became the native habitat of early wild forms of wheat and barley, which still grow in many locations throughout the Fertile Crescent today.

For many centuries, these wild cereals were harvested by hunters/gatherers but were gradually domesticated and cultivated along with other major food plants, including vegetables, oil crops, fiber crops, spices, fruit and nut trees. At about the same time, animals that still dominate the farm scene were domesticated—sheep, goats, cattle, pigs, and dogs (Miller 1992; Nesbitt 1995). Thus, a particular environment, a special plant community and an adaptive population combined to initiate the Neolithic—the New Stone Age—in the Fertile Crescent about 10,000 years ago in which the systematic development of organized settlements occurred. This development led to a further complex of cultural processes: politics, administration, organized religion, trade and writing. It is said that "man was domesticated by plants" (Willcox 1995).

Around 5,500 BCE the dryland farmers in the Fertile Crescent took a major step forward by minimizing their dependence on rainfall: they extended and then gradually shifted farming from dryland areas to the plains watered by the Tigris and Euphrates. This development in food production led to cooperative planning, organized engineering, expanded storage facilities for harvest surpluses, trade relations, defenses for the protection of food supplies, centralized administration to apportion water and coordinate activities, the establishment of the first city-states, and the appearance of great empires and civilizations (Miller 1992).

The area from the Levantine to Mesopotamia was the most fitting place for agriculture to begin, not simply because of its soil fertility (which waned considerably over the millennia) but also because of its landscape, its climate, its plants, and its animals. The Mediterranean climate is ideal for early cultivation and the Mediterranean region was magnificently well-stocked with cereals that lended themselves to domestication. Of the world's 56 species of large seeded grasses, 32 are found wild in the Mediterranean area. By contrast, North America and sub-Saharan Africa boast only four each; East Asia has six. These proto-cereals were abundant enough to allow hunter-gatherers emphasizing the second of their competencies to settle down, even before they started cultivation (Nesbitt 1995; Wilcox 1995).

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The "Fertile Crescent" draws its name from the achievement of a balance between humans and the natural ecosystems (including soils, water, crops selected from a rich flora, natural pastures in well-managed, productive agricultural systems and livestock). Unfortunately, this balance has now largely broken down and is expected to be further disrupted by increasing population pressures on a diminishing resource base. The solution cannot be simply a rescue mission for the remains of the flora (*i.e.*, collection and conservation of germplasm in gene banks) but rather must be grounded in a holistic approach to the major agroecosystems (and farming systems therein) in the region. If sustainable land management, in equilibrium with human societies, can be reinstated in the different farming systems of the Fertile Crescent, much of what is required for the conservation of biodiversity will also have been achieved (ICARDA 1995).

INDIGENOUS PLANT GENETIC RESOURCES

It is estimated that the WANA region has a flora of 32,000 species of higher plants, a high proportion of which are endemic (Table 1) and 10% of which are deemed threatened. The highest plant diversity occurs in Turkey (with 163 plant families, 1,225 genera, 9,000 species and 3,000 plant taxa as endemic) and Morocco (with 135 plant families, 940 genera, 4,500 species and 600 plant taxa as endemic). Oak (*Quercus calliprinos* Webb, among others) and Aleppo pine (*Pinus halepensis* Mill.) predominate the Mediterranean coastal forest west of the great bend in the Euphrates. In addition to oak, pistachio (*Pistacia* spp.) and carob (*Ceratonia siliqua* L.) are important trees that have edible fruit and nuts. Lebanon cedar (*Cedrus libani* A. Rich.) is found only at higher elevations. The drier inland regions of the folded zone are dominated by oak (*Quercus brantii* Lindl) but pistachio continues to be an important component. In the more arid regions of southern Iran where it is too dry for oak, pistachio-almond steppe forest predominates. The forest grades successively into steppe forest, steppe, and desert in northern Syria and Iraq. Riverine associations characterized by willow (*Salix* sp.), poplar (*Populus* sp.), and tamarisk (*Tamarix* sp.) cut across environmental zones. The wild grasses and legumes are at home in the open oak forest and steppe forest regions (Harlan 1992; 1995; Zohary and Hopf 1993).

CROPS ORIGINATING IN THE FERTILE CRESCENT

The majority of crops domesticated in this region as well as their wild ancestors are of worldwide importance (Harlan 1992). The following is a short list of those crops having their center of origin and center of diversity in one or more of the three recognized centers in the WANA region (Harlan 1992).

- **Cereals**: *Avena* spp. (wild oats); *Hordeum* spp. (Wild and cultivated barley); *Secale* cereale (wild rye);
- ***Triticum* species** (wild and cultivated wheat); *Aegilops* spp. (Goat grass);
- **pulses**: *Cicer spp.* (wild and cultivated chickpea); *Lens* spp. (wild and cultivated lentils); *Pisum* spp. (wild and cultivated peas); *Vicia faba* (cultivated faba beans);
- **vegetables**: *Lactuca sativa* (lettuce); *Brassica* spp. (turnip, cabbage and their wild relatives); *Raphanus sativus* (radish); *Allium* spp. (wild and cultivated onions and garlic); *Daucus* spp. (carrot and wild relatives); *Cynara scolymus* (artichoke); *Sinapis alba* (mustards);
- **spices**: *Cumminum cyminum* (cumin); *Mentha piperita* (peppermint); *Foeniculum vulgare* (fennel); Fiber/jute crops; *Linum usitatissimum* (flax, linseed); *Sesamum indicum* (Sesame);

Table 1 Native, endemic, and % endemic vascular plant species in countries of the WANA region (with Fertile Crescent countries in italics).

Country	Native Plant Species	Endemic Species	% Species Endemism
Afghanistan	4000	800	20
Algeria	3160	250	5
Bahrain	250	0	0
Cyprus	1650	90	5
Egypt	2080	70	3
Iran	*8000*	*1400*	*18*
Iraq	*3000*	*190*	*6*
Israel	*2200*	*170*	*7*
Jordan	*2100*	*150*	*7*
Kuwait	282	0	0
Lebanon	*2600*	*300*	*6*
Libya	1800	130	7
Morocco	3800	630	17
Oman	1200	70	6
Pakistan	5100	400	8
Qatar	300	0	0
Saudi Arabia	2000	30	2
Syria	*3100*	*400*	*13*
Tunisia	2200	?	?
Turkey	*8700*	*2700*	*31*
Yemen	>2000	>100	>6
Yemen-Socotra Island	800	>230	>28

- **forages**: *Medicago spp.* (medics and wild relatives); *Vicia sativa* (vetch and wild relatives); Fruit and nut trees; *Olea europea* (olives and wild relatives); *Ficus carica* (figs and wild relatives); *Phoenix dactylifera* (date palm); *Vitis vinifera* (grapes); *Punica granatum* (pomegranates); *Pistacia* spp. (pistachio and wild relatives); *Prunus* spp. (plum, pear, apricot, etc); *Amygdalus* spp. (almonds and wild relatives);
- **timber trees***:* *Abies* spp., *Acacia* spp., *Castanea sativa, Cedrus* spp., *Fagus orientalis, Juglans regia, Pinus* spp.;
- **dyes**: *Alkanna tinctoria, Anchus italica, Indegofera* spp., *Rubia tinctoria*;
- **essential oils and herbs:** *Achillea* spp., *Artemisia* spp., *Origanum spp., Thymus* spp.; and
- **plants of horticultural value**: *Allium* spp., *Asparagus* spp., *Colchicum* spp., *Crocus* spp., *Lilium* spp., *Rosa persica, Tulipa* spp.

The solution cannot be simply a rescue mission for the remains of the flora (i.e., collection and conservation of germplasm in gene banks) but rather must be grounded in a holistic approach to the major agroecosystems (and farming systems therein) in the region. If sustainable land management, in equilibrium with human societies, can be reinstated in the different farming systems of the Fertile Crescent, much of what is required for the conservation of biodiversity will also have been achieved (ICARDA 1995).

GLOBAL SIGNIFICANCE OF THE BIODIVERSITY OF THE FERTILE CRESCENT

The Fertile Crescent is also an area of crop species megadiversity. Several of the significant species (wheat, barley, lentil, pea and vetch) of temperate-zone agriculture originated there 10,000 years ago. These crops' wild relatives and landraces of enormous genetic diversity are still found in the region. Almond, olive, figs, pomegranates, grapes, and pistachio also originated there and have dominated its traditional agricultural systems (Harlan 1992; Jaradat 1995). These crops are present as a diverse range of wild relatives, weedy forms and local varieties. Olives and almonds, two of the most widely cultivated fruit trees in the Mediterranean, exist as numerous local clones with distinct variations in fruit and tree characteristics.

Wheat and barley have become two major staple crops upon which a large proportion (30%) of the world's population depends. Wheat currently occupies 16% of the world's arable land. World production of wheat averaged 550 million metric tons (MT) between 1992 and 1994, approximately 30% of the global production of all cereals, exceeding that of both rice and maize. The production of barley, averaged at 165 million MT from over 70 million hectares (ha) of land, contributes to 20% of the global production of coarse grains (Dalrymple 1986; Khaldi 1984).

An excellent example of the benefits derived from genetic pasture species of the Fertile Crescent is the Australian ley farming system, developed in the 1930s, using medics and clovers collected from the Mediterranean basin and introduced into rotation with cereals (Carter 1987; Cocks 1995). This system generates harvests worth hundreds of millions of dollars in terms of meat, milk, wool, added nitrogen fertility and cereal yield sustainability.

LANDRACES AND PRIMITIVE VARIETIES

Primitive landraces, wild crop relatives and other wild plant species from the Fertile Crescent continue to provide new sources of important genetic traits and to improve agricultural production worldwide as new techniques allow for the use of wider gene pools (Jana 1995). Primitive landraces have persisted *in situ* because the nature of the farming systems in the region has been dynamically conserved by farmers. By growing mixtures of diversified local germplasm of crops, farmers have been able to select varieties adapted to local farming systems and environmental conditions. However, most of this diversity is threatened by the adoption of uniform new crop varieties, nitrogenous fertilizers, increased agricultural mechanization, urbanization, and habitat destruction by overgrazing and forest clearing (Dalrymple 1986; Fowler and Mooney 1990). This has led to the disappearance of traditional diversity based on local farming systems. The region that gave sedentary agriculture to the world now experiences deficits in food production (Khaldi 1984); its population has simply outstripped its agricultural resources.

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Landraces which have been developed over many generations by farmers' selection for desirable traits tend to be genetically more heterogenous and more highly adapted to their specific agro-ecological environment. Conservation of the valuable and highly diverse genetic resources harbored by these landraces can be achieved through on-farm conservation and continuous use of these landraces in traditional farming systems (McNeely 1989; Brush 1995) as well as *in-situ* strategies, the success of which largely depends on community-based management (Brush 1986, 1991; Friis-Hansen 1994).

AGRICULTURAL BIODIVERSITY AND SUSTAINABILITY

Plant resources contain the genetic material which is the key to food security and sustainable agricultural production to meet both biotic and abiotic changes and challenges. Over time, agricultural production has become dependent on a narrow genetic base, both among and within species and crops (Harlan 1975). While traditional low-input farming systems in the Fertile Crescent maintain their diversity in order to preserve stability of production under climatic, disease and pest risks, they also tend to be less productive (Cooper *et al.* 1987; Jaradat 1991).

National, regional, and international research centers have already collected and evaluated the genetic makeup of agriculturally important species such as wheat, barley, and lentil (ICARDA 1995; Jaradat 1997). Characterization of these genetic resources was carried out for traits such as temperature and moisture stresses, resistance to disease pathogens, insect pests, and yield improvement potential. Although still far from completion, substantial gene banks have been established as a means of *ex-situ* conservation (FAO 1996a). Gene banks are especially important for those species with only scattered and small wild populations (e.g., wild lentil populations in Syria and Jordan), which can be more effectively conserved through *ex-situ* conservation. However, the richness of many field crops, fruit trees, vegetable crops, pasture and forage legume species and their weedy and wild relatives in the Fertile Crescent is now under threat due to one or more factors delineated below.

Gene banks are only part of the process of maintaining biodiversity. For spatially and temporally diverse populations, obtaining a representative sample is a formidable task (Jaradat 1997). It is increasingly recognized that *ex-situ* conservation is limited by the fact that only a small proportion of existing genetic resources may be sampled. Due to the dynamic nature of plant populations and their interaction with the environment, collections may not represent the total variation present at a given time. As a result, naturally occurring and evolving populations (e.g., wild emmer wheat in its centre of origin, wild almond, and pistachio species) must be maintained *in-situ* within their environments; this aspect of conservation is now receiving more attention than collection and *ex-situ* storage (see Engels 1995, for a review).

Comprehensive information about the characteristics and status of agricultural biodiversity in the ecosystems of the region is lacking. The diversity of some agriculturally important species has been covered in detail (e.g., wheat, barley, lentils); for other species (e.g., horticultural crops, medicinal crops, spices) information is virtually non-existent (Jaradat 1995).

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Sustainable agriculture is defined as the appropriate management of resources in agricultural production in order to satisfy current and future human needs while maintaining or enhancing the productive capacity of the natural resources (Univ. of California 1997). Sustainable agriculture depends upon the conservation of resources (land, water, and genetic resources) upon which agricultural production is based. Any strategy for the conservation of natural resources must include efforts at achieving sustainable agricultural production (Francis *et al.* 1986).

Destruction of natural habitats and over-exploitation of native vegetation inevitably lead to the degradation of biodiversity. However, in the Fertile Crescent, those habitats represent the resource base for productive agriculture and are often the only livelihood of farmers and herders (Barham and Mensching 1988; Tully 1989). Indigenous knowledge about cultivated species and their wild and weedy relatives, native vegetation, and traditional agricultural practices in land and water management is an invaluable resource in the search for new and appropriate methods of conserving and using biodiversity, in general, and plant genetic resources, in particular (Brush 1992; Daes 1993). Landraces which have been developed over many generations by farmers in the Fertile Crescent are usually genetically more heterogeneous and highly adapted to their specific agroecological environment. Little is known about farmers' criteria for selection, and the value of their knowledge has only recently been recognized for use in breeding programs (Crucible Group 1994).

Indigenous knowledge is critical to retaining the benefits of centuries of keen human observation, applied in different areas of the Fertile Crescent, on how agroecosystems function, on the characteristics of cultivated crops, and on their multiple uses. These knowledge systems were the only means to integrate the impact of long-term climatic and biological changes over many generations (Brush 1986), and they are quite necessary for developing new methods of adding value to agricultural products (Hodgkin 1995). This is particularly true in a region where farming is not only a marginal economic activity but also a vital social and environmental enterprise (Cooper *et al.* 1987; Jaradat 1990).

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Still, for many species, especially domesticates and weedy forms, active management may be required to preserve their diversity. Here, traditional knowledge must be complemented by methods to build niches for the maintenance of biodiversity (FAO 1996a, b).

CONSERVATION OF BIODIVERSITY

The loss of the region's biological diversity from habitat destruction, overgrazing, and pollution has continued despite mounting national and international efforts to conserve it (ICARDA 1995). Biological resources constitute a capital asset with great potential for yielding sustainable benefits. Urgent and decisive action is needed to conserve and maintain biodiversity at the genes, species, landraces, and ecosystems levels in the Fertile Crescent, with a view to the sustainable management and use of biological resources. Capacities for the assessment, study and systematic observation and evaluation of biodiversity need to be reinforced at national and regional levels in the region. Effective national action and regional cooperation are required for the *in situ* conservation and protection of ecosystems, for the *ex situ* conservation of biological and genetic resources and for the enhancement of ecosystem functions. The active participation and support of local communities are essential to the success of such an approach (Wood 1994; Porceddu 1995).

BACKGROUND: FACTORS CONTRIBUTING TO BIODIVERSITY IN THE FERTILE CRESCENT

Several factors (Jana 1995), both anthropogenic and natural, have contributed to the rich diversity of crops and wild species in the Fertile Crescent.

Socio-political Factors

The political climate and interests in agricultural innovation were important influences throughout most of the agricultural history in the Fertile Crescent. Each political administration, from Roman to Byzantine to Islamic rule, enabled agricultural progress and associated crop evolution (Held 1994). During the medieval Islamic period, this evolution was facilitated by favorable land tenure and taxation systems. There were also considerable royal interests in botanical gardens and other forms of aesthetic activities which promoted the conservation of plant diversity. The region's long history of human movement, for commercial and political purposes, contributed to the migration and diffusion of crop species in and out of the region (Harlan 1992).

Agro-climatic Factors

Environmental stresses, especially high temperatures and low soil moistures, are common during crop growth and development (Cooper *et al.* 1987). Crops and wild plant populations evolving under such stressful environments accumulated higher frequencies of resistant alleles at individual loci, and also enhanced the assemblage of desirable allelic combinations at both linked and unlinked loci.

Ecological Factors

Ecological diversity often correlates with genetic diversity. In their natural habitats in this region, indigenous crops and their wild relatives encounter diverse ecological habitats that contribute to adaptive diversity among populations in different ecological niches. This has been demonstrated by numerous studies (Jaradat 1996); subjected to heterogenous biotic pressures, intergenotypic, and interspecific interactions, diverse ecosystems were produced which promoted spatial divergence among local populations of crops and their pests.

Genetic Factors

Dynamic interaction between natural and human factors have maintained crop genetic diversity in traditional agroecosystems in this region for millennia. Evolutionary processes such as geographic isolation, limited gene migration through germplasm exchange, occasional introgression between cultivated varieties and their wild relatives, and natural selection in local populations caused adaptive divergence and geographical differentiation among primitive varieties and landrace populations of crop species (Harlan 1975).

THREATS TO BIODIVERSITY IN THE FERTILE CRESCENT

The major causes of plant genetic erosion and loss of biodiversity have been summarized in the *Report on the State of the World's Plant Genetic Resources* (FAO 1996a) as follows:

- replacement of local varieties;
- land clearing;
- over-exploitation of species;
- population pressure;
- environmental degradation;
- overgrazing;
- legislation/policy;
- changing agricultural systems;
- pests/weeds/diseases, and
- reduced fallow land

In an effort to achieve national food self-security, some countries in the Fertile Crescent have intensified and expanded agricultural land use, leading to degradation of the limited vegetation, soil, and water resources (Jaradat 1990). As a result, genetic diversity is being seriously eroded through the degradation of their natural habitats, the intensification and expansion of cultivation, and overgrazing in natural rangelands (ICARDA 1995). Overgrazing is especially threatening to annual crops such as wheat, barley and lentils (and their wild relatives), particularly in marginal areas and where cereal-livestock farming systems are practiced (Cocks 1995). Regeneration of horticultural crops and their wild relatives can be seriously impaired as a result of overgrazing, uprooting and cutting for fuel purposes (Barham and Mensching 1984; Cooper *et al.* 1987). As a result, wild relatives of crop species grow only in marginal land areas such as field borders, abandoned fields, and areas with shallow soil and remnants of natural vegetation. The habitats supporting these valuable genetic resources are already either patchy or degraded. During the last four decades, forest cover has continued to decrease in most countries in the Fertile Crescent despite substantial afforestation efforts (AOAD 1994). Intensive agricultural practices, such as removing rocks and terracing land to plant horticultural crops, also lead to serious habitat destruction and fragmentation which are seriously threatening the populations of wild and weedy relatives of major crops in the region (ICARDA 1995).

FARMING SYSTEMS IN THE FERTILE CRESCENT

The drylands of the Fertile Crescent are a major source of food and fiber for millions of people. However, current yields are very low as compared to yields of the same crops in developed countries. The main reasons for this are:

- traditional production practices used by most farmers (yields are low, as is the rate of adoption of new technology, for economic reasons, generally);
- non-implementation of improved soil and water conservation methods;
- soil erosion, which leads to loss of productivity;
- low soil fertility and inadequate and improper use of fertilizers;
- low and erratic rainfall; and
- loss of biodiversity and valuable plant genetic resources.

The high and growing population pressures on the limited natural resource base in most parts of the Fertile Crescent and the misuse of the limited land resources has resulted in the expansion of cultivated agriculture to the marginal areas, overstocking of rangelands, and destruction of forests. Firmly rooted in the physical environment, these traditional systems are the outcome of centuries of ecological experimentation and adaptation, and represent the best efforts of farmers to manage the resources of the arid and semi-arid environments of the Fertile Crescent (Oram 1979; Gibbon 1981). Unfortunately, they have encouraged neither tree crops and pasture planting nor the adoption of soil conservation and range management practices required in arid and semi-arid parts of this region (Cocks 1995; FAO 1996b).

Dryland agriculture in this region is characterized by small-to-medium traditional subsistence farms in the hills, mountains, plains and the drier parts of the region. Farm size, number of parcels, and ownership are among the important factors in understanding farmers' practices (Tully 1989).

Subsistence agricultural production in the region is significant due to large family size and small land holdings. Cereal consumption, mostly wheat, is approximately 200 kg/person/year, generally providing over 50% of dietary intake in terms of both protein and calories (FAO 1996a).

In traditional village settings over the past 10,000 years, farmers have been (1) growing wheat and/or barley in the plains and grazing their sheep and goats on the stubble, (2) growing olives, grapes and almonds on the lower hills and (3) raising vegetables in small land holdings around the village (Jaradat 1990). These practices have sustained plant genetic diversity over the millenia.

By its very nature, agriculture is highly interactive with ecological factors and cultural traditions, so it differs from one region to another, as well as within a particular region. The Fertile Crescent is no exception. Outside of the intensively irrigated lands, parts of Israel, and a few other scattered areas, low crop yields still typify regional agriculture, although yields have increased notably since the 1950s. Until the 1960s, mechanization was uncommon, but coordinated programs are increasing the number of machines, especially tractors (Held 1994).

Improvement in agriculture has been hindered by the persistence of traditional practices that are inimical to better farming and marketing. Agricultural land use has been intensified and expanded in efforts to meet national aims of food self-sufficiency, placing huge demands on the natural resources base, and leading to severe degradation of vegetation, land and water resources. Despite increases in the production of crops, in general, and horticultural crops, in particular, agricultural imports have been rising steadily. They now account for 25% of the region's total import bill and more than 40% of food imports by all developing countries. If current trends continue, the region will experience, by the year 2000, a six-fold increase in the cost of its food imports (Held 1994).

Agricultural lands in the Fertile Crescent fall into three broad domains, according to the availability of rainfall:

- **Sub-humid and moister semiarid areas** suitable for dryland farming of fruit trees in areas of higher rainfall and wheat, barley, lentils, chickpeas and other minor crops in the drier parts;
- **irrigated areas** suitable for intensive farming and the production of crops such as rice, cotton, sugar beets, etc.; and
- **arid and semiarid lands** suitable for grazing by sheep, goats and camels.

Farming systems in the Fertile Crescent include irrigated systems, wheat-based systems, barley-based systems, the Ley farming system, native pasture-based systems, and fallow systems (Jaradat 1990).

Irrigated Farming Systems

Irrigated agriculture originated in Mesopotamia (Zohary and Hopf 1993). Irrigation farming is situated in those areas where annual rainfall is less than 150-200 mm but which are characterized by high interannual variability (Gibbon 1981). Improved production practices are widely adopted in irrigated farming along the Euphrates, Tigris and Jordan rivers in Turkey, Syria, Iraq, Jordan and Israel (Held 1994), resulting in high and stable crop yields. However, sustainability of these high yields can only be maintained by proper management, irrigation scheduling and drainage (Steiner *et al.* 1988). Pesticide and fertilizer pollution of soil and water is also of concern.

Wheat-Based Farming Systems

These systems are largely crop-focused, and many other crops are grown besides wheat. Additional crops include barley, lentils, chickpeas, melon, sorghum, cotton, and vegetables (Tully 1988). Food and feed legumes play an important role in sustaining the productivity of cereals and livestock in the wheat-based system. The ability of legumes to fix atmospheric nitrogen and improve soil structure are key to the systems' sustainability (Osman *et al.* 1988; Cocks 1995). Fruit trees are also a central component of the wheat-based system and play a major role in the economy of most countries of the Fertile Crescent, covering extensive areas in southern Turkey, northern Iraq, northwestern Iran, western Syria, Lebanon, northern and central Jordan and Israel (Jaradat 1995). The most common fruit trees grown under rainfed conditions are grapes, olives, almonds, pistachios, figs and pomegranates. Apples, pears, cherries, peaches and plums are found at higher elevations where rainfall exceeds 400 mm.

Barley-Based Farming Systems

The barley-based system exists in wide areas along the dry margins (200-300 mm of annual rainfall) of cultivation in most countries of the Fertile Crescent. Barley is grown mainly as feed for livestock (Tully 1989). These systems support large numbers of resource-poor farmers; although they are of subsistence nature, they have become suppliers of livestock products to expanding urban centers (Jaradat 1990). However, these systems have contributed to the degradation of the marginal and fragile environments they occupy and the sustainability of the system as it is practiced is questionable.

The Ley Farming System

The Ley farming system involves planting annual forage legumes in rotation with wheat as a substitute for fallowing, and is being practiced on a small scale in parts of the Fertile Crescent (Carter 1987; Cocks 1995). Its benefits include (1) improvement of soil structure and fertility, (2) reduced soil erosion, (3) weed control without chemicals and (4) sustainable livestock and wheat production.

Native Pasture-Based System

This system is integrated with the wheat- and barley-based systems and is based in the steppe and other locations where rainfall exceeds 250 mm. It utilizes lands that are too steep or stony, or areas where the soil is too shallow for cultivation (Cooper *et al.* 1987). These pasture lands are usually found in foothills and slopes of mountain ranges in the eastern Mediterranean (Gibbon 1981). The pastures tend to have a low carrying capacity (1 ewe/ha) and overgrazing and high stocking rates have severely degraded the natural vegetation in these areas (Oram 1979).

The Fallow System

Fallowing is a common practice in the dryland farming systems of the Fertile Crescent. It involves leaving the land without a crop for one or more growing seasons. The benefits of fallow vary with different soils and climates, but include improved moisture storage, increased mineralization of soil nitrogen, weed control and better seedbed conditions (Papendick and Campbell 1974).

A HOLISTIC APPROACH TO SUSTAINABLE AGRICULTURE AND BIODIVERSITY CONSERVATION IN THE FERTILE CRESCENT

In order to sustainably conserve the remaining biodiversity in the Fertile Crescent, and in order for biodiversity to positively contribute to the establishment of sustainable farming systems in the region, activities leading to the *in-situ*, or on-farm conservation of biodiversity should include (Lowerance *et al.* 1986):

- **identification** of sites with large biodiversity of target cultivated, wild and weedy species;
- **assessment** of the threats to biodiversity of each of cultivated, wild and weedy species;
- **documentation** of the extent of cultivation of landraces and primitive or old varieties of field crops and horticultural crops in the region; and

- **characterization** of wild and weedy species and landraces and the documentation of the status of landraces and wild relatives in *ex-situ* collections, in an effort to fill gaps and capture maximum diversity in collections.

COMMUNITY-BASED BIODIVERSITY MANAGEMENT

The biodiversity which has been evolving as a part of the Fertile Crescent landscape over the centuries is of global importance (Table 2; Kloppenberg and Kleiman 1988). Maintaining sufficient heterogeneity in farming systems and providing the necessary habitats to sustain this biodiversity is a regional and international responsibility (IPGRI 1995). Although technology plays a major role in improving sedentary farming, the role of management is also crucial (McNeely 1988; 1989). The widely-practiced top-down approaches have proved to be ineffective in regulating land use and allowing sustainable biodiversity management and conservation within ecosystems (Lowerance *et al.* 1986), especially in the WANA region (FAO 1996a). Community-based management, on the other hand, is expected to result in a more effective and sustainable management of biodiversity. The agricultural community should be seen as part of a larger and more comprehensive ecosystem which provides both goods and services from nature through well-managed protected systems.

Diversity of crop species and the diversity of varieties within species have traditionally strengthened the resilience of agriculture (Harlan 1975). Protected areas can contribute to this effort through maintaining wild relatives of crops. Agriculture and protected areas are sometimes seen as opposite ends of a spectrum (McNeely 1995). However, they can play important complementary roles, especially when the protected areas are managed in ways explicitly designed to support agricultural development. Nonetheless, exclusion by means of protected areas is not necessarily the best means of all species or

Table 2 Examples of important indigenous economic plants in countries of The Fertile Crescent.

Category	Examples
Food plants	Almonds, apricot, barley, beets, carob, chestnut, sweet chestnut, chickpea, cherry, date palm, fig, sycamore fig, lentil, olive, pistachio, pomegranate, quince, rye, wheat
Fiber plants	Flax
Oil plants	Safflower, flax, olive
Timber trees	*Abies* spp., *Acacia* spp., *Castanea sativa*, *Cedrus* spp., *Fagus orientalis*, *Juglans, regia*, *Pinus* spp.
Dyes	*Alkanna tinctoria*, *Anchus italica*, *Indegofera* spp., *Rubia tinctoria*
Essential oils, perfumes, herbs	*Achillea* spp., *Artemisia* spp., *Origanum* spp., *Thymus* spp.
Plants of horticultural value	*Allium* spp., *Asparagus* spp., *Colchicum* spp., *Crocus* spp., *Lilium* spp., *Rosa persica*, *Tulipa* spp.

genetic resource conservation (ICARDA 1995). For many species and environments, active management is required to conserve their genetic diversity. This can be achieved through:

- **restoration** (or creation), within the farming system, of special niches or habitats for certain crops and their wild and weedy relatives;
- **promotion of traditional land management practices**, including the use of traditional land preparation, sowing, and harvesting of certain crops;
- **promotion of active participation of farmers** in surveys, selection and breeding, and utilization of their indigenous knowledge (Daes 1993);
- **providing farmers with a broader genetic base** (among and within crops and genotypes) to enhance sustainability; and
- **reform of social and economic policies** to encourage adoption, by farmers, of *in situ* and on-farm conservation measures.

Farm communities should be recognized as stewards in the continued management of biodiversity. Throughout their history, farmers have maintained diversity in order to preserve stability of production under biotic and abiotic stresses.

The Role of Farmers in Maintaining Biodiversity

Farmers, under traditional farming systems, have maintained biodiversity through the creative handling (use, conservation and improvement) of landrace and old crop varieties. Farmers' choices are usually based on the continued suitability of the traditional varieties under their prevailing farming systems (Brush 1991; 1995).

Traditional farming has been in long and close contact with a great range of different ecosystems (Wood 1994); characteristically, traditional farming taps and manages a range of natural resources beyond the limit of the farm. Farm communities should be recognized as stewards in the continued management of biodiversity.

Throughout their history, farmers have maintained diversity in order to preserve stability of production under biotic and abiotic stresses. Wild and weedy relatives of many crops (e.g., fruit trees, leafy vegetables) used to be left growing on field borders to supply food, feed, seeds or root stocks for grafting. The replacement of the traditional farming system by modern agricultural practices is endangering these wild relatives. Food demands and market forces have encouraged the replacement of adapted landraces and local varieties of field crops, vegetables and fruit and nut trees with higher-yielding, more uniform cultivars, thus hampering the gene pools of these crops (Fowler and Mooney 1990).

Demand, by consumers and farmers alike, for higher-yielding and more uniform food crops which must also be adapted to ever-changing biotic and abiotic stresses requires continuous and reliable access to genetic resources that can be used to impart such qualities. The loss of traditional agriculture to modern monocultures eliminates associated and potentially beneficial biological elements (Waage 1991) as well as the invaluable traditional knowledge of the distinct qualities, uses, and growth requirements of wild and weedy relatives of crop plants and landraces of these crops (Brush 1986; Crucible Group 1994).

There is a need for research strategies that will both increase the quantity and improve the quality of the genetic diversity being conserved by farmers (Voss 1992). Research objectives should include (1) the provision of usable variation for farmers to evaluate and incorporate into their cropping systems, (2) the dynamic on-farm conservation of germplasm as resources for farmers throughout the region, and (3) the protection of the environment by continued traditional management of proven sustainability.

Supporting On-farm Conservation of Biodiversity

Farmers choose to grow new cultivars for many reasons, including market conditions, family food security and environmental sustainability. Unfortunately, these choices often result in significant on-farm genetic erosion. Still, in some countries of the Middle East, including those in the Fertile Crescent, the overwhelming majority of farmers, as a matter of choice or necessity, engage in conservation and development of plant genetic resources as they select and save seed for the next planting season. These farmers typically practice low-input farming. Such farmers often lack access to new and diverse genetic materials which could be integrated into existing crops to improve production (ICARDA 1995).

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Prospects of markedly increasing the productivity of low-input and low-potential farms through genetic improvement alone, and without appropriate and creative approaches, would appear limited. Yet increased productivity is invaluable for food security and the reduction of pressure on fragile environments (Sobral 1997). Initiatives focusing on participatory, on-farm management and improvement of plant genetic resources may offer the potential to reach large numbers of farmers and promote further agricultural development (ICARDA 1995). Rigorous multidisciplinary scientific research is needed in relation to on farm conservation of biodiversity, including

- **ethnobotanical and socio-economic research** to understand and analyze farmer knowledge, selection/breeding, utilization, and management of plant genetic resources;
- **population and conservation biology** to understand the structure and dynamics of genetic diversity in local landraces and farmers' varieties;
- **crop improvement research**, including research on mass selection and simple breeding as a means of increasing crop

yields and reliability without significant losses of local biodiversity; and
- **extension studies** of little known crops, including seed production, marketing and distribution.

In this context, two major issues must be considered. The first concerns large gaps in knowledge about conservation requirements and crop diversity loss in traditional farming systems, farmers' attitudes concerning diversity, and the habitats supporting diversity. The second concerns yield limitations of traditional plant breeding systems by local farmers (which are constrained by the limited availability of germplasm) (Henne 1995).

Promoting *in situ* Conservation

Natural ecosystems hold important plant genetic resources, including endemic and threatened wild and weedy relatives of crop plants. This genetic diversity is an economically important component of natural ecosystems and cannot be maintained *ex situ* (Shands 1991). Unique and particularly diverse populations of these genetic resources must be protected *in situ* when they are under threat. Two reasons can be cited (ICARDA 1995) in favor of *in situ* and on-farm conservation of biodiversity. First, it promotes the evolutionary process, allowing germplasm to be kept in tune with the changing environment (biotic and abiotic elements). Second, it assures greater genetic diversity conservation than *ex situ* systems.

Underutilized Species

Many species typically regarded as marginal contribute substantially to household food and livelihood security (IPGRI 1995). They are often managed or harvested by women. Many medicinal plants, herbs (Oran 1996; Steinmann, this volume), and even fruit trees and some field crops in the Fertile Crescent can be considered as underutilized. Knowledge concerning the uses and management of these species is often localized and specialized. Many of these species have the potential for more widespread use, and their promotion could contribute to food security, agricultural diversification, and income generation, particularly in areas where the cultivation of major crops is economically constrained.

Seed Production and Distribution

Farmers benefit from having a wide range of seed varieties and other planting materials (Kloppenburg and Kleiman 1988). Availability can be constrained by (1) poor harvests, inadequate on-farm storage facilities, and insufficient means to multiply quality seed, and (2) poor seed distribution systems.

There is a need to strengthen local capacity to produce and distribute seed of many crops and local varieties, especially landraces and minor crops with specific adaptations, which can promote diverse and resilient farming systems.

NEW MARKETS FOR LOCAL VARIETIES

Increasingly, diversity is being replaced by uniformity in the agricultural market place. Changes in traditional cultures and in consumer preferences are one explanation. Concentration on productivity, the effects of advertising, the rise of global consumer markets leading to stringent requirements being imposed on farmers, and the often inadvertent disincentives arising from legislation, policies, programs and other institutional activities offer additional explanations (Fowler and Mooney 1990). Economic and social incentives could be offered to encourage farmers who continue to grow distinct, local varieties and produce "diversity-rich" agricultural products.

LAND USE MANAGEMENT

Land use management and planning of areas to be used for on-farm and *in situ* conservation is essential to:

- provide buffers, corridors or habitat strips for the target species;
- provide both water catchment and habitat for wild and weedy relatives of crop species;
- provide niches for diversified plant production and alternative income generation (weedy vegetables, spices and herbs);
- develop community-level water harvesting techniques where necessary;
- help protect target tree species as a genetic resource along with their use as rootstocks for grafting (e.g., wild *Olea* species in parts of southern Turkey, and wild *Pistachia* in Syria, Lebanon and Jordan);
- promote biodiversity-maintaining agronomic practices (e.g., sowing mixtures of cereal landraces in rotation with forage legumes to maintain soil fertility and production in rainfed cropping areas to avoid poor management);
- provide seed of locally-adapted pasture legumes for rejuvenation of degraded common grazing lands; and
- establish sustainable grazing management and monitor pasture and range condition and animal nutrition and health with the objective of preserving germplasm while maintaining animal production.

SPECIES MANAGEMENT

Species management can be achieved through *in situ* conservation to protect wild species of a particular crop gene pool in their original habitats. These habitats may be modified when necessary to ensure sufficient population size and gene flow. Different target species will require different management. For example, populations of wild progenitors of wheat, barley and lentils, growing on field borders of the respective crops, constitute a special case of *in situ* conservation. These three crops and their wild progenitors develop hybridizing complexes, allowing introgression and gene flow between the wild and domesticated species (ICARDA 1995). The hybridizing complexes may be enhanced by frequent planting of cultivated species in fields adjacent to the wild populations. A similar situation can be envisaged for vegetables, fruit trees and their wild relatives throughout the Fertile Crescent (Bromberg 1995).

On the other hand, farmers can be encouraged to practice on-farm conservation of landraces and old varieties through awareness building and incentives in the form of alternative livelihood. The latter may include (1) introducing apiculture into farming systems, especially where mixed farming is being practiced, (2) supply of locally adapted rootstocks and seeds, and (3) technical assistance in soil management and water harvesting.

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Establishment of field gene banks to grow vulnerable crop species for replanting in field margins and improved habitats as native trees or as adapted rootstocks will promote on-farm conservation. These field gene banks can be utilized to promote public awareness as well (Du Puy and Jackson 1995).

Finally, wild relatives and landraces, capable of withstanding particular biotic and abiotic stresses, can be utilized in breeding programs to make use of specific adaptation and thereby maintain genetic diversity within a crop (ICARDA 1995). Farmers' active participation is essential (McNeely 1989; ICARDA 1995) in the selection of lines in breeding programs to ensure that new genotypes are specifically adapted not only to the ecological conditions but also to the intended end-use and farmers' preferences.

SOCIAL, POLITICAL AND ECONOMIC FACTORS

Governments in the Fertile Crescent are preoccupied with supporting and improving agricultural production, since the region has some of the highest population growth rates in the world and a widening trade gap in food and agricultural products (Held 1994). Unfortunately, those policies directed at enhancing agricultural productivity also tend to negatively impact genetic biodiversity. Although there are limited biodiversity conservation policies in a few of these countries, there is no holistic plan for their implementation (ICARDA 1995).

Technologies appropriate for better management of biodiversity, water, soil, land and cropping systems are available but their adoption has been inhibited by disincentives to sustainable use of these natural resources (Altieri and Merrick 1987; Voss 1992; Sobral 1997). Also, uncertainties over property rights among users of the natural grazing and water catchments can become obstacles to proper management of land and other natural resources. Some tribal institutions which once regulated grazing or water rights have broken down (e.g., in Jordan) or been undermined by government nationalization of land (e.g., Syria). Some rangelands are being privately appropriated through new settlement and conversion to cropping (e.g., Jordan) while many (including the Hammad region bordering Syria, Jordan and Iraq) are open access areas where users have incentive neither to improve productivity nor to conserve biodiversity.

In the barley-based, and to some extent the wheat-based, farming systems, livestock is becoming increasingly dependent on supplementary feed, forage supplies and crop residues from biodiversity-rich areas in Syria, Jordan and Iraq (Jaradat and Haddad 1994). This is causing significant competition over resources which must be taken into account in any policy changes.

Although planners and policymakers are convinced that changes are needed, they posit that they will take time to implement. A strong emphasis on the communities and local land managers as well as the modification of current government incentives for the benefit of biodiversity conservation can bring about these changes in a relatively short time (ICARDA 1995).

In Syria, Jordan and Iraq, governments buy strategic crops (wheat, barley, cotton, sugar beet) at attractive prices; feed concentrates are distributed at cost through farmers' cooperatives, and governments control the price of many agricultural products (e.g., meat). Some of these policies may be modified after the demonstration of feasible policy alternatives conducive to biodiversity conservation.

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Agricultural and land use policies, legislation related to biodiversity, and resource management which include indigenous knowledge and property rights are well-acknowledged policy areas (Kloppenburg and Kleiman 1988; Doren-Adzobu 1997). It is vital to promote policies which favor biodiversity conservation without jeopardizing agricultural production. Such initiatives can be defined and tested and can be country- or region-specific. They must address current incentive practices of land clearing for fruit tree plantations in hilly areas, herbicide and pesticide use in intensive farming (e.g., the Jordan, the Beqa'a and the Ghab valleys, in Jordan, Lebanon and Syria, respectively), and land ownership and agricultural expansion in marginal and government-owned lands.

HUMAN RESOURCES

Human and institutional resources play a decisive role in the sustainability of agricultural production and biodiversity conservation. Long-term national plant genetic resources programs, complemented by coordinated regional activities, will provide the framework for sustainable biodiversity conservation (ICARDA 1995; IPGRI 1995). However, skilled personnel educated in biodiversity conservation and plant genetic resources are lacking in the region (Adham *et al.* 1995). Training needs of most countries range over a number of disciplines and involve both short and long term training (IPGRI 1995). They include specialized training in plant identification of wild relatives and landraces, *in situ* and on-farm conservation, agro-ecosystem ecology, population genetics, and agricultural socio-economics. Administrators and technicians in this field require specially adapted in-country training courses.

OPERATIONAL NEEDS TO PROMOTE ON-FARM MANAGEMENT OF BIODIVERSITY

The range of options for intervention in on-farm germplasm conservation and management (Henne 1995) in the Fertile Crescent is great. The often conflicting objectives of conservation, agricultural development, social equity, appropriate seed production and delivery systems, and the provision of samples for breeding work, all overlain with donors' changing interests, has in the past led to much confusion. In this context, it is important to address a variety of needs and priorities. More technical investigation is needed on genetic and agronomic aspects of on-farm conservation in order to quantify, improve and transfer both the genetic resources and traditional management technology, so as to supplement information generated by sociological and anthropological studies. Priority attention should be given to farming (and cropping) systems rich in species and varietal diversity. Information on farming communities with a history of crop and varietal experimentation should be used in planning on-farm conservation. Information on varietal movement in and out of cropping systems is vital to understanding the dynamic nature of on-farm management of germplasm. It is highly recommended that intervention start with farming systems with a history of traditional management, in regions of varietal diversification which are not yet targeted for agricultural development.

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CONCLUSIONS

The holistic approach to sustainable agricultural development and biodiversity conservation in the Fertile Crescent is hypothesized to:

- reduce risks to productivity under highly variable environments by utilizing the specific adaptation of landraces, the highly diverse wild relatives and other biodiversity assets in different farming systems in the region;
- allow for sound management of natural resources, including biological, water, and soil resources, for present and future agricultural development;
- build and strengthen human resources to cope with agricultural and environmental challenges, and
- create public awareness in environmental and biodiversity issues, especially those influencing agricultural production and its sustainability.

Promoting sustainable agriculture through diversification of crop production and broader diversity in crops in the Fertile Crescent calls for (Francis *et al.* 1988; Henne 1995):

- incorporation of a broader range of crops including *inter alia* crops which produce raw material or are sources of energy;
- use of more diversity in breeding programs and in varieties and species used on farms;
- implementation of innovative approaches in plant breeding for the purposes of domesticating new crops; the development of new plant varieties and the promotion of higher levels of genetic diversity in crops and on farms, such as planting mixtures of adapted varieties, are recognized as means for adding stability in agricultural systems and promoting agricultural production and food security; and
- support of efforts to identify those activities used in plant breeding, plant research and farming systems that foster on-farm diversity. Such research might include a review of non-homogenous farming systems, such as those based on intercropping, polycropping, integrated pest management and integrated nutrient management, for their possible wider applicability.

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Use of Land by Nomadic Pastoralists in Iran: 1970–1998

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ABSTRACT
This paper describes and analyzes changes in natural resource use by the Qashqa'i nomadic pastoralists of southwestern Iran between the early 1970s and the present. Drawing upon the author's anthropological fieldwork, including eight visits since the overthrow of the shah in 1979, the paper demonstrates how Qashqa'i land use strategies, which evolved over centuries as a means for survival in often marginal natural environments, have adapted to the pressures of an increasingly intrusive society with urban and technological biases. Despite these pressures, the Qashqa'i have used customary and new means to wrest a living from their remaining lands and have thereby preserved a measure of autonomy.

In this paper, I examine how some nomadic pastoralists in Iran changed their use of the physical environment over the past thirty years and how these changes related to their economic practices. I base this paper on my anthropological research among Qashqa'i nomadic pastoralists in southwestern Iran in the 1970s and 1990s, including eight visits since the revolution in 1978-1979 and the Islamic Republic's formation. I draw on my observations of the varying ecological adaptations and diversifying economic strategies of these tribal people as they exploited a vast section of the southern Zagros Mountains. Their practices included use and protection of pastureland, investment in arable land and agricultural techniques, construction of water-control systems, hunting, gathering, construction of shelters for people and animals, increased reliance on roads and motorized transportation, and closer ties with the national government and the market. Although much of the land these nomadic pastoralists used was not suitable for productive activities other than seasonal pastoralism, hunting, and gathering, they were increasingly forced to compete with settled agrarian communities for the available cultivable land and for access to water and rights of passage. They, did enjoy, however, the competitive advantage of a continuing reliance on migration, and the primary products of pastoralism (meat, dairy goods, wool, weavings) were in market demand.

This paper may inspire other scholars to take fuller consideration of the people actually making use of a specific territory. However land is used, it is obviously more than just physical features. Studies of the environment too often ignore or neglect the people who make a livelihood there and whose use of land is a major part of their vital social and cultural systems. People have developed strategies of land use through a process of trial and error over long periods—decades, centuries, and even millennia. Such strategies and the people who devise them deserve at least our respect and at most our support and possible protection.

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Mobile residents of the plateaus and valleys of the Zagros Mountains of southwestern Iran, the Qashqa'i are members of a tribal confederacy of some 800,000 individuals. They speak a Central-Asian-derived Turkish and constitute one of Iran's many ethnic and national minorities. Until the 1960s most Qashqa'i were nomadic pastoralists who migrated semiannually hundreds of kilometers between winter pastures at low altitudes near the Persian Gulf and

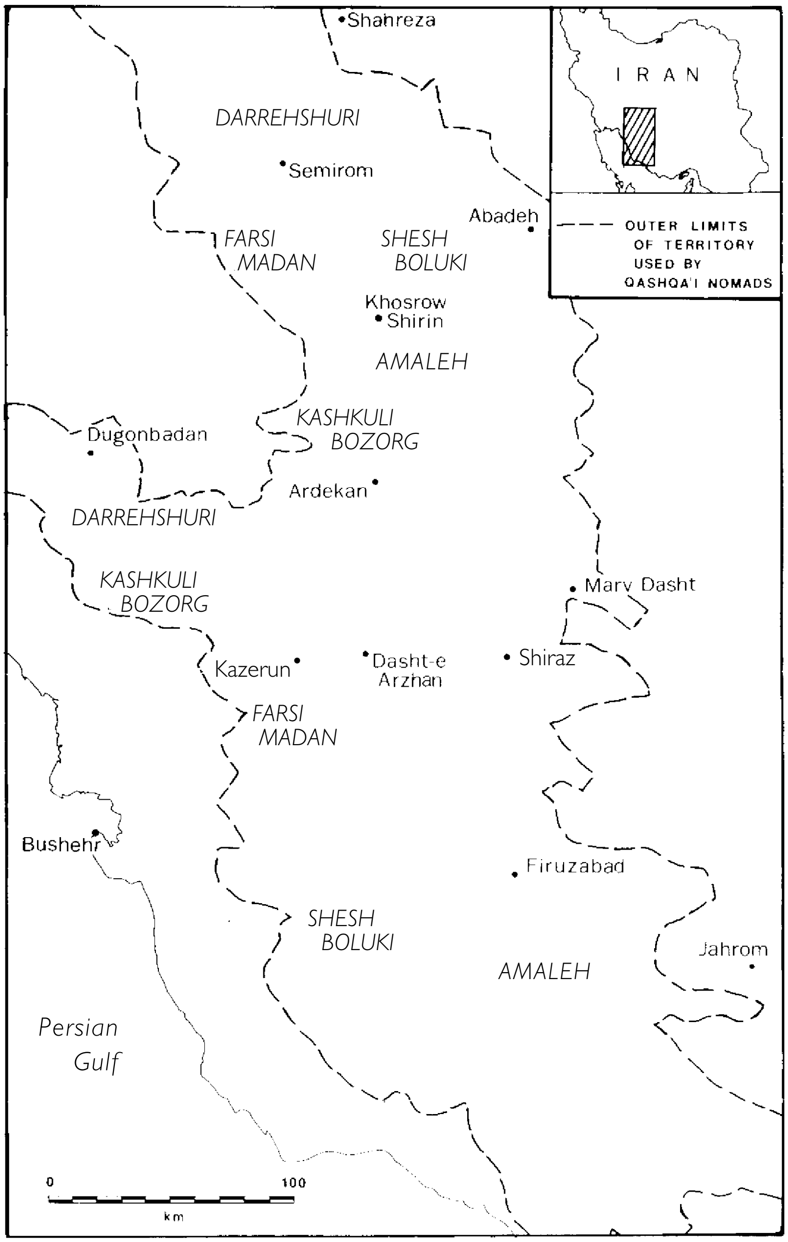

Figure 1 Qashqa'i territory (Beck 1991).

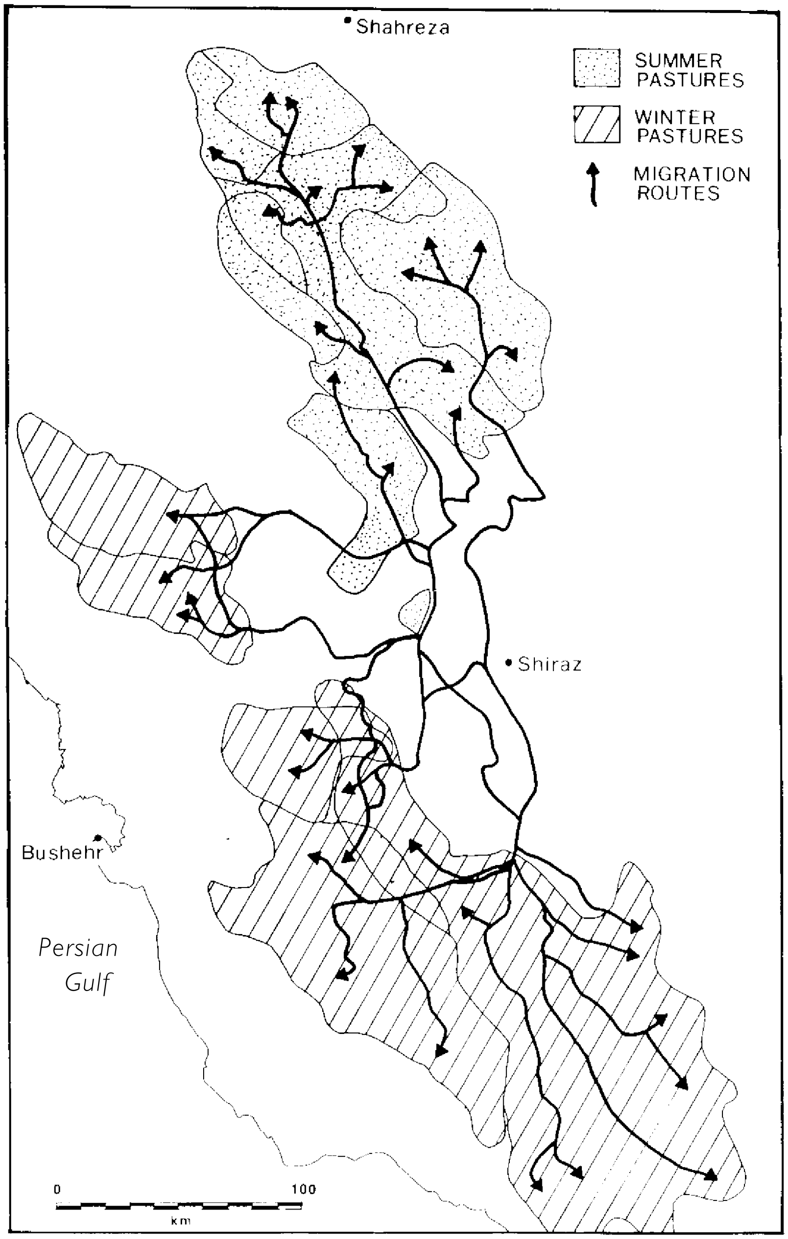

Figure 2 Qashqa'i winter pastures, summer pastures, and migration routes (Beck 1991).

summer pastures high in the mountains to the north and east (Figures 1 and 2).

Since the 1960s many Qashqa'i have settled in villages and towns, although often retaining pastoralism as one of several means of livelihood. Despite the new places and patterns of residence for many of these settlers, most remained attached to their customary seasonal pastures, visited their kin there, and continued to exploit the resources, often in cooperation with these kin.

This paper focuses on the contemporary ecological, economic, and social conditions in southwestern Iran as I have directly observed them during eight periods since the revolution in 1978-1979 and the Islamic Republic's formation, most recently in 1998. Because of research I also conducted there in the 1970s, I am able to follow precisely the changes that individuals, families, and tribal groups have made over the past thirty years.[1] My publications drawing on this earlier research provide comparative information about previous periods (*e.g.*, Beck 1980, 1981a, 1981b, 1991). Other aspects of post-revolutionary conditions are covered in existing and forthcoming work (Beck 1992).

I ask the following key questions:

- How have the Qashqa'i people made the best of the inherent environmental constraints of these rugged, mountainous, and semi-arid lands?
- How and why do many of them continue with pastoralism and nomadism, despite pressures to change their livelihoods and lifestyles?
- How have these pressures changed over the years?
- Why does the current Islamic government, unlike previous Iranian governments in this century, support nomads and their livelihoods?

[1] I conducted anthropological research among Qashqa'i nomadic pastoralists in Iran in 1969-1971, 1977 (two visits), 1979, 1991, 1992, 1995 (two visits), 1996,1997 and 1998. Research in the 1990s was supported in part by grants from the National Endowment for the Humanities, the Social Science Research Council, the American Philosophical Society, and Washington University.

Despite the many changes that all Qashqa'i have undergone in the past thirty years, I am still impressed by the remarkable continuities in their society and culture. In examining my photographs to find details to add to this paper, I was struck by how many of them could have been taken at any time during the past three decades, as long ago as 1969 or as recently as 1998.

A TYPICAL CAMP: 1970 AND 1998

Several brief descriptions will help to demonstrate the kinds of changes that have occurred for Qashqa'i nomadic pastoralists and to establish a context for this paper's discussion. Their winter and summer pastures are located in the valleys and on the slopes and plateaus of the southern Zagros Mountains. Mountain peaks rise above nomads' camps, each of which is usually secluded by the rugged terrain. The ecological differences between winter and summer pastures will be apparent here and in the rest of the paper.

A typical campsite in winter pastures in 1970 contained three woven goat-hair tents with slanted roofs to deflect rain and snow. Each dwelling held an extended family of seven or so people. The black tents were pitched on flat areas on the slopes of gullies to protect the occupants and their possessions from flash floods while also still providing some shelter from wind. Several nearby huts built of stones, tree branches, and bundled reeds were used for cooking, storage, and refuge in inclement weather. A simple, roughly circular, open-air enclosure made of rocks heaped with dried thorny bushes protected the animals at night and helped to discourage predators. Each household owned its own sheep and goats, which were tended together in herds of from one hundred to three hundred animals. Small trees and shrubs and low-lying plants grew in the terrain surrounding the camp. Green leafy shoots appeared as the weather warmed after the winter's rains. Several nearby shallow depressions, sometimes fortified along the sides with rocks and dried mud, held rainfall and runoff for the animals to drink. Accompanied by donkeys to carry the load, the camp's women and children spent many hours a day traveling to and from a well in the valley below, the nearest source of clean drinking water. Newborn lambs and kids were held in reed pens inside the tents and released several times a day to be reunited with their mothers for nursing. Before dawn shepherds took the herds to graze different parts of the surrounding hills and mountainsides, while a camel herder tended his animals and collected firewood for the camp's use. Men and boys kept periodic watch over several small fields of sown barley protected by rock walls, the crop to be used as supplemental animal feed if sufficient rain germinated the seeds and grew the plants to maturity. Birds seemed to eat as much grain as was eventually harvested.

By contrast, in terms of both time and space, a typical residential site in summer pastures in 1998 contained several simple one-room houses constructed from stones gathered nearby and mortared with cement and dirt. They stood on the very spots where tents used to be erected only a few years previously. A small kitchen area walled in by cement blocks and roofed with old tent fabric stood to the side of each house, and just beyond that lay heaps of firewood and miscellaneous equipment that had not found a place in these new dwellings. Gunny sacks filled with barley, dried alfalfa, and straw leaned against the houses' outer walls. A black goat-hair tent was pitched by one house, where a newly married son and his bride resided and where guests were entertained, as if to celebrate the past nostalgically. Holding the herds at night, pens made of metal mesh supported by wooden stakes stood behind the houses at the edge of the mountain slope. The mouth of the nearest spring had been cemented to form a small pool from which people drew water, and a cement channel led water to another pool where the animals drank. A decrepit Land Rover was parked beside one of the houses. The dirt track used by the vehicle's owner to reach the camp was also traveled

Photo: Lois Beck

by Persian and Lur cultivators in the area. The dust-raising traffic annoyed everyone, especially mothers trying to watch young children. These trespassers demonstrated no concern for the campsite's borders; they did not care that the camp was a defined territory to be used exclusively by its inhabitants. Down the hill near another water channel was a toilet, a small, open-air, cement-block structure containing a ceramic platform precariously balanced over a pit. The stumps of shade trees, planted along the channel but cut down by irate Persian cultivators who resented the nomads' presence, stood as stark evidence of the conflict. Their trunks lay on the ground, stripped of branches. The surrounding terrain was bare compared with winter pastures. No trees or large shrubs grew here naturally, only small bushes and low-lying vegetation. The valley below, its streams blocked against the pastoralists' animals since the 1980s, was green with walled orchards and cultivated fields. Hostile encounters between the Persian and Lur cultivators there and the pastoralists occurred almost daily.

Various topics mentioned in these two passages are discussed in the following eight sections. I focus on the post-revolutionary period (1979-1998) with comparative information provided for earlier periods. The wider context, in which many individuals and groups other than the Qashqa'i competed for the same resources, cannot be discussed in detail here.

Problems over land caused great uncertainty among Qashqa'i nomadic pastoralists and significantly affected the ongoing decisions they made concerning their livelihoods and lifestyles. No single government agency held all the information about land use and deeds for any given territory, and some offices possessed conflicting information.

LAND

Problems over land caused great uncertainty among Qashqa'i nomadic pastoralists and significantly affected the ongoing decisions they made concerning their livelihoods and lifestyles. No single government agency held all the information about land use and deeds for any given territory, and some offices possessed conflicting information. Such bureaucratic chaos offered the potential for great abuse. In part because the nomads were especially vulnerable due to their mobility and their only seasonal residence in winter and summer pastures, settled non-Qashqa'i individuals with influential government connections and sufficient wealth to bribe officials could determine their own land use. To support their own interests, Qashqa'i individuals held onto any documents pertaining to land. Even papers concerning disputes on other issues contained a record of people's location at the time, necessary for proof of residence. School records also provided evidence for the presence of certain families in specific places.

The status of nationalized pastureland, a broad policy introduced by Mohammad Reza Shah in 1962 as part of his "bloodless" revolution, was unclear after his ouster in 1979 and still remained so in 1998, in part because his programs, even exemplary ones, were tainted by their association with him. Since 1962, natural watercourses, following the pull of gravity and the contours of the often hilly if not mountainous terrain, were generally recognized by government officials as the legal division between pasture and "cultivable" land. Land above the channels was nationalized to be used as pasture; land below was subject to land reform and opened up for cultivation if not already cultivated. Most nomads were not eligible then for distribution of cultivable land. By the 1990s the dividing line between these two types of land was increasingly unclear because of the expansion of irrigation systems and new land brought under cultivation. Some changes did occur in the mid-1990s, such as new legal rights to rent, transfer, and sell pasture leases to others.

Rights over collectively used land were locally negotiated but not always formalized by legal documentation. The issue of land considered as privately owned with or without supporting legal documents was still under discussion in the national parliament in 1998, in part because of problems created by the many thousands of wealthy landowners who had fled into exile during or after the revolution and who later attempted to return and/or claim their (former) land. Although some influential members of the ruling Shi'i Muslim clergy supported a land reform that would give legal title to the cultivators who actually worked the land, others were themselves major landholders and resisted any new comprehensive reform that would jeopardize their own interests and those of their political and economic backers.

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NOMADISM AND PASTORALISM

Qashqa'i nomadic pastoralists herded their sheep and goats seasonally between lowlands and highlands, distances as much as 600 km each way, and exploited the pastoral resources along the routes. They spent approximately four months in lowland winter pastures, two months migrating in the spring to highland summer pastures, three to four months residing there, and two to three months migrating in the autumn back to lowland winter pastures. These migrations were not merely passages between two regions, for the vegetation along the way, especially in spring, was a vital part of the animals' sustenance. Also, seasonal pastures did not provide sufficient natural grazing and water to support the nomads and their animals for long periods. Once arriving in winter or summer pastures, the nomads did not stay in one location for the season. Rather, they moved periodically from place to place within these areas seeking fresh grazing, better access to water and other natural resources, clean campsites, and new neighbors.

Most Qashqa'i people spent the year traveling in these ways and residing in goat-hair tents wherever they set up camp. Diverse and flexible patterns had always emerged, however, as people made ongoing individual and group decisions to continue or to change their current modes of livelihood, residence, and lifestyle. For example, even by the 1970s some Qashqa'i lived in huts or small, rudimentary houses in winter or summer pastures and migrated in the spring and autumn. Some resided in tents and did not migrate at all. Others lived in villages in the winter and in tents at higher altitudes in the summer. Some Qashqa'i resided in tents and practiced only agriculture, while others lived in houses and practiced only pastoralism. Some families were divided into nomadic and settled parts and into pastoral and agricultural parts. And some Qashqa'i migrated without having any sheep and goats. All these patterns and the more standard ones could change on a yearly and even a seasonal basis. For any single local group, the specific patterns its members created during a year were never to be replicated.

By 1979 many nomads found the autumn's trek lasting two to three months to be too strenuous and troublesome for their animals because of the increasing shortage of pasture and water along the route and the detours caused by expanding human settlements and agrarian activity. Most began to hire trucks and transport their animals in a single day, a change that put new stress on the pastoral resources of their summer and winter territories, on which they were now dependent for longer periods than before. Remaining in summer pastures longer than in the past, beyond the time when natural vegetation was nearly depleted, they became increasingly reliant on growing, buying, storing, and transporting supplemental animal feed. They also entered winter pastures well before they had gone there in the past, exploited natural vegetation that they had formerly conserved until later in the season, and grew, bought, and stored quantities of fodder there as well.

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The newly growing natural vegetation along the migratory route in the spring was too lush and beneficial to bypass, and so almost all pastoralists continued to send their animals by hoof during that season. As they traveled from one point on the route to the next, each new one usually at a slightly higher altitude, they found fresh vegetation. On a slightly accelerated schedule, they entered summer pastures several weeks sooner than in the past, but natural vegetation there was usually adequate for their herds then. Their early use of this vegetation did decrease the pasturage available later in the season, when they also needed it. They enhanced methods they had used in the past to protect specific areas and to conserve vegetation, by careful scheduling and rotation, removing rocks to encourage plant growth, creating physical barriers, and guarding against encroachers in protected areas.

Before 1979 most nomads had relied on camels and other pack animals (mules, donkeys, horses) to carry their goat-hair tents and other household possessions between winter and summer pastures. Since then, many people have sold their camels and many of their pack animals because of their new reliance on motorized transportation. Although increasingly expensive, the use of such vehicles did offer many obvious benefits. Also, tending the camels during winter and summer, when the animals' services were not in much demand, had become burdensome and expensive even for those able to hire specialized herders. Twice a year families contracted with truck owners from nearby towns and cities to carry their goods to the other seasonal pastures. Formerly, herds, pack animals, and households had followed the same schedules and routes, but now animals were usually separated from households for part of the spring. Changes in dairy production were one result, for the women and girls previously present to milk and process the products did not accompany the herds. To the detriment of people's diets and needs for income, dairy production was delayed until people and animals were reunited in summer pastures. Care of lambs and kids during the spring migration was another problem, for they could not accompany the adult animals without special supervision. Now committed to formal education, the children who had formerly tended the young animals during the spring migration no longer migrated with the herds.

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The increasing availability of rapid transportation facilitated the nomads' further economic diversification. A family could engage in a variety of activities simultaneously, as long as at least one person could travel from one location to another quickly. For example, a man could irrigate his newly planted apple orchard for the stipulated twelve-hour period and then return to camp by motorcycle in time to select sheep to be driven to market by a hired truck. Another man could transport recently harvested fodder from summer pastures to winter ones, in anticipation of the herds' early arrival, while his son managed the animals during his brief absence. Trips to town for errands and government business were no longer as onerous and time-consuming.

The absence of camels and the decrease of other pack animals freed up some kinds of natural pasturage for sheep and goats, although camels had usually consumed plants that were too tall, thorny, or tough for the other animals, especially sheep. One single-stemmed thorny plant in particular was no longer grazed by any animals, and it grew to apparently unprecedented heights, two or more meters, and appeared to be taking over some areas of summer pastures to the detriment of other vegetation. With no camels to graze them, thorny bushes also proliferated, but in this case they supported the opportunistic growth of the surrounding low-lying vegetation that the sheep and goats preferred. Their populations expanding, small animals such as birds, rodents, rabbits, weasels, lizards, toads, and snakes found shelter in and around these bushes.

Slow-burning dried camel dung used to provide an important fuel for all pastoralists but was no longer available when they sold these animals. They eventually bought propane-gas cookers and lanterns and kerosene heaters when they saw that natural fuels (wood, charcoal, brush) were not nearly sufficient for their many needs (cooking, baking, milk processing, wool dyeing, lighting, heating).

In the 1960s and 1970s the shah's government had tried by various means to impede the nomads' migrations. After 1979, by contrast, the new Islamic government adopted supportive policies. Its Ministries of Natural Resources and Rural Reconstruction seeded many areas along major migratory routes and posted signs explaining their intentions. Officials chose locations where many pastoralists camped overnight during the migration, so that herd and pack animals could fortify themselves for the next day's journey without trespassing on anyone's grazing lands. According to local reports, the apparently successful program resulted in decreased pressure on other pastoral resources and fewer conflicts along the routes.

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Also offered by the new government at low or no cost to the nomads, modern veterinary medicine played a major role in the pastoralists' ability to keep their animals alive and healthy and less subject to the catastrophic diseases that used to wipe out entire herds. Regional veterinary clinics were established, and government-paid specialists toured seasonal pastures to dispense drugs and treatments. One apparent result of the increasingly widespread use of modern veterinary care was the pastoralists' decreased use of ritual and symbolic acts to attain these same ends. Until the 1980s most people had conducted rituals and prayers and employed amulets (always in combination with other, supposedly more practical efforts) to protect and care for their animals. In the 1990s many of these rituals were not practiced at all or only by a limited number of individuals who still believed in their efficacy. Many prized rams in 1998 were still outfitted with carved wooden talismans decorated by braided tassels, but the nomads sometimes stated that these charms simply reminded them of old Qashqa'i customs and did not offer any real protection to the animals. Almost all pastoralists continued to abide by their notions of auspicious and inauspicious days of the week in order to avoid jeopardizing acts central to their livelihood such as shearing the wool and transporting the sheep to market. People still talked about the rain ceremonies they used to perform and the rituals they conducted to mark and safeguard the critical stages of the seasonal round, but by 1998 most people did not actually engage in them, and children rarely knew anything about them.[2]

[2] In *Nomad* (Beck 1991) I discuss how these rites and practices fit within the seasonal round.

Since 1979 the new government paid special attention to building new roads and improving existing ones in Qashqa'i territory—especially in remote places—and in surrounding areas. A mixed blessing for the pastoralists, these roads assisted them in their new or increased reliance on motorized transportation and their efforts to carry products to and from markets (including supplies for construction—see below). But the roads also brought outsiders into their territories more frequently, thereby increasing the competition over pastoral and agricultural land and other resources. New and improved roads opened previously unexploited areas to outsiders wanting to plant orchards or engage in mechanized agriculture. Urban, middle-class, Persian tourists also took advantage of the new roads—and the greater security—to invade seasonal pastures for picnics and outings on Fridays and other holidays. Anxious to flee the city's heat, dirt, and crowds, they presumed upon the customarily offered hospitality of reluctant Qashqa'i hosts (Beck 1982).

By the early 1980s many commercial herds, owned by non-Qashqa'i urban entrepreneurs and tended by hired and often non-tribal herders, had virtually disappeared from the landscape because of newly enforced government regulations about the illegal use of nationalized pastures and because of changes in the economics of this kind of animal husbandry.

Commercial herds and animal contracts were a significant feature of pastoralism in southwestern Iran in the 1960s and 1970s. By the early 1980s many commercial herds, owned by non-Quashqa'i urban entrepreneurs and tended by hired and often non-tribal herders, had virtually disappeared from the landscape because of newly enforced government regulations about the illegal use of nationalized pastures and because of changes in the economics of this kind of animal husbandry. Also, the Qashqa'i, disarmed by the shah but re-armed during the revolution, were now better able to guard and defend their own pastoral resources. Commercial animal contracts, under which urban moneylenders and merchants became part owners of the nomads' herds because of the nomads' unpaid and deepening debts, also decreased and by the 1990s were rare. This change resulted in part because new government regulations covering moneylending and interest-taking forced at least a temporary refiguring of debts according to what were said to be Islamic principles. The most abusive of the moneylenders were publicly flogged by the government's revolutionary guards. Pastoralists were able to renegotiate their existing debts, and they took on new loans under revised terms. (They were now also eligible for loans for specific projects from government-run banks.) Interest rates declined, and debts did not escalate in the way they had done before the revolution. The absence of or significant decrease in herds belonging to outsiders significantly improved the quantity and quality of pastoral resources for the Qashqa'i users.[3] The numbers of herd animals owned by the Qashqa'i as a whole did not increase and in fact may have decreased as part of the process of settlement and the adoption of new livelihoods (see below).

AGRICULTURE

The legal status of land classified as "cultivable" was not yet settled in many areas of Qashqa'i territory and the periphery in 1998. Disputes were common, and many pastoralists were insecure about their own and others' rights and claims.

Agricultural production in Qashqa'i territory had rapidly increased since the 1960s, both by outsiders able to appropriate land in the area and by the Qashqa'i themselves. Sections of winter and summer pastures and many areas along migratory routes became cultivated. In the uplands above water courses, crops depended on moisture from seasonal rain and snow. Below water courses, crops were often irrigated. Pastoral land, never plowed before, was transformed into agricultural land and was off-limits during the growing and harvest seasons to the pastoralists' herd and pack animals. Even where the pastoralists themselves added or enlarged their own areas of cultivation, the land became lost or diminished as a viable pastoral resource. Villagers who expanded the land they cultivated in and near seasonal pastures and along migratory routes were often aided by mechanized equipment, such as tractors and combines, and they improved their own supply of water by digging wells, installing motorized pumps, and constructing irrigation works. As villages expanded in population size and land use, the surrounding areas became denuded of viable pastoral resources. The nomads found that they increasingly had to travel circuitous or indirect routes to avoid these growing settlements and to find adequate grazing and water.[4]

The creation and expansion of fruit orchards was a major part of these changes. Trees planted in summer pastures were mostly apple, apricot, walnut, almond, and pistachio, while in winter pastures, an area of high summer heat and dryness, they were primarily date, lime, lemon, orange, and pomegranate. Many villagers also grew grapes and figs, especially in areas between winter and summer pastures. People with claims to land and access to sufficient water planted saplings and vines, constructed irrigation systems, erected containing walls, and committed themselves to a dependence on chemical fertilizers and pesticides. The sources of water they walled in, often natural springs or the mouths of *qanats* (man-made underground water channels; see English, Afkhami, this volume), were

[3] Linda Schilcher notes that this pattern of government intervention to rescue rural people from urban entrepreneurial greed was also found elsewhere, such as in Syria under the Ottoman Empire in the 1880s and 1890s (personal communication, December 1997). She offered helpful comments on an earlier draft of this paper.

[4] Nick Kouchoukos *et al.* (this volume) note certain major trends in southwest Asia: the extension of cultivation into marginal steppe lands, expansion of irrigation, and degradation of the vegetation of the steppe. Unsustainable production systems, such as many forms of agriculture in arid and semi-arid lands, also cause the rapid depletion of resources and the destruction of the natural environment (Christensen, this volume).

thereby now off-limits to pastoralists, either traveling through the area or resident in nearby seasonal pastures. When I asked pastoralists in the 1990s to tell me the single most troubling difficulty threatening their main livelihood, many answered, "orchards."

Most pastoralists tried to increase the production of fodder crops for their animals and wheat for household use—flat bread remained the people's staple food. During times of inadequate rain and snow, naturally growing vegetation was insufficient for the herd and pack animals, and quantities of supplemental feed were needed. This feed included barley, straw, and fresh and dried alfalfa, clover, and hay. The prices of these commodities rose rapidly during times of low moisture, because crops grew poorly under such conditions and the regional demand for them was great, especially from settled people who also owned animals and did not have much if any natural pasturage. Hence pastoralists with available land, water, labor, and time tried to produce as much fodder as possible, to avoid high and often escalating market prices, without jeopardizing other aspects of their livelihood. In recording household budgets, I noted that barley and alfalfa comprised the single largest annual expense for many pastoralists. Dried sugar-beet pulp, a by-product of sugar factories in the province and used widely in the area in the 1970s, was no longer much used by the 1980s because of its apparent lack of adequate nutrients.

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The main advantage for the pastoralists in the expansion of their own and others' cultivation was their ability to graze animals on the stubble and other crop residues after the harvests were completed. Because of the mountainous terrain and the different altitudes where cultivation was practiced, the pastoralists herded their animals from one elevation to another in order to exploit sequential harvests. Remaining in their summer territories beyond the point when natural pasturage was depleted, the pastoralists came to rely heavily on the remnants in these fields. Mechanized combines, increasingly used in wide flat areas free of large stones, left the stalks of harvested crops standing as high as fifteen centimeters, which the pastoralists used for grazing. (By contrast, cultivators who harvested grain by hand sickles cut the crop close to the ground and left little for ruminants.)

Another new advantageous factor—one related to expanded irrigation—was the lush, wild, and opportunistic vegetation growing at the edges of cultivated fields, between trees in orchards, and along water channels. Pastoralists grazed their animals on the live vegetation, cut armfuls and filled gunny sacks to bring to the animals, and dried and stored quantities for use later on. They competed for this resource with the cultivators, who also needed animal fodder or who wanted to sell it for a profit. Some crops, such as dry-farmed barley and irrigated pulses, had spaces between plants where pastoralists could gingerly walk to collect wild vegetation.

In the 1970s and 1980s, some far-sighted pastoralists had planted poplar trees in summer pastures in order to use the trunks as roof beams and other supportive structures for the houses they expected they would ultimately build. During late autumn and early spring, unhampered by the heavy snows of winter, trespassers sometimes cut down these unguarded trees for their own use or just out of spite.

MANAGEMENT OF WATER

Many changes also occurred in the management of water. Until the 1960s and early 1970s most pastoralists in this large stretch of the southern Zagros Mountains had relied, without much human intervention, on the natural sources of water available. In winter pastures they sometimes deepened or fortified naturally occurring shallow basins to collect seasonal rainfall and runoff for the animals, while in summer pastures they dug shallow trenches to direct the flow of water from natural springs to the small pools they excavated. They always tried to find fresh spring or well water for drinking, food preparing, milk processing, and wool dyeing. Women and children aided by pack animals and goat-skin bags spent time and effort traveling to and from the nearest sources. An area of seasonal and unpredictable water, winter pastures were more troublesome than summer pastures, an area of many natural springs.

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Since the early 1980s, the management of water has become more controlled and government-assisted. Through officials of the Organization for Nomadic Affairs, the Ministry of Rural Reconstruction was instrumental in transforming water use for Qashqa'i pastoralists. With aid from the Ministry of Agriculture, these officials helped some people to secure low-interest bank loans and low-cost or subsidized construction supplies (such as cement) and assisted them in acquiring land-use permits from the Ministry of Natural Resources. In many areas, pastoralists together with hired professionals and workers dug wells, repaired or improved access to *qanats*, and constructed cement channels and catchment basins, all of which delivered clean, reliable water. In winter pastures, where springs are not common, the government dug many wells in convenient locations and also constructed or set up large, covered or enclosed, holding tanks and periodically filled them with clean water from tankers, at either low or no cost to the pastoralists.

Some of these recent efforts to manage water caused at least a temporary and possibly a longer-term or even a permanent decrease in water in the vicinity. In some areas of summer pastures, many natural springs dried up in the summer of 1997 following the winter's sparse snow and rain. Whether winter snows and rains in 1997-1998 will replenish the ground water and restore the flow of these springs is not yet known, although the seasonal residents in some areas did say that they expected the water to return, perhaps at decreased levels. More pessimistic, other residents blamed the nearby non-Qashqa'i cultivators and their over-exploitation of groundwater for the death of the springs. Where orchard owners and other large-scale cultivators, mostly non-Qashqa'i outsiders, dug deep wells and installed motorized pumps, a lowered water table resulted. According to residents and observers, once the pumps began to operate, water in the vicinity never returned to its previous levels and quantities. In the summer of 1997 many orchards held dead, dying, stunted, or fruitless trees due to insufficient irrigation water, although whether this condition came about primarily because of the year's poor supply of rain and snow or from a more long-term lowering of the water table is not yet clear.[5]

[5] Many authors, including Paul English (this volume), note that deep wells in arid and semi-arid areas, which extract water beyond replacement levels, fail to increase agricultural production and are in fact an ecological threat.

CONSTRUCTION OF SHELTERS

Human dwellings, accompanying structures, and animal pens and shelters also altered the landscape of areas formerly inhabited only by the seasonal, mobile tents of nomads. These developments are explained by the processes of modernization and the nomads' insecurity about their claims to land.

The building of dwellings accompanied a general rise in the standard of living for most Qashqa'i, who also wanted to protect and shelter the new possessions they now owned. Many pastoralists, even those who were fully nomadic, chose to construct huts and houses for themselves and pens and shelters for their animals in winter and/or summer pastures. When they saw that these dwellings were likely to be vandalized during the seasons when they were absent, they cut back on their efforts and investments. For example, they bought previously used, inexpensive wooden and metal doors and window frames when the new ones they had purchased and installed were roughly pried away from the walls and stolen by trespassers. Even though they always stored miscellaneous equipment in these dwellings when they departed for their other seasonal pastures, they learned not to lock the doors, for the cost to repair the damage that thieves caused by breaking locks, doors, and windows was greater than the cost of replacing any stolen items.

Using locally available rocks for the foundations and tree branches, long reeds, and woven-reed mats for the walls and roofs, many men built simple one-room huts for their families in winter pastures, which helped to protect them from the winter's rain, snow, mud, wind, and cold. Some men built more substantial huts by also using cement mixed with dirt for mortar and flooring, cement and plaster for the walls, and wooden beams for the roofs. They often talked about how miserable life had been in past winters when only goat-hair tents sheltered them. Their perception of the nomadic life's rigors seemed to have changed, especially when they compared their physical comfort in the winter with that of their house-dwelling relatives.

Many nomads also built more substantial one-room or two-room houses in summer pastures. They did not need physical shelter as much in the summer, when the weather is dry and usually mild, but because they have recently chosen to arrive there earlier in the spring and to stay later in the summer, they did want more protective shelter during these two often cold and windy periods. People with increased agricultural activities, more prevalent in summer pastures than in winter ones, occupied the land for a longer duration than in the past. Those owning trees or vines bearing fruit needed to collect or oversee the autumn's harvest.

People who improved their access to water also wanted to live nearby on a more permanent basis. Until the late 1970s the nomads had moved periodically from place to place in seasonal pastures to find fresh grazing and clean campsites, but more recently they have remained in specific locations, often to exploit the water over which they have now claimed greater rights. Needing to travel farther and farther away from camp every day to locate adequate grazing, shepherds and animals were burdened by these more stationary residential practices.

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The pastoralists' decreased reliance on hired shepherds figured in their decisions to construct animal pens and shelters, where they could temporarily leave their animals unsupervised. Herd animals in summer pastures and sometimes in winter ones used to sleep or rest in the open and were subject to predator attacks and stampeding if the owners and shepherds were not vigilant enough. Since the late 1970s, many households were forced to devise new ways of handling the actual herding and daily animal care, largely because of the scarcity of hired shepherds in the region. Reflecting the shortage, shepherds' salaries rapidly escalated, making the hiring of herders even more problematic and forcing the nomads to rely on more protective pens and shelters.

Use of animal pens facilitated the accumulation of dung, which all pastoralists periodically collected for use as fertilizer in their orchards or to sell to other orchard owners. Mounds of dung stood beside the pens to await transport.

Many pastoralists also built huts, houses, and animal shelters in their seasonal pastures because of their insecurity about land rights.

By 1998 the government had still not passed the land-reform legislation that was promised soon after the revolution, and pastoralists claimed that the existence of permanent structures would help them to fortify their rights to the land in any eventuality. Dwellings offered "hard facts" to touring government agents assigned to handle disputes over land.

HUNTING AND GATHERING

Patterns of hunting and gathering continued in the 1990s in many of the same ways as in the 1960s and before. The major changes were in the use of firearms and the decreased exploitation of natural resources along the migratory routes.

The shah had forcibly disarmed the Qashqa'i in the 1960s because of his fear about their military threat to him. With his ouster in 1979, many Qashqa'i men immediately rearmed themselves and resumed game hunting in their territories. The climate of freedom also affected other Iranians who were enthusiastic about hunting. Within a year or two of the revolution, the most prized game animals in southwestern Iran were said to be exterminated. The game included wild sheep and goats, ibex, gazelles and other antelopes, and deer—in fact, any animals with horns to be displayed as trophies. Several wildlife preserves created by the shah in the southern Zagros were rapidly decimated, the few game wardens still coming to work profiting from bribes and even partaking in the slaughter themselves. Many Qashqa'i men claimed to have practiced wildlife conservation in the past, but their efforts after the revolution were pointless, given the many outsiders eager to shoot any and all wildlife. Qashqa'i men had grown up learning the mountaineering skills necessary to collect the game after they had pursued and shot it, skills many urbanites and other outsiders lacked. These outsiders often shot animals that they left dead or dying where they fell, and hence the activity was simply sport and not, as in the Qashqa'i case, also an important source of food. Qashqa'i hunters continued to track wild boars, bears, mountain lions, wolves, hyenas, and other predators preying on their flocks, and, as before, they avidly sought wild game birds (partridges, quail) to consume as food. Those living near lakes and rivers hunted water fowl and fished. At least a few men found the use of dynamite to be an effective way to capture quantities of fish with little effort.

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Gathering of many natural resources was still a major part of the Qashqa'i subsistence and economy in 1998. In fact, reliance on these items allowed some families to continue with migratory pastoralism when they would not otherwise have had adequate food or income. Dairy products for home consumption were available only in the spring and part of the summer (except for limited quantities of dried milk solids saved for the winter), and hence all pastoralists enjoyed, if not depended on, the many foods they gathered throughout the year. The seasonal residents of winter and summer pastures, and their settled kin who came to visit, continued to exploit their own and surrounding territories for many kinds of human foods (wild fruits, nuts, vegetables, herbs, mushrooms, truffles, bird eggs), animal fodder, medicines, salt, dyes, fuels, and raw materials (wood, reeds) for tools and other constructed objects. Most of the items were seasonal in nature, and the pastoralists sought them according to the schedules and techniques they knew in detail.

Because most people now traveled by truck between winter and summer pastures, they were no longer able to gather resources along the migratory routes. The paved roads they followed bypassed the valleys and mountainsides where most resources were located. Those who had acquaintances in villages along the migratory routes were eventually able to barter for some items, and itinerant peddlers brought others. People who visited these areas always collected the resources that were unique or special there and later shared them with others. The men who accompanied the herds on the spring migration gathered what they could, but their time was occupied by herding and safeguarding the animals, and they lacked the means to process or to transport quantities of gathered resources.[6]

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The non-Qashqa'i people who used to gather natural resources before the 1970s in Qashqa'i territory, primarily for sale but also for their own consumption, came less frequently or not at all in the 1990s. The resources included wood (for firewood, making charcoal, and construction), wild fruits and nuts, herbs and many other green plants including wild artichokes, mushrooms, truffles, garlic, and tree and shrub saps including the exported gum tragacanth. Guided by western-inspired notions of environmental protection, the Ministry of Natural Resources was supposed to control or eliminate these activities on what was usually nationalized pastureland, but it did not do so successfully under the shah's regime. Under the Islamic government, the ministry was more effective in preventing outsiders from exploiting Qashqa'i pastures in these ways or in limiting their numbers. Collectors of gum tragacanth, for example, could buy permits from the ministry enabling them to exploit certain territories if they also obtained the approval of the resident pastoralists. Qashqa'i people, many of whom relied on selling and consuming these same resources, collected them on their own lands, especially if they held title or usufructuary deeds.

Because of the increasingly widespread use of electricity and propane and natural gas by many people in southwestern Iran, the

6 For a detailed discussion of gathering by pastoralists in Morocco, see the article by Susanne Steinmann (this volume).

demand for firewood and charcoal decreased. Agents of the Ministry of Natural Resources tried to protect the environment from further deforestation and depletion of other natural resources. Until the revolution, the ministry's forest rangers used to patrol sections of Qashqa'i territory but were susceptible to bribery and appeared to cause little change in how people actually exploited the land. Since the early 1980s their activities have focused instead on pursuing the claims that residents brought against trespassers engaged in destructive acts. Aided now by motorized vehicles, many Qashqa'i pastoralists transported quantities of firewood from winter pastures to summer ones, where wood was scarce and where camel dung, formerly used as fuel, was no longer found.

THE GOVERNMENT

The government continued to play a major role in the 1990s in determining who resided on and worked which parcels of land, but in some different ways from the government in the 1960s and 1970s. The Islamic government supported people it classified as "nomads" (*ashayer*) and offered them services and support that the previous two shahs (1925-1979) had not. Short-term and long-term leases for land still classified as "pastures," as well as leases and ownership deeds for land still considered as "cultivable," were obtained by many people through various government ministries. People who chose to settle in villages and especially in towns found it difficult to hold onto pastoral and agricultural land in their customary seasonal territories. Some families chose to divide their labor force in order to retain rights to land. As an example of an increasingly prevalent pattern found within extended families, one man migrated between winter and summer pastures with the sheep and goats and maintained the family's pasture-use deeds, while his brother lived in a village to cultivate grain and fodder crops on land he rented or purchased, and a third brother resided in a town to work for wages in a factory or government office.

Because of the increasingly widespread use of electricity and propane and natural gas by many people in southwestern Iran, the demand for firewood and charcoal decreased.

As previously indicated, governmental ministries and agencies also aided the pastoralists in many other aspects of their lives by building roads and bathhouses in remote areas and by offering veterinary care, pasture seeding, water management, bank loans, commodity pricing, economic cooperatives, and formal education.

Some high-level officials of the Islamic government were fascinated by people in Iran whom they considered to be exotic or picturesque. While the last two shahs had feared many of these same people for the military and political threat they were believed to pose, the current government appeared to be less concerned. While providing such people with many services, the Islamic government also developed programs to use them for its own purposes and by various means, including the media. For example, from the 1980s until 1995 a national, annual Day of the Nomad was officially celebrated in different regions by provincial dignitaries and spectators to mark the nomads' many contributions to Iran's history, economy, and cultural diversity. The Ayatollah Khomeini had declared that nomads were the "treasures of the revolution." Government-sponsored or-supported publications, films, and television programs about nomads were designed to provide appealing images for a national and sometimes international audience.

Apparently unintentionally, and perhaps ironically, such official attention helped the Qashqa'i (and other similar groups) to pursue their chosen lifestyles, which for many remained a combination of pastoralism and nomadism, and to engage in customary practices that these officials considered colorful or quaint. For example, many Qashqa'i women were allowed to maintain their customary dress and head gear, despite the attire's violating the requirements of modest "Islamic" dress imposed on almost all other Iranian women, especially in urban areas.

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Many agents of the Islamic government, especially in ministries having special interests in nomads and pastoralists, were of ethnic, tribal, pastoral, and nomadic backgrounds and had often been born and raised as nomadic pastoralists themselves. They had benefited from the government's expansion of formal education into tribal areas and had continued their education in towns and cities. They tended to be supportive of and sympathetic to the needs of people who perpetuated nomadic and pastoral lifestyles despite difficulties. When I asked Qashqa'i people about the changes in their relationship with the government after the revolution, many responded by noting that people with identities similar to their own were now government officials who supported rather than hindered or oppressed them.

THE MARKET ECONOMY

The impact of the market economy is another important factor in understanding the ways the Qashqa'i used land. They had always directed their productive activities toward market demands and not just toward household consumption. When the price of sheep and goats was considered good, they placed more attention on animal husbandry. When regional needs for agricultural products were great, they tried to produce their own and relied on the market for the purchase of more. Market demands for the pastoralists' dairy products, other pastoral produce (woven goods, sheep wool, goat hair, skins), and gathered resources also played a role in determining the economic decisions that households made on a seasonal and yearly basis.

Since the revolution, especially during and since the Iraq-Iran war (1980-1988), national inflation was high and rising, and all Iranians, not just Qashqa'i pastoralists, were forced to change their patterns of production and consumption. Qashqa'i and other producers of essential market commodities were especially affected by volatile and unpredictable economic trends. The pastoralists complained that the prices they received for live sheep and goats did not rise as rapidly as the costs of the goods they needed to buy. They were especially disturbed by the high mark-up in meat prices, from the amount they received per kilogram at government slaughterhouses to the amount customers paid in urban butcher shops. The government and a series of middlemen, and not the actual producers, derived the most profit from the pastoralists' enterprise. In some years the pastoralists incurred more expenses for tending the animals than they received for their sale. Because of rapidly escalating prices in general, by 1996 most Qashqa'i people were financially unable to make major changes in the ways they exploited the land, such as adopting new mechanized agricultural equipment and installing irrigation works. Even commonplace construction materials such as bricks and cement became prohibitively expensive. The election of a new, moderate president of Iran in 1997 brought hopes that the national economy would be brought under greater control.

CONCLUSION

In this paper I have outlined a variety of factors that have influenced the ways that many Qashqa'i nomadic pastoralists used land during the past thirty years and how and why these patterns have changed. Although the subject is beyond this paper's discussion, I will mention that certain new patterns of local social organization were in large part explained by changes in the productive activities of people during this period. Groups of families could better exploit a larger territory, engage in diversifying economic activities, and interact with the market more successfully if they cooperated with one another.

At a time when we see that some locally managed and controlled subsistence strategies appear to be more viable, sustainable, and protective of the environment than, for example, large-scale agropastoral corporations, the case provided by the Qashqa'i may be informative. The Qashqa'i make the best of the inherent environmental constraints of their rugged, mountainous, and semi-arid lands, in ways that have served them, their ancestors, and those who preceded them for hundreds if not thousands of years. They have also made frequent adjustments in the ways they related to the land. They do not blindly follow patterns that they had practiced in the past, nor do they ignore the consequences of the actions they do take. Outsiders can at least try not to impede them as they continue to find

The Qashqa'i make the best of the inherent environmental constraints of their rugged, mountainous, and semi-arid lands, in ways that have served them and their ancestors for hundreds if not thousands of years. They have also made frequent adjustments in the ways they related to the land. They do not blindly follow patterns that they had practiced in the past, nor do they ignore the consequences of the actions they do take.

solutions to the many constraints that confront them. One prevalent theme in the recent literature on the natural environment is the concern about depletion and destruction, and the solution often proposed is the removal of people. But when we compare, for example, Qashqa'i land-use strategies with the whole-scale destruction wrecked upon the environment by multinational corporations, nation-states eager for "development," and warfare, it seems ridiculous to try to prevent people such as the Qashqa'i from living in the ways they have deemed productive for themselves and their society.

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Gender, Pastoralism, and Intensification: Changing Environmental Resource Use in Morocco

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ABSTRACT
Through a study of the sedentarization of the Beni Guil pastoral nomads of eastern Morocco, this paper examines how gender interacts with environmental and socio-economic change. Based on extensive fieldwork with the Beni Guil, this paper demonstrates how gendered resource exploitation–in particular, the collection of mushrooms, medicinal plants, and fuelwood–is recast through sedentarization, urbanization, and commercialization. The case of the Beni Guil suggests that certain accepted theories of the consequences of settlement for nomad women and their local environments should be re-examined in order to understand better the past and present, and to plan for the future.

INTRODUCTION

Nomadic pastoralism was once a dominant feature on the North African landscape. Since the end of World War II, however, extensive nomadic herding has steadily shifted toward more intensive agro-pastoral production on marginal grazing lands (Bencherifa and Johnson 1990). This trend raises concerns about the social consequences of cumulative land-cover change, particularly land-use intensification, land degradation and declining species diversity, and challenges researchers and policy makers to address the complexities of local scale land-use systems (Turner *et al.* 1990). Studies that explore the interaction between cultural change, economic development and environmental sustainability have generally recognized the importance of understanding the socio-political contexts within which land-users make resource decisions (Blaikie 1985). Yet, questions about how gender relations affect intra-household environmental management remain unclear, particularly in the Middle East and North Africa.[1] Identifying the constraints and opportunities that shape gendered land-use behavior assures a more accurate assessment of environmental change at the scale where decisions are made.

Understanding the human dynamics of environmental change is important in semi-arid rangelands of North Africa, which cover approximately 385,000 square kilometers and represent 25% of the region's productive food raising area (Abbab 1994). More than 15 million people, or one quarter of the region's population, derive their livelihoods directly from land-based activities of mixed farming and herding (Abbab 1994; Le Houerou 1993). Such an understanding is particularly important to Morocco, where 64% of the land area is classified as rangeland, pasture, woodland or forest and where almost half of the working population derives its livelihood from agriculture or livestock raising (UNEP 1993).

[1] Despite the prolific literature on gender, resources and sustainable development, in Asia, Latin America and sub-Saharan Africa, geographical literature on women and the environment still ignores these nature-society questions in the Middle East and North Africa (e.g., Momsen and Townsend 1987; Momsen and Kinnaird 1993; Rocheleau, Thomas-Slayter and Wangari, eds. 1996).

Central to the broad discourse on sustainable natural resource use in developing countries is whether change results in positive or negative social and ecological outcomes (Blaikie and Brookfield 1987). In North Africa, as elsewhere, more intensive herding and farming practices help sustain a growing human population. But overgrazing, soil erosion, expansion of cultivation, and irrigated agriculture threaten the long-term productivity of these rangelands and the livelihoods that depend on them (Swearingen 1994). These problems persist in part because the perceptions and interests of land users are neglected in environmental change analysis and conservation planning (Blaikie 1985).

In the Middle East, and in Morocco specifically, researchers have generally addressed the causes of nomadic sedentarization and associated environmental consequences at the community or regional scales. Their literature generally approaches the problem of landscape change through an analysis of demographic, historical and political economic factors, or transformations of regulatory institutions and land tenure systems (Abbab 1994; Artz, Norton and O'Rourke 1986; Bencherifa 1996; Bencherifa andJohnson 1991; Mendes and Nargisse 1992; Tozy 1994; Trautmann 1989). However, these analyses obscure the changing production decisions at the household level where broader economic and environmental consequences are felt.

The paucity of intra-household environmental research in the region also results from cultural values that limit contact between male researchers and local women. With few exceptions, male researchers have predominated field work in pastoral and agro-pastoral communities in North Africa. Furthermore, conservation and development projects in Morocco are generally implemented and managed by men who work with male, but not female, land users. However, women are quite visible across the rural landscape collecting water, fuelwood and other plant resources, herding animals and working in fields.

Using gender as the entry point for understanding household natural resource management could lead to more accurate information about how gender-specific tasks shift in response to ecological and socio-economic changes. The research and findings of this article are, therefore, gender-based. This article hopes to contribute to more effective range conservation projects that solicit input from the appropriate land-user groups while, at the same time, challenging assumptions and myths about who manages what resources.

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This article addresses these concerns by studying the settlement of the Beni Guil pastoral nomads in eastern Morocco. Two interrelated questions will be raised: How do gender-specific natural resource uses respond to ecological and socio-economic change? And, how do shifting gendered land-use patterns affect environmental change at the local scale?

Based on data collected during 10 months of field research[2] among the Beni Guil pastoral nomads, findings suggest that:

- in mobile tents, women and men operate with separate sets of resource management tasks, but these tasks are increasingly shared as households become settled;
- sedentarization and female seclusion reduce women's opportunities to collect natural rangeland resources and is most acute in villages where (unlike larger towns) few alternative points of access exist; therefore,
- the gender ratio for who collects wild mushrooms, truffles, medicinal plants and fuelwood is most equal in villages and suggests that control shifts from women to men; and truck transportation and the weekly market (*souk*) in towns provide alternative opportunities that women use to regain control over resources that contribute to their household responsibilities.

[2] Field research was conducted in eastern Morocco from September 1996 to June 1997. The project was sponsored by the Social Science Research Council's Near and Middle East Program and the National Science Foundation. The research contributes to the completion of a doctoral degree in geography at Clark University.

GENDER THEORIES AND RELEVANCE TO THE BENI GUIL CASE

The rationale for a gender analysis of land-use practices is that women and men have different, vested sets of interests in the natural resources they manage depending on their responsibilities in maintaining the household (Fortmann 1996; Rocheleau 1991). Men and women, particularly in sex-segregated societies, face different constraints and opportunities in meeting rapidly changing livelihood responsibilities. In contrast to the scanty research on women and the environment in the Middle East and North Africa, a large literature exists in anthropology, sociology, and history analyzing how urban Muslim women's status and political power change in response to development (*e.g.* Ahmed 1992; Keddie and Baron 1991; Lazreg 1994; Saadawi 1986; Tucker 1993). The literature on "la condition Feminine" in rural Morocco is also dominated by anthropological (*e.g.* Hilse-Dwyer, Maher and Rosen, in Beck and Keddie 1978; Schaefer-Davis 1993) and sociological research (*e.g.* Belarbi 1995; Mernissi 1984; 1997). These studies attempt to understand how development affects womens' economic, social or political gains and losses and provide useful insights for development projects that target women's needs. But, their research agenda does not address the flexibility of household gender roles and the implication, if any, for environmental change if those roles shift. Although largely absent from the Muslim Arab regions, the importance of gender analysis in explaining environmental change is demonstrated in the case-study literature from rural communities in Asia (Agarwal 1994; Joekes 1995), Sub-Saharan Africa (Carney and Watts 1991; Fortmann 1996; Jackson 1993; Schroeder 1997; Thomas-Slayter and Rocheleau 1995), and Latin America (Rocheleau *et al.* 1996; Townsend 1993).

The literature on gender, environment and sustainable development is inspired to varying degrees by two dominant approaches: (1) gender and environment and, (2) ecofeminism. The first grew out of the WID (women in development) approach to project and development planning interventions. This perspective emphasized the importance of women as managers of environmental resources, their vulnerability to diminishing natural resources, and the need to direct conservation programs toward assisting women (parallel or separately from men).[3] The practice of adding women on without considering fundamental inequities in class and gender relations eventually led some socialist-feminists to adopt alternative gender and development (GAD) or genger and environment (GED) approaches.

[3] The currently on-going range conservation project in eastern Morocco is an example of this approach.

The ecofeminist approach is ideologically driven. It rests on the philosophy that women have an inherent affinity with nature, as opposed to men's desire to control and dominate nature through science, technology and development (see Merchant 1989; Mies and Shiva 1993; Plumwood 1993; Shiva 1987). Although both of these approaches draw attention to women's interests in environmental resources they often have rigid conceptualizations of gender relations (Agarwal 1995; Jackson 1995; Joekes *et al.* 1994) I agree with those who propose an alternative approach that analyzes the flexibility of social, economic and ecological contexts that either maintain or transform traditionally male and female resource management tasks (Braidotti *et al.* 1994; Rocheleau, Thomas-Slayter and Wangari 1996; Jackson 1993).

These theoretical advances in gender and environment studies have been supported primarily by case studies in agricultural communities and still need to be examined within livestock-based livelihood systems. To date, gender-based research among pastoral nomads has examined the links between economic development, commercialization, sedentarization, over-exploitation of nature and women's poverty (see Horowitz and Jowkar 1992).

One such study has assessed the role of technology in encouraging settlement and the consequent gender-based resource losses or gains. Dawn Chatty's work among nomads in Syria (1976) analyzed the gender-specific consequences of the introduction and rapid adoption of trucks. Chatty found that trucks deepened gender-based inequalities over household resources. More recent research in Oman showed that women utilized a variety of informal institutions and networks to reclaim their interests within the realm of male decisions, including adoption and use of new technologies (Chatty 1996). Similarly, in her detailed ethnography of pastoral nomads in Iran, Lois Beck argues that women acknowledged the benefits of new technologies and encouraged their adoption (Beck 1991; 1997). These anthropological studies, however, do not address the environmental outcomes of gendered interests and control of new technologies.

For example, during the late 1970s and early 1980s, the Moroccan government installed motor-driven deep wells in drought-prone rangelands. These technologies secured permanent water resources and encouraged more intensive land use (Bartel 1985). Greater availability of truck transportation today also facilitates access to commercial town markets where animal feed is sold. Beni Guil men use trucks to haul water and fodder to remote tent sites and villages, a practice that allows rural households to support more animals on smaller parcels of land. This practice has encouraged sedentarization and over-exploitation of rangeland resources. Moreover, since men spend more time in town securing feed resources, women increasingly assume men's herding responsibilities. But women herd only close to home, a practice that further denudes vegetation cover near fixed settlements (Steinmann, in press).

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Among the Beni Guil, trucks facilitate access to commercial opportunities in towns and increase women's dependency on male income earners. Women, however, are not passive agents. Older women, particularly those in tents and villages, find ways to access truck transportation into town where they take advantage of commercial opportunities. The author often observed older women—who are less constrained by the cultural norm of seclusion— successfully negotiate rides with male truck drivers. This observation points to a weakness in feminist development theories that ignore the diversity in women's abilities to secure their interests within broader structural constraints.

Throughout the Middle East and Africa, case studies from livestock-dependent households suggest that pastoral women lose economic and political power as a consequence of economic development and environmental degradation (Abu-Lughod 1993; Carr 1977; Horowitz and Jowkar 1992). This literature argues that in geographically isolated mobile tents pastoral women's roles as providers of subsistence foods, medical resources and fuelwood gave them status and power. But, as nomadic households become integrated into a cash economy women lose control over those resources thereby becoming more dependent on male income earners (Horowitz and Jowkar 1992; Talle 1988). These approaches address the social implications of settlement and commercialization, but they do not consider the environmental consequences.

The Beni Guil case suggests that the effect of settlement on women's access to natural rangeland resources is more nuanced. For example, with the exception of poor women in towns, Beni Guil women's collection of natural resources declined linearly and significantly from mobile tent to village to town households. Corresponding to this change, men's collection activities increased. However, access to rangeland products (such as wild mushrooms, truffles and medicinal plants) and knowledge about them declined only for women in villages and not among women living in town.

Furthermore, many Beni Guil households divided their livelihood activities between two locations: mobile tents and fixed homes. In this way they took advantage of diverse commercial and natural resources. This represents a strategy that alleviates pressure on those resources and requires flexible intra-household labor roles. The Beni Guil example therefore suggests that theories that do not question the simplistic dualism of nomadic versus settled households need reassessment.

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The differences in gendered resource management across locations from tent to village and larger commercial towns also demand moving beyond static gender analyses to more complex analysis of flexible gender roles. Both a 'developmentalist' view (see Joekes 1994) and feminist political ecology (see Rocheleau, Thomas-Slayter and Wangar 1996) provide alternative and corrective approaches. While acknowledging gender differentiated resource control and management tasks, these perspectives argue that gender roles are not ascribed but are "merely part of general entitlements and capabilities" (Joekes 1994). They posit that understanding local-scale environmental change requires attention to class, ethnic and gender relations among land managers (Carney and Watts 1991; Rocheleau 1991; Schroeder 1993). These approaches address both the social and environmental consequences of changing livelihood systems.

In an attempt to better understand the complexity of household land-use decision making, academics and development practitioners have also recognized the value of incorporating indigenous environmental knowledge systems and gender analysis into conservation planning (Bebbington 1990; Carney and Watts 1991; Chambers 1983; Davis 1995; McCorkle 1989; Richards 1985; Rocheleau 1991; Thrupp 1989). In eastern Morocco, growing concern about land degradation in the 1970s led to a series of studies, including one on traditional range management institutions and indigenous knowledge systems.

These land-user perspectives provided guidelines for the implementation of one of Morocco's most costly and extensive range conservation projects (hereon after referred to as the PDPEO

Project).[4] Project extension workers solicited input from local herders concerning their use and knowledge about rangelands. The project's gender component, however, focused only on women's income generating opportunities - not on their resource use.[5] The project design also conceptualizes women's and men's activities as operating in entirely separate spheres. This WID approach of "adding women on" obscures the ways gender relations within households meet changing livelihood responsibilities.

Settlement and commercialization's impact on gendered management of range resources remains unclear. This fieldwork is particularly problematic in more conservative pastoral societies, such as the Beni Guil and other bedouin, where female seclusion and gender segregation has prevented male researchers from gathering gender-specific information.[6] Only a few recent studies in Morocco (*e.g.* Alaoui 1995; Davis 1996; Steinmann 1993) and one edited volume (Belarbi 1995) have analyzed how socio-economic and environmental change affect gendered management of natural resources. The Beni Guil case provides a new empirical study that focuses specifically on flexible intra-household resource strategies and how these adjust to and shape environmental change.

BACKGROUND AND ECOLOGY OF THE BENI GUIL STUDY AREA

Much like other pastoral nomads across the region, the Beni Guil represent a large community whose livelihoods are rapidly shifting from extensive large-scale animal herding to intensive and sedentary agro-pastoral activities (Bencherifa 1996). Although the Beni Guil's population is small (54,000 based on the 1994 CENSUS) their territory covers 25,000 km^2 of the semi-arid steppe of Morocco's Eastern High Plateau region. This represents a significant portion of Morocco's rangeland resources. And while large scale nomadic movements of the past represented a sustainable adaptation to the ecology of arid environments, demographic, social and economic pressure has resulted in more intensive land-use practices. Some evidence suggests that the long-term sustainability of agricultural and pastoral livelihoods in this region are threatened (Le Houerou 1993; Sidahmed 1992). Others have found that the social and human benefits outweigh the environmental costs (Bencherifa 1996). Findings here suggest that these environmental and socio-economic changes also carry different implications for gendered land-use practices.

Until the middle of this century, Beni Guil livelihoods depended on raising their livestock by utilizing seasonally available grazing and water resources throughout their territory. Seasonal climate change prompted the Beni Guil to move their tents on camels and herd

[4] The "Project de Developpement des Parcours et de L'Elevage dans L'Oriental" (PDPEO Project) is a State and internationally funded range conservation project at a cost of $10 million (Department of Agriculture, Bouarfa 1996). The 10-year project began in 1990 and covers some 3.2 million hectares of Morocco's eastern High Plateau region. The objectives of the project are to curb land degradation and increase living standards for the 76,000 inhabitants in the project zone. The project goals are met through: (1) diversification of fodder resources through government subsidized feed supplements, veterinary services, and transportation services; (2) placing 750,000 hectares of key rangeland into grazing fallow; (3) restoration of range cover through planting of fruit, fuelwood trees and fodder shrubs; (4) setting up wind barriers to curb dune accumulation; (5) better management of water points; (6) establishment of local pastoral cooperatives to manage distribution of new inputs and assume range-management responsibility, and; (7) income generating projects for women. The PDPEO Project is funded by the African Development Bank, International Fund for Agricultural Development, and the Moroccan Government.

[5] BenJelloun (1996) conducted an extensive study among Beni Guil women evaluating their constraints in accessing natural and commercial resources. The results of the research identified appropriate income generating activities for women. Three female extension workers currently manage women's extension services. These include: wool and rug weaving cooperatives; chicken and rabbit raising; health care education, and; sewing lessons for girls.

[6] As a foreign and formally educated woman, I was able to engage in participant observation and conduct research among both men and women.

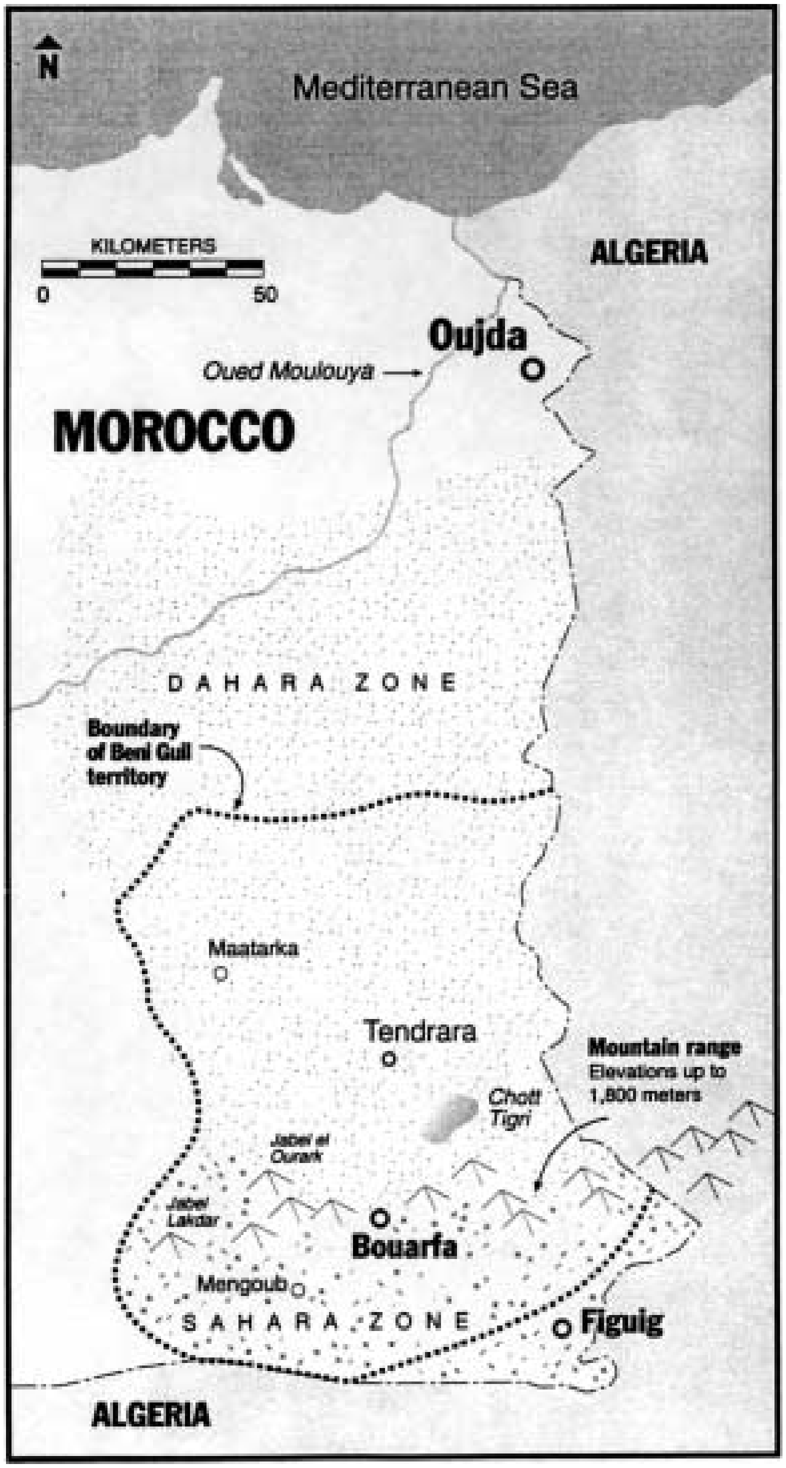

Figure 1 Research area of author. Map: Steinmann.

their sheep and goats over distances of some 250 km to take advantage of resources in diverse ecological zones. Although there are several ecological niches within this area, two dominant environments define the territory: the northern high plateau (*Dahara*) and the more arid southern pre-saharan environment (*Sahara*). These two landscapes are separated by a small mountain chain with elevations of up to 1,800 meters.

Rainfall diminishes from north to south with a maximum of 450 mm in the Dahara and 150 mm in the Sahara. Corresponding to the aridity index, vegetation cover varies between the two regions. In the Dahara, perennial grass *(Stipa tenacissma*) and the woody shrub *(Artemisia herba alba)* dominate. In more arid conditions of the Sahara, a greater variety of woody shrubs and succulents (*Arthrophytum scoparium, Festuca algeriensis, Retama retam, Ziziphus lotus*) replace perennial grasses. Annual plants (valued for their fodder and human medicinal properties) thrive in moist ecological niches such as low lying depressions (*dayas*) where rainfall run-off water collects, and at higher elevations in the mountains that divide the Dahara and Sahara. Wild mushrooms (*Agaricaceae*) and large ground truffles (*Terfezia, Tirmania*) are found in areas where soils maintain moisture, such as in the *daya* Chott Tigri.

Until the late 1960s almost all Beni Guil households were fully mobile tent units. But, over the last thirty years, 35% of the Beni Guil families have settled permanently, and almost 80% of the households have shifted production to mixed farming, herding and other commercial activities.

Large-scale migrations were well adapted to these ecological and climatic variations (Bencherifa 1996; Johnson 1993). Threat of winter snowfall encouraged the tribes on the Dahara's high plateau (1600 m) to move their herds to lower elevations and warmer climates in the Sahara. On their migration, the Beni Guil crossed alluvial plains, the Chott Tigri *daya* and several small mountains (Jabel El Ourark; Jabel Lakdar; Jabel Dakh). Along the way, men herded animals to diverse grazing resources and women stopped to collect a variety of wild foods, medicinal plants and fuelwood. Similar reverse migrations from the Sahara to the Dahara occurred in the spring.

Until the late 1960s almost all Beni Guil households were fully mobile tent units. But, over the last thirty years, 35% of the Beni Guil families have settled permanently, and almost 80% of the households have shifted production to mixed farming, herding and other commercial activities (Bencherifa 1996). This change has discouraged large scale migrations between the Dahara and Sahara. Only wealthy households that own trucks still move animals across these diverse ecological zones. The increased use of trucks or the interruption of long-distance migrations for settled households has had variable effects on intra-household resource uses.

METHODOLOGICAL APPROACH AND DISCUSSION OF FINDINGS

Gender analysis, as an entry point to this research, sheds light on hidden male–female power dynamics that affect access to and management of natural resources. It uncovers complexities of land-use decisions at the household scale and helps explain emerging land-cover patterns associated with pastoral settlement. Identifying gender-specific resource management roles has important implications for development and range conservation programs, particularly where culturally prescribed gender roles influence the range of acceptable strategies for dealing with changing social, economic and natural environments.

Both quantitative and qualitative methods were used to examine the two research questions:

- How does gendered access to and management of natural rangeland resources change in response to sedentarization and commercialization of pastoral livelihoods in eastern Morocco?
- How does gendered resource use affect the environment?

This discussion presents data concerning three types of vegetation resources: wild mushrooms and truffles, medicinal plants and fuelwood. The author selected these resources because they represent important food and health resources to the household and because their collection has variable environmental consequences. As stated earlier, primary data was collected during ten months of participant observation in 159 Beni Guil households. These households represented various points on the continuum from mobile to settled (tent, village, town). Because Beni Guil migration patterns have essentially ceased between the ecologically distinct areas of the Sahara and Dahara, research was carried out in three geographic locations of the Beni Guil territory:

- among fully nomadic mobile tent households in the Dahara and Sahara areas;
- in two small rural villages (Maatarka and Mengoub Gare); and
- in the two larger commercial towns: Tendrara and Bouarfa.[7]

[7] According to the 1994 national census, human population numbers in villages were 286 in Mengoub Gare; 520 in Maatarka. As for towns, the population of Tendrara was 5,633 and Bouarfa 19,616.

PRELIMINARY RESEARCH AND QUESTIONNAIRE SURVEY DESIGN

After a two month period of preliminary research and participant observation, the author confirmed that the degree of household mobility and socio-economic class constituted important variables determining gendered resource collection patterns. Since household wealth is culturally specific, five local informants from a cross-section of the settled Beni Guil communities helped define the class categories and compiled a list of households within each strata. This participatory *wealth ranking* exercise provided the author with local definitions of class (Grandin 1988).

Long distances between tent households prevented gathering a group of informants for the wealth ranking exercise. Instead, the author asked local Beni Guil political representatives (*Sheiks* and *Mukkadems*) from each tribal lineage to rank tent households. The author then re-confirmed the classifications with key indicators including: tent size; approximate number of animals; types of animals owned; transportation resources (*e.g.* mule-drawn carts or trucks); and, the number of non-pastoral wage earners contributing to the household. Households were then randomly selected for formal interviews. In the selected households, 159 women and 70 men answered formal survey questions about mushroom, truffle, medicinal plant and fuelwood collection.

In order to identify gender-specific management of these resources, the survey asked male and female interviewees to:

- indicate what rangeland resources they collect for the household;
- identify locations and distances to these resources;
- identify other household members who provide this resource to the household;
- note whether the quantity and quality of the resource had gone up or down;
- identify the number of medicinal plants they knew; and
- indicate whether they bought or sold any of these resources at town markets.

Data gathered in formal survey questionnaires was analyzed using the SPSS 6.1 statistical program. The author analyzed categorical variables using chi-square tests and logistical regressions. For interval data, t-tests and multi-variate regression tests were employed. However, formal questionnaires failed to capture the full range of insights needed for the study; therefore, several qualitative methods supplemented survey data.

QUALITATIVE AND PARTICIPATORY METHODS

In order to understand how settlement affected resource management and landscape change, men, women, boys and girls from each research site were asked to participate in ***gender resource mapping.***[8] This technique helped elicit input from women and men about their land-use practices, degrees of accessibility to the resource and knowledge about the diversity of plant species and their locations in the landscape.

The maps revealed that men and women have very different ideas about the relative importance of natural resources. These differences were related to gender-based responsibilities for providing the resource to the household. While men's maps identified and located almost all of the *dayas* and water wells (sites where men take animals to graze and water), women's maps included many mountains (where medicinal plants grow) and sites where they collect fuelwood and mushrooms. The scale of the maps also varied significantly by age and gender, reflecting mobility constraints associated with settlement and female seclusion. Strict surveillance of women and their infrequent interaction with outsiders sometimes led women to answer survey questions that matched culturally prescribed gender myths[9] rather than current activities. Consequently, *participant observation* verified that more flexible gender roles existed than revealed by the formal survey.

In order to measure environmental changes associated with changing gendered collection patterns the author measured land cover and species diversity rates using 100 meter intercepts. These land cover intercepts were carried out in several key locations: on remote portions of uninhabited rangelands, near mobile tent sites, near villages, and near larger towns. The author measured the height and the width of each plant along the intercept line and catalogued its name for information about species diversity in a given area. Several 10 meter by 10 meter square transects were laid out to measure the frequency and diversity of plant species at given locations. The author also solicited local input in these exercises in order to catalogue land user's knowledge about various plant species.

8 For further information about this methodological tool, see Rocheleau 1987; 1995; Slocum *et al.* 1995.

9 Gender myths are powerful stereotypes or ideas about appropriate roles and activities for men and women. A gender myth can be a legend or an interpretation of religious scripture that defines gender-specific characteristics and behavior. Often these exist in theory rather than in practice, but will be resorted to when confronted directly, such as in an interview. For more information about gender myths and methods for revealing the differences between myth and reality see Fortmann and Rocheleau 1985; Slocum and Kindon 1995.

FINDINGS AND DISCUSSION

KNOWLEDGE ABOUT AND LOCATION OF MUSHROOMS AND TRUFFLES

The disappearance of large-scale migrations in the Beni Guil territory has had a disparate impact on households settled in the Dahara and Sahara. Only 46% of interviewees in Dahara households said they collected mushrooms, compared to 85% in the Sahara.

Wild mushrooms and truffles do not grow on the Dahara plateau, and since few Dahara households still move their animals and tents across the Chott Tigri to the *dayas* in the Sahara, most have lost access to these resources. A closer analysis of those Dahara households still collecting mushrooms showed that they all had fixed homes and owned tents which they moved to the Sahara. The loss of access to these food resources, therefore, affects primarily fully settled Dahara households.

Diminishing access to wild mushrooms also corresponded to a loss in knowledge about the locations of these resources. Respondents in the Dahara knew, on average, 5.5 mushroom locations, compared to 10 known by Sahara respondents. Further loss of this environmental knowledge may eliminate opportunities for mushroom and truffle collection in the Dahara's younger generation, especially if more households become permanently settled.

The recently established commercial value of mushrooms and truffles ($4 per kilo for mushrooms and $7-10 per kilo for truffles) provided women with a new income generating opportunity. Moreover, 85% of land-users who collected mushrooms were women (see Figure 2). The commercial and food value of wild mushrooms and truffles explains why almost 70% of all surveyed households collected these resources. Figures 2 and 3 illustrate that for mushroom and truffle collecting class and location were key variables that determined gendered mushroom and truffle collection.

Figures 2 and 3 show that compared to men, women in all locations and class categories assumed primary roles for providing the resource to the household. This represents the continuation of a

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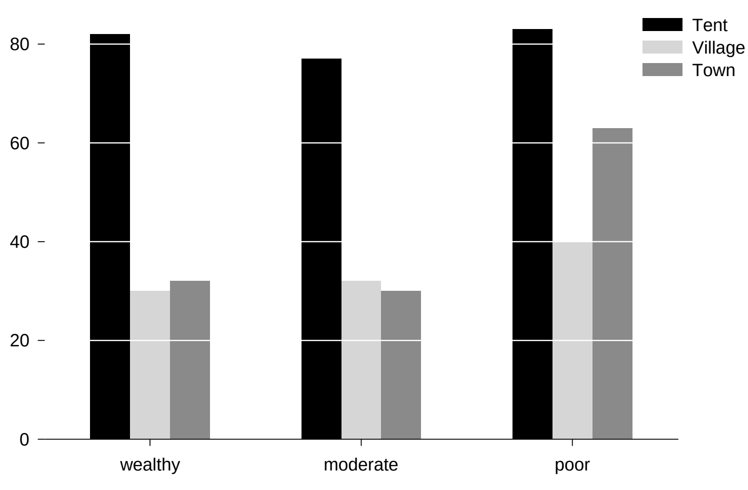

Figure 2 Percent households where women collect mushrooms and truffles by location and class.

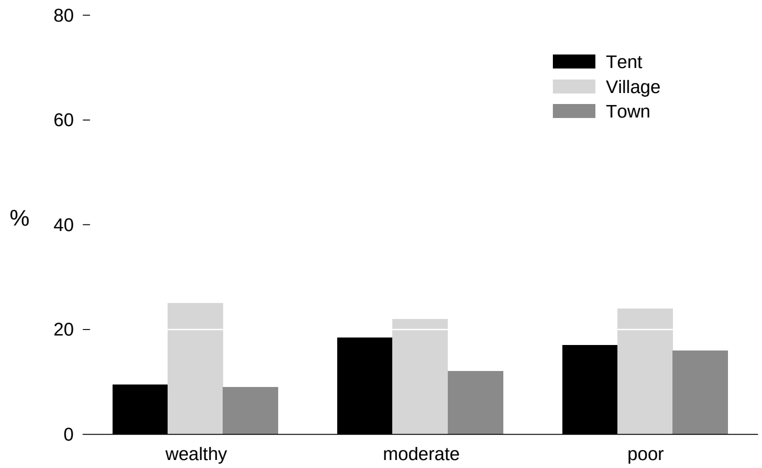

Figure 3 Percent households where men collect mushrooms and truffles by location and class.

traditionally female activity. Data revealed, however, that among women, class and location influenced access. The most significant finding was the rapid decline of women collecting these resources from tents to villages and towns. This suggests that the mobility of the household to various locations on the rangelands was a key variable that determined access.

Another interesting pattern emerged from the data: the percentage of households that collected mushrooms was lowest in villages, not in towns. In villages the gender ratio of mushroom and truffle collection was almost equal, although rates were low for both groups. As mentioned earlier, land users in villages (particularly those in the Dahara) have lost access to wild mushrooms and truffles that grow in the Sahara. Furthermore, truck transportation to towns or to the sites where mushrooms and truffles grow was sporadic. Villagers therefore could not easily transport these goods home or to the town *souks*.

All respondents in this class category who said they collected wild foods lived in households that were both nomadic and settled and said that they collected only when spending time out at the tent. This important finding suggests the need to move beyond a dualistic conceptual model of the household as either nomadic or settled.

Truck transportation was more readily available in town, particularly around weekly market days. This explains why a greater percentage of poor women in town, not in villages, collected mushrooms and truffles. Poor women in town took advantage of this transport in order to secure these resources for home consumption or to sell at the market. The significant increase of mushroom and truffle collection among poor town women suggests that their husband's income was insufficient to cover food costs, so they collected free range resources to meet livelihood needs.

In town households, class and mushroom/truffle collection showed a linear correlation for both men and women, though this was not immediately apparent among the women. The likelihood of collecting mushrooms decreased as wealth increased. For example, only 8% of men in wealthy households collected mushrooms or truffles, compared to 13% in middle class and 16% in poor households. In town, 32% of women in wealthy households collected these fungi, compared to 30% in the middle class and 63 in poor households. The surprisingly high percentage of wealthy town women who collected mushrooms and truffles was explained by the fact that most wealthy Beni Guil have two households: a home in town and a tent on the rangeland. All respondents in this class category who said they collected wild foods lived in households that were both nomadic and settled and said that they collected only when spending time out at the tent. This important finding suggests the need to move beyond a dualistic conceptual model of the household as either nomadic or settled.

Class can also be an important variable depending on location of the household. For example, collection rates were universally high for women in tents. But class became an important variable in town, where mostly poor women collected mushrooms and truffles. The data suggest that the economic importance of mushrooms and truffles was linked to family food needs and the degree to which women could rely on male income earners. This case challenges conclusions which posit that commercialization and settlement diminish women's control over natural resources and increase their dependence on male income earners (Horowitz and Jowkar 1992; Talle 1988) Among the Beni Guil, economic development, commercialization, and settlement did not uniformly diminish women's control over resources. In fact, commercial opportunities and availability of truck transportation in town created opportunities for the poor to access locations for collecting mushrooms and to generate income by selling them. The settlement of households in towns and greater integration into a commercial economy did not create a homogeneous class of female dependents.

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The Beni Guil case also suggests consequences for future generations. Data revealed that while only 10% of older women sold mushrooms they collected, 45% of women aged 20 to 45 and 70% of women under the age of 19 sold them. Older women were less accustomed to the cash economy and collected mushrooms and truffles primarily for consumption. But younger women, especially those not yet married or in female headed households, took advantage of commercial opportunities. Young men were also increasingly involved in the collection of these resources while their older counterparts rarely participated.

More research is needed to confirm these trends in the future, but the data suggest that increased dependency on cash incomes has intensified searches for and extraction of these resources. The data presented here identifies which land users were most involved in the collection activity that could help target appropriate groups for participation in conservation efforts.

The impact of these activities on the environment, particularly soil and wind erosion, warrants further research. Observations in the field suggested that truffle collection (which creates a hole of up to six inches in diameter) loosened soil and contributed to wind erosion. Increased demand for and use of trucks to access collection sites has resulted in the rapid expansion of a network of dirt roads throughout the Beni Guil territory. The roads have degraded large tracts of vegetation and have encouraged rain run-off and gully erosion during the rainy season.

This example illustrates that both men and women have vested interests in commercial and technological change, regardless of negative environmental consequences. Findings also suggest the importance of moving beyond essentialist ideals of ecofeminism to more contextual analyses of gender roles and environmental management in relation to social and economic change.

CHANGING MEDICINAL PLANT COLLECTING ACTIVITIES AND SPECIES KNOWLEDGE

Medicinal plant collection patterns share both similarities and differences with the findings discussed above. One major difference is that the overall percentage of households that still collect medicinal plants (48%) was relatively low compared to households collecting mushrooms (70%). The decline in the collection of traditional

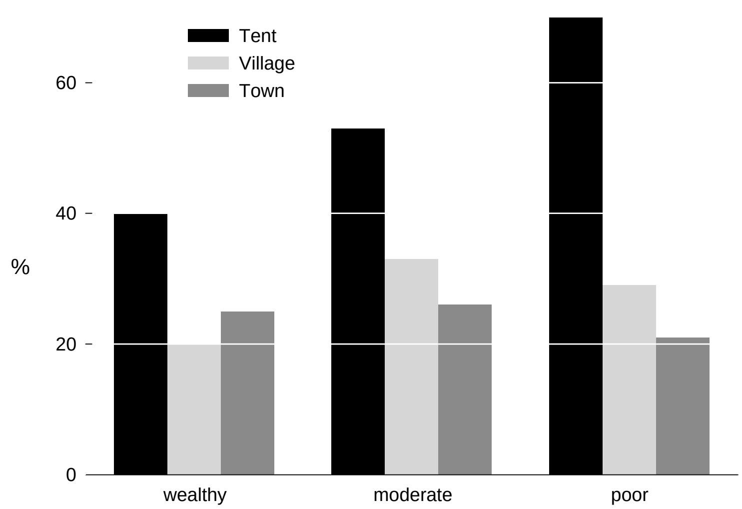

Figure 4 Percent households where women collect medicinal plants by location and class.

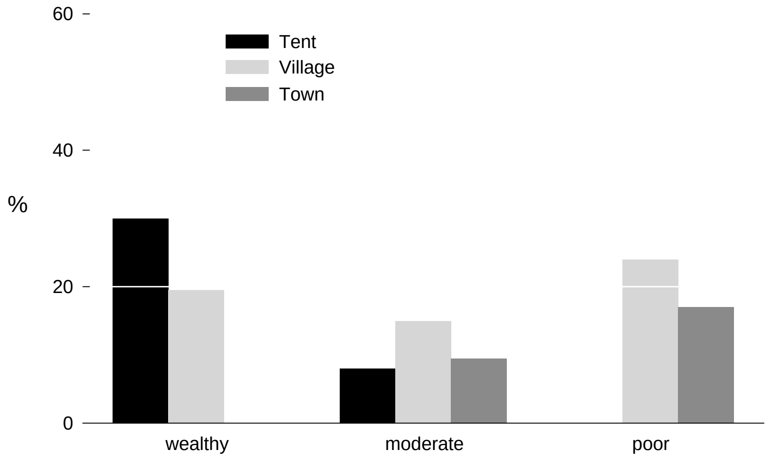

Figure 5 Percent households where men collect medicinal plants by location and class.

medicinal plants suggests that land-users rely on alternative resources to meet family health needs: they either buy medicinal plants at the town *souk* or use modern medical services.

As noted with mushroom and truffle collection, the interruption of nomadic migrations from Dahara and Sahara reduced access to medicinal plants. In households that still collected medicinal plants women accounted for approximately 80% and men for 20% of individuals who collected. Primarily women performed the task. The survey results show, however, that men also collected medicinal plants and that class and degree of settlement influenced gendered patterns of collection.

While overall collection rates were low, Figures 4 and 5 indicate that percentages were much higher for tent households than for those in villages or towns. Holding class constant, the percentage of women who collected medicinal plants declined as families became more settled. The exception, however, were wealthy women in town. As with mushrooms and truffles, these women came from households that had both house and tent and maintained access to rangeland resources while at the tent.

For men, class more than location influenced collection patterns. For households in town, and to a lesser degree in villages, a higher percentage of poor men collected medicinal plants than middle class men, who collected more than wealthy men. The reverse was true for men in tents where a larger percentage of wealthy men collected medicinal plants compared to men in moderate and poor households. This pattern among men in tent households complemented the trend in women's collection activities which were inversely related to class (40%). In tents, more poor women collected medicinal plants (70%) compared to moderate (53%) wealthy women.

The data suggests that medicinal plant collection is still important in tent households compared to villages and towns. Cultural values of female seclusion explain why men take over this activity as household wealth increases. However, because tent households move to diverse locations on range lands, women in these households retain proximity and access to medicinal plant resources. Class did not influence women's collecting activities in villages and towns and suggests that location was the key obstacle for accessing the plants.

Access to (and knowledge about) medicinal plants declined most significantly for village households due to several reasons. Reduced household mobility was the primary factor. According to older women, the interruption of migrations and changing environmental factors discouraged younger women from collecting and learning about medicinal plants. The women argued that the landscape was not as green as it once was, particularly around villages. Opportunities for teaching younger generations about these plants therefore became limited. Drought severely affected the region in the 1980's and early 1990's so many of these annual plants did not grow during these years. Among respondents who did not collect medicinal plants, most gave one of the following reasons: "The plants are too far away;" " They grow in the mountains;" "I don't know them;" "I buy them at the *souk*" or, "I see the doctor in town."

Collection rates suggest that medicinal plants represented a valuable resource to women in mobile tent households and among the poor settled in town. Although rangelands were also denuded around larger towns of Bouarfa and Tendrara, the *souk* provided an alternative access to medicinal plants and constituted a new space for learning about medicinal plants. Younger generation women in towns knew more about medicinal plants than their village counterparts. Since herbalists at the town *souks* were not necessarily from the local area and often imported plants from other parts of Morocco, women may have increased their knowledge about a greater variety of medicinal plants. Moreover, town women, who were generally dependent on male income earners, used this opportunity to maintain control over their role as family healers. These data caution against assuming that all women who used traditional medicinal plants for healing relied on local or indigenous knowledge.

This case supports some but not all the findings of the indigenous knowledge literature.[10] These theories generally posit that commercialization and integration of subsistence economies into a cash market reduces access to and knowledge about traditional medicines. Among the Beni Guil, declining collection of rangeland medicinal plants didn't necessarily imply reduced access nor diminishing knowledge about medicinal plant species. The Beni Guil

This case supports the need for employing integrated approaches to evaluate local knowledge and resource use. These perspectives challenge the orthodox theoretical dualism that pits "local knowledge and indigenous, sustainable systems" against "external, Western, non-sustainable systems" (Agrawal 1995; Batterbury 1997). Indeed, research suggests that more than half of all Beni Guil households surveyed said they bought traditional medicinal plants at the weekly souk. *This demonstrates that at least for now, people benefit from commercial markets that allow them to combine traditional medicinal practices with modern alternatives.*

[10] For a compilation of studies on the consequences of economic development on indigenous knowledge systems, see: *Agriculture and human values* Volume VIII. Numbers 1 and 2, 1991.

living in towns used *souk* herbalists as a way to access and learn about medicinal plants, although it is doubtful that future generations will be able to identify where these diverse plant species grow on their landscape.

This case supports the need for employing integrated approaches to evaluate local knowledge and resource use. These perspectives challenge the orthodox theoretical dualism that pits "local knowledge and indigenous, sustainable systems" against "external, Western, non-sustainable systems" (Agrawal 1995; Batterbury 1997; Bebbington 1997). Indeed, research suggests that more than half of all Beni Guil households surveyed said they bought traditional medicinal plants at the weekly *souk*. This demonstrates that at least for now, people benefit from commercial markets that allow them to combine traditional medicinal practices with modern alternatives.

The fact that medicinal plants have become commercially available raises questions about environmental change and the availability and rejuvenation potential of these diverse plant species. Further research is necessary to understand where *souk* herbalists collect plants and how their commercial activities affect plant diversity and availability in specific rangeland locations.

MANAGEMENT OF FUELWOOD RESOURCES AND LAND-COVER IMPLICATIONS

Compared to medicinal plants and wild mushrooms, it is easier to measure the environmental impact of changing fuelwood collection patterns. Based on dry wood weights, PDPEO project research found that average household fuelwood consumption ranged from 5 Kg/day in the summer to 10 Kg/day in the winter (Bruck 1996). There were only slight variations of this consumption pattern between mobile tent households and settled village households although the impact of fuelwood collection was most severe around villages (Maatarka and Mengoub).

Primary data using land-cover intercepts indicated 10% vegetation cover near Maatarka, compared to averages of 25 to 40% near tents, and up to 50% coverage in uninhabited areas of the Dahara. Differences in regional vegetation ecology also represented important factors affecting the impact of fuelwood collection. For example, a large variety of woody shrubs make up the dominant vegetation cover in the Sahara, whereas quick-burning perennial halfa grass (*Stipa tenacissma*) dominates in the Dahara. Consequently, households settled in the Dahara concentrate fuelwood collection on the halfa grass. It burns quickly, so women remove the grasses by the roots because this part of the plant burns longest. This practice removes vegetation cover and interferes with the rejuvenation potential of the perennial grass. Pressure on fuelwood resources was also heavy in the Sahara. But, the relative demand on woody shrubs was lower since these are slow-burning fuel resources. Although land users also up-rooted some of these shrubs, they often cut species above the roots (e.g. *Retama retam*). This practice encourages plant rejuvenation.

Village women also over-exploited fuelwood resources close to home because they preferred not to walk far from the surveillance of others, in accordance with the value of female seclusion. Fuelwood collection was concentrated around settlements diminishing both ground cover and species diversity.

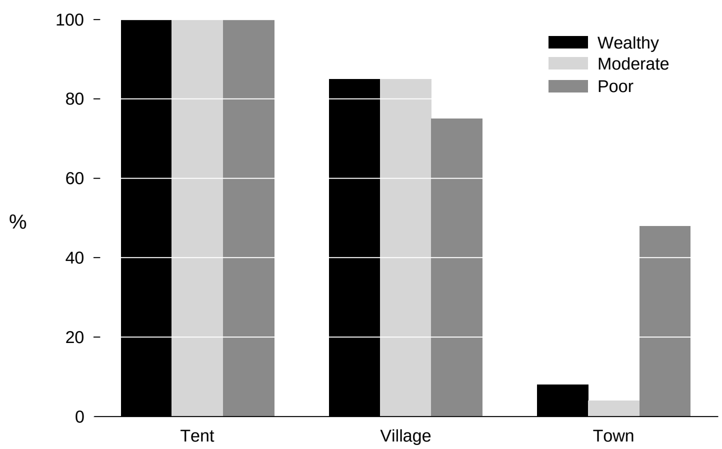

Figure 6 Percent women collecting fuelwood by location and class.

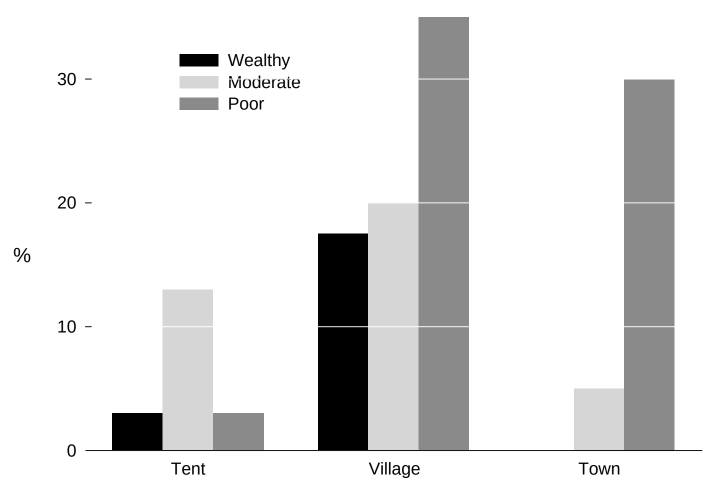

Figure 7 Percent men collecting fuelwood by location and class.

Preferences and access to various fuelwood species depended on whether households were mobile tents or fixed in villages or towns. For example, in tents, land users collected on average 3.6 different fuelwood species, villagers used only 2.3 varieties, and in town only 1.5 different plants were used. Research revealed that the best fuelwood species diminished relatively quickly compared to fast-burning resources. The best hardwood species (e.g. *Retama retam* and *Arthrophytum scoparium*) were rarely found around villages, but were re-generating around larger towns. Range extension workers at the Agriculture and Development office in Bouarfa noted that around Bouarfa vegetation cover had actually improved due to the increased use of commercial fuel sources such as natural gas.

The degree to which households relied on fuelwood resources depended on class and location variables. And, as illustrated in Figures 6 and 7, these variables shaped gendered fuelwood collection activities.

Many household resource responsibilities such as collecting wild foods, medicinal plants and fuelwood are increasingly shared by women and men as households adapt to economic and environmental changes associated with sedentarization.

Considering the differences in the scale, Figures 6 and 7 demonstrate that women bore the burden of fuelwood collection, particularly in tent households. In villages and towns, both class and gender variables came into play. In the villages, most women (between 75 and 85%) collected fuelwood. But, some 18 to 35% of the men also participated in this activity. In villages, natural resources provided cooking and heating fuel for most households. But, compared to women in tents, villagers travelled much farther (up to 12 miles one way) to collect wood. Since the cultural value of female seclusion discouraged women from travelling long distances alone, they engaged in concentrated and less cautious extraction methods. This degraded not only vegetation cover but also species diversity around villages. Distances to fuelwood collection sites gradually increased so men more commonly accompanied women or were needed to drive mule-drawn carts or trucks in order to haul wood back home.

The same pattern existed in towns, with some variation: only men and women in poor households collected fuelwood. As with the patterns for mushroom and medicinal plant collecting, the trends suggest that as households become more settled gender roles shifted from sex-specific activities to increasingly shared resource collection and management strategies.

These data point toward several important findings. First, that access to some fuelwood species declined with settlement, threatening over-exploitation of particular species at some but not all settled locations. Range cover had actually improved around larger commercial towns where alternative fuel resources were used. Second, concentrated fuelwood collection activities around villages and sedentary tents resulted in significant range cover loss and increased distances to fuelwood collection sites. Third, longer distances to abundant fuelwood resources shifted the gendered nature of fuelwood collection and more men participated. Yet, interviews with PDPEO conservation project managers indicated a continuation of the perception or "gender myth" that fuelwood collection was women's work. Men had not been identified as a 'user group' and were not included in educational efforts that encouraged cutting fuelwood resources above the roots. Understanding that these roles have begun to shift provides important information for targeting both men and women in conservation programs.

CONCLUSION

The Beni Guil case study in eastern Morocco demonstrates that gender-based resource management patterns shift in response to settlement, commercialization, and more intensive land-use practices. Many household resource responsibilities such as collecting wild foods, medicinal plants and fuelwood are increasingly shared by women and men as households adapt to economic and environmental changes associated with sedentarization.

Contrary to the various theories, the weekly commercial market in towns provide Beni Guil women settled there with new opportunities to maintain control over resources. Lower collection activities among women in town does not necessarily imply a corresponding loss of access to resources nor a loss of knowledge about them. In towns, women take advantage of the market.

Structural theories on women, environment and development posit that women lose control over resources as pastoral nomads settle and become integrated into a cash economy. The Beni Guil case suggests, however, that important nuances exist which cannot be reduced to class variables, gender stereotypes, or simple household mobility categories. In mobile tents men and women maintain easy access to a variety of range resources from different ecological niches. These households continue to move in order to take advantage of seasonally available resources and assure women of close proximity to natural resources. Despite the integration of tent households into a commercial economy, most tasks remain sex-segregated according to traditional roles.

As households become more fixed in villages and towns, however, collection activities shift from women to men. According to the gender and environment literature, women's loss of access to natural resources increases their dependency on male income earners. A more complex gendered adaptation occurs among the Beni Guil. Women often find alternative ways to access resources they need to fulfill their household responsibilities. However, this is more difficult in villages where access to natural rangeland resources or markets is limited. In villages, gender roles become most flexible.

Weekly commercial market in towns also provide Beni Guil women settled there with new opportunities to maintain control over resources. Lower collection activities among women in town does not necessarily imply a corresponding loss of access to resources nor a loss of knowledge about them. In towns, women take advantage of the market. Depending on class characteristics, women use the market in various ways. Wealthy and moderate town settlers no longer collect rangeland resources themselves but buy them at the market instead. Women in poor households use truck transportation available on market days to collect and then sell wild mushrooms and truffles. The weekly market provides poor women with an opportunity to generate income.

The market also represents a new space for learning about medicinal plants. Some research suggests that commercialization erodes indigenous knowledge systems and devalues women's roles as family healers (Mehta 1996). The Beni Guil case suggests otherwise. Findings from this case support recent critiques of the orthodox dualism of indigenous/local/traditional versus external/commercial/modern (Bebbington 1997; Batterburg 1997). Instead, a new approach necessarily recognizes hybrid livelihood systems as complex strategies that rural households utilize to preserve tradition while adapting to social, demographic, economic and environmental change.

Further, the Beni Guil example also points to a theoretical weakness in studies among pastoralists that view households as either mobile or settled. Among the Beni Guil, some households are split and represent units that are both fully mobile and settled. The reconceptualization of household mobility as well as careful attention to the type of settlement (rural village or commercial town) provides more accurate insight into the gendered aspects of social adaptations to sedentarization and environmental change.

The reconceptualization of household mobility as well as careful attention to the type of settlement (rural village or commercial town) provides more accurate insight into the gendered aspects of social adaptations to sedentarization and environmental change.

Examining how gender is embedded in ecological, cultural and economic structures at a given point in time also proves more useful than ecofeminist views that essentialize women with nature. The Beni Guil case demonstrates that women take advantage of new truck technology to reach more remote sites where they collect commercially valuable wild mushrooms and truffles. This strategy helps them maintain control over their roles as providers of food and fuel to the household even though this activity carries with it negative environmental consequences. Women also respect the cultural norm of female seclusion, which encourages over exploitation of fuelwood resources close to home, suggesting a greater affinity with culture than with nature.

By addressing the gendered responses to the environment as well as considering potential environmental impacts, this case study fills a gap in the geographic literature in North Africa and the Middle East that has looked at the environmental impacts of nomadic settlement and land-use intensification through larger-scale processes including: historical, political and economic contexts; erosion of local resource management institutions; land tenure changes; and demographic or technological change. By shifting the focus to intra-household dynamics, new insight is gained concerning environmental change and the future potential for sustainable livelihoods in North Africa's arid lands.

Promoting sustainable environmental management of Morocco's rangelands requires adding intra-household analyses of constraints and opportunities in meeting livelihood needs. More information about gendered land-use practices will promote development policies and conservation programs that target appropriate land-user groups. Identifying how men and women's resource interests intersect with class, location, and household variables suggests more accurate trajectories of local scale land-cover change in the future.

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Environmental Degradation in Eastern Turkey: The Case of Contract Farming

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ABSTRACT
This paper examines the integral links between a region's economy and its natural resource degradation. Through a case study of the commercialization of agriculture in Igdir, Turkey, the paper seeks to show that natural resource degradation in particular and environmental change in general must be seen within the context of prevailing social and economic relations. Although it is, of course, impossible to examine resource change in isolation from the wider economy, it can also be difficult to appreciate fully the complex interaction of socio-economic and environmental processes.

CONTEXT: THE SOCIETY-ENVIRONMENT RELATIONSHIP IN RURAL AREAS

The "environment" in a relatively narrow sense is associated with the biophysical world. Environmental problems are, therefore, considered simply to be negative impacts on the natural world, such as the degradation of air and water resources and the loss of biological diversity. The dichotomy between natural science as the appropriate discipline for the assessment of nature and social science as the discipline for the assessment of social relations sometimes tempts us to consider environmental problems as biophysical changes somehow separate from their social and economic impacts. After all, natural scientists and social scientists draw on distinct epistemologies and therefore have different ideas of what constitutes evidence or proof. One cannot ignore the fact that natural "science has… a central role since it is key to the identification and interpretation of environmental problems," but analysis in the social context remains essential (Yeardly 1992). The fact that much of the available data on environmental problems in rural areas tends to be exclusively quantitative and biophysical means that the available facts are not always sufficient for understanding the anthropogenic processes behind environmental change.

Humanity's increasing capacity to manipulate nature has been a cornerstone of the development process. Human action has transformed nature through technology and labor to the extent that we have mixed "our forces with its (nature's) forces too deeply to be able to draw back and separate either out" (Williams 1980). Thus, it does not make sense to analyze "society" as the domain of human action which operates in the "environment," the domain of natural cycles and processes. Conceptualizing environment as merely the material setting for social action implies that the two operate independently of each other, which is simply not the case.

Nature can no longer be said to exist independently of human intervention nor to structure social activity (Giddens 1994). Since without some form of human agency environmental issues do not exist, it is essential that our understanding and application of the concept "environment" be based on the interaction of society and nature (Dicken 1992; Blaikie 1987). The ability of human beings to manipulate nearly every aspect of the natural world challenges the notion that nature is somehow separate or autonomous from human culture.

In rural areas, including those of the Middle East, environmental problems reflect the interrelationships among resource change, human productive activities, and the accompanying transformations of people's lives. An environmental problem is therefore logically understood to be a situation in which human action affects natural resources in such a way as to place people's welfare, income or livelihood at risk. In this sense environmental problems are social problems.[1]

The interrelationship of society and environment has been largely neglected in academic literature on the Middle East in general and on Turkey in particular, insofar as little attention has been paid to the subject of environmental problems at all at the policy level. In the Middle East, governments' principal objective has been economic growth. In this context, programs aimed at intensifying agriculture have brought about significant social change in rural areas, in particular the restructuring of production relations through the integration of small subsistence farmers into the market. What governments have tended to ignore are the patterns of environmental degradation associated with the intensification of farming at the microlevel. Intensification (that is, increased yield) has become dependent on rising use of external inputs and mechanization. Many of the practices which are the manifestation of this policy, including excessive use of fertilizers, poor irrigation management, ignorance of fallow periods, and improper use of heavy machinery, seem to have driven environmental degradation in rural areas.

Although land and water resources are not intentionally degraded, many forms of intervention which increase yields in the short-term pose risks for resource quality in the long-term. Unsustainable practices are not only associated with poor farmers desperate to increase productivity and unable to afford the correct balance of external inputs or capital investments; richer farmers also use fertilizers inappropriately at times. In an attempt to understand why farmers implement such practices, this paper examines production relations and underlying social tensions in the context of agricultural commercialization in Turkey.

[1] This is not to deny the fact that natural processes cause biophysical changes which affect people. At the same time, I am of the position that natural disasters such as floods and volcanic eruptions are distinctly *not* environmental problems because although such events may impact negatively on people's lives, they are a result of natural processes and not human action.

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I first studied the process of commercialization of agriculture in the Igdir region in 1982-83 and returned to it in 1995-96, with the intention of analyzing the continued process of macro- and micro-level changes and the relationship between the two. Commercialization has involved the restructuring of production relations: contract farming, which ties growers to larger markets, has become the new norm, although the exact nature of contractual conditions has changed in line with government strategy. My examination of the data from two decades of commercialized agriculture focuses on the longer-term effects of continued cash cropping at both the regional and village levels. (The case study material is drawn from Ak village in Igdir province[2] of eastern Turkey.)

The processes of commoditization and intensification can put natural resources under pressure, often creating a need for greater "landesque capital," i.e., investments in the long term maintenance of land quality and strategic decisions geared toward securing future continuity of production (Blaikie 1997). In this case study of sugar beet production in Igdir province, production expansion encouraged by government policy has led to the over-exploitation of land and water, amounting to the depletion of landesque capital. The government's encouragement of farmers to increase crop yields without policies aimed at conserving the underlying resource base has resulted in numerous instances of environmental degradation.

[2] In 1992 Igdir was upgraded from a "district" to a "province" under the government's Eastern Regional Development Program to reinforce the area's improved economic status and to encourage trading with Central Asia.

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GOVERNMENT POLICY AND ENVIRONMENTAL PROBLEMS IN RURAL TURKEY

Since the 1980s, the Turkish government has moved toward liberalization and export-oriented economic reforms and away from the macroeconomic policies of the 1960s and 1970s (in which there was a growing role for state intervention in the economy through import substitution and industrialization). Moreover, since the demise of the Soviet Union, Turkey has been in a position to initiate new policies with regard to Central Asia, leading to growth in trade and thereby furthering its integration into the global network.

How has agrarian development been affected by changes in macrolevel government policy? Since the 1960s the Turkish government has attempted to transform the structure of agricultural production by integrating family farms into the commercial market with the assistance of a price support policy, subsidies, and credit facilities provided by government agencies (Aksit 1993). The "liberalization" of domestic trade and investment and the privatization of state-owned enterprises in the late 1980s and 1990s have resulted in cutbacks to reduce farmers' dependence on the state and to fully integrate them into the market. However, the extent to which this has been successful has yet to be fully examined, particularly at the microlevel. There is some evidence that farmers' real incomes have declined and that even when state agencies continue to support farmers to some degree, delays in payments for crops to farmers and high inflation have added pressure to farmers' incomes (Turel 1991).

It is estimated that the Turkish population will double to 120 million by the year 2050. The government therefore faces the problem of increasing agricultural productivity to meet the needs of a growing population. Greater than one third of the total land area in Turkey is used for arable farming (see Table 1).

Given the constraints of land availability, climate, and topography, the Turkish government has sought to intensify existing agriculture. Several environmental problems have become increasingly apparent since the intensification of agriculture on arable land, although there is little data available identifying direct links between intensification and environmental problems. These problems include both soil erosion and reductions in soil quality (see Table 2).

Because intensification has coincided with economic liberalization and a growing demand not only for exports from rural areas, but also for the products of industry, there has been a shift of investment to urban areas. This has undermined the subsidies and support made available to rural areas during a time of agrarian change. What effect has this had on resource use? Are practices that result in environmental degradation a response to changes in macrolevel government policy?

The impact of government policies is offered here as a case study in a sugar-growing region of eastern Turkey. Igdir, bordered by Kars to the northwest, Agri to the south, and Armenia, Iran, and Azerbeijan to the east, is located in a valley with fertile land. Cereal (wheat and barley) and cash crops (sugar beet and cotton) are the principal crops cultivated. The case study of Igdir illustrates how macrolevel policy that links farmers with a state agency through cropping contracts affects production, farmers' livelihoods, and natural resource degradation.

Table 1 Land Use in Turkey

Type of Land Use	Area (million ha)	% Total
Agriculture	27.8	35.8
Pasture	21.7	27.9
Forest/shrub	23.5	30.2
Urban	0.6	0.8
Other	3.2	4.1
Inland Water	1.1	1.4
TOTAL	**77.8**	**100**

Source: Statistical Yearbook of Turkey 1994.

CONTRACT FARMING AND ENVIRONMENTAL PROBLEMS: THE CASE OF IGDIR

Turkey is striving to be self-sufficient in sugar production. Given current population figures and an average annual consumption of 28 kg/capita, it is estimated that approximately 1.8 million tons of sugar are consumed each year. The Turkish Sugar Corporation, the state agency responsible for sugar cultivation, has planned for increased cultivation by establishing sufficient infrastructure to cope with the increasing demand associated with population growth. As part of the drive for self-sufficiency, increased sugar beet cultivation has been encouraged since the 1960s under government regional development programs aimed at bringing about the commercialization of agriculture. Igdir is typical of an area where sugar has been the dominant commercialized crop, made possible through expansion of the cultivated area, the adoption of new technology, and improved infrastructure such as irrigation and roads.

State support for sugar cultivation, which has been essential in regions such as Igdir to achieve the commercialization of farming households, is coordinated by the Turkish Sugar Corporation, which has a complete monopoly over the purchase and sale of sugar beet at fixed prices. Other crops such as cereals are bought and sold by both private merchants and government agencies. The Turkish Sugar Corporation has established vertical integration in local production through legal contracts with individual growers. Contract farming enables the Corporation to control both supply and demand for sugar beet. Contracts detail future purchase agreements, which include grade and quality standards and methods of cultivation including the application of inputs such as fertilizers.

Contract farming can put farmers in a position to achieve greater access to credit, inputs (in particular, new technologies), and the market than their peers who are not operating under contractual arrangements. However, the grower is tied to the Corporation by market dependence and by credit for the purchase of capital inputs. The farmer's loss of autonomy is particularly pronounced when debts to the Corporation are incurred, since the Turkish Sugar Corporation is the only external agency involved in sugar cultivation.

Contracts tend to cover land management measures intended to optimize crop growth, crop quality, and production levels in the short-term agricultural cycle. The objective of maintaining resource quality over the long-term is not mentioned. Thus, the grower, and not the Corporation, is responsible for decisions about investment in the long-term maintenance of land quality and productive capacity—landesque capital—under conditions in which the Sugar Corporation encourages production growth. Environmental problems, such as deterioration in soil quality, waterlogging, and salinization have been identified in Igdir villages by the World Bank and by the State Hydraulic Authorities (DSA). Unfortunately, investments to mitigate environmental problems are not always undertaken, nor are they even possible for small farmers. At the same time, it appears that farmers adopt a variety of measures, such as the improper application of fertilizers or reduction of fallow periods, which produce high short-term yields but do lasting environmental damage. Why?

Table 2 Types of Environmental Degradation in Rural Areas

Environmental Problem	Area (million ha)
Medium Soil Erosion	14
Severe Soil Erosion	2
Salinization	1.5
Urban Encroachment	3
Waterlogging	2.8
Total Affected Area	**23.3**

Source: General Directory of Rural Services, 1995.

ENVIRONMENTAL PROBLEMS AND SUGAR CULTIVATION: THE FARMER VERSUS THE CORPORATION

Any analysis of the links between crop cultivation and environmental degradation in Igdir involves analysis of the Sugar Corporation's policy in the region since the 1980s, because production relations are centered on sugar cultivation and contracts between the farmer and the Corporation. Following liberalization in Turkey, the Sugar Corporation has cut back on support to farmers and is more wary of its dealings with them.

Since the 1980s, the number of sugar beet contracts in Igdir province has increased substantially, and the area under sugar beet cultivation has risen from around 1,500 ha in 1970 to 6,500 ha in 1995, while cotton cultivation has decreased from approximately 7,200 ha to 1,400 ha over the same period (see Figure 1). With the support of a recent World Bank-funded irrigation program, the Sugar Corporation intends to cultivate a further 6,000 ha of sugar beet.

The number of sugar beet factories in the area has facilitated increases in cultivation by making processing more accessible. The Erzurum Sugar factory was the only plant in the area in the early 1980s, but now over 220,000 tons of beet is processed annually by four factories (see Table 3).

Increases in cultivation have been achieved through several changes to contractual conditions. The Sugar Corporation has lifted many of the former restrictions on cultivation. In the 1980s each farmer was given a strict quota for the cultivation of sugar beet, which was not often more than two ha. This often meant that farmers would register other members of their families–spouses, children–in order to increase production (Morvaridi 1990). In the 1990s, such restrictions were lifted and farmers could cultivate as much as they wanted. During the 1980s, the Corporation refused to contract with sharecroppers, believing that the risks were too high, but it does so today with the names of both the landowner and the tenant entered in the contract. The landowner provides land and plowing, the sharecropper provides labor, and the cost of water and fertilizer is shared. The sharecropper receives cash from the corporation for crops, in contrast with traditional sharecropping arrangements in which he received a portion of the crop.

Interviewed farmers said that the cultivation and rotation of crops on each plot of farmland is determined by sugar beet since it is the crop that produces the highest income per unit area. By reducing production rotation from once every four years to once every three years, under the instructions from the Corporation, farmers have been intensifying their resource use increase yields. The rotation in 1982 was sugar beet /wheat/cotton/fallow or sugar beet/wheat/

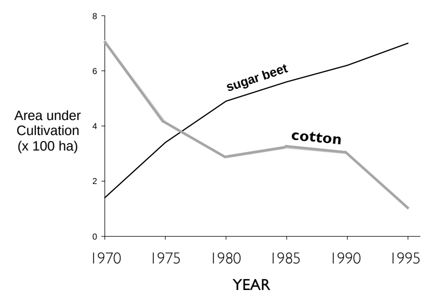

Figure 1 Area under sugar beet and cotton cultivation in Idgar as a function of time.

Table 3 Amount of Sugar beet processed in Igdir.

Factory location	Tons processed
Agri	166,000
Kars	42,000
Erci	11,000
Erzurum	3,500
TOTAL	**222,500**

fallow/wheat. In 1995 the rotation, shortened from four years to three, was sugar beet/wheat/wheat, or sugar beet/wheat/water melon. There has been a considerable reduction in, and even elimination of, fallow periods. For example, as Table 4 shows, in 1995 no land was left fallow.

The Sugar Corporation deliberately targeted cotton as the crop to be substituted for by sugar beet, because the two products were in direct competition over resources, such as labor, land and water. When any product is increased at the expense of another, the marginal rate of substitution is always negative. When both sugar beet and cotton were cultivated, farmers needed to ensure that they had sufficient labor to manage both crops during hoeing and harvesting, since these tasks were carried out during the same period. A major managerial problem resulted for many farmers who found the crops competing over limited available labor (Morvaridi 1992, 1993).

Sugar beet is purchased by weight according to sugar content. If the sugar content is below 16%, the purchasing price is 15% lower than the original set price. If sugar content is higher than 17%, farmers are paid 15% more. This is assessed by the scales (*kantar*) or weigh-bridge at one of four delivery locations—Igdir, Akyumak, Kikoynco, Yayci—not on individual farms. The price paid is based on an average of the total crop delivered to the weigh station, not on

Table 4 Cropping patterns in Ak village, 1982 and 1995, area in ha.

Crop	Cultivated area (1992)	Proportion of total	Cultivated area (1995)	Proportion of total
wheat	156	27%	270	46%
sugar beet*	187	32%	210	35%
cotton	81	14%	32	5%
barley	73	12%	31	5%
fallow	58	10%	13	2%
clover	13	2%	15	2%
fruit	10	2%	10	2%
trees	4	1%	1	0.2%
other**	7	1%	0	0%
degraded land***	-	-	10	2%
TOTAL	**589**		**592**	

Source: Turkish Government Water Authority. *Sugar Corporation, Igdir 1982/1995; **includes corn, vegetables, watermelon, etc.; ***field data.

the crop presented by each individual farmer. This system encourages farmers to increase their income through tonnage rather than content. The Corporation is aware of the drawback of not being able to monitor weight and sugar content of crops raised by individual farmers, and the head of the Corporation admitted "we know all the farmers. We know the best farmers and the worst ones." The Corporation plans to weigh and purchase from the farmers individually, but has yet to do so as a result of their own cost considerations.

Farmers harvest their sugar crop on the instructions of the Sugar Corporation. The Corporation argues that it is logistically difficult to manage all farmers' harvests concurrently because the sugar factory does not have the capacity to cope with the high volumes that would result. The Corporation therefore staggers the harvest time, and farmers complain that as a result of prolonging the harvest period they lose out. The later a farmer harvests, the more his cane gains in weight. This would appear to be to his benefit. However, farmers protest that when the sugar beet is weighed at the weigh-bridge and the Corporation washes and cuts soil away from the beet they deliberately cut away too much of the skin. As a result the farmers lose revenue because the crop weighs less.

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The price of sugar beet is determined in relation to other crops, such as wheat and sunflowers. The Ministry determines the price of all crops in consultation with state agencies and the State Planning Organization, which advise on prices annually. The Corporation purchases sugar beet for 4,500 Turkish Lira (TL)/kg. This price takes into account the interest-free advance payments of 35% of their crop money (calculated as the cost of production) that the Sugar Corporation gives to the farmers. The real price for sugar beet would be 6000 TL/kg (1996 prices). The Corporation knows that the farmers would not cultivate sugar beet if they were charged interest on loans or advances and that if they were operating in the private sector they would not be paid advance money for cultivation. It deliberately pays the remainder of the price six months late. It argues that this allows for the necessary time to process and sell the sugar beet crop so that it can afford to pay the farmers the cash owed them. The Corporation believes that farmers are fortunate to be advanced money interest-free, in any event.

Many farmers complain that it is unfair that they receive crop payment up to six months late and that they continually lose out because inflation is high (up to 70% according to government and up to 100% by some unofficial estimates). Farmers assert that the sugar beet price is low in relation to the cost of fertilizer inputs. Additionally, over the past few years, the Corporation has offered farmers consumer goods such as stoves, televisions, refrigerators, heating fuel, cooking oil, and even sugar itself, instead of paying them for their crops. One farmer told me, "They say that it is not compulsory to accept, but at the end of the day you have to accept some payments in kind."

The head of the Corporation justifies its payment policy stating that: "Instead of their sugar beet money, we give them consumer goods…and then reduce them from their crop money. We purchase them cheap because we buy in bulk and then we exchange them cheaply with sugar beet. That is why they all have televisions. They couldn't purchase all these goods otherwise with their own income. That would be impossible. They are happy and we are happy because we need to save money."

The reality of contract farming is that farmers and the Corporation have an adversarial relationship based on mutual mistrust. Farmers in Igdir are dissatisfied with the Sugar Corporation, complaining that its policy is geared to expanding production, but not to helping them. The Corporation complains that farmers refuse to accept their advice or appreciate the conditions under which the Corporation operates. This tension, centered on the constraints and limitations of contractual conditions, is manifested in approaches to land management. The dynamics between commercialization based on contract farming, social relations, and environmental problems become apparent at the local level.

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AK VILLAGE

Ak is a village with household patterns, land distribution, and cropping patterns typical of Igdir province (see Table 4). To reduce costs, the Sugar Corporation concentrates sugar beet growing in designated areas in the village. The Sugar Corporation has selected the most fertile areas of the village for sugar beet growing on the basis of rotation. Land is fragmented in the village, and the major landowners who possess parcels of land in various locations are more likely to secure contracts to cultivate sugar beet every year.

Table 5 shows the partitioning of land in parcels as a function of land holdings in Ak village.

Households may cultivate sugar beet once every three years, but only if their land is in the selected area. The larger farmers are thus in an advantageous position to gain contracts and earn the high returns that sugar beet cultivation generates.

The contract requires the formation of a group of between five and 30 farmers able to guarantee repayment of benefits received to protect the Corporation against any loss. Article Eight of the Growth of Sugar Beet Contract makes clear the joint responsibility of the group. Individual contracts are possible, but generally, only select

Table 5 Land Fragmentation in the Village, 1995.

Cultivated Area (ha)	No. of Households	No. of Land Parcels	No. of Sites	Avg. No. of parcels	Avg. No. of Sites
0-1	28	34	28	1.2	1
1.1-5	41	125	79	3.1	1.9
5.1-10	24	189	93	7.9	3.9
10.1+	11	169	58	15	5.4
TOTAL	**104**	**517**	**258**	**5.5**	**2.5**

Source: author's field data, 1995, 1996

The Sugar Corporation attempts to monitor inputs and yields of sugar beet, but the farmers often deliberately ignore the Corporation's advice in order to secure increases in their beet weight, the basis on which they are compensated.

wealthy farmers maintain individual contracts and in Ak village all belong to a group. The groups have direct contact with the Sugar Corporation through a local manager who supervises the implementation of the contract, the distribution of inputs, cash and other supports to the farmers in order to insure proper growth and the production of quality beet. Table 6 shows the distribution of cash and subsidies by the Corporation to the contracted farmers by groups (1982 and 1995).

Farmers receive cultivation income—that is, payment for the crop—and they are advanced wage money in two stages with which they are to employ wage labor during hoeing periods (Table 6: column 1). Farmers also receive fertilizers and seeds from the Sugar Corporation. The Corporation currently provides more and better quality seed varieties than it did previously—2500 to 3000 kg/ha seeds in 1995 as compared with 1500 kg/ha seeds provided 15 years ago. Yields have improved substantially, from 25 tons/ha in 1972 to 35 in 1982 to 54 in 1995, well above the Turkish national average of 40 tons/ha. This increase in yield is attributable to higher fertilizer inputs.

Yield is one benchmark for land productivity: degraded land can be identified by lower yield characteristics. At the same time, land sustaining high yield may nonetheless be degraded, especially if increasing fertilizer inputs are required to sustain steady yield. In this case study, yield declines are not detected, but it is evident from fertilizer use patterns that soil degradation is occurring.

INPUTS AND LAND QUALITY

The intensification of agriculture in Ak relies on the greater use of external inputs to achieve good yields. The Sugar Corporation distributes two types of commercial fertilizers: "nitrogen-based" fertilizers (*Azotlu Gubreler)* consisting of $(NH_4)_2SO_4$ (ammonium

Table 6 Distribution of cash and advances by the Corporation to the farmers of Ak Village, 1982 and 1995.

Group #	No. of Members	Area (ha)	Output (tons)	Cultivation income (x 1000 TL*)	Wages for hoeing (x 1000 TL)	Fertilizers (x 100 kg)	Yield (tons/ha)
				1982			
130	39	1370	59000	1220	238	35	43
2	30	48	1700	65300	1440	276	35
3	30	42	1360	58700	1240	261	33
4	30	52	1690	73500	1380	334	32
5	8	6	250	5510	150	23	39
'82 TOTAL	**128**	**187**	**6370**	**262000**	**5430**	**1132**	**34**
				1995			
1	30	43	2170	21500	720	295	50
2	30	45	2560	22700	740	334	57
3	30	40	2230	20600	670	277	56
4	30	40	2120	20400	660	289	53
5	30	38	2100	20300	640	363	55
'95 TOTAL	**150**	**207**	**11180**	**105500**	**3430**	**1556**	**54**

Source: Local Sugar Corporation Office 1983 and 1996. *In 1983, US$1=TL186; in 1996, US$1=TL42000 (source: IMF International Financial Statistics, April 1995).

sulfate, 20-21% N), NH_4NO_3 (ammonium nitrate, 33% N), NH_4NO_3-$CaCO_3$(ammonium nitrate limestone, 26% N) and $(NH_2)_2CO$ (urea, 46% N); and "composed" fertilizers (*Kompoze Gubeler*), 8-24-8 NPK (Sugar Corporation 1996).

According to Corporation field technicians, Ak soils have become acidic because of the incorrect application of fertilizers. The distribution and use of fertilizer is often an issue of contention between the Corporation and the farmers. The Sugar Corporation attempts to monitor inputs and yields of sugar beet, but the farmers often deliberately ignore the Corporation's advice in order to secure increases in their beet weight, the basis on which they are compensated. In 1994 the Corporation gave the farmers 500 kg/ha of composed fertilizer and 150 kg/ha of nitrogenous fertilizer. The majority of farmers believe these amounts to be inadequate since they have only managed to produce yields of 25 tons/ha. If a combined total of 2000 kg/ha were applied, they argue that yields could surpass 45 tons/ha.

The Corporation's distribution of fertilizers varies from farmer to farmer. Poorer farmers generally receive more generous fertilizer applications than their wealthier counterparts, since the Corporation is aware that some wealthier farmers who complain that the Corporation does not give them adequate fertilizer will buy additional supply from other sources. For this reason they deliberately offer rich farmers less fertilizer out of the knowledge that these farmers have the financial resources to purchase extra on their own. However, poorer farmers tend to sell their fertilizers to the wealthier farmers because they need the immediate cash and the Sugar Corporation is late in providing crop payments. To compensate, they often apply high levels of the nitrogenous fertilizer to increase tonnage, guided by desire for the greatest yield in any one agricultural cycle, rather than by the desire to maintain soil quality over the longer term.

The application of nitrogenous fertilizer alone (without composed fertilizer) results in growth of the sugar beet root (that is, increased tonnage) at the expense of sugar content. Low sugar content becomes apparent in the factories and raises the costs of production. Since this affects its accounts, the Sugar Corporation attempts to strictly monitor fertilizer application. The Corporation manager complained that "the farmers do not listen to us when we tell them to apply fertilizers in the following periods; for instance in the case of phosphorous we tell them to apply 10 kg during cultivation, 10 kg in the first hoeing, and 15 kg in the first irrigation, but the farmers apply fertilizers all in one go in March."

Some farmers complain about delays in harvesting the sugar crops brought about by the Corporation's timetable. They argue that they are given little time to prepare land for the next sowing and end up having to plow wheat straight after sugar beet is harvested. They are also concerned about residual fertilizers. The Corporation tests soil under contract to analyze the amount of fertilizer required during the cultivation process, but once the sugar beet is harvested the soil is not re-tested so that farmers can judge the next application of fertilizer for the rotation crop to follow. The farmers argue that the Corporation shows no concern for resource quality and production beyond the current crop cycle.

Another farmer admitted: "If we leave our land fallow, productivity will increase. However, we no longer leave our land fallow because we cannot afford not to cultivate. In the old days we used to, but not nowadays. We need to keep applying more and more fertilizer because when we use the same amount of fertilizers as before we do not get the same yield. We have to apply more fertilizers in order to guarantee productivity even though we know that this has damaged our land."

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Generally, Ak farmers rely on chemical fertilizers rather than organic nutrient inputs such as manure. One interviewed farmer combines manure with fertilizer he receives from the Corporation and enjoys high yields, but he is in the minority. Before sugar beet was cultivated in the village, manure was used for organic fertilizer and to make *tezek*, used for fuel or to build houses. In recent years many farmers, in particular wealthier farmers, have decided not to keep livestock. Poorer households have continued to keep animals, but tend to use manure exclusively to make *tezek* for their own use and for sale to richer farmers. Rather than using manure on their own land for the benefit of their land, poorer farmers opt for immediate cash.

As well as impacting land quality, fertilizer application also constitutes a threat to surface and drinking water through NO_3^- (nitrate) pollution. There are also human consumption threats: a poor household in the village remarked that cucumbers, watermelons, and other produce have acquired a strange taste from fertilizer residues since the application of fertilizers for sugar beet began.

IRRIGATION AND SALINIZATION

Waterlogging and salinization have been identified in several areas of the village. The long-term impacts of salinization are deteriorating land quality and lower yield. In recognition of the potential extent of the salinization problem, a land rehabilitation and on-farm irrigation improvement project was funded by a substantial loan from the World Bank, in collaboration with DSA.[3] The project, partially completed in 1996, aimed at mitigating the adverse affects of waterlogging, salinity, siltation and soil-plant-water reactions under irrigation. Both salinity and sodicity have affected parts of the area.

Ak and other villages in Igdir are irrigated by the Aras river via a joint Turko-Soviet dam project completed in 1963. The State Hydraulic Works (DSI) controls and coordinates water distribution. In the case of Ak, traditional methods of on-farm irrigation have been used in the village because of irregular terrain which makes even water distribution difficult. On-farm irrigation involves dividing fields into 4-6 strips, separated from each other by a ridge. Water is released from the top of the field and each strip is irrigated separately under strict control to ensure sufficient infiltration. The ridges are constantly maintained by a farmworker running up and down the field adding more soil with a spade to prevent seepage into adjoining strips of land. Control of water application is difficult and waterlogging and salinization have resulted.

Some farmers, especially the poorer ones, deliberately apply more water than is necessary for sugar beets. There is no incentive

[3] Although the project was due to be completed in 1997 it is expected the DSA will continue implementation. Cost was estimated at $100 million, of which a third is financed by the World Bank and the remainder by the Turkish government. The irrigated area addressed by the project reached 63,570 ha in 1996.

for efficiency since water charges are based on acreage and crop-type rather than on volume. They also underestimate the area of their land to the DSA so that they may pay lower water charges. One farmer explained the motivation: "Those who irrigate the field many times are not concerned with their land but with the size of the root of the crop. The bigger the root, the heavier it is and therefore the more it is worth. It's another way of earning more money. The more water and fertilizer you use the heavier the root will be. Because we apply too much water and too much fertilizer our land has degraded. We are aware of the consequences."

Waterlogging and salinity can be prevented, both by reducing the application of water in excess of crop needs and by augmenting drainage, each of which has been an objective of the World Bank project.

CONCLUSION

In an examination of the dynamics of contract farming in sugar beet cultivation, this paper illustrates the links between social relations and environment. It demonstrates how farming contracts between a farmer and a state corporation are concerned with production methods and levels, detailing land management measures which ensure crop growth and quality. However, the majority of contracts are incomplete in that they do not specify every eventuality. The sugar beet grower is responsible for all costs of production and it is the farmer, not the Corporation, who bears risks related to labor and resource quality. Landesque capital and other environmental costs are externalized from production contracts, allowing the Corporation to avoid any long-term responsibility for resources beyond the immediate short-term agricultural cycle.

It is the peculiar construction of the "independence" of farmers' contracts that is of value to large corporations, but this also leads to complex and tense social relations at the local level. It seems clear that the Corporation strives to gain high yields from farmers in return for little commitment. Farmers are aware of this and in turn attempt to beat the Corporation to gain as much income as possible through land management practices which in the long-run cause environmental problems on their own land.

Analysis of environmental problems must go further than the quantitative natural scientific analysis, since quantifying resource change alone will not provide the whole picture. Qualitative data and longitudinal studies at the local level will enable us to better understand the complexity of environmental issues. As this paper demonstrates, declines in resource quality and availability are closely linked to the production process and accompanying social relations. To separate the two would result in superficial dualism.

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Monitoring Desert Locusts in the Middle East: An Overview

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ABSTRACT
Desert Locusts, *Schistocerca gregaria* (Forskal), are the most dangerous of locust species. Under favorable environmental conditions, a few solitary individuals can dramatically multiply, form large swarms able to migrate great distances, and threaten agriculture over a large part of Africa, the Middle East[1] and Southwest Asia. There have been six plagues of Desert Locusts this century, one of which lasted almost 13 years. Initial Desert Locust control efforts were largely curative; the trend in the twentieth century has been toward preventing such plagues from occurring. Affected countries have assumed ever more responsibility for monitoring locust breeding areas and treating infestations before they increase in size and number. Five of the 18 countries which currently undertake comprensive surveys for, and control efforts against locusts, are in the Middle East. Most recently, Saudi Arabia completed large scale control operations to prevent a sudden outbreak of locusts from becoming a plague. Over the years, our knowledge of the Desert Locust has evolved along with our ability to manage locust plagues. The challenge in the future lies in the implementation of control strategies that insure food security with minimal environmental consequences.

INTRODUCTION

Locusts are part of a large group of insects commonly called grasshoppers belonging to the family *Acrididae*. The Desert Locust, *Schistocerca gregaria* (Forskal), is one of about a dozen species of short-horned grasshoppers (*Acridoidea*) that are known to change their behavior and physiology in response to changes in population density by forming swarms of adults or bands of wingless nymphs called hoppers. Swarms may contain billions of individuals behaving in unison; they can migrate over hundreds or even thousands of kilometers. Bands can contain a similar number of non-flying nymphs which also act as a cohesive unit. True grasshoppers form neither bands nor proper swarms. However, the distinction between locusts and grasshoppers is not entirely clear-cut. There are some species, such as *Oedaleus senegalensis*, which occasionally form small loose swarms. Locusts such as the Tree Locust (*Anacridium* sp.) rarely form bands. Some locust species, such as the Australian Plague Locust (*Chortoicetes terminifera*), do not change shape and color in response to changes in density.

[1] For the purposes of this paper, the Middle East is defined as those countries that extend from Egypt to Turkey eastwards to Iran, including the entire Arabian Peninsula.

DESERT LOCUST LIFE CYCLE

The Desert Locust poses the greatest threat of all locusts to humans because hopper bands and adult swarms can rapidly arise and migrate, potentially threatening food security in some 60 countries in Africa, the Middle East and Asia. A desert locust lives three to five months although this is extremely variable and depends on weather and ecological conditions. The life cycle comprises three stages: egg, hopper, and adult (Figure 1).

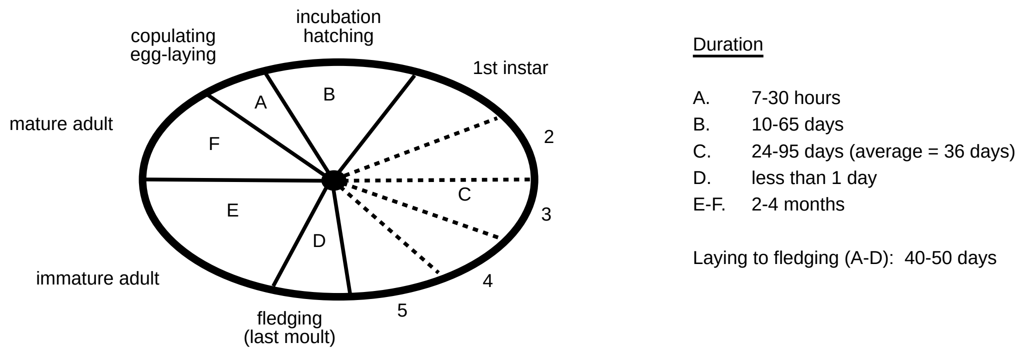

Figure 1 The life cycle of the Desert Locust.

Females lay egg pods containing 80 to 158 eggs in bare ground and often, but not exclusively, in moist sandy soil. They usually lay about three times. The eggs hatch in about two weeks although this can vary from 10 to 65 days (Ashall and Ellis 1962; Roffey and Popov 1968). The emerging hoppers develop in five to six stages over a period of about 30-40 days, depending on temperature. At the final molt, the young adult (or fledgling) emerges. Under optimal conditions (lush vegetation, maximum day temperatures of 30°C or more, and sufficient rain for vegetation growth), adults generally mature in about three weeks, although this process can take as along as eight weeks. If conditions are cool or dry, and therefore unfavorable for final maturation, immature adults can survive for six months or more.

The great majority of the eggs that are laid survive and hatch. On the other hand, very few of the hoppers which emerge from the egg survive to fledge. Most die during the first instar stage due to inadequate water reserves, cannibalism and predation by ants. Cannibalism, parasitism, and predation continue to take a toll during the rest of the life cycle. Nevertheless, between 5 and 10 viable adults result from a single female (Greathead 1966; Roffey and Popov 1968).

PHASE CHANGE

A Desert Locust has different states called phases: solitarious, when individuals are at low population densities; gregarious, when they are at high densities; and a transition from the solitarious phase to the gregarious and vice-versa known as transiens.

The behavioral change depends on micro-scale environmental factors such as the spatial distributions of food plants, and macro-scale factors such as convergent wind fields that force locusts to become concentrated in relatively small areas. This change can rapidly take place, often within a few hours of crowding (Roessingh and Simpson 1994). The capacity to behave gregariously is passed from parents to their offspring and increases over several generations of crowding (Islam *et al.* 1994ab). The color of the locust also changes from brown in solitary adults to pink and yellow in immature and mature gregarious adults, respectively. Morphological changes (i.e. in color and shape) occur after the change in locust behavior. The full gregarious color takes one crowded generation to develop and shape takes two or more. The pronounced differences between gregarious and solitarious adults (their ambi-morphism if you will) meant that until 1921, scientists believed that gregarious and solitarious locusts were actually two different species.

MIGRATION

Temperature and wind influence the migration of both solitary adults and swarms. Solitary adults fly for only a few hours at night. Swarms generally take off several hours after sunrise in warm weather and fly throughout the day until just before or just after sunset. On especially hot days, swarms may settle around midday and take off again in the afternoon. Temperature limits the height of a flight. Swarms are thought to fly between 1,500 and 1,800 meters above the surface of the ground (Rainey 1963; Schaefer 1976). All major swarms travel downwind. In sunny warm weather, swarms tend to fly about 10 hours, but they have the ability to fly continuously for 13-20 hours. A swarm is displaced at some fraction of the wind speed because many of the adults spend some time on the ground. The ground speed of a swarm is usually about 20-50% of the wind speed. The average daily rate of net displacement of swarms varies from 5 km in cool weather to 200 km in warm weather with a consistent wind direction.

Desert Locust adults and swarms can migrate great distances in a short amount of time. They can stay in the air for long periods, for example, they regularly cross the Red Sea, a distance of more than 300 km, and sometimes move across the Sahara from Sudan to Mauritania to Morocco, a distance of nearly 5,000 km (Figure 2).

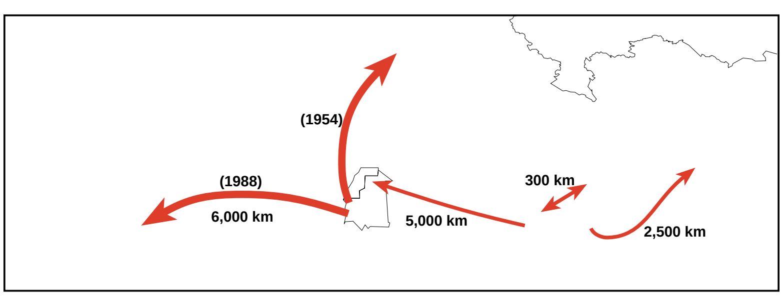

Figure 2 Some examples of long distance Desert Locust migration.

There have been some exceptionally impressive swarm migrations, for example from Northwest Africa to the British Isles in 1954. Over ten days in October, 1988, in the most spectacular migration in recent history, Desert Locusts crossed the Atlantic Ocean from West Africa to the Caribbean, a distance of about 6,000 km.

DESERT LOCUST RECESSIONS AND PLAGUES

In most years, Desert Locusts are usually restricted to the semi-arid and arid deserts of Africa, the Middle East and Southwest Asia that receive less than 200 mm of rain annually. This is an area of nearly 16 million km^2 covering 30 countries (Figure 3).

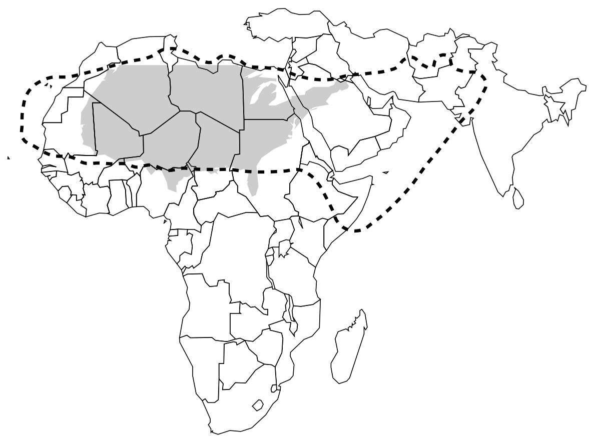

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Figure 3 The Desert Locust recession area (dotted outline) in relation to the size of the continental United States.

Within this area, low densities of solitarious locusts are permanently present and breeding on a small scale in favorable habitats. The numbers are so low that hopper bands and swarms rarely form, and the threat to crops or food security of the host country is insignificant. Scientists have labeled these relatively quiet periods as recessions. In the past, recessions have lasted from less than a year to seven years.

When a favorable combination of conditions occurs, locust numbers and densities markedly increase, which leads to gregarization. This occurs in desert areas after rain falls in sufficient amounts and duration to allow locusts to concentrate and multiply which, unless checked, can lead to the formation of hopper bands and swarms. This is commonly referred to as an outbreak. After two or more successive seasons of solitarious-to-gregarious breeding occur in the same or neighboring regions, a dramatic increase in locust numbers and simultaneous outbreaks may follow; this is commonly referred to as an upsurge. During this period, both the size of the total gregarious population and the size of the bands and swarms that make up that population increase and can lead to a plague. Outbreaks occur often but they do not necessarily lead to upsurges. Similarly, most upsurges die out before leading to a major plague.

During plagues, Desert Locusts may spread over an enormous area of some 30 million km^2, extending over all or part of 60 countries, which encompass more than 20% of the total land surface of the world. The Desert Locust thereby threatens the livelihood of a tenth of the world's population. There have been nine major plagues between 1860 and 1997. Plagues occurred in 75% of the years between 1860 and 1963, but in only 12% of the years since then. They have varied in length from one to 22 years. The last plague occurred in 1987-89.

PLAGUES IN THE MIDDLE EAST

During this century, Desert Locust plagues have occurred in the Middle East on seven different occasions: 1901–1908, 1912–1917, 1926–1933, 1941–47, 1949–1962, 1968 and 1987–89 (Waloff 1976) (Figure 4).

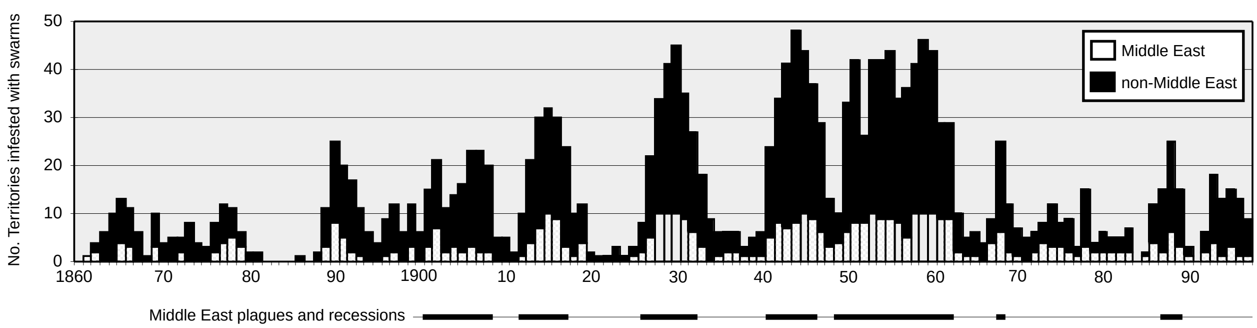

Figure 4 Plagues and recessions of the Desert Locust in the Middle East and elsewhere, 1860-1997.

These plagues lasted between one and 14 years; they were separated from each other by one to 19 years of calm (recession) in between. After the 1941-47 plague, there was a brief recession the following year, broken by an upsurge that led to a major plague that lasted 13 years, the longest continuous plague in the Desert Locust area this century (Waloff 1966). This plague was believed to have started in the Empty Quarter of Saudi Arabia following unusually high rainfall (Lean 1965). During 1949, it spread into the Arabian Peninsula and Iran as well as further east and west. Egypt reported swarms from 1950 onwards, Iraq, Israel, and Jordan in 1951, and Syria in 1953. By 1962, the plague was declining in the Middle East and a long recession period persisted from 1963 to 1985, occasionally interrupted by a small outbreak or upsurge and one short-lived plague (1968) until the next major plague of 1987-89. There was an upsurge in 1993-96 which did not lead to a plague. Most recently, there was an outbreak in Saudi Arabia in 1997 which was controlled.

Since 1860, swarms have been reported more frequently in southwestern Arabia than in other parts of the Middle East. There were a total of 72 years in which at least one swarm was sighted in this area (Table 1).

Table 1 Swarms in the Middle East between 1860 and 1997.

	No. yrs w/swarms 1860-1997	% yrs w/swarms 1860-1997	No. yrs w/swarms during plagues	% plague yrs w/swarms
S. Arabian peninsula (south of 20N)	72	52.2	41	56.9
N. Arabian peninsula (north of 20N)	69	50.0	39	56.5
Arabia (east of 55E)	54	39.1	33	61.1
Iran (south of 30N)	51	37.0	34	66.7
Egypt & Sinai	44	31.9	36	81.8
Israel & Jordan	39	28.3	30	76.9
Iran, other areas	31	22.5	28	90.3
Iraq	27	19.6	25	92.6
Syria & Lebanon	25	18.1	19	76.0
Turkey	13	9.4	13	100

The Desert Locust threatens the livelihood of a tenth of the world's population.

Swarms occurred more often in territories adjacent to southwestern Arabia and in southern Iran than in northern areas of the Middle East. In these northern regions, swarm reports tended to coincide with plague periods. (These frequencies do not indicate the number of swarms, only whether any swarms occurred in a given year.)

During the winter and spring of most years, relatively few solitarious locusts are present along the coastal plains of both sides of the Red Sea and the Gulf of Aden. Occasionally, similar numbers of locusts are present on the coast and in the interior areas of northern Oman as well as in southeastern Iran. Only after locusts in these places substantially increase in numbers under unusually favorable conditions and form swarms do they threaten other countries in the Middle East. This is rare, however; Iraq, Kuwait, Lebanon and Syria last reported swarms in 1962. Swarms may also invade the Middle East from Southwest Asia or Africa, but such swarms mostly affect the Arabian Peninsula.

DESERT LOCUST MONITORING IN THE MIDDLE EAST

HISTORICAL SURVEYS

Desert Locust monitoring and control was first the responsibility of farmers as they struggled to defend their crops. During the twentieth century, governments have accepted the responsibility for organizing country surveys and control campaigns (Lean 1965). Although locust experts discussed the establishment of an international anti-locust organization at a number of conferences (including Rome 1931; Paris 1932; London 1934; Cairo 1936; Brussels 1938), early international cooperation remained confined to research activities rather than operational monitoring and control (Lean 1965). During World War II, the British established the well organized Middle East Anti-Locust Unit (MEALU), which commenced operations in Saudi Arabia in 1943, and in Yemen, Kuwait and Oman shortly thereafter. MEALU hired the explorer Wilfred Thesiger after WWII to undertake Desert Locust surveys in the Arabian Peninsula (Thesiger 1959). Experts from Egypt and India and workers from Sudan and Palestine assisted MEALU. In Egypt, a similar unit existed and operated as well in northwestern Saudi Arabia. In Iran, MEALU worked with Iranian, Russian, Indian and, later, American specialists (Lean 1947). MEALU was disbanded in 1947 and replaced by the East African Desert Locust Survey (DLS) in 1948.

DLS was responsible for monitoring known outbreak areas and making regular surveys of solitarious locust populations in Ethiopia, Iran, Libya, Oman, Saudi Arabia and Yemen. Its headquarters was in Nairobi with field bases in Asmara, Hargeisa, Jeddah and Aden (Uvarov 1949).

In the 1950s, there was a growing interest in international cooperation in monitoring locust populations. This led to United Nations Food and Agriculture Organization (FAO) coordination of international locust control efforts in the Arabian Peninsula beginning in 1956, at which point the British units disbanded (Lean 1965). In that same year, DLS merged into the DLCO-EA (Desert Locust Control Organization for Eastern Africa) which was based in Addis Ababa. In 1958, FAO and other UN agencies began ecological surveys in desert regions and marginal lands where Desert Locust outbreaks most often occur. During the ten year project, they surveyed more than 110,000 km^2, half of which were in Egypt, Iran, Saudi Arabia and Yemen. Equipment was provided to affected countries to allow regular monitoring and forecasting. International experts and field workers assisted in those countries where areas requiring regular surveys were too large for the national government.

In 1965, three long distance surveys were undertaken in Algeria, Saudi Arabia and Iran as part of the FAO ecological surveys. These surveys are thought to be the precursor to the system of national and international surveying and monitoring which now operates in locust affected countries.

Monitoring and control efforts in the field before and after WW II were supplemented by the efforts of the Anti-Locust Research Center in London (UK) which established a centralized system of reporting, mapping, and data analysis on the changing distribution of the Desert Locust in 1929. This organization provided monthly bulletins and forecasts to affected countries. Its work continued under the International Desert Locust Information Service (IDLIS) at the center from 1958 onwards, funded by the UK and FAO (Uvarov 1958). In 1979, FAO assumed this responsibility as part of its mandate and as a result IDLIS was replaced by the Desert Locust Information Service (DLIS) at FAO Headquarters in Rome. The DLIS is now part of the Locust and Other Migratory Pests Group at FAO.

CURRENT SURVEY METHODOLOGY

Over the years, strategies of Desert Locust control have evolved from curative efforts to an emphasis on prevention, that is, finding and treating infestations before they form large hopper bands and swarms. This requires regular monitoring of locust breeding areas and the ability to quickly mount small scale control operations in many of the 60 countries affected by the Desert Locust. Currently, about 18 countries in Africa, the Middle East and southwest Asia maintain a regular survey program for monitoring the Desert Locust (Cressman 1996). These are countries that are frequently infested and have therefore established specialized anti-locust units responsible for survey and control. These units are usually part of the Ministries of Agriculture under the supervision of the Plant Protection Departments. Some units are autonomous while others are incorporated into the national plant protection or agricultural extension programs.

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Of the sixteen Middle Eastern countries considered in this paper, five have well established National Locust Units with nearly regular monitoring programs (Egypt, Iran, Oman, Saudi Arabia, Yemen), four have smaller and less active programs as part of the general Plant Protection Department (Iraq, Jordan, Kuwait, UAE), and seven do not have specialized units nor do they maintain programs (Bahrain, Israel, Lebanon, Palestinian Territories, Qatar, Syria, Turkey).

There are two basic types of surveys. Assessment surveys are conducted in areas that have a history of locust breeding or presence, or where rain has been recently reported or is thought to have occurred, or where reports of locusts have been received from local inhabitants, scouts, or agriculture extension agents. The purpose of an assessment survey is to monitor locust populations and assess the suitability of the habitat for breeding, and to determine whether significant populations are present that may require control. Search surveys are conducted in areas known to contain significant populations in order to estimate the total infested areas, and to delimit the areas that require control. Results from searching permit decisions on if, when, and how control should be conducted.

Assessment surveys are generally the first type of survey to be undertaken in order to determine if locusts are present in an area or to identify areas of green vegetation where locusts are likely to gather. Estimates of densities made at each survey stop can be used to identify those areas where significant numbers of locusts (*i.e.* gregarious locusts, groups, or high numbers of solitary locusts) may be present. Once these areas are identified, a search survey in the identified areas determines the geographical extent and size of the infestations. From this information, the scale of risk and level of required control can be estimated. Information from both types of survey provides a more complete picture of the overall locust situation (Figure 5).

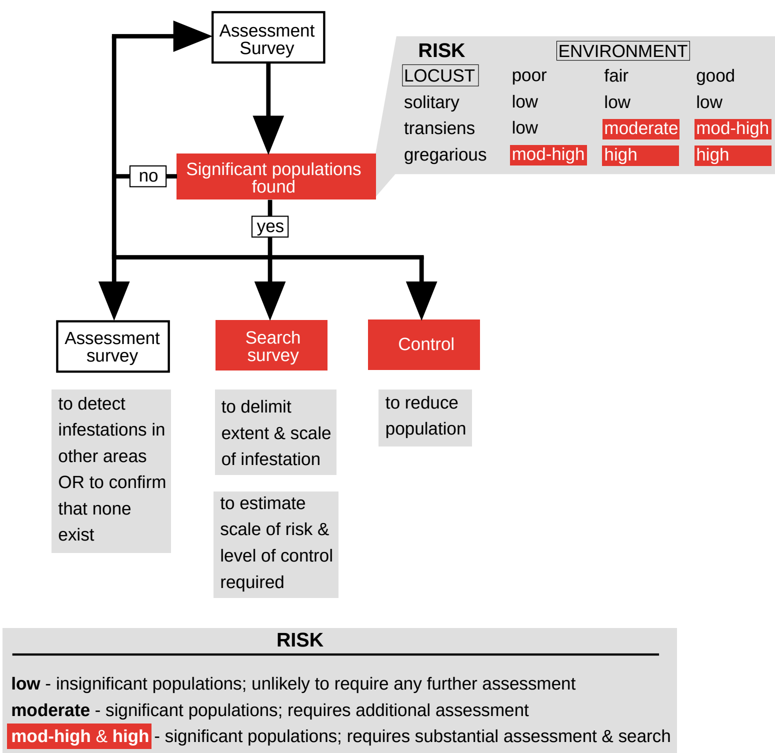

Figure 5 Schematic of Desert Locust monitoring and related decision-making.

Assessment surveys are regularly carried out in those countries with National Locust Units. Specialized staff from these units conduct ground surveys in four-wheel drive vehicles in desert areas. Survey itineraries usually include those areas where locusts or green vegetation were previously seen, areas that are known to be favorite locust habitats and areas in which there is no information. Surveys concentrate primarily on areas of natural vegetation, often in remote, hard to access areas, rather than crop lands. Survey officers also gather information about locust sightings, green vegetation blossoming, and recent rainfall from agricultural extension agents, villagers, truck drivers, travelers, and nomads.

At each survey stop, survey officers will walk several hundred meters, depending on the extent of the vegetation, and count the number of adult locusts that they disturb. Officers will also stop and closely inspect the ground or small bushes for hoppers. The results including the date, location, and notes on the vegetation and soil moisture are written on a standardized reporting form. More and more survey officers are using a hand-held geographic positioning system (GPS) to determine the latitude/longitude coordinates of their position. Surveys are generally conducted early in the morning and late in the afternoon when locusts are most active.

Based on the results of a survey, the need for further assessment or search surveys can be determined. During search surveys, control targets may be identified which allow decisions to be made on the most suitable control method.

Aerial surveys are sometimes undertaken at the beginning of the rainy season to identify areas of green vegetation for later inspection by ground teams. Another aerial survey may be conducted midway through the season and perhaps a final one at the end to provide updated information on the habitat. Most affected countries do not have the resources to carry out such surveys, with the exception of Pakistan which has its own fleet of aircraft. The DLCO-EA uses its aircraft to provide survey services to its member countries.

Remote sensing imagery can assist in the detection of green vegetation and thereby help to guide ground survey teams. Since the late 1980s, imagery has been used in parts of West Africa and more recently (1997), in the Red Sea area. The imagery is captured and processed within the region of interest, in this case, Niamey (Niger) for West Africa and Asmara (Eritrea) for the Red Sea area. Remote sensing imagery currently has several limitations that must be overcome before it can be used on a regular and operational basis. The primary limitation is the need for ground validation which is a time consuming and expensive exercise that must be carried out in several areas within a region since it is not possible to extrapolate

Remote sensing imagery currently has several limitations that must be overcome before it can be used on a regular and operational basis. The primary limitation is the need for ground validation which is a time consuming and expensive exercise that must be carried out in several areas within a region since it is not possible to extrapolate results from one area to another.

results from one area to another. Such validation is required to calibrate imagery and reduce the difficulty in interpretation. Furthermore, a procedure must be developed to deliver processed and calibrated imagery to users in locust-affected countries in a timely manner. Several research institutes and FAO are currently investigating these issues.

ANALYSIS AND FORECASTING

Ground and aerial survey teams transmit their findings to the National Plant Protection Headquarters for collation and analysis as well as to FAO Headquarters where analysis and forecasting at the international level is performed. In the case of a highly mobile pest such as the Desert Locust, a centralized system offers several advantages over national or regional systems in terms of a global view of the locust, habitat and weather situation, access to data not easily available at other levels, objective interpretation of data, and the ability to provide affected countries with information that they themselves would not readily produce or otherwise obtain (Cressman 1997a).

Until recently, data analysis was undertaken manually by plotting survey results, rainfall reports, and habitat conditions on a series of maps of differing scales. These data were compared to historical data including locust frequencies and long-term average rainfall. In 1996, FAO introduced a geographic information system (GIS), SWARMS (*Schistocerca* Warning Management System). The system allows for storage of data in several databases, display of current data on maps consisting of various thematic overlays, and comparison to historical data (Cressman 1997a). In this way, the forecaster can better visualize the spatial and temporal relationships between the various data types and query the data in order to gain a good understanding of the current situation and how it may develop.

At present, a smaller national GIS has been developed and is being evaluated for operational use in one of the affected countries (Cherlet, personal communication). The purpose of the system is to allow a National Locust Unit to better manage and analyze data collected in its country. There are strong links between the national GIS and SWARMS to allow sharing of data. In this way, it is anticipated that Desert Locust monitoring will become more of a cooperative effort and partnerships will develop among countries and with FAO in terms of data collection, transmission and analysis.

THE LOCUST OUTBREAK IN THE ARABIAN PENINSULA, 1996-1997

OVERVIEW

An outbreak of Desert Locust during the 1996-97 winter was a classic example of a situation that could have led to an upsurge or a plague. Successive rainfalls made conditions extremely favorable for breeding along 900 km of the Red Sea coastal plain in Saudi Arabia (Figure 6).

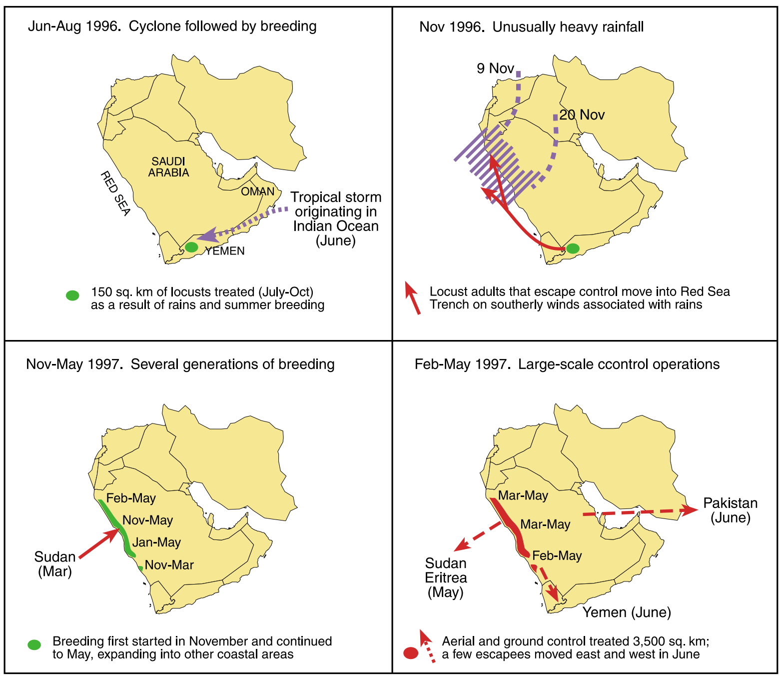

Figure 6 Overview of the origins and development of a Desert Locust outbreak in the Arabian Peninsula, 1996-97.

Good conditions persisted for nearly six months which led to a dramatic increase in locust numbers, most notably during March and April when hoppers and adults changed phase from solitary to transiens (Cressman 1997b). Large scale control operations involved more than 70 teams and four aircraft and used 340,000 L of pesticide. (Saudi Arabia 1997). This effort prevented significant swarm formation and migration as well as any major loss to crops.

ORIGINS AND DEVELOPMENT

Solitarious Desert Locust adults were first reported on the Red Sea coastal plains of Saudi Arabia in November 1996. These adults probably originated from locusts from the Yemeni interior which had themselves appeared after a cyclone in June. Some of the

Yemeni locusts perished in control operations but others were probably drawn into the Red Sea Trench on southerly winds associated with an unusually strong and persistent depression over the northern Red Sea in mid-November 1996. This depression also resulted in light to moderate rainfall over a large portion of the coastal plains along both sides of the northern Red Sea from 15-25 November. In Saudi Arabia, rains were reported on the coast from Al-Lith to Khulais but were estimated to have extended to Al-Wajh in the north.

The majority of the incoming adults landed on the coastal plains of Saudi Arabia and most likely dispersed over a wide area from Al-Lith in the south to Al-Wajh in the north, making it difficult to find them. Small scale breeding first occurred shortly after the rains, primarily near Al-Lith and Badr, producing a new generation of solitarious adults that appeared from late January onwards. Densities were still relatively low, mostly from 1-3 per ha with a few locations reporting up to 100 per ha.

In mid-January, widespread light to moderate rains fell on the coast north of Jeddah to Yenbu. Adults are thought to have concentrated in this area during the following weeks, increasing in density to nearly 1-2 adults/m^2 (10,000-20,000/ha) which was probably enough to induce a partial phase change from solitarious to transiens. Egg laying occurred shortly after the rains on the coastal plains near Khulais and Badr.

Heavier laying by solitarious adults and groups of transiens occurred in late February in Al-Lith, Usfan-Tuwwal, Khulais, Rabigh, and during the first half of March in Usfan-Tuwwal, Masturah, Badr, Yenbu, and Umm Lajj. Breeding during the latter period was supplemented by several low density mature swarms reportedly coming from the western shore of the Red Sea on 8-15 March. The swarms, which also laid eggs upon arrival, were estimated to vary in size from 5-50 km^2 with densities of 5-20 adults/m^2. Other laying adult densities were estimated to be about 2-5/m^2. Consequently, locust numbers rapidly increased during this period.

High density hatching commenced about mid-March and increased over the next few weeks in all areas. This led to large numbers of hoppers and, in some cases, grouping and small band formation during April. By the end of April, hoppers were fledging and new adults started to appear.

Another period of laying occurred in early April that coincided with more rainfall. The breeding was primarily concentrated on the northern coast near Yenbu, Umm Lajj and Al-Wajh as well as further south near Khulais. It consisted of late maturing adults from the incoming swarms combined with adults produced locally earlier in the year. Those in the north were not reported by locals who collect them for both personal consumption and for sale in local markets. Densities of laying adult groups were probably higher in northern areas than near Khulais and were estimated to be about 5-20/m^2. Hatching occurred in late April and new adults started to appear by late May. Fourth and fifth instar gregarious hopper groups were present near Al-Wajh at the end of May in densities of up to 50 hoppers per m^2 (Cressman 1997b).

Vegetation rapidly dried on the coastal plains in early May. As a result, most of the immature adults and a few small groups and swarmlets that had survived the control operations moved off the coastal plains and migrated across the Red Sea to Sudan where they arrived on 15 May and in Eritrea at the end of the month. By the end of the month, hopper groups and only low numbers of adults remained on the Red Sea coastal plains of Saudi Arabia. Most of these became concentrated in the few remaining green areas along the base of the foothills and some of the adults moved up the valleys of the foothills east of Khulais and Al-Wajh. By mid-June, vegetation was completely dry and the few remaining adults had left the coastal plains. On 21 June, one small swarm was reported in northern Yemen which later dispersed.

CONTROL

The National Locust Unit (Locust Control Center, Jeddah) of Saudi Arabia mobilized its resources, which are significantly greater than those of most affected countries. It began ground control operations in mid-February against mature adult groups at Al-Lith, Khulais and Rabigh, treating a total of 1,000 ha. During March, the Saudis extended operations to all other areas with the assistance of a helicopter; they were able to spray more than 25,000 ha of laying adults, hopper groups, bands, and fledglings, including incoming swarms. During April, two fixed-wing aircraft joined the on-going operations and more than 81,000 ha of hopper bands and immature adults were treated. In May, an additional fixed-wing aircraft was added and 140,000 ha of mostly immature adults and some hopper bands were treated. In June, more than 28,000 ha were treated. During the entire campaign, more than 70 ground teams and four aircraft from the Saudi National Locust Unit applied more than 340,000 litters of pesticide to approximately 3,500 km^2.

ASSESSMENT

During the outbreak, average infestation levels (the percent of green vegetation in which locusts are present) were about 8% but varied from 1-30%. The initial buildup of locust numbers was missed during the first four months (November - March) because adults were scattered along the coastal plains and foothills and often were not reported by locals. Such a large area is not only extremely difficult to monitor effectively but impossible to treat because of the wide dispersion and low density of the locusts involved. This problem was compounded by the fact that large expanses of green vegetation encouraged a general increase in locust numbers rather than concentrating the infestations at particular points. Hence, good control targets in which high numbers of locusts could be treated in small compact areas did not exist until the end of the season when vegetation began to dry up. This was after several periods of breeding had occurred.

Nevertheless, the Government of Saudi Arabia was able to mobilize a large amount of resources to undertake a ground and aerial campaign that, given the difficult circumstances, significantly reduced locust infestation levels and effectively prevented the formation of large and numerous swarms. As a result, only groups of adults and a few small swarms formed and migrated from the coastal plains to the west, south and perhaps east. There were no reports of significant crop damage.

The Desert Locust has adapted to one of the harshest environments on Earth. It has developed a variety of mechanisms to survive in conditions of high temperatures, low rainfall, strong winds and sparse vegetation.

DISCUSSION

The Desert Locust has adapted to one of the harshest environments on Earth. It has developed a variety of mechanisms to survive in conditions of high temperatures, low rainfall, strong winds and sparse vegetation. Its ability to migrate long distances gives it access to vegetation over a huge area while at the same time decreasing threats to the species by natural predators. It quickly capitalizes on favorable conditions by rapid maturation and reproduction. As conditions become less favorable, it changes its behavior to that of an individual organism, which is more likely to survive in situations of diminished habitat.

During the twentieth century, our understanding of the Desert Locust has evolved. It was originally thought that the Desert Locust was two different species, one solitarious and one gregarious. Dr. Boris Uvarov first demonstrated that it was indeed one single species with the ability to change its behavior in response to environmental changes. Since then, its biology, behavior, and population dynamics have been extensively studied in the field and the laboratory. Locusts and grasshoppers in general have often been the focus of research due to their conveniently large size and their relative ease of captive rearing. The remarkable ability of this species to survive during times of drought and vegetation scarcity, and also to capitalize in more humid times on relatively brief flowerings of vegetation has meant that it poses a particular challenge to the human beings with whom it shares a habitat.

Control techniques have also evolved from simply burying hopper bands and collecting adults to more complicated methods of chemical treatment. Most of this development occurred during this century and coincided with the advent and use of synthetic compounds after WW II. The types of pesticides commonly used in locust control have changed from strong organochlorides to safer organophosphates as humans have become more aware of the effect of pesticides on the environment. For example, the organochloride dieldrin was the pesticide of choice from the 1950s onward because it persisted for months in the desert. However, such persistence also appeared to have detrimental effects on human health and the environment and dieldrin was banned in the late 1980s. The concept of using a different formulation and applying pesticides at a lower dose rate in overlapping swaths was first tried out against locusts. This is commonly referred to as ultra-low volume (ULV) spraying and is the basis of current locust control. Today, the evolution of control agents continues as scientists develop and test alternative products such as insect growth regulators and mycopesticides, which are more target specific and environmentally friendly.

It has only been during this century that our understanding of the Desert Locust and its relationship with the environment has increased to a point that allows for better management of this pest through improved strategies of monitoring and control.

Application methods have changed over the years from the spreading of arsenic by hand in the late 19th century to manual baiting and dusting, to the present day use of hand, vehicle-mounted, and aerial ULV sprayers. Although the latter methods require a higher level of skill and expertise, they are much safer for the user.

Finally, the strategies of managing Desert Locusts have advanced. Historically, farmers tried to control locust infestations using any available means when their crops were attacked. This rather unsystematic approach, comparable to putting out brush fires as they flare up, often led to poor results and did not stop plagues from developing or spreading. WW II marked a turning point for locust survey and control. International cooperation was strengthened, specialized field units were established, systematic survey and control operations were undertaken, and new pesticides were developed and became available. Based on these advances as well as knowledge gained in the previous 50 years about the Desert Locust and its environment, alternative strategies were developed.

The current strategy used by national and regional locust units focuses on the need to keep locust numbers at a sufficiently low level to prevent swarm formation and the development of plagues. Control decisions are based on information gathered by and exchanged with national agencies and international organizations that have developed programs to regularly monitor locusts and the weather in the desert before they reach agricultural areas. This strategy is quite effective because countries have come to accept that international cooperation is critical in the fight against the Desert Locust. Nevertheless, plagues are not always prevented and often substantial control operations are required to reduce locust numbers and try to bring a halt to an upsurge or plague. It has become apparent that such operations could be strategically applied at certain times or in specific areas. One example is the delaying of control operations until locusts become concentrated into a relatively small area, which would allow more locusts to be treated using a lower quantity of pesticides applied over a smaller area.

CONCLUSION

Desert Locusts have threatened agricultural crops for the past 5,000 years or more. It has only been during this century that our understanding of the Desert Locust and its relationship with the environment has increased to a point that allows for better management of this pest through improved strategies of monitoring and control. The use of modern technology has been of some help in reducing the large desert areas that must be surveyed and treated. Undoubtedly, the fragile environment of the deserts in Africa and the Middle East will continue to change in the future, partially as a function of human activity. It is likely that the Desert Locust will adopt itself to these changes in order to continue to survive as it has done in the past. Therefore, the challenge in coming years will be to adopt Desert Locust management strategies accordingly and apply them in a manner that continues to insure food security while minimizing any detrimental effects on the environment.

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Section II: Water

"Virtual Water:" An Essential Element in Stabilizing the Political Economies of the Middle East

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ABSTRACT
Why has there been no war over water despite the fact that many economies in arid regions have only half the water they need? This paper posits that the Middle East region has been able to access water in the global system via trade, enabling economic systems to solve the water supply problem for the region. Water in the global trading system is known as "virtual water"– the water embedded in key water-intensive commodities such as wheat. The international wheat trade is a very effective and highly subsidized global system which operates to the advantage of countries experiencing water and food deficits.

MIDDLE EAST AND GLOBAL WATER RESOURCES: THE LINK

Whether there will be enough water for a future global population double its present size is the subject of considerable controversy. The answer to the question is of particular importance to the peoples and political leaders of the Middle East and North Africa (MENA). The region's economies are already as dependent on imported water as they are on the renewable waters of the region, and that dependence is likely to increase over the coming decades.

Whether there will be enough freshwater for future populations is a mega-question which is not given a fraction of the attention it deserves by scientists.

Freshwater needs are driven by rising populations. The range of the estimates of future global population vary by over 50%. In this uncertain information domain there is the opportunity for pessimists and optimists to offer opposing interpretations. Whether to believe the optimists, including the author and most economists (Islam 1995; IFPRI 1995 and 1997; Dyson 1994), or the pessimists (Brown 1995 and 1996; Brown and Kane 1996; Postel 1995) depends upon the assumptions used.

Mega-questions tend either to be ignored or to attract difficult-to-test ideological interpretations of religious intensity. Whether there will be enough freshwater for future populations is a mega-question which is not given a fraction of the attention it deserves by scientists. In the 1960s and 1970s there were attempts in the former Soviet Union to review the world's water balance (L'vovich 1969 and 1974) and in the years since there have been further efforts to address global water availability and use (Shiklamanov 1985, 1986; Shiklamanov and Sokolov 1983; Shiklamanov and Markova 1987; and Gleick 1994).

Meanwhile international funding agencies are prepared to devote millions of dollars annually to the provision of advice on water management and lending for water projects without offering a view on the status of global water. The World Bank has produced shelves of reports on water allocation and management for the interested professional and general reader (World Bank 1993a; Serageldin 1994 and 1995) and for the specialist focused on local and regional issues (World Bank 1991, 1993a, and 1997). It has not, however, situated the debate in the global resource context. Only since 1994 has there been an attempt to address the subjects of water availability for the Middle East and North African region (FAO 1995a and 1997a) and water use by irrigation, the major water-using sector (FAO 1995b and 1997b). These publications provide first approximations whose reliability should continue to be tested.

The upper and lower bounds of the above projections are quite high, but about Middle East water there is far less uncertainty.

Although it is generally not publicized, the Middle East as a region actually ran out of water in the 1970s (Rogers 1994; Allan 1994). In politics, facts which are judged to have costly political consequences can easily be ignored or de-emphasized. For leaders in the region, political imperatives are more compelling than scientific facts. On water, these imperatives have led to denials of the scope of domestic and regional water scarcity. An ex-Prime Minister of Egypt (Higazi 1994) and mid-1990s Egyptian ministers of water resources, agriculture and planning have all publicly asserted that Egypt has sufficient water (Arab Research Centre 1995). The discrepancy between the views of scientists and politicians in the assessment of acute scarcity generally stems from the politicians' failure to account for the water required for increasing food production. Politicians limit their analysis to municipal, industrial, and agricultural job sustenance, and in doing so, claim water sufficiency despite the absence of large water volumes needed to grow crops to feed their populations. For politicians in almost all countries in the region the food gap caused by the insufficiency of water has to be ignored, because to draw attention to the food gap is politically suicidal.

The reason the Middle East is important with regard to water is because it is the first major region to run out of water. The Tigris-Euphrates riparians have not yet fully utilized their water resources but will do so in the coming decades. Similar problems are envisioned among the upper riparians of the Nile.

The major indicator of the scale of the water deficit of an economy is the level of its food imports, since water used in the agricultural sector exceeds by ten times the water used by the industrial and municipal sectors combined.

Although it is generally not publicized, the Middle East as a region actually ran out of water in the 1970s….For leaders in the region, political imperatives are more compelling than scientific facts. On water, these imperatives have led to denials of the scope of domestic and regional water scarcity.

Table 1 World population in the year 2100 (IFPRI 1995).

Low scenario:	7.7 billion
Mid scenario:	9.4 billion
High scenario:	11 billion

In the humid temperate latitudes, attention is rarely drawn to the relative demands of the agricultural and the municipal/industrial sectors, since crops can generally be grown in those regions without irrigation. In the arid and semi-arid Middle East, however, the dominance of the agricultural water demand is stark. There is little or no naturally occurring soil moisture there even during the winter rainy season.

In the semi-arid and arid Middle East and North African region, water for irrigation is expensively won because of the costs of storage and distribution. Moreover, that water which is diverted for the purposes of irrigation is lost to the industrial sector, putting water-stressed riparians at a competitive disadvantage in terms of economic (non-agricultural) production. The effective allocation of water between sectors to gain high returns and high levels of employment is fundamental to economic and political stability.

Table 2 Per-capita annual water consumption.

Drinking water:	1 m^3
Municipal and industrial uses:	100 m^3
Food production:	1000 m^3

THE REGIONAL WATER GAP AND THE GLOBAL WATER SURPLUS

The production of every metric ton (1000 kg) of a food commodity such as wheat requires an input of about 1000 metric tons of water (equivalent to 1000 m^3). The interannual trend in cereal imports reflects a reasonable approximation of the capacity of an economy to meet its strategic food needs. Figure 1 illustrates the trend in cereal and flour imports in the Middle East and North Africa since the 1960s.

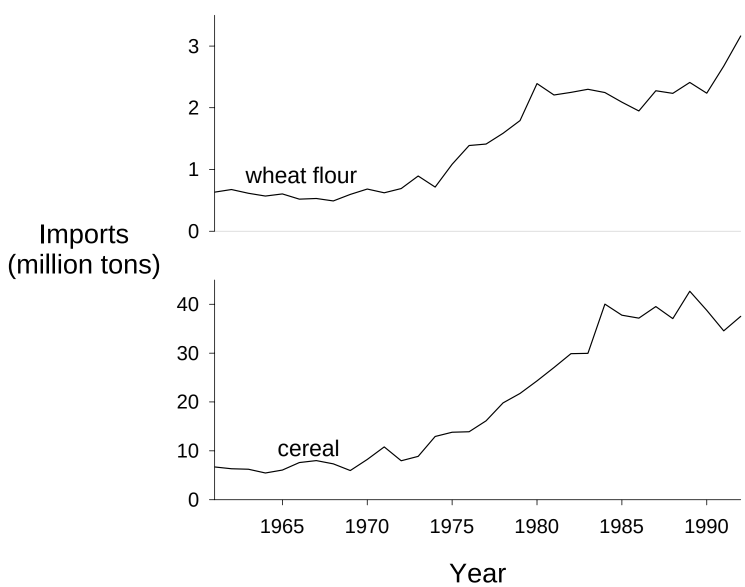

Figure 1 Wheat and cereal flour imports to the MENA region, 1961-1992.

The leveling off in the trend in 1986 reflects changes in particular agricultural and food production policies by Egypt and Saudi Arabia, the two biggest players in both cereal and flour production and consumption in the region. Egypt introduced wheat subsidies (to begin a shift away from cotton) and Saudi Arabia's irrigation projects began to produce sufficient wheat for most of its needs (as it became a significant wheat exporter in the world market). Saudi Arabia has subsequently reduced its wheat production because it was palpably an unrealistic way to use its fossil water.

Although the region has suffered fairly acute water scarcity since the 1970s, the peoples and their leaders refuse to recognize these resource and economic realities. Their interpretations of Middle East hydrological and economic contexts are at best underinformed and at worst dangerous. Figure 2 provides the estimated status and utilization of MENA water resources.

Although the region has suffered fairly acute water scarcity since the 1970s, the peoples and their leaders refuse to recognize these resource and economic realities. Their interpretations of Middle East hydrological and economic contexts are at best underinformed and at worst dangerous.

Scientists cannot provide truly reliable information on either the supply side (the availability of water) or on the demand side (the current and future consumption of freshwater driven by future populations). In any event, the capability of the region's hydrological system to meet the rising demands being placed upon it is in question.

At the same time, however, the global hydrological system is expected to be able to meet the most significant element of global water demand, the global consumption of food. Assuming a medium water consumption scenario of 1500 m^3/capita/yr, global freshwater needs are about 8.25 billion m^3 (BCM) annually. Consumption of this magnitude is well within the estimates of global freshwater availability (Rodda 1996), but there are differing interpretations of the position *vìs-a-vìs* future demands driven by higher world population (Brown 1996; Postel 1997; IFPRI 1996).

At this stage in history the Middle East's water deficit is not serious because global systems (i.e. trade) balance the Middle East's deficit (Allan 1994). It is economic systems and not hydrological and water engineering systems which achieve water security for the economies of the region. At the regional level there can only be degrees of pessimism about the future availability of water, at least for irrigated food production. On the other hand, optimism about the capacity to use the region's water more productively is sound. It is on this aspect of water management that politicians and regional optimists focus. At the global level there is certainty neither about volumes of freshwater available nor about the capacity to use the water effectively. In these circumstances there is evidence to support the arguments of both optimists and pessimists. Because of the mighty error bars on the statistics produced by the as yet inadequate models of global change (Conway 1993; Conway and Hulme 1993

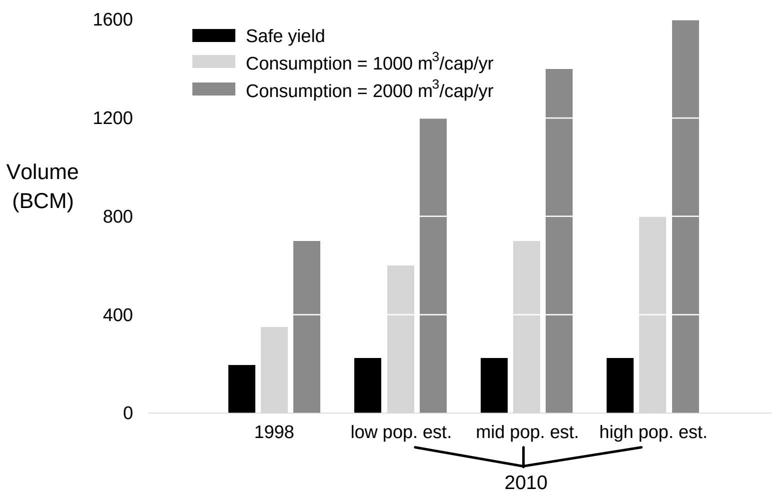

Figure 2 Uncertain MENA scenarios: population and water consumption.

and 1996; Conway *et al.* 1996) very different views emerge concerning the capacity of the world's agricultural systems to raise food. The pessimistic global freshwater scenario is persuasive if we assume:

- static patterns of food and water consumption by individuals;
- high estimates of the demographic transition;
- static technology;
- inflexible political and international institutions; and
- ineffective trading systems.

If, however, we assume:

- increasing food and water consumption efficiencies;
- lower range population projections (7-9 billion people); and
- continued open trade,

then we can conclude that the world's water and food futures are uncertain but not seriously insecure.

The specific deficits of the MENA region arise not from poor local resource endowment, which is significant, but from the inability of agricultural sectors, governments, and international institutions to adapt to the resource scarcity and take measures to find and mobilize substitutes. It must be recalled that human consumption should not be assumed to remain in the 1000-2000 m^3/capita/yr range. Consumption rates in the vast semi-arid tracts of Africa south of the Sahara have been measured at as low as a mere 3.5 m^3/capita/yr.

Anxiety over municipal and industrial needs – even in the MENA region – is misplaced. The genuine tension over water in the region has been and will continue to be in the agricultural sector. Food production requires about 90% of a community's water; should there be insufficient water for local food needs (the predicament of the Middle East since 1970) then "virtual water" has to be imported. Domestic water is likely also to be augmented by desalination.

While the underlying message in this paper is optimistic, it must be very strongly emphasized that the types of adjustment anticipated by the optimists cannot be achieved quickly. Thirty years is a rather short transitional period for the necessary major adjustments in water policies to be developed in response to limited water availability. Adjustments such as the changes in the public perception of the value of water take time. The associated political discourses enabling fundamental changes in water policies may take decades. So deep are the belief systems and so challenging any proposal that beliefs should change that politicians are loathe to contradict them, even though the measures are essential for the stabilization of the political economy.

How is it that the two camps, pessimists and optimists, can exist simultaneously and dispense such confusing contradictory interpretations? The central reasons are analytical uncertainty in the areas of freshwater availability and the impacts of various climate change scenarios on the supply side and of consumption rates on the demand side.

Anxiety over municipal and industrial needs – even in the MENA region – is misplaced. The genuine tension over water in the region has been and will continue to be in the agricultural sector. Food production requires about 90% of a community's water; should there be insufficient water for local food needs (the predicament of the Middle East since 1970) then "virtual water" has to be imported. Domestic water is likely also to be augmented by desalination.

VIRTUAL WATER AND THE PROBLEMSHED

Watershed-based water budgets do not provide a complete source of explanation because they are not determinant of the options available to those managing a national economy. If national hydrological systems restrict economic options then politicians have to find remedies in systems that do provide solutions. United States water resource specialists have coined the term "problemshed," to make the idea of the "system" in which solutions can be found more accessible. National economies operate in international political economic systems – in problemsheds – and not just in hydrological systems – or watersheds. The political economy of the global trade in staple cereals is the relevant analytical catchment for water deficit economies. Access to, and management of, the problemshed is not restricted to environmental systems; it necessarily includes extremely powerful and flexible economic systems as well.

The shared and limiting watershed-based water budgets, with all their troublesome international relations, are dangerously misleading frameworks of analysis. The existence of solutions in "problemsheds" enables politicians to avoid the stresses of inter-riparian relations in the "watershed." In brief, if half of the water needed to feed the MENA region's people in the 1990s lies in the soil profiles of temperate humid environments in North America, South America and Europe, it would be scientifically derelict to ignore that water. It would also be neglectful of scientists in general and the governments of water-short economies in particular to ignore predictable future competition for this water. The scientific neglect is just as serious as the predictable devious and selective hydropolitics engaged in by political interests.

The coming fifty year transformation of the perceptions of the value of water (Allan and Radwan 1998) will be a tough environment for those looking for quick solutions. There is no reliable checklist with which to change the perceptions of large groups of people quickly. And people "convinced against their will (tend) to be of the same opinion still." Even when perceptions have transformed and shifted, the implementation of new water policies, especially water re-allocation policies, must be gradual. These processes will all be slow, sometimes painfully slow, for anxious agency officials and for economists and engineers because of limited funding and career horizons.

As noted above, the foundation scientific concepts for economically and environmentally sound water policies require reforms and adjustments with high political prices (World Bank 1997). Politicians will defer for as long as possible paying these political prices, which can be so extreme as to involve loss of power. It requires a nearly inhuman level of courage for a political leader of a country that for five thousand years has enjoyed water security to announce that water resources are no longer adequate.

Those innovators purveying economic and environmental facts of life which contradict the deeply held belief systems of whole populations will be ignored if they do not shape their message and pace its delivery to accord with political realities. The authors of the 1997 World Development Report (World Bank 1997) put it another way, quoting Machiavelli:

> The innovator makes enemies of all those who prospered under the old order, and only lukewarm support is forthcoming from those who would prosper under the new.
>
> *The Prince*, Machiavelli, N., 1513.

CONCLUSION

Ultimately the water pessimists are wrong, but their pessimism is a very useful political tool, enabling the innovator to shift the eternally interdependent belief systems of the public and their politicians. The water optimists are right, but their optimism is dangerous because it enables politicians to treat water as a low policy priority, to delay innovation, and to thereby please those who perceive that they are prospering under the old order. Pessimists also bring more sensational stories to the media. Optimists bring a version of good news which is complicated and indigestible, as well as unsensational.

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Playing Chicken on the Nile? The Implications of Microdam Development in the Ethiopian Highlands and Egypt's New Valley Project[1]

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ABSTRACT
How Egypt and Ethiopia will defend or promote their interests in the Nile basin has recently become clearer. Egypt will again seek to create "facts on the ground," this time a large new land reclamation and settlement scheme called the New Valley Project. Ethiopia too will create facts by proceeding with water resources development in the Blue Nile basin, including the construction of low-cost microdams. If Egypt and Ethiopia pursue these two unilateral initiatives, they may find themselves on a collision course that both may have difficulty changing. The challenge facing the Nile riparian countries is to find a balance between the upstream countries' support for the principle of "equitable use," and Egypt's and Sudan's support for the principle of "no appreciable harm." Of all the riparian states Egypt has the most to gain from the establishment of a basin-wide framework for water resources development. It can ill-afford a future in which upstream riparians take unilateral actions with respect to water development projects. If Egypt would reduce its existing water use by 5–10 billion m^3 and scale back or abandon the plans for the New Valley Project, there would be enough water available to strike a deal that would bring Ethiopia into the framework of a comprehensive Nile Waters Agreement.

It is clear that the next century, if not the next millennium, will witness rising international tensions over natural resources. What is not at all clear is the way in which those tensions will be expressed and, one hopes, resolved. The issue facing nation states will be how best to conduct and manage the arduous, time-consuming search for cooperative solutions to resource utilization challenges. This search is underway for the most efficient ways to use transboundary waters, but it has so far yielded meager results. Without greater success in the future, the daunting challenges of satisfying the demands of growing, and, one hopes, better-off, populations will not be met.

The problem is that the search for cooperation and the search for economic efficiency do not always complement each other. Countries, states, or communities like the European Union, cannot fully control the economic benefits arising from their own investments. Reducing power plant emissions may mitigate rain acidity and global warming, but also allow other countries to avoid undertaking similar investments. When the threat of such "free-riding" is large, no one has much incentive to invest at home, nor is the situation right for a search for binding cooperative undertakings.

International rivers provide striking examples of these problems, none more so than the Nile Basin. The authors have spent decades studying and writing about issues of water development and coordi-

[1] Reprinted from "Playing Chicken on the Nile" by John Waterbury and Dale Whittington, with the permission of the *Natural Resources Forum*, a publication of the United Nations Department of Economic and Social Affairs.

nated resource use among the ten countries that share the Nile.[1] This article does not propose to cover all or even most of the complex issues facing the Nile riparians, but rather to focus on one set of bilateral relations, and arguably the most important, that between Egypt and Ethiopia.

The Nile is a very long river but not one with much water. Its discharge is dwarfed by those of the Congo/Zaire, the Amazon, the Mississippi, and the Mekong. Its annual discharge is now pretty much used in its entirety by Egypt and Sudan, except in years of exceptional floods. In fact, by the terms of a 1959 agreement, significantly called the "Treaty for the Full Utilization of the Nile," Egypt and Sudan divided the annual flow between them with 66% going to Egypt, 22% to Sudan, and the remaining 12% allocated to surface evaporation and seepage at the Aswan High Dam (AHD) reservoir. It was on the basis of this treaty that construction of the AHD went forward.

No other riparians were party to this accord, nor was any share in the annual flow prudentially set aside for them. The treaty did anticipate future demands from the excluded riparians, but merely stipulated that Egypt and Sudan should deal with those demands jointly. Predictably, the upstream riparians, many at the time still under British control, were not pleased. However, Cold War rivalries, their own political instability combined with bouts of civil war, and their feeble economies did not allow upstream riparians to press any realistic claims to Nile water arising in or traversing their territories. The economic weakness has endured until today, although there are signs of recovery in Uganda, Eritrea, Ethiopia, and Tanzania. Some political stability has been secured in the last decade in Eritrea (independent in 1993), Ethiopia, and Uganda.[2] The time has come when a few upper basin riparians may test the Egypto-Sudanese status quo (Waterbury 1997).

None of the projected demand scenarios involve truly large amounts of water. Many potential projects are hydroelectric power stations, which do entail reservoirs and attendant storage losses. But, even though the upper basin states have relatively abundant rainfall, it is erratic, seasonally concentrated, and not often in the regions where the soils are best for agriculture. Capturing river water for irrigation is an option that few upper riparians have exercised, but, with increasing demand for food from growing populations, they inevitably will in the near future. Because the flow of the Nile, so Egypt and Sudan claim, is fully used today, reductions in flow caused by an upstream state could disrupt existing patterns of agricultural production in the downstream states.

1 They are roughly from north to south: Egypt, Sudan (Main Nile), Eritrea, Ethiopia (the Blue Nile watershed), Kenya, Tanzania, Burundi, Rwanda, Uganda, and Zaire (Kagera Basin, Lake Victoria Basin, Lake Albert, and the White Nile).

2 The fact that Sudan is still locked in civil war, Rwanda and Burundi trying to deal with the aftermath of or to avoid genocide, and Zaire (now the Congo), under the as-yet untested grip of Lauren Kabila, means that any coordinated stance among the upper basin riparians will be nearly impossible to achieve.

Egypt in particular has insisted that sunk costs in harnessing the Nile within its national boundaries give it a kind of property right to the resource. This right is all the more vital to Egypt in that it does not add a single drop to the Nile's flow through its territory. Therefore, Egypt will probably not relinquish any part of its "right" except under duress.

Ethiopia, by contrast, on average provides 80-85% of the annual discharge of the Nile (through the Akabo-Baro, Blue Nile, and Atbara/Teccaze tributaries) yet to date uses virtually none of it. International law and the guidelines of international financial bodies such as the World Bank make it extremely difficult for an upstream riparian to undertake unilateral development of its portion of the river in the absence of consultation with and the consent of the downstream states. In this sense the downstream states hold veto power over third-party financing of upstream development. Ethiopia does not yet have the financial strength to undertake more than a few large-scale water resources development projects on its own and thus finds itself in a box.

Egyptian and Ethiopian interests are thus in potential conflict.[3] How they will defend or promote their interests has recently become clearer. Egypt will seek, once again, to create "facts on the ground," this time a grandiose scheme of land reclamation and settlement called the New Valley Project (Figure 1). Ethiopia too will create facts by proceeding with low-cost construction of microdams. As the two strategies unfold, we expect to see a game of "chicken" on the Nile.[4]

MICRODAMS IN THE ETHIOPIAN HIGHLANDS

In Tigray province alone, Ethiopia has plans to build 500 microdams over the next decade.[5] These are small-scale projects that typically provide water for irrigating a few hundred hectares. They can be built without foreign technical assistance or financing, largely with local labor. They are simple to design and can be constructed quite rapidly. Ethiopian farmers already possess many of the skills necessary to proceed with a microdam strategy. A tradition of small-scale irrigation is well-established; there are many small-scale irrigation schemes along streams and tributaries throughout the Ethiopian highlands. If peace and economic growth continue, these farmers will almost certainly pursue further efforts at small-scale irrigation and microdam development. It is unclear how many sites exist in the highlands for these microdams, but there are probably thousands (although many potential sites are not in the Blue Nile watershed, and thus their development would not affect Blue Nile flows).

[3] Although Egypt's and Ethiopia's interests do conflict, there are important opportunities for cooperation and sharing of joint gains (Whittington and McClelland 1992).

[4] This image has already been invoked with respect to the Nile by Wolf (1996). The game of "chicken" is played in various forms in different cultures, but the essence of the game is to set in motion a course of action that will lead to a collision for both parties unless one party takes action to prevent the calamity. But then the party that takes action, instead of being rewarded for averting disaster, loses the game because he is thrown off course. For example, a game of chicken is sometimes played by automobile drivers who start at different places on a road, and start driving straight at each other. If they continue on course they will crash and both be killed. The driver who veers off course first prevents the crash, but ends up off the road, and is termed the "chicken" because his fear of death overcame his desire to "win" the game.

[5] Tigray has historically been drought- and famine prone. It is also the province from which several of Ethiopia's most powerful leaders, including Prime Minister Meles Zenawi, hail.

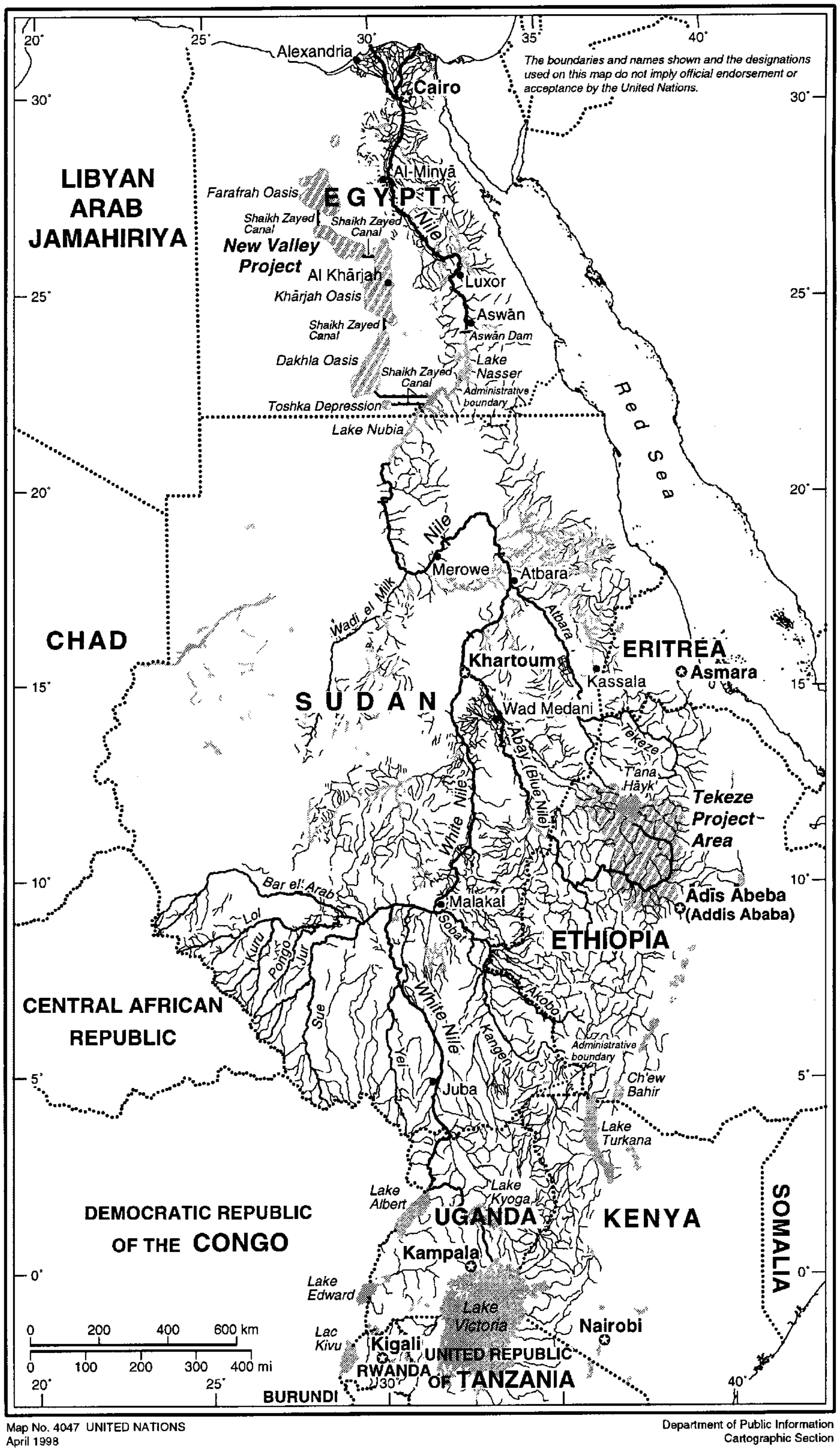

Figure 1 Nile Drainage Basin. Source: Cartographic Section, DPI, United Nations.

These microdams have numerous potential problems. Many sites appear likely to silt up rapidly, and thus lose water storage capacity. Malaria may spread through the highlands as sites for the mosquito vector increase (Cropper et al. 1998). Moreover, it is not clear how much water such schemes will use and what the effect of this use will be on downstream flows. However, if Ethiopia is to undertake, through micro-dams, anything that would have a significant effect on downstream flows, it would have to build thousands of microdams.

There is currently little literature on microdam development in Ethiopia, but the storage capacity of approximately 500 microdams planned for North Gondar appears to be in the range of 100,000 to 500,000 m^3 each. However, for purposes of illustration let us assume microdams with larger storage capacities than these. Assume that 5,000 microdam schemes were developed in the Nile drainage system in Ethiopia, each with sufficient storage capacity to supply water to an associated irrigated area of 200 hectares each. This would involve a total irrigated area of one million hectares. If each hectare of irrigated land used 5,000 m^3 annually, the total water use would be 5 billion m^3 per year. Again, for purposes of illustration, let us assume that 5 billion m^3 of water use in the Ethiopian highlands resulted in a net reduction at Aswan of 4 billion m^3. This is over twice Egypt's anticipated increase in long-term yield from the Jonglei Canal, should it ever be finished.[6]

There is evidence from other parts of Africa that microdams can indeed affect downstream flows. For example, in his study, "The Impact of Small Farm Reservoirs on Urban Water Supplies in Botswana," Jeremy Meigh (1995) concludes:

> These results…show clearly that development of small dams upstream of major reservoirs should never be allowed to proceed unplanned. Small dams can have significant effects on the runoff into and the yield from the large reservoirs, and therefore it is necessary to assess these effects and weigh the benefits of rural developments against the adverse effects of urban water users.…The development of fewer, somewhat larger dams, which minimizes evaporation losses, should be preferred to numerous smaller dams of the same total capacity, if it is found that this reduces the downstream impact.

Thus, if one takes a long term view, the effect of thousands of microdam projects on water use in the Blue Nile basin and downstream flows should not be dismissed lightly.

[6] The Jonglei Canal project, begun in the late 1970s and suspended in 1983, is designed to reduce spillage of the Albert Nile into the swamps of the southern Sudan, and to channel water that would otherwise be lost to evaporation downstream to northern Sudan and to Egypt.

There are at least three important features of the microdam projects that would appear to make them especially attractive to Ethiopia. First, such microdam projects do not require international financing. Second, it will be difficult to estimate accurately how much such projects reduce downstream flows of the Nile. Third, the microdam projects are militarily invulnerable. In the past Egypt has periodically threatened to intervene militarily if any upstream riparians interfered with its water supply. If Ethiopia's use of water was based on thousands of small-scale irrigation schemes and microdams, Egypt would have few military options other than an attempt to occupy Ethiopia. It does not seem that this would be a credible threat. One can hardly imagine a worse place for Egypt to conduct a military campaign than the heavily-populated Ethiopian highlands.

If Ethiopia continues to liberalize its economy and is politically stable, it may be anticipated that funds will be available from a variety of sources to finance microdams and other, larger water resources development projects in the Blue Nile watershed. Because Ethiopia is now a major recipient of donor funds, it has considerable flexibility with its development budget. Local finances can be shifted away from projects that donors will fund to projects that they will not support.[7] Donors can be played off against one another in the competition to finance attractive projects.[8] Moreover, international capital markets will be an increasingly attractive option for financing many infrastructure investments. One must remember that potential hydroelectric projects in the Blue Nile basin, first described in the U.S. Bureau of Reclamation's 1964 study, have some of the highest economic rates of returns of any hydroelectric projects in the world, assuming the power generated could be marketed regionally (Guariso and Whittington 1987). Investment opportunities such as these have a certain inevitability about them, particularly in a world awash with private capital.

There is a linkage between the development of hydroelectric projects in the Blue Nile drainage area and a microdam strategy. Very little of the Ethiopian highlands is now served with electricity. Thus, many microdam projects will have to rely on diesel pumps to lift water to fields (some can be gravity-fed). This will be expensive and often unreliable. Electricity from hydropower projects is thus needed to supply households in towns and villages throughout the highlands, and also to run pumps for microdam schemes. One of the problems associated with hydroelectric development in the Blue Nile basin is the lumpiness of most investment opportunities and the inability to use all of the hydropower generated quickly. The pumping necessitated by thousands of microdams might ameliorate this difficulty somewhat.

[7] Consider, for example, the Finchaa Dam, currently the only water storage facility in the Ethiopian Blue Nile Basin. This project was commissioned ca. 1970 exclusively as a hydropower scheme (to our knowledge, the only project identified by the U.S. Bureau of Reclamation to have been implemented). However, with some assistance from the United States Agency for International Development, construction of a sugar cane refinery was initiated in 1995. The Ethiopian government intends to finance an irrigated cane sugar scheme of some 6000 hectares downstream of Finchaa.

[8] Also, the World Bank has fewer restrictions on funding projects which improve or expand existing projects—so microdams are a kind of foot in the third-party funding door.

It is sometimes argued that Ethiopia does not really need irrigated agriculture because it has the alternative of rain-fed agriculture, while Egypt has no alternative except increasing its irrigated area. Two points need to be made about this argument. First, many parts of the Ethiopian highlands are quite arid during the dry season, and farmers in such areas would clearly benefit from irrigation.

Second, both Egypt and Ethiopia have the option of pursuing economic development strategies that will enable them to pay for imported food rather than expanding irrigated agriculture, and if their populations increase at current rates, both will have to do this. In the long term irrigated agriculture is not a feasible alternative for achieving food security for either Egypt or Ethiopia.

There is precedent throughout the semi-arid regions of the world for what Ethiopia intends to do. A fairly dramatic example lies in Syria's development of its watershed in the Yarmouk river basin. This river, whose annual discharge is only 380-400 million m^3, serves as the border between Syria and Jordan, before emptying into Lake Tiberias (or Kinneret as it is known in Israel). For decades Jordan and Syria proposed the construction of a dam on the Yarmouk to capture winter flood waters and to generate hydroelectricity. Part of the stored flood water was to be diverted into Jordan's East Ghor Canal and used in the Jordan-Dead Sea valley for agriculture. The hydropower was destined exclusively for Syria. The dam, first known as the Maqarin project and later as the Unity Dam, has never been realized because of initial objections by Israel (the downstream state).

What is important for our story is that in the intervening years Syria proceeded quietly and unilaterally to construct dozens of small dams in its portion of the watershed. These dams store on the order of 155 million m^3 of water. Since 1975 alone, 19 dams have been constructed with an aggregate storage of nearly 100 million m^3 and five more are on the drawing boards (Soffer and Kliot 1991; Garber and Elias Salameh 1992). Even if Israeli acquiescence to the Unity Dam were obtained, it is now doubtful that the dam would make good economic sense, at least on the scale that it was originally conceived. Syrian action has reduced the average annual flow by roughly a third.

Ethiopia's microdam strategy does not preclude the development of larger water resources development projects in the Blue Nile basin. Indeed, Ethiopia is proceeding with both types of projects. In the fall of 1997 the Government of Ethiopia issued tenders for the construction and supervision phases of the first major hydroelectric power project on the Tekeze River. Located on the Upper Tekeze southwest of Mekelle, the final project is likely to have a total storage capacity of about 8 billion m^3 and an installed capacity of 200 MW. Ethiopia is financing this project itself, and, importantly, has not formally notified Egypt or Sudan of its plans.

EGYPT'S NEW VALLEY PROJECT

Information about this project available to the authors is limited to reports in the international and Egyptian press, and these news stories have often contained self-contradictions and obvious mistakes. However, the general scope of the project seems clear. Egypt plans to pump 5–10 billion m^3 of water per year from the Aswan High Dam Reservoir, and put it in a new canal that will transport it to a series of new land reclamation projects in the Western Desert. When the plan is finished, perhaps 25 years from now, between 300,000–500,000 additional hectares will be irrigated.[9]

The interesting question, of course, is: where does Egypt imagine that it will get this much additional water? There was some confusion in the initial press reports that this would be surplus water from the Tushka canal spillway. The Tushka canal spillway was built to discharge excess flood waters from the Aswan High Dam Reservoir when it reached extremely high levels (Whittington and Guariso 1983). Discharges into the Tushka canal spillway have been and will be very rare; indeed if the New Valley Project is finished as now envisaged, and its water demands factored into the operation of the Aswan High Dam Reservoir, the Tushka canal spillway will probably never be used again. So it is important to be clear that water for the New Valley reclamation efforts will be needed every year and thus must come from Egypt's long term water allocation.

Egypt contends that it will find the water supplies needed for the New Valley Project by using existing irrigation water supplies more efficiently, fostering water conservation efforts, abstracting groundwater, using reclaimed wastewater, and shifting out of sugar cane and rice to less water-intensive crops.[10] These measures, particularly conservation efforts and shifts in crop mix, could have a significant effect on Egypt's water use. Egypt thus argues that it will not withdraw more than its share specified in the 1959 Nile Waters Agreement.

The international press has consistently reported that Egypt's allocation of Nile waters is 55.5 billion m^3. This misses the real story.[11] As all the Nile basin riparians are well aware, Egypt's allocation under the 1959 Nile Waters Agreement is best understood as a deal with Sudan. Egypt's allocation of 55.5 billion m^3 is *contingent* upon zero water use by upstream riparians. At the time the 1959 Agreement was signed, both Egypt and Sudan recognized that this assumption of zero water use by upstream riparians was not realistic in the long run, and they made provision for how the 1959

[9] The costs of the canal, the pumping stations, and ancillary projects in the New Valley, have been estimated at LE 300-500 billion over the next twenty years, or about US$90 to $150 billion at the 1997 exchange rate. Projected investments of that magnitude will attract many multinational firms. The Arab Fund for Social and Economic Development, representing the member states of the League of Arab States, has in principle agreed to finance some of these investments. Private investors, such as Prince Al-Walid Bin Talal of Saudi Arabia, intend to reclaim over 162,000 hectares in the New Valley. (see *al-Ahram Weekly,* July 24-30, 1997: 8). By contrast, Ethiopia cannot contemplate projects even fractionally as large or nearly as attractive to international contractors, purveyors of equipment, and agribusinesses.

[10] It is important to note here that groundwater in the old Nile Valley is not a different water source, i.e. it is replenished by Nile river water. In the New Valley, groundwater supplies are nonrenewable, and the groundwater level will likely fall rapidly as intensive pumping begins.

[11] For an exception, see "Water fight: Egypt faces problem it has long dreaded, less control of the Nile." *The Wall Street Journal*, Friday, August 22, 1997.

Agreement would be revised as upstream riparians started to claim rights to use Nile waters. Specifically, Egypt and Sudan agreed to reduce their water allocations equally to accommodate increased use by upstream riparians.

In 1994 the authors proposed that the 1959 Nile Waters Agreement should be revised soon to include Ethiopia (Whittington, Waterbury, and McClelland 1994). At the time, the authors argued that a reasonable reallocation of Nile water should give Ethiopia something on the order of 12 billion m^3; and that Egypt and Sudan would need to reduce their water allocations by approximately 3 billion m^3 each—assuming Jonglei I and II and other "water conservation projects" in the White Nile basin (Machar Marshes and Bahr el Ghazal) are not undertaken. The difference of 6 billion m^3 could probably be made up by more efficient operation of an expanded system of reservoirs, including new dams on the Blue Nile, and reduced evaporation losses from the Aswan High Dam Reservoir.[12]

Even if the upstream riparians did not use any Nile water in the future, Egypt would still need to find water savings on the order of 5–10 billion m^3 per year to complete the New Valley Project. While Egyptian policymakers' willingness to take on the task of using Egypt's existing water supplies more efficiently is laudable—this is without question the right thing to do—it is not clear, however, what it will cost to achieve water savings of this magnitude, nor how long it will take. It will clearly be an expensive undertaking that will require not only substantial capital investments, but changes in the institutional arrangements for farm-level irrigation management.

As water becomes increasingly valuable in the Nile basin in economic terms, all riparians—not just Egypt—will need to use water more efficiently. However, since Egypt is by far the largest user of Nile water, its efforts in this regard will have the largest effect on the availability of basin-wide supplies. It is useful to separate two issues: (1) the extent to which Egypt can use its existing water supplies more efficiently, and (2) whether these water savings should be applied, or allocated, to the New Valley Project.

For example, if Egypt really does have the ability to save 5–10 billion m^3 of water annually, these savings could conceptually be allocated in a variety of ways. For example, they could be used to

(i) achieve a revised Nile Waters Agreement;
(ii) accommodate future industrial, municipal, and tourism growth in Egypt;
(iii) undertake the New Valley land reclamation projects.

Stated most simply, the New Valley Project requires water that could be used to reach a new Nile Waters Agreement that accommodated the upstream riparians.

[12] Reservoirs upstream on the Blue Nile would reduce evaporation losses from the Aswan High Dam Reservoir because the surface-to-volume relationships are more favorable than at Aswan, and evaporation rates are lower.

IMPLICATIONS FOR NILE BASIN DEVELOPMENT

The New Valley Project and the microdam strategy would appear to carry significant risks for Egypt and Ethiopia. If Egypt and Ethiopia pursue these two unilateral initiatives, they may find themselves on a collision course that both may have difficulty changing.

To better understand the nature of the problem, assume that Egypt is indeed committed to proceeding with the New Valley Project, and that it is as yet unclear (1) whether Egypt will succeed with its efforts to save 10 billion m^3; and (2) whether Ethiopia will proceed with a microdam strategy. Table 1 presents the four possible outcomes; the numbers are not meant to be precise. In Case A Egypt succeeds in saving 10 billion m^3 and Ethiopia pursues the microdam strategy. There is still a 4 billion m^3 water deficit (measured at Aswan). In Case D Egypt fails to achieve its water savings and Ethiopia does not pursue a microdam strategy: there is a 10 billion m^3 deficit.

Case B is the worst scenario. Here Egypt fails to achieve the promised water savings, but still pursues the New Valley Project. Ethiopia proceeds with a microdam strategy, and the riparian countries are faced with a 14 billion m^3 deficit. Only in Case C are serious problems avoided. Even in this case it is still assumed that the economics of both the water savings and land reclamation work in Egypt's favor.

Because there is no comprehensive agreement on the Nile basin, any deficits will fall on Egypt and Sudan. The economically rational solution to the economic problem caused by water deficits is to import more grain (Allan 1996). Egypt is in a much better position to pursue this option than the other riparian states because of its stronger, more diversified economy and better infrastructure. But water deficits create not only economic problems but political difficulties as well. Farmers and communities that run short of water

Table 1 Four hypothetical scenarios for Nile basin development.

	Egypt proceeds with the New Valley Project and **succeeds** in achieving 10 BCM in water savings at acceptable cost	Egypt proceeds with the New Valley Project and **does not succeed** in achieving 10 BCM in water savings at acceptable cost
Ethiopia **proceeds** with a microdam strategy that uses 4 BCM *(measured at Aswan)*	*CASE A:* Egypt has sufficient water supplies	*CASE B:* Egypt is short 14 BCM annually
Ethiopia **does not proceed** with a microdam strategy that uses 4 BCM *(measured at Aswan)*	*CASE C:* Egypt has sufficient water supplies	*CASE D:* Egypt is short 10 BCM annually

may have difficulty perceiving that the best solution is to import more grain; such parties may feel that their water has been stolen from them and seek noneconomic (diplomatic or military) solutions to their problems.

In light of this analysis, let us examine the basic character of the "game" that appears to have developed between Egypt and Ethiopia. We will simplify greatly in hopes of capturing the essence of the problem and look at just three "moves." In the first move, the Egyptian leadership must decide whether to proceed with the New Valley Project; this has already been decided in the affirmative, but let us try to better understand this decision.

Assume that Egypt has two choices: to pursue the New Valley Project or not (ignoring the question of the scale of the New Valley Project). If Egypt pursues the New Valley Project, Ethiopia can react in two ways: it can pursue its own water development options, or it can abandon (or delay) them. Consider each outcome from Egypt's point of view. If Egypt proceeds with the New Valley project and then Ethiopia proceeds with its water development options (e.g. a microdam strategy), Egypt confronts a major water deficit. The Egyptian leadership can either deal with this deficit by importing food or pursuing a noneconomic strategy to force Ethiopia to reduce its water use. By this we mean that Egypt will use the political, diplomatic, or military powers at its disposal to pressure Ethiopia to reduce its water use.

If Egypt reasons that it can easily deal with such a deficit by importing food, this outcome is perhaps not too bad. On the other hand, if Egypt proceeds with the New Valley Project, and Ethiopia does not pursue its water development options (in order to avoid a confrontation with Egypt), then Egypt wins the game: pursuing the New Valley Project has forced Ethiopia to back off of its water development plans.

Now consider Egypt's option not to pursue the New Valley Project. If Egypt decided not to proceed with the New Valley Project and Ethiopia proceeds with its water development options, Egypt faces a modest water deficit that it can choose to deal with either by importing food or by noneconomic means. If Egypt does not proceed with the New Valley Project and Ethiopia does not proceed with its water development options, the status quo is preserved.

The difficult calculation from Egypt's point of view is whether pursuing the New Valley Project will change the probability that Ethiopia will pursue its water development options. It is possible that Egypt hopes the New Valley Project will deter Ethiopia (and perhaps international lenders) from proceeding with water resources development in Ethiopia because the latter parties can foresee where this collision course might lead (i.e., to Egypt pursuing noneconomic alternatives for dealing with a water deficit). Seen from this perspective, the Egyptian decision to proceed with the New Valley Project has a certain strategic rationality because it provides Egypt the possibility of achieving the best outcome without major risks.

In the second move, the Ethiopian leadership must decide how to respond to Egypt's decision to proceed with the New Valley Project. Assume Ethiopia's choice is whether or not to proceed with a water resources development option. If Ethiopia proceeds with water resources development, the most severe of the water deficits will occur (Table 1). The Ethiopian leadership must attempt to forecast how Egypt will respond in move three to this water deficit. If Egypt were to respond to Ethiopian water resources development by reducing water use and importing more food, this is the best outcome for Ethiopia: in effect Ethiopia wins the game. On the other hand, if Egypt responds by noneconomic means, Ethiopia has much to lose. Although this could be a very poor outcome for Ethiopia, it is by no means clear that it is the worst. Failure to develop its water resources may leave Ethiopia with increasingly complex political and economic problems, as population growth, soil erosion, and deforestation contribute to a downward spiral of environmental degradation, decreasing food supplies, and famine.

If the Ethiopian leadership responds in move two by not pursuing a water development option, they avoid a possible collision with Egypt, but pay a high cost: an inability to develop irrigated agriculture. Also, it may be the case that the Ethiopian leadership would not be able to prevent microdams and small-scale irrigation development in the highlands even if it wanted to. If millions of peasants come to believe that small-scale irrigation will lead to a better life for them, it is questionable whether any government would have the political capital to stop them.

We do not know, of course, which option the Ethiopian leadership will choose. Let us assume that they decide to proceed with the water resources development option. We then turn to move three: how will Egypt respond to an Ethiopian decision to proceed with its water resources development option? From a rational perspective, Egypt's choice should almost certainly be to deal with the resulting water deficit by importing more food and scaling back the New Valley Scheme. However, the Egyptian leadership may not be able to contain popular opinion in Egypt in favor of a confrontational response to Ethiopian water development.

It is should now be clear why Egypt's first move of proceeding with the New Valley Project carries such large risks. Under some plausible scenarios, the Egyptian and Ethiopian leadership could lose their ability to control events. Just as it is important to recognize that there are win-win situations for the Nile riparian countries (e.g., moving long-term storage upstream could provide water savings that can be shared), it is equally important to understand that there are lose-lose scenarios.

We believe that, of all the riparian states, Egypt has the most to gain from the establishment of a basin-wide framework for water resources development. It can ill afford a future in which upstream riparians take unilateral action with respect to water development projects. Yet that is the precedent that Egypt has established by proceeding with the New Valley Project. If Egypt would reduce its existing water use by 5–10 billion m^3—as it says it can do—and abandon the New Valley Project, there would be more than enough water available to strike a deal that would bring Ethiopia into the framework of a comprehensive Nile Waters Agreement.

There is another conceivable option for Egypt to find the water necessary to do a deal with Ethiopia: water could possibly be saved from the White Nile swamps of Sudan. The White Nile water conservation projects (Jonglei I, Jonglei II, Machar Marshes, and Bahr el Ghazal) are estimated to yield a total of 18 billion m^3 in water savings. Given their environmental repercussions, it seems unlikely that all of these projects will be built within any meaningful planning horizon. But Jonglei I and II alone would result in water savings of about 8 billion m^3, roughly what is needed to bring Ethiopia into a new Nile Waters Agreement (in combination with water savings from resulted evaporation losses from the Aswan High Dam Reservoir). At some point in the future, Sudan might conceivably find itself in a pincer movement, in which Egypt and Ethiopia both want Jonglei I and II water savings for their joint purposes. Sudan could thus come under strong pressure from both Egypt and Ethiopia to press ahead with Jonglei I and II, but not share substantially in the projects' benefits.[13]

However, in the medium to long term, Sudan needs these water savings from the White Nile projects itself. Indeed, increased Sudanese water use may pose a greater problem for Egypt than water use in Ethiopia. Sudan has at least 8 million cultivable hectares between the Blue and White Niles; it currently irrigates only about 10% of this area. It is hard to imagine a Sudanese future that is not based on intensive agricultural production. The day will come when Sudan may push ahead with this development option, even though it will be reluctant to confront Egypt. The development of Sudan's potential would be best realized through cooperative development with Ethiopia, i.e. water storage sites in Ethiopia for transborder irrigation projects and the export of hydropower from Ethiopia to

[13] The implementation of the White Nile water conservation projects would have another important consequence for the hydropolitics of the Nile basin. As long as water from the Equatorial lakes is lost in the Sudanese swamps, the regulation of these lakes has little value to Egypt. But if the White Nile water conservation projects are ever completed, then Egypt will have an intense interest in the development and regulation of reservoirs on what is Ugandan territory (particularly Lakes Victoria, Kyoga, and Albert). Uganda will then find itself in an entirely new political relationship with Egypt.

Khartoum-Omdurman. In the long run, a strategic alliance between Sudan and Ethiopia is thus a possibility, and is an outcome that Egypt would try to avoid at all cost.

DISCUSSION: THE OPPORTUNITY COST OF WATER

It would seem appropriate for the Egyptian people to have a serious discussion about the water requirements of the New Valley Project, because the decision to proceed with the existing plans will have profound economic and security implications for their country. Central to this discussion should be an examination of the opportunity cost of water in different uses and locations. Thoughts on this issue are shared in this concluding section of the paper.

The Nile Basin is water-scarce not because of too many people but because of too much agriculture relative to water supply. Agriculture here, as just about everywhere else in the world, accounts for upwards of 80% of all water use. Moreover, water is in most instances used inefficiently, above all in agricultural systems like Egypt's, where farmers are not made to pay anything for the water itself.

In proposing the New Valley Scheme, Egypt, in a back-handed way, has acknowledged just how much waste and misallocation exists in the current system. By shifting cultivation from more to less water-intensive crops, by recycling more water, and by improving irrigation practices (from open surface delivery systems relying on gravity to pressurized drip or sprinkler irrigation), the 5-10 billion m^3 that the New Valley Project will require can be found. Egypt had heretofore been at pains to assert that it had very little slack in its system, thereby defending the absolute necessity of retaining its full share as stipulated in the 1959 Nile Waters Agreement.

However, this leads to the question whether or not there might be a better way to achieve the goals of the New Valley Scheme without using anywhere near the same amount of water. This is not to contest the goals in themselves. It is a fact that Egypt's 60 million people are crammed into only 19,000 square miles, or a territory roughly the size of Switzerland. Over 90% of Egypt's surface is uninhabited. The New Valley project aims to move population out of the crowded Nile valley and into a sparsely inhabited set of oases lying to the west of the Nile valley. These oases are separated from the valley and major markets by several hundred miles of desert, and they are equally far from the Mediterranean coast and Egypt's major ports.

We should not lose sight of the fact that in the last one hundred years, Egypt's densely inhabited areas have expanded significantly and in a manner that seems more logical than what is now being proposed. At the same time that the Suez Canal was excavated so, too, was the Ismailia Canal (named after Khedive Ismail, Egypt's governor at the time) to bring fresh water from the Nile to the new cities in the canal zone. From the 1870s on, the Ismailia canal has supplied irrigation water to what eventually became Sharqia Province, an agricultural zone that today is a region virtually indistinguishable from much more ancient areas of settlement. The governorate of Sharqia, which directly benefited from the new canal, witnessed major population influx and growth. The census of 1907 recorded Sharqia's population as 876,000. By 1976, it had grown to 2.6 million, and in 1986 reached 3.4 million. It boasts several large towns and cities, and it is fully integrated into the road and power grid of the Delta downstream of Cairo.

More recently, beginning in the mid-1950s, a similar expansion took place along the western fringe of the Nile Delta, fed by the Western Nubaria canal. However, the process of settlement is relatively new, and at present farming in the western zone is not in the hands of peasant smallholders but rather in those of commercial, mainly urban-based farmers. The point is, that Egypt has expanded its settled areas, and it has done so in a way that minimizes transport costs and disruption of existing patterns of settlement. If new settlement is to be a function of expanded areas of cultivation and attendant use of water for irrigation, it is suggested here that it is best to build out from the Delta and the valley lying to its south. Rather than distant and costly satellite colonies scattered across Egypt's desert hinterland, the authors envisage new contiguous layers adjacent to the zones of traditional settlement.[14]

However, there is a further question. We are not convinced that such settlement expansion need be dependent on agriculture. President Anwar Sadat launched, in much the same way as has President Mubarrak, his own scheme for breaking out of the old Nile valley. He proposed and launched a series of new cities in the desert, but not far from the settled areas. Although the schemes were seen at the time as a kind of publicity stunt, real money was invested and, in some instances, such as 10th of Ramadan City, a real boom in medium and light manufacturing, all in the private sector, has taken place. Real, as opposed to fictitious, residency in these cities has been slow in coming, but it will doubtless come if their economic bases are sound.[15]

It is suggested here that it is in this vein that the real opportunity cost for the water to be used in the New Valley Scheme, and for the capital that will be required to deliver it, should be seen. A simple bit of arithmetic will show what is at stake. Assuming that the New Valley will bring 500,000 new hectares under cultivation, and that reclamation and initial cultivation of those lands will require 20,000 m^3/ha per year for at least twenty years after the water is first deliv-

[14] Such new settlements should, however, be located far enough away from the coast to avoid the risks associate with sea level rise from long-term climate change.

[15] The Government has offered a host of incentives to encourage businesses to locate in the new cities, and many entrepreneurs have established 'dummy' firms in them in order to take advantage of the incentives. Even when the firms are real, both management and labor may prefer to commute from near-by urban centers rather than to take up residence in the new cities.

ered.[16] That would mean a water duty driven by agriculture of 10 billion m^3/yr or 18% of Egypt's 1959 allotment.

Supposing, on the other hand, that Egypt decides to develop a new city of 200,000 inhabitants over the same twenty-year period. Assuming also that each inhabitant uses 140 liters a day (a kind of mid-range average for households with private water connections in low and middle income countries). Households in this new city would use about 10 million m^3/yr. If one increases this by 50% to allow for commercial and industrial use, then the city would use 15 million m^3/yr. The agricultural water use for the New Valley project (10 billion m^3/yr), would be sufficient to support over 650 new cities of this size (with a total population of over 130 million people).

Would food security be sacrificed by pursuing an urban, industrial economic development strategy instead of expansion of irrigated agriculture? Not really. As Egypt's population grows, albeit at slower rates, it will have little choice but to import at least half of its food and food-product needs. Increasing its cultivated surface by 15% will not make much of a dent in that reality. Egypt's future has to lie in the non-agricultural sector and the exports of manufactured goods and of services. New cities can be platforms for both.

Why then is Egypt pursuing the New Valley Scheme? In part President Mubarrak is surely emulating both predecessors and contemporaries. In the 1950s, Egypt's President, Gamal Abd al-Nasser, captured the country's imagination with the Aswan High Dam project, and, in the last decade, Mo'ammar Qaddafi certainly captured attention — if not admiration — for his Great Man-Made River scheme in Libya. Engineering projects on this scale spin off billions of dollars in contracts, which is politically attractive (but alternative projects, such as new cities, would yield similar benefits). There may be a strategic consideration: to wit, that Egypt would like to create a buffer center of population in its hitherto mainly empty western desert.

Finally, if the New Valley Scheme is brought to completion, it will be a major bargaining chip when and if Egypt is obliged to enter into negotiations with the other Nile riparians over reallocation of shares in the river. Established facts, based on actual water use and sunk costs, have always weighed heavily in establishing legitimate claims to shares in transboundary rivers. If the New Valley Scheme proceeds as planned, Egypt will have created a huge "fact." In that sense, and even though Egypt may not use any water beyond the share allotted in the 1959 Agreement, it will have effectively precluded accommodation of the growing needs for water of its upstream neighbors, especially those of Ethiopia.

[16] Note that in this illustrative calculation, we have used much higher water use per hectare estimates than we did for irrigation in the highlands of Ethiopia. This is because: (1) evapotranspiration is higher in the western desert of Egypt, (2) the Egyptian estimates assume year-round irrigation, while Ethiopian farmers may need irrigation only part of the year, and (3) the Ethiopian microdams may not have the storage capacity to supply higher amounts of water for irrigation.

CONCLUSION

To summarize the above discussion: the challenge facing the Nile riparian countries is to change the existing property rights regime to the waters of the Nile without running the risks of the collision course described. This will require that the Nile riparians find a balance between the upstream countries' support for the principle of "equitable use," and Egypt's and Sudan's support for the principle of "no appreciable harm." These two principles are in conflict, and their balancing will require accommodation and compromise on the part of all parties.

Albeit in fits and starts, the Nile riparian countries now seem to be committing themselves to a process of dialogue, and international donors are apparently ready to underwrite this effort with a major infusion of funds. However, both Egypt's New Valley Project and Ethiopia's microdam strategy create serious problems for this long-term strategy of dialogue and consensus building because they offer Egypt and Ethiopia unilateral water resources development options that both will find difficult to resist. The possibility of credible unilateral investments and rising populations means that time is not necessarily on the side the riparian countries and the donor agencies as they embark on a process of consensus building and dialogue. It may be easier to negotiate a revised Nile Waters Agreement sooner rather than later.

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Restructuring of Water Usage in the Tigris-Euphrates Basin: The Impact of Modern Water Management Policies

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ABSTRACT
This paper examines the ramifications of late twentieth century water management schemes–especially those initiated by the Republic of Turkey–for the riparians of the Tigris and Euphrates rivers. The Turks' geographical position, and their ability to construct large water storage systems, has essentially given them command of the headwaters of the Euphrates and, to a lesser degree, the Tigris. The recent changes in water management of the Tigris-Euphrates basin have had, and will continue to have, profound consequences for the agricultural sectors of the economies of the riparian nations. By unilaterally decreasing the water available for irrigation in Syria and Iraq, Turkey has presented these nations with an aqueous conundrum that remains to be solved.

INTRODUCTION

The Tigris-Euphrates basin reveals evidence of water management projects dating back over six millennia. Throughout this period empires have waxed and waned. However, their power base has consistently been constructed on the wealth generated by irrigated agriculture (Beaumont, Blake, and Wagstaff 1988). The historical location of this activity has always been in the lower part of the basin in what is now the country of Iraq. The scales of development have varied from small diversion works to major engineering feats such as the Nahrawan canal built during the sixth century CE. Since the twelfth and thirteenth centuries, however, widespread land abandonment has occurred, associated with a breakdown of the strong central government necessary for sustained widespread irrigation. It was only in the late nineteenth century and early twentieth century that major irrigation development began to appear once more in the lower part of the Tigris-Euphrates basin.

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During this whole period, water management had been confined to the manipulation of the snow-melt flood waves of the two rivers in the lower part of the basin in the period from April to June. In low flood conditions there would be insufficient water available to irrigate all the crops which were planted and crop failures would occur in those highest areas of the flood plain at some distance from the river. In contrast, high flood conditions could not be easily controlled by the prevailing irrigation systems and so crop failure through excess amounts of standing water occurred. Besides these vagaries of the annual flood there were also problems associated with the high salinity of the soils. Given these difficulties, the drainage of saline irrigation waters from the fields was always a prime concern. The system of water management which grew up was one which attempted to minimize the risks to crop growth. Another characteristic feature of this era was that only a small proportion of the total water in the river was being utilized for human activity. The vast majority of the water flowed unused into the Persian Gulf.

HYDROLOGY OF THE TIGRIS-EUPHRATES BASIN

Understanding the hydrology of the basin is crucial to understanding the effects water management projects have on the rivers. The topography is such that all the highland regions are located in the north and eastern parts of the basin in Turkey, Iraq, and Iran. These mountains reach heights of almost 3,500 m to the south of Erzincan and of around 4,500 m in the upper part of the Euphrates catchment near Lake Van. In the Tigris basin heights of up to 4,200 m are recorded in southeast Turkey in the catchment of the Greater Zab. It is in these highlands that almost all of the flows of the two rivers are generated as annual precipitation totals commonly exceeding 1,000 mm. Precipitation in the basin is largely confined to the winter months from October through to April. This means that a large proportion of the total falls as snow on the uplands and consequently the water is locked in the solid state on the mountain slopes until temperatures begin to rise in spring and early summer.

Both the Tigris and the Euphrates are characterized by river regimes which exhibit strong snow-melt peaks....there still remains controversy over the actual annual flows of the two rivers, with different authors quoting different totals. However, these values tend to reflect differing observation periods, rather than fundamental disagreements as to how much water is present within the two river systems.

Both the Tigris and the Euphrates are characterized by river regimes which exhibit strong snow-melt peaks. On the Tigris the month of peak discharge is April, while on the Euphrates it is a month later in May. Measured in Iraq, the months of March, April and May account for 53% of the mean annual flow of the Tigris. The period of maximum flow on the Euphrates in Iraq is shorter and later than that of the Tigris and is usually confined to the months of April and May. Discharge during these two months accounts for approximately 42% of the annual total.

There still remains controversy over the actual annual flows of the two rivers, with different authors quoting different totals. However, these values tend to reflect differing observation periods, rather than fundamental disagreements as to how much water is present within the two river systems. The total flow of the Euphrates at Hit in northern Iraq is given as 31,820 MCM by Beaumont (1985). However, Kolars (1994) quotes a figure of 32,720 MCM. On the Tigris the overall discharge from the catchment is much greater and attains a value of around 52,665 MCM (Beaumont 1978). Kolars in 1994, however, quotes a value of 49,200 MCM.

The main difference between the Euphrates and Tigris in terms of how their discharge is generated is that the Tigris receives water from a series of major tributaries in the mid-portion of its course.

The mainstream of the Tigris has a flow of 23,210 MCM annually at Mosul in northern Iraq (Kolars quotes 20,500 MCM), while the tributaries contribute a further 29,455 MCM each year (Kolars quotes 28,700 MCM). The largest tributary is the Greater Zab, which produces almost half the flow of all the tributaries.

In contrast, on the Euphrates, all of the major tributaries are in the extreme upper part of the basin. This has important ramifications for the control of the two rivers. With the Euphrates it means that a single dam in the upper part of the catchment is capable of controlling a very large proportion of the flow of the river. The Ataturk Dam in Turkey achieves this level of control. On the Tigris, however, the fact that it receives water from the Greater Zab, the Lesser Zab, the Adhaim and the Diyala means that overall water management is more complex and requires the construction of a series of major dam projects on the individual tributaries to provide a comparable control of the flow.

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One of the problems in the Tigris-Euphrates system has been the variability of flow from year to year. Long-term records on the upper Euphrates before the construction of major dams (1937-1964) have revealed that minimum discharge can fall to 16,871 MCM/y (1961), while a maximum value of 43,457 MCM/y was recorded (1963). An even wetter year was recorded in 1969 when the flow just north of the Turkish border registered an annual discharge of 53,548 MCM. Such large variations in discharge have always made it difficult to plan irrigation schedules efficiently in the lower part of the basin when no water storage capacity has been available. On the Tigris River a similar pattern of flow variation can be observed. The observation period is 1946 to 1985 for the Cizre gauging station, Turkey. The average annual flow here is 16,800 MCM. In 1961 the flow fell to a minimum value of only 7,891 MCM, while in 1969 it peaked at 34,340 MCM.

On the Euphrates, approximately 88% of the total flow of the main stream of the river is generated in Turkey, and a further 12% is added in Syria from the Sajur, the Balikh, and the Khabur. A substantial amount of precipitation which feeds these rivers falls over Turkey and enters them directly as runoff or as groundwater discharge. It is very difficult to estimate just how much of the flow of these rivers is contributed from Turkish precipitation. However, it does seem likely that precipitation falling over Turkey accounts for at least 95% of the total flow of the Euphrates. Along the Tigris River, Turkey provides approximately 32% of the river's discharge in terms of the mainstream. A large, although unknown, amount of the flow of the Greater Zab River also originates in Turkey. This discharge, together with that of the mainstream, probably raises the Turkish contribution to around 44% of the total flow of the Tigris.

Of the combined flow of the two rivers, approximately 63.2% is generated on Turkish territory. With so much of the water of the two rivers coming from precipitation falling over Turkey, it is not surprising that the Turkish government feels that it has a strong claim to make use of what it considers to be its own waters.

DEVELOPMENTS IN THE TWENTIETH CENTURY

The most important change in the twentieth century has been in the location of water management activity and the type of water controls introduced. In the Tigris-Euphrates basin it is only in the post-World War II period that the emphasis switches from downstream diversion schemes to upstream water storage projects. This represents a fundamental change in river management activity within the basin, brought about largely by the growing human ability to manipulate the environment through fossil fuel subsidies and technological change. This restructuring in the patterns of water usage has had a profound effect on all aspects of development within the basin. This is especially the case as the population distribution within the basin up to the 1960s reflected the traditional patterns of water management and agricultural production.

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Besides technological change there has also been an important political change. Prior to the twentieth century the whole of the Tigris-Euphrates basin was under the control of a unified, although sometime weak, government. This situation lasted through World War I with the collapse of the Ottoman Empire. After the War different political units controlled the upper, middle and lower parts of the basin. As a result the chance for unified development of the waters of the basin using twentieth century technology became increasingly remote.

After World War II, water management focused on the construction of water storage facilities in the highland parts of the basin in Turkey on the Euphrates and in both Turkey and Iraq on the Tigris River. This form of water management usually had two objectives: generation of hydro-electricity and provision of large quantities of water for irrigation purposes. As this development activity and planning took place in the 1960s and early 1970s, it soon became evident that there was not going to be enough water available in the two rivers to satisfy the planned needs of the three major countries located in the basin (Beaumont 1978). Negotiations to reach a settlement to the dispute over water volumes available to each of the riparian states have been attempted on a number of occasions, but have never been able to produce an agreement. Consequently, the three nations (Turkey, Iraq and Syria) all went ahead with their own development schemes with little consideration of the impact their projects would have on the other states in the basin.

Without doubt Turkey is in the strongest position with regard to its potential control of a large part of the water resources of the Tigris-Euphrates basin. It can develop its water management schemes, and the two downstream countries of Syria and Iraq will have to suffer the consequences of lower flow conditions. Initially Turkey constructed the Keban Dam in the 1960s on the upper Euphrates. However, it built this dam largely for the generation of hydro-electricity, and therefore, the volumes of water flowing down the river remained constant. What did change, however, was the pattern of discharge along the Euphrates. With the volume of water in the reservoir behind the Keban Dam, which amounted to 30,700 MCM of gross storage and 17,000 MCM of active storage, it was now possible for the Turkish government to exercise a large measure of control over the flow of the river. It did this to achieve a more uniform flow pattern, attempting to limit minimum flows to 400 m^3/s and maximum flows to 1000 m^3/s. As a result, major floods or extremely low flow conditions were effectively eliminated from the Euphrates River. With the opening of the Keban dam a new chapter in the water management of the Euphrates River began. Greater control of flow was now possible, but as yet there was little need to use the water within Turkey for any productive purposes. The first stage of the restructuring of water usage had begun.

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To utilize more of the water in the Tigris and Euphrates, Turkey has embarked upon an ambitious series of schemes which are now usually referred to as the South-East Anatolia Project (Bagis 1989; Bilen 1994a and b; Altinbilek 1997). This project consists of 13 individual, but related, schemes on the Tigris and Euphrates rivers. Seven of these schemes are located on the Euphrates River. When fully implemented in the early years of the twenty-first century, they will permit the irrigation of 1,083,000 ha and will utilise up to 9,000 MCM of water each year. On the Tigris River, the six planned schemes will irrigate 558,000 ha and use 3,700 MCM each year. These figures for water use come from official Turkish sources presented in the main planning documents for the scheme. However, field evidence suggests that water usage will be around 10,000 m^3/ha. This indicates that actual water use figures could be in excess of 10,000 MCM/y on the Euphrates and over 5,580 MCM on the Tigris. The second stage of water restructuring in the Euphrates basin can be said to have begun with the first delivery of irrigation waters through the Urfa Tunnels in 1995.

Of particular interest with the South-eastern Anatolia Project is the high level of commitment the government of Turkey has shown toward it. The financial provision for such projects from international organizations such as the World Bank is always dependent upon an agreement as to water use by all the states within the river basin. From an early stage in the planning process, Turkey realized that it would not be able to gain the agreement of Syria and Iraq for the use of the water volumes it proposed. Consequently, it was forced to finance the project entirely from funds generated within Turkey. This was a substantial drain on the finances of the nation, but indicates just how important the project was to the economic development of the nation.

On the Euphrates in Turkey, the key structure is the Ataturk Dam, which is located approximately 80 km upstream from the Syrian border. Its two main purposes are to produce hydro-electricity and to provide water for the irrigation projects being developed along the Syrian border. The reservoir has a gross storage capacity of 48,700 MCM and an active storage capacity of 19,300 MCM. As a result of the construction of the Ataturk Dam, Turkey has now stated that in the future (since 1990) it would only guarantee a flow downstream from the dam of 500 m^3/sec. This represents about 50% of the natural flow of the Euphrates River at the Turkish border. Both Syria and Iraq have disputed this figure and have stated that the minimum flow should average at least 700 m^3/sec. Turkey has so far rejected this claim.

Of particular interest with the Southeastern Anatolia Project is the high level of commitment the government of Turkey has shown toward it…On the Euphrates in Turkey, the key structure is the Ataturk Dam, which is located approximately 80 km upstream from the Syrian border. Its two main purposes are to produce hydro-electricity and to provide water for the irrigation projects being developed along the Syrian border.

The pattern of water release from the Ataturk Dam is further complicated by the fact that there are eight turbines in the dam which are capable of generating electricity. When running at full power, each of these turbines has a water throughput of 225 m^3/sec. This means that if all eight were running at the same time at full capacity, the water discharge from the dam would be 1800 m^3/sec. It would seem likely that maximum electricity generation from the Ataturk Dam will take place during the winter months, but actual amounts are difficult to predict. As far as water discharge is concerned, what seems likely to happen is that during winter the release of water from the dam may be well in excess of the 500 m^3/sec guaranteed by the Turkish government. In effect, this might mean a major change in the discharge pattern of the river, with maximum flow conditions in future occurring during the winter months instead of in April and May. Downstream states are, therefore, likely to receive more water than they perhaps expected, but it will arrive at a time of year when it is not very convenient in terms of their likely water needs.

In the future, Turkey may well face a choice between irrigation and hydro-electricity generation. Irrigation has such a large demand for water that the use of the generators in the Ataturk Dam will have to be severely limited in terms of their operating times if the maximum irrigation program is to be attained. At the current time this might not be a problem for the Turkish government. However, as demands for electric power increase in the next century it is possible that Turkey might be willing to sacrifice some of its newly irrigated land so that more power can be produced. In the final analysis, everything will depend on whether the highest monetary value can be obtained from a cubic meter of water used for irrigation or for power production.

When all the reservoirs on the Tigris-Euphrates system have been completed in the early years of the next century, the Turkish government will have substantial control over the flows of the two rivers. On the Euphrates, the active, or usable, storage of all the reservoirs which have been built or planned is 42,000 MCM. This compares with an annual flow of the Euphrates at the Syrian border of 30,377 MCM. Effectively, therefore, the storage capacity of the system is 1.38 times the annual discharge of the river, which means that the flow of the river can be easily regulated except during long drought periods, or a run of very wet years. On the Tigris, Turkey's degree of control over the flow of the river is less marked. The planned active storage of the reservoirs on the upper Tigris is expected to be 15,246 MCM. This compares with an average annual flow of 16,718 MCM for the river at the Cizre gauging station, which indicates that total water storage is less than the discharge of an average year.

In the future, Turkey may well face a choice between irrigation and hydro-electricity generation…what is quite clear from this analysis is that Turkey really does have a stranglehold on the waters of the Euphrates River.

What is quite clear from this analysis is that Turkey really does have a stranglehold on the waters of the Euphrates River. At least 88% of the river's flow is generated within the country, and it has the ability to store a water volume equivalent to 1.38 times the average annual flow of the river at the Syrian border. However, Turkey has claimed that it will maintain a flow of 500 m^3/sec of water across the border into Syria (15,768 MCM). Given the high storage capacity which Turkey now possesses along the river it seems likely that it would be able to achieve this objective without cutting back on its own irrigation needs. The expected irrigation demand in Turkey is thought likely to be at least 10,000 MCM each year, while the downstream flow requirement is 15,768 MCM. This gives a total annual demand of 25,768 MCM. To cause serious problems, the flow of the river would have to fall below 20,000 MCM/y for a number of years. The available long-term records reveal that the flow of the River Euphrates has only fallen below 20,000 MCM on three occasions in the 40 year period prior to 1980.

On the Euphrates, the key to the downstream states of Syria and Iraq making the best use of the waters of the river lies in their storage of as much of the water made available to them from Turkey during the winter period as possible. Both states already have storage facilities available, but their combined capacity is low. In Syria the Tabqa Dam, built by the Russians in the late 1960s and early 1970s, has a storage capacity of 11,900 MCM. In Iraq, the Haditha Dam, another project constructed by the Russians, has a storage capacity of 6,400 MCM. Taken together, these two facilities are capable of holding only about 58% of the original annual flow of the river at Hit, Iraq. Given Turkey's need for hydro electricity, the water releases from the Ataturk Dam in winter may well exceed the 500 m^3/sec guaranteed by the Turkish government. The strategy of the two downstream countries must be to ensure that their reservoirs are full at the end of the winter period so that the water can be utilized for irrigation as soon as the agricultural season begins. Iraq will find itself in a very difficult position. With only 6,400 MCM of storage it is possible that a proportion of the winter flow of the river will flow into the Shatt al-Arab and effectively be wasted. The only other possibility might be early season watering of the fields to build up soil moisture concentrations.

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Syria is in the unusual position of being a downstream country with regard to Turkey and an upstream one in comparison with Iraq. Like Turkey, Syria had not made much use of the waters of the river prior to the 1960s. With the construction of the Tabqa Dam in the 1970s, there had been ambitious plans for major irrigation projects along the Euphrates, particularly in the lower reaches of the Rivers Balikh and Khabour (Manners and Sagafi-Nejad 1985). However, owing largely to a lack of funding, these projects did not commence large-scale development until the late 1980s. In the mid-1980s it is claimed that no more than 208,000 ha were being irrigated (Kolar and Mitchell 1991). Over the last few years, however, the pace of development of irrigation networks has been considerable. Associated with this trend has been a marked increase in water use. There is still uncertainty as to just how much irrigated land will be developed adjacent to the Euphrates River, but estimates suggest that it will be at least 475,000 ha by the early years of the twenty-first century. The expected water demand will be on the order of 4,750 MCM each year. However, certain government sources have suggested that the total irrigated area along the River Euphrates may eventually rise to close to one million ha. This does appear to be rather optimistic, but if achieved it would raise the water need to around 10,000 MCM/y. The greatest potential for this extra irrigation development would seem to be located in the lower part of the Khabour basin.

The actual amounts of land which are cultivated in Syria are crucial as far as Iraq is concerned. If the lower figure proves to be the correct one, then Iraq should receive slightly more than 10,000 MCM of water each year. If the Syrian irrigated area grows to around 1 million ha, then the volume of water Iraq will receive will fall to about 5,000 MCM. It should be remembered that these figures probably represent minimum values and that Turkey is likely to release larger quantities of water than it has guaranteed as a result of power generation during the winter months. It is worth noting that during the 1960s Iraq was claimed to be using at least 16,368 MCM of water each year for irrigation in the region between Hit and Hindiyah (Ubell 1971).

Syria also has a border on the Tigris River in the extreme northeast of the country with Turkey on the opposite bank. Over the last few years Syria has approached Turkey about the possibility of extracting water from the Tigris and releasing it into the upper part of the Khabour basin. From an engineering point of view this would be a fairly straight forward project. Iraq, however, is not keen to lose water from the Tigris which it considers to belong to itself, even though in the long term it might well benefit from greater flows along the Euphrates.

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Since the early 1980s and the beginnings of the war with Iran, it has been extremely difficult to obtain accurate statistics on agricultural activity within Iraq. Although Iraq has known for almost 20 years that it would face smaller water amounts once the Southeastern Anatolia and the Syrian irrigation schemes were completed, there is little evidence to suggest that Iraq has planned any formal adjustments to its own irrigated areas. Indeed, it is only in the 1990s with the opening of new Syrian projects and the completion of the Ataturk Dam that Iraq has had to face up to the issue of smaller water amounts. Its response seems to have been to leave it to the local districts to cope as best they can with the smaller water volumes. This seems to imply that the more difficult areas to irrigate in any region will be abandoned first, thereby causing the total irrigated crop area to contract.

The position in the Tigris watershed is at the moment less critical than in the Euphrates. In the first place, Turkey controls a much smaller part of the total flow, namely 16,800 MCM out of a total of 52,665 MCM each year. This represents only 31.9% of the average flow. Turkey also theoretically could control the upper part of the Greater Zab, but topographic conditions make this highly unlikely. Of the total volume of water in the Tigris, Turkey, at the moment, has plans to utilize up to 5,500 MCM for irrigation schemes, although many of these projects will not be complete until the early years of the twenty-first century. As yet, Turkey has not made any statement as to a particular value of flow level which it will guarantee on the Tigris. Equally, in terms of the total active water storage capacity which it controls, Turkey will have only 15,246 MCM located within its borders. This represents only 29.4% of the mean annual flow for the basin as a whole.

From the above, it can be seen that Iraq has much greater control of the waters of the Tigris than it has of the Euphrates. Once Turkey's needs have been met, this will leave about 47,165 MCM for Iraq. This is an enormous quantity of water and should, theoretically, permit the irrigation of up to 3,628,000 ha with a water rate of 13,000 CM/ha or up to 4,716,500 ha with an irrigation rate of 10,000 m^3/ha.

The fact that Iraq has so much water available in the Tigris basin may go some way to explaining why its criticism of Turkey's stance on the Euphrates River has been so restrained. It is true that complaints have been made about the release of only 500 m^3/sec by Turkey on the Euphrates, but they have not been pursued with the vigor that might have been expected if Iraq's vital interests were indeed being threatened.

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FUTURE WATER DEMANDS

The demand for water can be thought of in two principal ways: first, a demand which can be satisfied because water is available, and second, a demand which cannot be met owing to water scarcity. Until the 1960s the water demands of all three countries in the basin could be satisfied with water to spare. Since then, as water demands in the upper part of the basin have increased, the situation has changed and will continue to do so for the next two decades until all the planned irrigation projects are fully commissioned.

Several scholars have addressed the problem of demand for water over the years and all have reached the same conclusion, namely, that there is not sufficient water in the Euphrates River to meet the needs of the three countries with interests in the watershed (Beaumont 1978; Kliot 1994; Kolars 1994; Altinbilek 1997). On the Tigris, the situation is less serious, but even here the most optimistic scenarios only register a flow into the Shatt al-Arab of about 9,500 to 10,500 MCM when all the irrigation schemes are in operation (Kolars 1994; Altinbilek 1997).

On the Euphrates, both Kolars and Kliot suggest a maximum water demand in Turkey of around 21,500 MCM each year when all the irrigation projects are commissioned (Table 1).

This seems a very high figure when it is remembered that the planned irrigation area on the Euphrates only amounts to 1,083,000 ha. With the water volume quoted this would seem to imply a water usage rate of 19,853 cubic m per hectare or a much larger area under irrigation. A more realistic calculation would seem to be a figure of about 10,000 m^3/ha, giving a total water demand figure of 10,830 MCM. Even if an irrigation tariff of 12,000 m^3/ha was used, a maximum demand of only 12,996 MCM is reached. On top of this there are, of course, evaporation losses from the major dams along the Euphrates which amount to 1083 MCM. This gives a total of between 11,913 and 14,079 MCM, which is reasonably close to the figure quoted by Altinbilek (Table 2).

Table 1 Potential water demand on the Euphrates after the year 2020 in MCM/y.

Country	Kolars	Kliot	Altinbilek
Turkey	21,600	21,500	14,500
Syria	11,995	13,400	5,500
Iraq	17,000	16,000	15,500
Total demand	50,595	50,900	35,500
Available water	32,720	31,000	31,680
Balance	-17,875	-19,900	-3,820

(Kolars 1994; Kliot 1994; Altinbeck 1997)

For Syria, Kolars quotes a water demand of 11,995 MCM and Kliot, 13,400 MCM, while Altinbilek gives a total of only 5,500 MCM. Here the situation is much more difficult to assess, because everything depends on the size of the irrigated area which is eventually developed by Syria. It would seem that the total figure will be between 475,000 and 1,000,000 ha when all projects are completed. However, at the moment, it is difficult to be any more precise than this as the Syrian government has been extremely slow to begin the schemes which were planned more than 20 years ago. Annual water demands for these irrigated regions would be 4,750 MCM (for the lower value of 10,000 m^3/ha) to 12,000 MCM (for the higher value of 12,000 m^3/ha). On top of this evaporation from the reservoirs along the Euphrates is 630 MCM each year (Table 2).

The question of water demand in Iraq becomes something of a theoretical concept. If Turkey and Syria extract the maximum expected volumes of water from the Euphrates, the discharge into Iraq will be reduced to around 5,000 MCM each year. Evidence suggests that even in the 1960s Iraq was extracting 16,368 MCM between Hit and Hindiyah to irrigate around 1,230,000 ha (Ubell 1971). It is also known that considerable irrigation was taking place downstream

Table 2 Revised water demand estimates for the Euphrates basin for the period after the year 2020 in MCM/y (author's estimates). (Note: for Syria and Turkey the minimum irrigated area values are calculated using a minimum water tariff of 10,000 m^3/ha and the maximum area values with a tariff of 12,000 m^3/ha. For Iraq the water tariffs used are 13,300 m^3/ha and 15,000 m^3/ha respectively.)

Country	Irrigation Water Use	Evaporation	Total
Turkey	10,830-13,000	1,100	12,000 -14,000
Syria	4,750-12,500	630	5,400 -12,600
Iraq	24,400-27,500	600	25,000 - 28,100
		Total demand	42,300 - 54,800
		Available water	31,800
		Balance	-10,500 to 23,000

from Hindiyah at this time, though exact amounts are unknown. Altinbilek (1997) states that in 1970 only 400,000 ha were being irrigated along the Euphrates and 800,000 ha along the Tigris. However, these figures would seem to be incorrect. McLachlan (1985) states that the irrigated area in Iraq in 1970 was 3,680,000 ha. The vast majority of this would be located in the Tigris-Euphrates basin. Kliot quotes figures from the late 1980s and early 1990s which estimate the actual irrigated area along the Euphrates River in Iraq as 1.0 to 1.29 million ha. It is, however, acknowledged that at this time the irrigated area had been reduced as a result of the Iran-Iraq war of the 1980s. The total area on the Euphrates which can be irrigated is thought to be 1,833,000 ha (Kliot 1994). If this is a realistic figure it means that total water demand at some time in the future could rise to 24,379 MCM/y with an irrigation rate of 13,300 cubic metre/hectare. For a rate of 15,000 cubic m per hectare the total demand would rise to 27,495 MCM (Table 2). Table 2 clearly shows that the potential water deficit on the Euphrates River after the year 2020 might be as high as from 10,500 to 23,000 MCM each year. Since there will be enough water in the river to satisfy the full needs of both Turkey and Syria, it will be Iraq which will be least able to satisfy its potential needs.

On the Tigris the overall situation is similar. There is general agreement that water demand for Turkey will be between 6,700 and 8,000 MCM each year (Table 3). The calculations of the present author suggest that the likely water demand for the planned irrigation of 558,000 ha will be between 5,580 and 6,696 MCM/y (Table 4). Evaporation from a total of nine proposed reservoirs, with a total surface area of 693 km^2 is likely to add a further 624 MCM to the demand. This is based on an evaporation rate in these upland valleys of 900 mm/y.

Syria's use of water from the Tigris remains something of an enigma. It would be possible to divert water from the Tigris and pump it into the upper Khabur. However, without the active support of Turkey it would only be possible to obtain significant quantities of water during the high flow period. What is certain, though, is that Syria's demand for water to be used within the catchment of the River Tigris itself will be small as it does not have access to suitable land.

Potential water demand in Iraq is high with estimates from 29,200 to 40,000 MCM/y (Table 3). As with the Euphrates, it is exceedingly difficult to obtain accurate statistics as to the area of irrigated land. Kliot quotes a figure of 2 million ha being irrigated in the Tigris basin in the late 1980s and a total irrigable area of between 2.8 and 4 million ha (Kliot 1994). If these figures are correct, potential water demand could rise to values of between 37,240 and 60,000 MCM/y based on water tariff figures of 13,300 to 15,000 m^3/ha (Table 4). Prediction of maximum evaporation losses for all the reservoirs in Iraq is difficult to calculate owing to the lack of data, but will be at least 1,000 MCM/y. Taking these figures for the Tigris as a whole suggests a surplus of around 8,000 MCM/y for the lowest figures, but a deficit of over 15,500 MCM/y if the higher values are utilized (Table 4).

If the newly calculated water demand data for the Euphrates and Tigris Rivers are summed, they provide an estimate of the overall balance for the basin in the period after 2020 (Tables 2 and 4). The minimum data estimates point to a possible water deficit of 2,233 MCM /y. However, the maximum values reveal a huge potential deficit of 38,641 MCM. This, it will be noted, is greater than the average flow of the Euphrates River.

WATER QUALITY AND ENVIRONMENTAL / RESOURCE ISSUES

In all the water management projects which have been planned to date for the Tigris-Euphrates basin, the emphasis has been on water volumes, with relatively little consideration being given to water quality. In general, the natural water quality of the Tigris-Euphrates basin is high, especially during the spring/early summer snow-melt period. Within the next decade or so it is possible that water quality along the mainstreams of the Tigris and the Euphrates might change significantly for the worse. The main problem is that, with most of the diverted water being used for irrigation, there is a potentially serious problem with regard to the quality of the irrigation return waters. In general about 20% of the water which is applied in irrigation drains off the fields and makes its way into adjacent water courses or percolates downwards to the water table. From here this water will eventually drain back into stream and river systems.

This water will carry with it a wide range of dissolved chemicals. Some of these will be naturally occurring, including various salts

Table 3 Water demand and water availability on the Tigris in the period after 2020. MCM/annum. (Kolars 1994; Kliot 1994; Altinbilek 1997).

Country	Kolars	Kliot	Altinbilek
Turkey	6,700	7,200	8,000
Syria	0	500	0
Iraq	29,200	40,000	31,900
Total demand	38,700	47,700	39,900
Available water	49,200	48,000-52,600	49,570
Balance	10,500	300-4,900	9,670

which are present in dryland soils. However, these waters will also pick up a wide range of chemicals, including pesticides, herbicides and petroleum products which are associated with modern agricultural practices. The net result is that the quality of any receiving waters can be severely affected by these irrigation return waters. What is difficult, however, is to be able to predict just how severe an effect will be generated, as this depends so much on local environmental conditions and the actual agricultural practices which are being utilised. On the Euphrates it is possible to identify two rivers which will carry most of the return waters from the Turkish irrigation projects. These are the Rivers Balikh and Khabur. On these rivers, estimates suggest that flows are likely to increase significantly as a result of the addition of irrigation return waters. This will be of especial significance on the Balikh River, which has a low annual discharge. Estimates here suggest that when all the Turkish and Syrian irrigation projects are in operation, the flow of the river might increase up to 3.5 times its normal flow as a result of the impact of irrigation return waters (Beaumont 1996). Just what the impact of these waters will be on the quality of the mainstream of the Euphrates is unknown, but it might well be considerable during the low summer flow period.

In all the water management projects which have been planned to date for the Tigris-Euphrates basin, the emphasis has been on water volumes, with relatively little consideration being given to water quality.

Water management projects, wherever they are located, will also have an impact on the overall ecology of the river. The most important changes will be in terms of the regime of the river as well as on water volume. With all the storage facilities now located in the upper part of the basin of the two rivers, the snowmelt peaks, which were such characteristic features of the two rivers, have been greatly reduced. This is particularly the case on the Euphrates River. The effect of this will probably be greatest in the lower part of the basin in the wetlands of the Shatt el-Arab, where the whole ecology of the marshes has evolved in response to these snow-melt peaks. With the attenuation of these peaks, together with the much lower overall flows which the marshes will be receiving, the impact on the natural

Table 4 Revised water demand figures for the Tigris River for the period after the year 2020 in MCM/year (author's estimates). (Note: For Turkey the minimum irrigated area values are calculated using a minimum water tariff of 10,000 m^3/ha and the maximum area values with a tariff of 12,000 m^3/ha. For Iraq the water tariffs used are 13,300 m^3/ha and 15,000 m^3/ha respectively.)

Country	Irrigation Water Use	Evaporation	Total
Turkey	5,600-6,700	630	6,200-7,300
Syria	0	0	0
Iraq	37,200-60,000	1,000	38,200-61,000
Total demand	44,400-68,300		
Available water	52,700		
Balance	+8,200 to -15,700		

environment will be considerable. The future survival of the marshes must, therefore, be put in question merely as a result of the changes which have occurred, or are likely to occur, in the upper parts of the basin in Turkey, Syria and Iraq. However, there are other more local pressures which the marshes have to face as well. These concern the large drainage canals which the Iraqi government has decided to build through the marshlands of southern Iraq. When fully completed these channels will carry the water from the two rivers through the marsh regions much more rapidly and lead to further dewatering of these wetland regions.

Given the political standing of Saddam Hussein in the West it is not surprising that many Western commentators have placed all the blame on Iraq for the potential disruption of the ecology of the marshes of the Shatt al-Arab. This is, however, a rather extreme view of the situation as the future of the marshes has already been threatened by the major new irrigation works in the upper part of the basin. In reality, the Iraqi actions have merely exacerbated what was already a critical situation. It also has to be recognized that attitudes to the draining of wetlands have changed markedly in the relatively recent past. When the Israelis drained the Huleh Marshes in the 1950s, it was regarded at the time as a great feat of human ingenuity in converting a marshy "wasteland" into productive agricultural land. When the Iraqis undertook the same operation in the 1990s current convention wisdom accuses them of ecological devastation.

When the Israelis drained the Huleh Marshes in the 1950s, it was regarded at the time as a great feat of human ingenuity in converting a marshy "wasteland" into productive agricultural land. When the Iraqis undertook the same operation in the 1990s current convention wisdom accuses them of ecological devastation.

There is no doubt that the marshes of the Shatt el-Arab represent one of the world's great wetlands and that the drainage of this ecosystem will destroy a rare environment. However, the Iraqis will claim that valuable agricultural land can be produced from the marshes. While it is likely that high quality agricultural land can be created, the question has to be posed as to where the water to irrigate this new land will come from. There is also concern that at least part of the Iraqi government's reason for draining the marshes is to exercise greater political control over the inhabitants of this highly inaccessible landscape rather than to produce more food for its people.

All three countries of the basin are suffering from the effects of continued population growth, which will greatly increase the pressure on available resources (see Winkler, this volume). Although it is true that the populations of the three countries do not all dwell within the basins of the Tigris-Euphrates, there can be no doubt that the impact of this growth will be felt there. The population growth rates experienced by all three countries during this century have been remarkable (Table 5). From the 1940s to the present day their populations have increased by between three to five-fold, and between 1995 and 2025, in the cases of Iraq and Syria, they look likely to more than double again. Even in Turkey a more than fifty percent growth rate is postulated.

While it is likely that high quality agricultural land can be created, the question has to be posed as to where the water to irrigate this new land will come from. There is also concern that at least part of the Iraqi government's reason for draining the marshes is to exercise greater political control over the inhabitants of this highly inaccessible landscape rather than to produce more food for its people.

Besides population increases, there are also increases in the standards of living of the populations. In turn this means that water usage in an urban/industrial context is likely to go up also. Although the increases are high in percentage terms, the actual water volumes remain low when compared with the predicted irrigation demands. Even so, obtaining sufficient water for some of the rapidly growing cities may begin to cause problems.

This leads us to the question of whether water in the twenty-first century can continue to be used for irrigation purposes in dryland regions (Beaumont 1994; 1997). The issues are water availability and maximum economic productivity. There is no doubt that if water is available at zero cost, as is the case with water in most rivers in the Middle East, then it will be used by local farmers for irrigation purposes. This is, indeed, the basis of traditional agriculture throughout the region and it is often the only way available for the peoples of the area to farm. In the future, however, with continued increases of pressure on available water resources, many governments will be forced to cut back the volumes of water allocated to irrigated agriculture in an attempt to ensure that the urban/industrial regions receive all the water they need for continued growth. It is important

Table 5 Populations in millions. (Population Reference Bureau, 1995)

Country	1940s	1960s	1972	1995	2025
Turkey	17.8	27.7	37.6	61.4	95.6
Syria	2.5	4.4	6.6	14.7	33.5
Iraq	4.1	6.7	10.4	20.6	52.6

to realize that this urban/industrial demand is relatively small when compared with irrigation needs and should be able to be easily met from available resources (Beaumont 1997).

CONCLUSION: THE QUEST FOR MAXIMUM WATER PRODUCTIVITY

It is possible to recognize in the Tigris-Euphrates basins evidence of water management strategies stretching over more than six millennia. However, the length of time of operation of the different systems varies enormously. The system which lasted the longest was one which can be described as manipulation of the flood waves of the two rivers. With this method, the water volumes provided by the rivers were accepted as fixed and the management strategy consisted of utilizing a relatively small proportion of the spring and early summer flood-melt waves for irrigation purposes in the lower part of the basin. In some years, the diversion works were overwhelmed by the sheer magnitude of the floods, while in other years there was insufficient water to irrigate all the land that it had been intended to cultivate. This strategy was utilized from about six thousand years ago when irrigation first began in the Tigris-Euphrates lowlands up to the opening of the Keban Dam in the 1960s.

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The second stage began in the 1960s with the creation of significant water storage capacity behind dams in the upland parts of the two catchments. For the first time, there was an attempt to store water from the time it was generated by nature to the time it was needed by human societies. At first the storage capacity was small, but with time, as more dams were completed, the total volume of water in storage has grown. By the time the South-eastern Anatolia project in Turkey is completed in the early years of the twenty-first century, total water storage capacity in Turkey alone will be in excess of the annual flow of the two rivers within its boundaries.

Through the forty year period, from 1960 to the end of the twentieth century, there has also been a change from excess water availability to a situation in which there may not be enough water to meet the planned requirements of the riparian countries. From the year 2000 onwards we can foresee a new phase in water management, characterized by growing water shortages. This pressure on the available water resources will be compounded by major declines in water quality along the mainstreams of the Tigris and Euphrates Rivers as more and more irrigation projects are opened in the upper parts of the basin. Just how severe this decline in water quality will be and its impact on other water users is impossible to estimate at the present time.

With continued population growth, increasing attention will be focused on the feasibility of using irrigation water to produce food crops. It is certainly possible that during the early decades of the twenty-first century there might well be a decrease in irrigated agriculture throughout the basin as increasing volumes of water are transferred to economically more productive uses in urban/industrial environments.

In effect, the twentieth century has seen a restructuring of water use in the basin of the Tigris-Euphrates. Although the main elements of the new management strategy are already in place, in terms of the major dams and reservoirs, the full impact of these changes will not be realized for at least another decade. Inevitably the restructuring of water usage will have economic and social impacts as well, which will be painful for the local inhabitants. In the lower part of the basin, rural areas will not be able to sustain the same high level of population that has been the case in the past. This might suggest that rural depopulation will increase, putting further pressures on the already crowded urban centers. By contrast, both rural and urban populations seem bound to increase in the upper part of the basin in Turkey, as economic opportunities grow hand in hand with the expansion of irrigated areas which have previously not been cultivated in any widespread manner.

In effect, the twentieth century has seen a restructuring of water use in the basin of the Tigris-Euphrates. Although the main elements of the new management strategy are already in place, in terms of the major dams and reservoirs, the full impact of these changes will not be realized for at least another decade.

The next stage in water management in the Tigris-Euphrates basin is likely to concern adjustments with a new emphasis on the value of water. The critical factor is likely to be the maximum economic productivity which can be achieved from the utilization of a cubic meter of water. Just how quickly this approach will permeate the basin will depend on the pressure put on the water resource base and how individual governments will react. In Turkey, considerable political and financial resources have already been committed to agricultural development. However, it will be interesting to see if there is a change in cropping patterns within the basin with less emphasis being placed on the lower value crops such as wheat and barley. Under the proposed irrigation schedules for the Southeastern Anatolia Project, wheat is planned to account for 25% of the irrigated area, and barley and other feed grains a further 15% (Altinbilek 1997). A relatively small cut-back in these figures would release large quantities of water which could be utilized for other purposes, including hydroelectric power.

A similar change will probably also occur in Iraq. In the short-term it seems inevitable that there will be land abandonment along the Euphrates as Turkey's use of the Euphrates increases. 1995 was the year when the first water for irrigation purposes was sent through the Urfa tunnels in Turkey from the lake behind the

Ataturk Dam, and over the next decade the volume of water utilized for such purposes seems set to increase rapidly. Iraq will, therefore, have to come to terms quickly with a changing situation in which available water amounts along the Euphrates will steadily decline. However, Iraq is fortunate in possessing large oil reserves, which means that it should be able to substitute money for water and so obtain the food it needs by the purchase of crops on the world market (see Allan, this volume).

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Qanats and Lifeworlds in Iranian Plateau Villages

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ABSTRACT
Through a review of the literature on *qanat* history, this article provides an overview of one of the most significant hydraulic technologies of the pre-modern Middle East. The article covers *qanat* origins, diffusion and construction techniques, then compares the productivity and sustainability of *qanats* with modern deep well systems powered by motorized pumps. The replacement of *qanats* with deep wells has serious implications for the ground water resources of much of the Middle East. The profound importance of *qanats* in shaping the lifeworlds of villagers in pre-modern Iranian plateau settlements has meant that the shift towards reliance on deep well systems has had ramifications for plateau society that go far beyond water resource exploitation.

INTRODUCTION

Throughout the arid Middle East and North Africa, water shortages have become increasingly acute. Population growth combined with agricultural expansion and intensification have heightened demand for domestic, industrial, and agricultural (especially irrigation) water use. Local surface and subsurface water resources are no longer sufficient to meet these burgeoning needs throughout the region. Domestic water is in such short supply that it is rationed in a number of Middle Eastern cities, and, as the region's cities continue to grow, it is likely that urban water demand will also grow. In rural areas, irrigation water is increasingly scarce. A scarcity of irrigation water will force small farmers off the land and increase food imports across the Middle East.

Domestic water is in such short supply that it is rationed in a number of Middle Eastern cities, and, as the region's cities continue to grow, it is likely that urban water demand will also grow.

To meet growing demands for water, governments and other investors in the Middle East have abandoned traditional, sustainable (but less productive) water supply systems in favor of modern, less sustainable (but more productive) hydraulic systems. In river valleys, modern dams have been constructed to trap surface water. Where surface water is not available, modern pumping technologies that provide access to previously unknown or inaccessible groundwater reservoirs are coming into widespread use.

One of the most striking example of this shift in water technologies has been the case of *qanats.* These ancient, gravity-flow water supply systems, which have provided dependable, renewable supplies of water to Middle Eastern towns and villages for millennia, are being rapidly replaced by a more productive but less sustainable water technology, deep wells. On the Iranian plateau, an important heartland of *qanat*-watered settlement, this change in water technology is draining aquifers, altering the distribution of towns and villages, and transforming the lifeworlds of Iranian villagers.

QANATS AND SETTLEMENT IN THE OLD WORLD

THE NATURE OF *QANATS*

Qanats are gently sloping subterranean tunnels dug far enough into alluvium or water-bearing sedimentary rock to pierce the underground water table and penetrate the aquifer beneath. Water from the aquifer filters into the upper reaches of these channels, flows down their gentle slope, and emerges as a surface stream of water at or near a settlement. *Qanats* are generally constructed on the slopes of piedmont alluvial fans, in intermontane basins, and along alluvial valleys. In these locations, this groundwater collection system has long brought water to the surface and supported settlement in regions where no other traditional water technology would work.

Most of these gravity-flow tunnel-wells are relatively short, some five kilometers or less in length (Beaumont l989). The longest, however, extend 40 or 50 kilometers beneath ground level before surfacing at a settlement (English l966). The cross section of a *qanat* tunnel is roughly one-and-one-half meters high and one meter wide, large enough to accommodate men working. Every 50 to 100 meters or so on the surface, vertical shafts are dug down to a depth of anywhere from 10 to 100 meters to the water-bearing tunnels. These shafts provide air to *qanat* diggers working beneath the surface and also enable excavated soil to be removed from the tunnel and lifted to the surface. The shafts provide repair teams with relatively easy access to tunnels when blockages occur. The donut-shaped spoil heaps around the tops of these vertical shafts appear on the surface as a chain-of-wells, a distinctive feature of landscapes in *qanat*-watered regions. These markers chart the subterranean pathways of the *qanat* tunnels (English 1968; Beaumont 1971; Goblot 1979).

The need to dig tunnels in the search for minerals meant that the inhabitants of the region had mastered the basic technology necessary for qanat construction.

ORIGINS AND DIFFUSION

Qanats first appeared in the mountains of Kurdistan in western Iran, eastern Turkey, and northern Iraq more than 2,500 years ago in association with early mining in that region. Several factors explain this origin. Most importantly, perhaps, this region is one of the oldest mining and metallurgical centers in the Middle East. The need to dig tunnels in the search for minerals meant that the inhabitants of the region had mastered the basic technology necessary for *qanat* construction. *Qanats* differ little from the horizontal adits dug into hillsides by early miners. Indeed, these adits may well have been sloped to drain unwanted seepage as they are today. Additionally, and somewhat ironically, the earliest report of a *qanat* system is chronicled on a tablet narrating the destruction of the *qanats* which provided water to the city of Ulhu (modern Ula), located at the

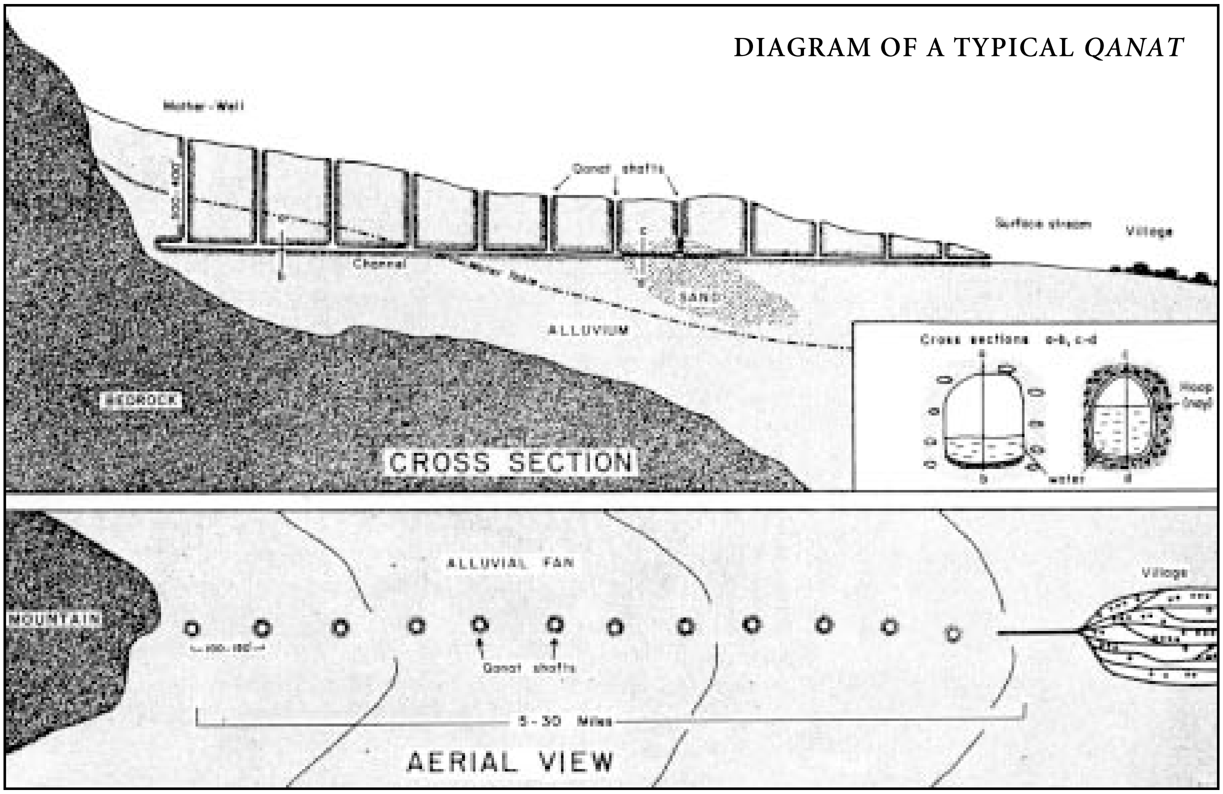

Figure 1 **Cross Section and Aerial View of a *Qanat*.** *Qanats* are ancient water supply systems constructed using a simple technology. The vertical shafts are not "wells," despite the term "chain-of-wells" often used to describe their appearance on the landscape.

northwestern end of Lake Urmia by Sargon II in 714 BC (Laessøe 1951). Soon thereafter, Assyrian cities, particularly those located on the upper Tigris River, relied on *qanats* for drinking water. Somewhat later, the capital city of the Medes, Ecbatana (modern Hamadan) was watered by qanats as was Darius's capital city of Persepolis (Forbes 1955; Goblot 1963).

Under the Achaemenids (550–331 BC), when Persian rule extended from the Indus to the Nile, *qanat* technology spread well beyond the confines of the Iranian Plateau. The Achaemenid rulers provided a major incentive for *qanat* construction by allowing *qanat* builders and their heirs to retain profits from newly-built *qanats* for five generations. As a result, thousands of new settlements were established and others expanded. To the west, *qanats* were constructed from Mesopotamia to the shores of the Mediterranean as well as southward into parts of Egypt and Arabia. They were particularly important sources of water in the foothills of eastern Iraq, the Syrian Desert, and the Hadhramaut. In the Yemen and in Oman, *qanats* are locally called *falaj* (plural: *aflaj*).

To the east of Iran, where they are generally known by the Persian term *kariz, qanats* came into use in Afghanistan, the Silk Road oases settlements of Central Asia, and the Chinese province of Sinkiang (now Xinjiang), although whether this diffusion occurred under the Achaemenids or some later Persian dynasty is uncertain. Strangely, in the Turfan Basin, which has one of the most extensive *qanat* systems in the world, it is possible that many of the *qanats* were built by imported Turki laborers in the 1700s (Stein 1933).

The expansion of Islam initiated a second major diffusion of *qanat* technology. The early Arab invasions spread *qanats* across North Africa into Spain, Cyprus, and the Canary Islands. In most of North Africa, they were called *fughara*, and were built and maintained by a specialized caste of black slaves. In Morocco, *qanats* were referred to as *khittara* (or *rhettara*).

Qanat use was especially intense in three areas of the Maghrib: on the borders of the Tademait Plateau just south of the Great Western Erg in central Algeria; on the northern slopes of the Atlas Mountains of Morocco, particularly near the city of Marrakech; and south of the Atlas in the Tafilalt of Morocco (Fenelon 1941; Lo 1953; Margat 1958). Interestingly, *qanat* technology may have been introduced into the central Sahara and later into Western Sahara by Jews or Judaized Berbers fleeing Cyrenaica during Trajan's persecution in AD 118 (Briggs 1960).

Because qanats *could provide reliable and sustainable access to previously unavailable supplies of groundwater, populations throughout the arid zone embraced their use, despite the cost in money and time to build and maintain them.*

In Spain, *qanats* were used marginally in the province of Catalonia and at Madrid where they were called *gálerias* (Asin 1959: Plate XVII). They are important sources of water in Cyprus and on Gran Canaria and Tenerife in the Canary islands (Humlum 1965).

New World *qanats* are found in Mexico at Parrás, Canyon Huasteca, Tecamenchalco, and Tehuacán and in the Atacama regions of Peru and Chile at Nazca and Pica. The *qanat* systems of Mexico came into use after the Spanish conquest; those of the Atacama, however, may predate the Spanish entry into the New World (Kaeger 2, 1901; Troll 1963).

QANAT CONSTRUCTION

The spread of *qanats* throughout the arid lands of the northern hemisphere during the pre-modern period may be explained by the fact that they use an efficient mix of available capital and technology to supply critically scarce water. Because *qanats* could provide reliable and sustainable access to previously unavailable supplies of groundwater, people throughout the arid zone embraced their use, despite the cost in money and time to build and maintain them.

During much of the pre-modern period, many *qanat* systems were built by powerful political leaders, whose rule was often

Figure 2 **A *Qanat*-fed Alluvial Fan Village.** A detailed understanding of subtle variations in topography, landscape, and subsurface water conditions is required in the siting of a *qanat*. Only well-known and respected *muqannis* are entrusted with site decisions. *(Illustration by Ann Coffin Delano)*

appraised by the number of *qanats* constructed during their reign. For example, slaves and captives were trained to construct *qanats* under the Achaemenid and Sassanian kings. Maintenance and repairs were accomplished by corvée (forced labor).

THE *MUQANNIS*

More recently in Iran, a hereditary class of professional *qanat* diggers called *muqannis* build and repair these systems. These specialists travel from place to place on the Iranian plateau, for example, working at one settlement where a flash flood has damaged a *qanat*, and then moving on to another where a lowered water table requires that a *qanat* tunnel be extended deeper into the alluvium.

The most famous *muqannis* come from the desert city of Yazd. They are paid high wages, and command respect. The hazardous nature of their work has inspired a body of folk custom and belief. A *muqanni* will not work on a day he considers to be unlucky, or if he sneezes on that day. Floods and cave-ins in the *qanat* tunnels are frequent, and deaths among *muqannis* occur. Older *muqannis* are considered blessed or at the very least lucky. Prayers are said over a *muqanni* each time he descends into a *qanat*, a ceremony that makes a deep impression on Iranian villagers.

SITE, GRADE, AND ALIGNMENT

The construction of a new *qanat* (which is quite rare at present) is a sophisticated engineering feat accomplished with simple tools. The success of the undertaking is determined by two decisions made by a *muqanni* before the actual construction of the *qanat* begins. The first of these is to determine the site of the "mother well" (*madari chah*) which marks the furthest extent of the *qanat* from the settlement; the second is to establish the alignment and grade between the *qanat's* origin and destination.

When the *muqanni* decides on a potential site for the *madari chah*, one or more trial shafts (*gamaneh*) are dug deeply enough to penetrate the water table. A variety of geographical factors are weighed in the *muqanni's* decision as to where these shafts are located. Among these factors are local slope conditions, the surrounding topography, subtle changes in vegetation, available groundwater, and the proposed destination of the water.

The many hazards that attend qanat construction have, not surprisingly, endowed the profession of muqanni *with a certain notoriety.*

Favorable site conditions for relatively short *qanats* often occur near the mouths of dry alluvial valleys. For long *qanats*, the general topographic setting is more indicative of the likelihood of accessible sources of groundwater. Once a trial shaft has struck water, the *muqanni* must be certain that this well has pierced the water table or alternatively has penetrated a relatively constant source of groundwater perched on an impermeable stratum. If so, this shaft becomes the "mother well" of the *qanat* whose length will be measured from this point to the place where water surfaces (*mazhar*).

Next, the *muqanni* must measure the precise alignment and grade of the *qanat* tunnel, the most difficult engineering task in the entire construction process. The alignment of the *qanat* must connect the water-filled base of the "mother well" with a point on the surface immediately above the settlement by means of a gently sloping tunnel. If the alignment is miscalculated and the *qanat* emerges some distance away from the settlement, water will have to flow in an open channel from this point to the houses and fields below, increasing both evaporation and seepage. If the gradient of the tunnel is too steep, water rushing down its course will erode the walls and collapse the *qanat*. If the gradient is too shallow, water will pond and stagnate in the tunnel. In many cases, the *qanat* tunnel follows an indirect, looping pathway to its destination, curving to maintain proper grade on steep slopes.

The maximum gradient for a short *qanat* is roughly 1:1,000 or 1:1,500. In a long *qanat* tunnel, the grade is close to horizontal. These calculations are made using a spirit level suspended between two pieces of twine each about 10 meters long (Beckett 1953: 48). Using only these tools, a skilled *muqanni* is able to determine both the proper alignment and grade of the *qanat* tunnel even when it runs for kilometers beneath rugged terrain.

EXCAVATION

The excavation of the tunnel starts in the dry, downslope section of the qanat at the *mazhar* and works back toward the "mother well." Vertical shafts connect the tunnel with the surface every 50 to 100 meters or so, as noted above. In some cases, these shafts are dug first, and the tunnel is constructed to connect their bases.

A team headed by a *muqanni* works together in the construction of a *qanat*. The *muqanni* excavates the tunnel with a small pick and shovel, while his apprentice packs the loose dirt into a rubber bucket (in earlier times a skin bucket). Two laborers at the surface haul the dirt up the shaft using a windlass (*charkh*). If the *qanat* tunnel reaches depths of 75 to 100 meters, a second windlass is set in a niche halfway down the vertical shaft and the dirt is transferred from one bucket to another at this point in order to facilitate the excavation process.

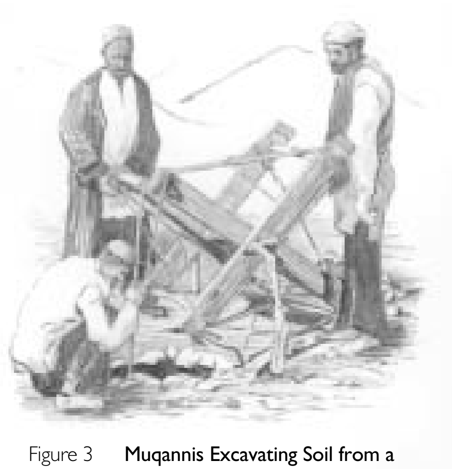

Figure 3 **Muqannis Excavating Soil from a Qanat Shaft.** Spoil lifted by windlass encircles the vertical shafts that link the qanat tunnel with the surface. Clearing blockage from qanat tunnels is usually required every few years.
(Illustration by Ann Coffin Delano)

The greatest dangers in *qanat* construction occur when the tunnel reaches the wet, water-bearing section. Here, the *muqanni* and his apprentice work with water flowing around them, in poor ventilation, and with the constant threat of cave-ins. In some cases, vertical shafts fill with water before reaching tunnel depth. The *muqanni* must then dig upward from the tunnel to the pooled water in the shaft, and try to avoid the rush of water when the break-through is made. Where the tunnel passes through a deposit of soft sand and the tunnel is likely to collapse, baked clay hoops (*nays*) are inserted in the tunnel to provide extra support.

Below ground, *muqannis* carry a castor oil lamp for both illumination and testing the quality of the air in the tunnel. If the flame dies for want of oxygen, the diggers know to leave the tunnel and dig another vertical shaft to provide more air. Where the *qanat's* tunnels are very deep and ventilation is particularly poor, vertical shafts are dug on either side of the tunnel. A fire is lit to make the stale air rise up one shaft and draw fresh air down the other (Noel 1944). In some areas, notably Yazd, twin *qanats* are built side-by-side, enabling *muqannis* to move from one tunnel to the other. The many hazards that attend *qanat* construction have, not surprisingly, endowed the profession of *muqanni* with a certain notoriety.

TIME AND COST

The time required to construct a *qanat* varies with the capital of the owner, the stability of ownership, underground soil and water conditions, the length of the *qanat*, the amount of water desired, the skill of the *muqanni*, and a variety of other social, economic, and environmental factors. In an alluvial fan village in Kirman, a *qanat* one kilometer in length with a mother well 45 meters deep was in construction for twenty-seven years, largely due to three changes in ownership. By contrast, a *qanat* in a similar location some three kilometers in length with a bifurcated tunnel and two mother wells 50 and 55 m in depth began to flow after seventeen years. The respective costs of these short, alluvial fan *qanats* were approximately $10,000 to $11,000 per km in the late 1960s (English 1966).

The cost of constructing a 40 km long *qanat* to the basin city of Kirman with a mother well 90 m deep was approximately $213,000 when completed in 1950. Given inflation, higher wages, the dwindling number of *muqannis*, and the political instability of modern Iran, the costs of building such a *qanat* today would likely be prohibitive. Confidence in future political and economic stability would have to be considerable to induce an investor to finance new *qanat* construction today.

The rate of flow of water in a qanat *is controlled by the level of the underground water table. Thus a* qanat *cannot drain an aquifer, because its flow varies directly with the subsurface water supply. When properly maintained, a* qanat *is a sustainable system that provides water to settlements indefinitely.*

QANAT TECHNOLOGY AND DEEP WELLS

Qanats were in wide use throughout the dry lands of the Old World until recently for several reasons. First, *qanats* are made of local materials. Second, they tap aquifers using no source of power other than gravity. Third, water is transported for substantial distances in these subterranean conduits with minimal loss of water through evaporation and with little risk of pollution. Water loss through percolation is reduced by lining the tunnels with clay hoops when they pass through loose sand, and by infusing their beds with layers of impermeable clay.

QANATS: WATER AS A RENEWABLE RESOURCE

The rate of flow of water in a *qanat* is controlled by the level of the underground water table. Thus a *qanat* cannot drain an aquifer, because its flow varies directly with the subsurface water supply. When properly maintained, a *qanat* is a sustainable system that provides water to settlements indefinitely. *Qanats* exploit ground water as a renewable resource.

The self-limiting features of *qanats* that make them a sustainable technology can, however, be their biggest drawback, particularly when they are compared with the range of technologies available today. First, the flow of water in *qanats* varies from year to year depending on the recharge rate of the aquifer. In the Middle East, where drought hits on average once every four years, this uncertainty often results in conservative cropping strategies geared to the cultivation of low-risk, low water-consuming, low value crops like wheat and barley.

Second, water flows continuously in a *qanat*, and although some winter water is used for domestic use, much larger amounts of irrigation water are needed during the daylight hours of the spring and summer growing seasons in Middle Eastern villages. Although this continuous flow is frequently viewed as wasteful, it can, in fact, be controlled to a large degree. During periods of low water use in fall and winter, water-tight gates can seal off the *qanat* opening (*mazhar*) damming up and conserving groundwater for periods of high use. In spring and summer, night flow may be stored in small reservoirs (*ambar*) at the mouth of the *qanat* and held there for daytime use (Beaumont 1989). Moreover, much perceived seasonal water loss infiltrates the soil beneath the *qanat* tunnel and thus recharges the aquifer.

Third, the body of custom and law (*shari'a*) relating to *qanats* codified in the *Kitab-i Qani* (Book of *Qanats*) in the ninth century strives to protect the investment of *qanat* owners in permanent agricultural settlement. The law of *harim* (borders), for example, prohibits the sinking of new mother wells within one kilometer of existing *qanats*. As a result, large areas of land in the vicinity of cities like Tehran, Sulamaniyah, Yazd, Kirman, Herat, and Qandahar, where the density of tunnel wells is high, are closed to new settlement. This, in effect, stabilizes agricultural acreage in regions with growing populations (English 1966).

By far the major disadvantage (and advantage) of deep wells, however, involves their success in meeting the growing need for water in the Middle East. Deep wells can draw water from permanent aquifers on demand without regard to rates of recharge. The technology, therefore, enables people to exploit their water resources in an unsustainable fashion.

Again, the major limitation (and paradoxically the major advantage) of *qanats* is that their rate of flow is limited by the aquifer height. Should the water table fall during a drought, so will the amount of water filtering into the water-bearing section of the *qanat*. If the aquifer rises, the flow of water increases. This makes *qanats* a sustainable, renewable source of water, but it also makes them inadequate water producers *vis-à-vis* modern demands. The rapidly increasing demand for water generated by population growth and agricultural expansion in the modern Middle East cannot be accommodated by *qanats*.

DEEP WELLS: WATER AS A NON-RENEWABLE RESOURCE

By contrast, deep wells have several putative advantages over *qanats*. First, deep wells are not limited by slope or soil conditions and can be located at sites convenient to transportation networks, populations centers, and markets. Second, they draw water from deep in the aquifer where seasonal variations in flow do not occur. Third, because deep wells can be turned on or off at will, they are, theoretically, conducive to water conservation.

But deep wells also have disadvantages. The construction, maintenance, and fuel costs (for motorized pumps) of deep wells are high

(Overseas Consultants 1949). Moreover, deep wells cannot be built using local materials and local labor. By far the major disadvantage (and advantage) of deep wells, however, involves their success in meeting the growing need for water in the Middle East. Deep wells can draw water from permanent aquifers on demand without regard to rates of recharge. The technology, therefore, enables people to exploit their water resources in an unsustainable fashion. The ability of deep wells, and motorized pumps, to withdraw water in excess of an aquifer's recharge rate makes this modern technology very attractive in the short term. As a result, however, water is fast becoming a non-renewable resource in areas where deep wells are used.

QANATS AND VILLAGE LIFEWORLDS

Like all water technologies, *qanats* require a nexus of environmental and social conditions in order to be effective over time. On the Iranian plateau, reliance on *qanats* promoted high levels of social and ecological adaptation. They inspired a need for social cohesion that permeated virtually all areas of village life.

Qanats defined village lifeworlds on the plateau by (1) determining settlement location; (2) structuring built environments within settlements; and (3) requiring social cohesion in water allocation, water distribution, water use, and system maintenance. These lifeworlds framed the horizons of everyday life in plateau settlements, encompassing people's firsthand involvement with the practical world, the world of values, and the world of goods (Buttimer 1976; Seamon 1979). With the shift from *qanats* to deep wells, water-based social patterns are in flux.

WHERE PEOPLE LIVE

Qanat technology was known in Iran by the sixth century BC, when Indo-Iranians began to settle as agriculturists, to worship one god (Ahura Mazda), and to conquer the Old World. Three centuries later, when the Parthians invaded Iran, *qanats* were in widespread use on the Iranian plateau (Polybius X: 28; Vitruvius VIII: 6.3). By this time, *qanats* had opened alluvial fans to settlement, enabled basin cities to expand, and established the foundations of modern plateau settlement patterns.

Qanats became an important factor in where people lived. The largest towns were still located at low elevations on the floors of intermontane basins and in broad river valleys. Most of these early settlements were defended by a fortress (*qal'eh*) whose water was drawn from hand-dug wells that reached down to shallow water tables. *Qanats* enabled these settlements to grow by tapping water-rich aquifers located deep beneath neighboring alluvial fans. *Qanats* carried water from the fans below ground for many kilometers to such settlements providing supplementary water to irrigate more extensive fields and sustain larger urban populations.

Even more dramatically, *qanats* made it possible to establish permanent settlements on the alluvial fans themselves. Earlier settlers had bypassed the alluvial fans because water tables there were too deep for hand-dug wells, and the wadis on these slopes were too deeply incised in the fans for simple diversion channels. In these locations, *qanats* tapped somewhat more limited "water hinterlands" with underground water drawn from upslope alluvial deposits in mountain valleys. For the first time, small towns and villages were built at these higher elevations. And further up river valleys in the mountains, small *qanat*-watered hamlets appeared.

Figure 4 ***Qanats* Converging on the City of Kirman.** Built during the course of many centuries, large numbers of *qanats* converge on most Iranian Plateau cities. Some of these old *qanat* tunnels cross back and forth between channels, others are twin *qanats* one or both of which may be active, and many have been abandoned. No map of the resulting labyrinth of *qanat* tunnels is available. Note the differences in surface definition on the image caused by drifting sand.

In many areas, these water hinterlands formed a series of progressively smaller arcs with the *qanats* of each higher settlement starting where those of the next lower settlement ended. Although configurations varied on the plateau, frequently the regional settlement pattern exhibited a correlation in age, size, water rights, and elevation. The largest place was the oldest and the lowest, and usually had prior rights to the largest water catchment basin. In any case, over much of the Iranian plateau these new upland settlements increased the cultivated area, supplied additional food to urban centers, provided living space and work for a growing population of farmers, as well as upland bases for herders and fuel collectors.

The Iranian plateau was the first core area of intensive *qanat* use. Even today, as much as one third to one half of the irrigated fields and orchards on the plateau–an estimated 15 million acres–are still watered by *qanats*. Cities like Tehran, Qum, Qazvin, Hamadan, Nishapur, Yazd, and Kirman received virtually all of their water from tunnel-wells until deep wells were introduced after World War II. In the 1960s, an estimated 21,000 *qanats* were still functioning in plateau settlements with an additional 17,500 used but in need of repair (Ghahraman l958). Their aggregate length has been placed at more than 160,000 kilometers, and their total discharge at 20,000 cubic meters per second (Goblot l962).

Although these figures are not precise, they convey a sense of the scale of *qanat* use on the Iranian plateau, the role of *qanats* in defining the location of settlements, and their importance in the day-to-day lives of Iranian villagers. In more immediate ways, *qanats* defined the built environments of towns and villagers, the architecture of daily lives.

THE BUILT ENVIRONMENT

The built environments of most alluvial fan towns and villages on the Iranian Plateau are aligned along the major watercourses (*shahjub*) that run from the mouth of the *qanat* down slope through the length of the settlement. In larger and more complex basin settlements, smaller streams of water emanating from the points of division (*maqsam*) of several *qanats* form a spatial skeleton of parallel pathways lined by village structures, walled orchards, and gardens. They are trunk lines of human activity.

Most alluvial fan settlements are triangular in shape. Below walled orchards and gardens at the top of the village, secondary distribution channels (*jub*) branch outward from the *maqsam* to form "water lattices" that broaden the area being cultivated. These smaller streams irrigate an elaborate grid of rectangular plots (*kort*) of irrigated land bounded by low, parallel levees (Bonine 1982; 1979).

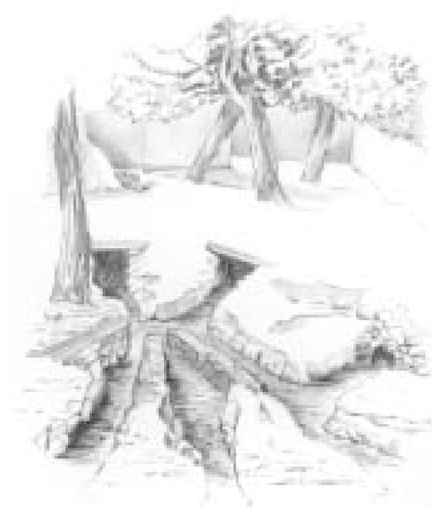

Figure 5 **A Water Divider in Mahan.** Two granite blocks were imported to Mahan to build a *maqsam* which subdivided the water emerging from two *qanats* into three major streams (*shahjub*) of equal flow. At some past time, one of the granite blocks was dislodged by a flash flood. Because of disagreement about its precise location prior to the flood, it was never repositioned. The owners of the major stream on the right clearly gained water because of the new position of the divider after the flood. The owners of the central stream lost water. Note that a third *qanat* enters the stream on the right below the *maqsam*. *(Illustration by Ann Coffin Delano)*

The rectangular shape of these fields is designed to deliver the required amount of water to the *kort* by the time its flow reaches the plot's downstream end. Rectangular fields also assist in measurement of area at times of land subdivision, inheritance, or sale.

The linear constraints that *qanats* place on settlement morphology is most obvious in small alluvial fan villages, where a single watercourse runs downstream through the settlement providing water to each household compound, orchard, and garden before irrigating grain fields downslope. Each household compound has the right to water its courtyard garden and to utilize the water for domestic purposes. The structures in these small places are strung out along the major stream channel; they parallel the slope of the land along the axis of the alluvial fan.

Interestingly, *qanats* also underlie the street patterns of larger cities as well. In some cities, *qanat* water flows in tunnels beneath residential areas and surfaces near the cultivated area. Staircases from the surface (*payab*) reach down to these streams. The first *payab* usually is at a public cistern where drinking water is available to the entire community. Sometimes these cisterns are sizable vaults as much as l0 meters across and 15 or more meters deep with spiral stairs leading down to small platforms at water level. In cities like Herat in Afghanistan, these cisterns are ancient constructions encased in tile. Other more modest urban *payabs* are found along major streets, and even in some alleys, a factor that probably played an important role in the social and physical layout of the town.

Where tunnels run beneath houses, private *payabs* slope down to the stream providing water for various domestic uses. In wealthy homes, special rooms are constructed beside the underground stream with tall shafts reaching upward to windcatchers (*badgir*) above roof level. Air caught by the *badgirs* , which are oriented to prevailing summer winds, is forced down the shaft, circulates at water level, and provides a cool refuge from the afternoon heat of summer. Needless to say, land located above submerged *qanat* tunnels, and houses with private *payabs* , are highly valued (Honari l989).

Bonine has discerned an orthogonal street pattern in cities like Kirman, Yazd, and Sabzevar where long, straight streets intersect at right angles forming huge "superblocks" with many short, blind alleys branching off major thoroughfares at right angles (Bonine l979). These grids do not conform to the rigid geometry of classical Greek or Roman towns, but they have distinctly geometric configurations. In Bonine's view, these configurations were established on a network of water channels used to irrigate nearby orchards and fields. As in alluvial fan settlements, slope is crucial. Topography and water flow are the elemental principles of Iranian settlement geography (Bonine 1979).

SOCIAL PATTERNING

In some rural settlements, the location of structures reflects the dynamics of water use and social status. Above the village, particularly where the slope is relatively steep, one or more water mills (*asiab*) are built to grind the grain of nearby villages and hamlets. In these Norse-style mills, water drops five or more meters to power a vertical shaft that turns a heavy mill stone (Wulff 1966). Closer to the top of the settlement, at least one branch of the *qanat's* water is diverted at a *maqsam* to a public reservoir or cistern, a communal bath (*hammam*), and a mosque. The reservoir or cistern provides clean water to all people in the community. The communal baths, which are only found in larger settlements, are used by surrounding villagers for bathing. The pool of water at the mosque is used for religious ablutions in *kur* , or sacred water (English 1966).

Within the settlement, the location of each household compound along the primary stream determines the quantity and quality of its water supply. As a result, household location frequently reflects the social and economic status of its residents or owner. The more prosperous households of landlords, merchants, and religious leaders are in the upper section of the village where water is clean and plentiful. The courtyards of these dwellings display central pools with canals lined by flowers dividing the gardens into sections. The poorer households of small landowners, sharecroppers, and day laborers are located downstream in the village where the volume of water is diminished and more polluted. The compounds in this district are given over to the cultivation of alfalfa (for fodder), fruit trees, spices, herbs, and vines.

Qanats *usually are built by wealthy individuals, but the constant need for tunnel repairs owing to natural disasters or social dislocations leads to rapid fragmentation in ownership. Many* qanats *have as many as two to three hundred owners and the water of some* qanats *is divided into as many as 10,000 time shares.*

Moving downstream through the village, water loss by evaporation, seepage, and domestic use can result in as much as a 40% decrease in water available to the lower sections of the village. Though there is a difference in the price of a share of water depending on where it is used in the settlement, the price difference is rarely commensurate with water loss which varies considerably during the year. In most settlements, then, the powerful live in the upper reaches. The *qanat*, more often than not, enters the village at the household compound of the most influential local landlord (*arbab*) (Cressey 1959).

In larger towns watered by several *qanats*, these water-based social gadients often are obscured by settlement history. Frequently, a maze of twisting distributary channels covers the landscape whose diversions are vestiges of past business transactions, marriage agreements, and bequests. But in most settlements, social patterns are directly related to water quantity and quality. Alterations in one system involve changes in the other.

Variations in water quality from one part of a village to another are reduced by customs of sequential water use that demand cooperation, an example of community needs taking precedence over personal influence. As noted above, a public cistern is often located at the top of the settlement. Its water is reserved specifically for drinking and cooking. In a pool below the cistern, dishes and cutlery may be washed using sand as the cleansing agent. After water is directed to the communal bath, additional pools are drawn off from the main channel (*shahjub*) in which household utensils may be washed with soap, and still further downstream animals are watered and straw soaked for use in construction. After these communal needs are met, the now polluted water flows directly to the fields. This hierarchy of use conserves water and reduces pollution (Roaf 1989).

QANAT OWNERSHIP

In many villages, *qanat* ownership is widely diffused throughout the population, and this widespread stake in the water supply system reinforces social cooperation. *Qanats* usually are built by wealthy individuals, but the constant need for tunnel repairs owing to natural disasters or social dislocations leads to rapid fragmentation in ownership. Many *qanats* have as many as two to three hundred owners and the water of some *qanats* is divided into as many as 10,000 time shares.

Strict and unforgiving adherence to communal methods of water rotation and maintenance of the water supply system are perhaps most important in maintaining the social cohesion of qanat*-watered villages.*

In some cases, the system of dividing water goes back hundreds of years. The current division of water at Ardistan in central Iran, for example, dates back to the 1200s when Hulagu Khan, the grandson of Genghis Khan, ordered that the town's water be divided into twenty-one shares with each share allotted to a specific quarter (Lambton 1953).

A complete record of changes in ownership exists for the Vakilabad *qanat* built in Mahan, a town southeast of Kirman, in the 1860s (English 1989). Initially, its water was divided among three men in six shares. One-sixth of the water was allotted to the then custodian of the Shah Ni'matullah Vali Shrine. This portion has increased to one-third of the water and is now owned by twenty of his descendants. The remaining water was sold off bit by bit such that some seventy families now own shares in the *qanat*. In another *qanat* system in the same town, water ownership has fragmented to such a degree that the owner of the smallest portion has rights to only thirty seconds of water once every twelve days. In Lambton's view, the historic inability of the Iranian upper class to retain property intact over time is the primary reason that Iran never developed a feudal aristocracy comparable to that of medieval Europe (Lambton 1969).

WATER DISTRIBUTION AND SYSTEM MAINTENANCE

Strict and unforgiving adherence to communal methods of water rotation and maintenance of the water supply system are perhaps most important in maintaining the social cohesion of *qanat*-watered villages. The distribution of water in these settlements is based on ownership of time shares in the annual flow of a *qanat.* These rotations take account of variations in diurnal and seasonal flow as well as differences in plot location, soil conditions, rates of seepage, and evaporation.

In general, water is divided into an indefinite number of time shares, or *sahms*, in a given water rotation period (Lambton 1953; Bonine 1982). The *sahms* are measured by volume in terms of *qasabs*, the theoretical amount of water required to flood-irrigate an area of roughly thirty square yards once every twenty-four hours. One hundred *qasabs* (in theory) would irrigate an acre of land, except that a *qasab* varies in volume from one place to another. Moreover, *qanats* as well as subdivisions of *qanats* (e.g. streams created after division at a *maqsam*) rotate water on different time schedules ranging from once every six days or twelve days to once every eighteen, nineteen, twenty-one or twenty-two days. The length of the rotation period varies with volume of flow and crops under cultivation, but a host of other lesser environmental factors also come into play.

When communal efforts fail, village water supplies diminish and in some cases the settlements are abandoned. Government land reform programs in the 1960s, for example, required written deeds to determine water ownership. Some settlements honestly or otherwise produced deeds that taken together made up more than twenty-fours hours of water a day. The resulting chaos led to violent ownership disputes and sometimes to total social breakdown.

In a relatively simple example from Mahan near Kirman, water from one of the towns' four *qanats* is divided into fifteen *sahms* with a volume of forty *qasabs* per day on a twelve day rotation. In this case, each *sahm* is equal to ninety-six minutes of water once every twelve days or enough water to irrigate forty *qasabs* of land. In addition, each *sahm* is subdivided into six *dangs*, each composed of six *habbeh.* According to this measurement system, one *dang* would equal sixteen minutes of water and one *habbeh* a single minute of water once every twelve days.

Most systems of water distribution, however, are much more complex. In a more typical case based on another *qanat* in the same settlement, the flow of water passes through twelve separate water dividers or *maqsams* that allocate water to specific fields at specific times on specified days in a conjoined eighteen, nineteen, and twenty-one day rotation (English 1989).

The person responsible for guiding the water through channels to the right field at the right time is the water master (*mirab*) or water bailiff (*mubashiri ab*). This official often directs a bevy of assistants who keep the channels clean, open and close small gates to specific fields, and breach levees when required. In some smaller communities, these tasks are handled directly by the community of water users (Spooner 1974). In the past, *mirabs* measured units of flow with a water clock (*tas*) based on the time it took for a metal cup with a hole in the bottom to sink in a container of water. Recently, these clepsydras have been replaced by clocks.

Annual repairs and cleaning of the *qanat* are usually required to maintain its flow, and communal meetings of *qanat* owners are held to decide the annual allocation of funds for this purpose. Although large water owners tend to dominate these meetings, votes are cast by shares. Other system responsibilities such as the payment of the *mirab*, his assistants, and crop watchers (either in cash or kind) are also decided in this fashion. In addition, more general community needs are dealt with by vote or custom—among these are payments to the carpenter, blacksmith, and other artisans vital to village life. Although social equality is rare in *qanat*-watered villages, village cooperation is a necessary adaptation to the ecological and social demands of this water technology. This social cohesion, and the water systems they are designed to preserve, defined the lifeworlds of Iranian villagers.

When communal efforts fail, village water supplies diminish and in some cases the settlements are abandoned. Government land reform programs in the 1960s, for example, required written deeds to determine water ownership. Some settlements honestly or otherwise produced deeds that taken together made up more than twenty-fours hours of water a day. The resulting chaos led to violent ownership disputes and sometimes to total social breakdown. In other very small settlements where disputes over water rights occurred, lotteries were held on the autumnal equinox in an effort to distribute scarcity more equitably. Water owners formed a circle, and at a signal from the village headman threw out any number of fingers on one or two hands. Starting with the headman, the fingers were counted around the circle of owners. Counting off the resultant total, the person at the end of the count received water on the first hour of the first day of the rotation. The lottery continued until each man had a definite time to receive water. Needless to say, owners near the end of the rotation usually received no water.

CONCLUSION

Qanats are renewable water supply systems that have sustained agricultural settlement on the Iranian plateau for millennia. By their very nature, *qanats* have encouraged sustainable water use. Their major limitations are that they are expensive to build and produce relatively small amounts of water. As a result, few *qanats* are being built today. Instead, *qanats* are being replaced by deep wells which produce more water to meet the current demand and support more intensive patterns of land use.

These deep wells mine water from fossil aquifers at rates well beyond replacement levels. Most are drilled in basin areas where water tables are close to the surface. As aquifers are drained, the *qanats* of alluvial fan settlements that share the same aquifer dry up when the water table lowers, and settlements eventually disappear. The communal patterns of social adaptation that bound together the lifeworlds of Iranian villagers for centuries disappear as well. In fact, evidence suggests that deep wells have made many small farmers dependent on well owners, have failed to increase agricultural production significantly, and bode poorly for the long term survival of many long-established settlements (Ehlers and Saidi 1989; Kielstra 1989). The desire for short term benefits has prevailed; the long term costs remain to be seen.

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Disease and Water Supply: The Case of Cholera in 19th Century Iran

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ABSTRACT
This paper explores why Iran was a particularly fertile ground for repeated visitation of cholera in the 19th century. Along with certain unique Iranian cultural and religious factors, the author demonstrates how Iranian urban ecology, particularly the *qanat* system, contributed to the fatal spread of the epidemic. These multi-faceted conditions, the author concludes, resulted in distinct modes of disease transmission and mortality in Iran.

"The cholera is the best of all sanitary reformers; it overlooks no mistake and pardons no oversight."

The Times (London), 5 September 1848

INTRODUCTION

In recent years, the subject of national identity and the verity of topographical boundaries as reflections of a tangible identity has been an immense source of controversy among academics (Jackson and Penrose 1994; Anderson 1991; Hobsbawm 1993; Ranger 1992). The Middle East has been at the heart of this debate, principally due to the nature of its shifting national frontiers and the relative youth of a number of its nation-states (Khalidi 1997; Bozdogan and Kasaba 1997). It should come as no surprise, therefore, that aside from the obvious cultural, linguistic, and historic antecedents, the physical environment of the Middle East has also been utilized by scholars as an identity-building apparatus.[1] In this paper I hope to expand this debate by looking at a Middle Eastern national entity's unique experience with a pathogen during the great pandemics of the 19th century. By examining Iran's encounter with the *Cholera bacillus*, this paper will reveal environmental and cultural factors that made Iran's experience with Asiatic cholera distinct from that of other countries across the globe which were gripped by the same microbe.

I seek to demonstrate how the Islamic disposition toward "sacred-law" as the yardstick for purity, together with the lack of any sanitary base, made Iran a fertile ground for repeated visitations of cholera. Aside from Iran's own unique legacy, the attributes which predisposed it to repeated invasions of Asiatic cholera can also be used as an opportunity to assess the larger Middle Eastern legacy with epidemic diseases, which sets it apart from its European, Asian, and African counterparts. Furthermore, in evaluating these cultural and environmental factors, one can see the emergence of a degree of

[1] One does not need to look any farther than the colloquial use of the great river-systems from the "Oxus to the Nile" in delineating the geographical-cultural boundaries of the Middle East.

continuity in Iranian urban ecology as well as in its human dimensions, embodied by its religious ideologies, which stem from Avestan and Talmudic traditions. More than anything else, these continuities attest to the importance of considering historical trends in the ecology of illness in the Middle East, so as to better understand current environmental issues in that region.

ORIGINS OF THE ASIATIC CHOLERA PANDEMICS

The cradle of cholera's numerous visitations in the 19th century can be traced to the banks of the Ganges River where the *Cholera bacillus* had been thriving for centuries in its warm waters and the intestines of its neighborly human hosts. A "fecal-oral" disease, cholera is passed from the excrement of its victims into the food or water source of a community whereby it is ingested by a slew of new victims. The bacteria eventually find refuge in their hosts' digestive tracts, at which point the warm alkaline environment of the small intestine provides the ideal environment for the germs to multiply with great rapidity. Ironically, it is not the presence of the bacterium that causes the demise of its victims; rather it is the host's immune response that unleashes the lethal poison of the germ. Consequently, the most violent symptoms of cholera emerge as a result of the bacterial cells' destruction by the immune system, which releases the powerful toxin that they contain. It is this venom that causes the lethal manifestations of the disease (Snowden 1995). The pallet of these symptoms, which includes massive vomiting, diarrhea, and the blue-gray pallor of its victims, paints an abysmal picture. Indeed, one could say that the victims of the disease bear the very faces of death as a result of the loss of a quarter of their body fluid, which is the cause of the emaciated, blue-gray pallor and sunken eyes of the stricken. The Hippocratic signs of impending death are further brought to bear with the comatose and apathetic state of cholera's victims (Snowden 1995).

The penetration of the East-India Company into inner-Hindustan and the globalization of trade with the Indian sub-continent, provided the *Cholera bacillus* with a suitable vector through which it could spread on an international scale.[2] Maritime trade with India, which provided fast ships and frequent ports of call, allowed infected goods, such as recycled clothing or foodstuffs, to be spread from port to port. Furthermore, the relative rapidity of travel from India to a variety of ports of call, such as southern Iran, allowed infected human vectors also to serve as reservoirs for the spread of the disease. This vector was especially significant during the heyday of the anti-contagionist philosophy regarding cholera, in the mid-19th century, which had partly emerged as a result of the

[2] Of course this trend in global pandemics is nothing new. Ever since the first civilizations and emergence of global trade, disease has accompanied human quests to penetrate new markets. The genesis of Black Death in medieval Europe was a product of the newly globalized economic position of Europe, through Venetian trade in the Crimea, which incidentally (and fatefully) was also the port of call for caravans from China and central Asia. Patterns of epidemics and their impact on civilization have been beautifully exposed in recent works by William McNeill and Alfred Crosby. Unfortunately, the views on the nature and impact of disease on civilization seem to be fairly uniform, and the field is certainly in need of some dissenting views as to the nature and impact of these diseases on humanity; see W. H. McNeill, *Plagues and peoples* (New York: Doubleday, 1979) and Alfred W. Crosby, *Ecological imperialism: the biological expansion of Europe, 900–1900* (Cambridge: Cambridge University Press, 1986).

futility of quarantines and was to some extent due to the epidemic's selective impact.[3]

GROUNDWORK FOR AN EPIDEMIC

Iran was perfect territory for acquiring and subsequently "exporting" epidemics to other continents. Known as the "crossroad of civilizations" on account of its central position within the Eurasian plateau and its strategic position in the path of the historic trade and invasion routes, Iran had a long history of also being on the "crossroad" of global pandemics. In classical times it was *The Plague of Justinian* that crossed this land, followed by the medieval bubonic plagues, and, in the 1880s, an influenza pandemic. This singular position in the path of visitations was also due to Iran's territorial vastness. With a geographical area of about 1,648,000 km^2 and a frontier length of roughly 4,440 km, about half of which rested on the shores of the Caspian Sea and the Persian Gulf, the Iran of the 1890s presented many venues for the overland and maritime importation of disease into its lands. During this time, the Iranian dominions bordered the Russian Empire to the north, Mesopotamian and Anatolian districts of the Ottoman Empire to the west, and Afghanistan and British India to the east. Regrettably, this meant that Iran was in an ideal position to acquire epidemics from the east and subsequently export them to European territories through its extensive common border with the Russian Empire.

The cholera pandemics of the 19th century illustrate Iran's role as Europe's "hazardous underbelly." Indeed, during the very first cholera pandemic (1830–1837), Europe acquired the disease through the common Russo-Iranian border. This event was replayed during the fifth European cholera epidemic (1869–74), when the disease entered Europe via Iran and Russia. In 1892, Iran again served as the transit point for cholera's westward journey.[4] Naturally, it was a new-found position in the global maritime trade economy which had played an important role in sustaining Iran's key position in the export of cholera to Europe. Indeed, the British-Indian commerce, with its important relay ports in the Persian Gulf, served as a critical vector for the propagation of Asiatic cholera from its home in India to Iran. Consequently, visitations of cholera usually began their European-bound journeys in Persian Gulf ports that had important commercial links with British India. However, it should be acknowledged that British trade alone was not solely responsible for abetting the epidemic. Iran's central position in the Islamic pilgrimage route from the east also served as an important vector for the importation of cholera from India.

[3] In contrast to the blind and indiscriminate ravages of the medieval Black Death, cholera's victims in Western Europe and North America belonged to the category of the poor and disenfranchised. Categorized as "the dangerous classes" by the Victorian elite, this group, more than any other, was feared as a source of radical predisposition and social unrest; see Evans 1988.

[4] Contrary to the accusations of 19th-century sanitarians, the Ottoman Empire and Russia, rather than Iran, bore the brunt of the responsibility in cholera's westward transmission. Indeed, although Iran lacked effective sanitary defense mechanisms to protect it from the eastern flow of the epidemic, it very frequently acquired the disease from its northern and western neighbor.

The pilgrimage to Mecca, better known as the *hajj*, is one of the five pillars of the Islamic faith. After the opening of the Suez Canal in 1869 and the development of effective railway routes in the Caucasus and between Alexandria and Port Said, many wealthier pilgrims from Iran, Afghanistan, and central Asia took advantage of this circuitous, but more comfortable, northern route to Mecca (Farahani 1990). Characteristically, pilgrims travelling this route would leave Tehran by caravan or horse carriage to the Caspian port of Enzeli. From there, a Russian steamer would transport them to Baku, where they could acquire railroad passage through the Caucasus to the port of Batum in Turkey. From Batum a steamer would transport them to Istanbul and onward to Alexandria in Egypt. From Alexandria, they could continue by rail to the Suez, where maritime passage could be obtained to Yanbo and Jedda, and from those ports caravan transportation could be obtained to Mecca (Farahani 1990).

With the ubiquity of the steamer and railroad in the Middle East, not only did pilgrimage to Mecca become faster, but cholera's spread also achieved a greater velocity and diffusion throughout the region. On that account, the 1871 and the 1892 cholera epidemics followed this new pilgrimage route into Iran, either disseminated by pilgrims coming back through the Red Sea or carried by Mecca bound travelers from northern India and Afghanistan (Lorimer 1915). Incidentally, Iran's unique Shi'ite sectarian identity also served to further compromise its people to the threat of cholera visitations. This was due to Shi'ite *ziyarats* (devotional visits) to the holy shrines Najaf and Karbala in Mesopotamia, which provided a regular flow of traffic to cholera stricken areas. Located near the banks of the Euphrates and the Gulf, these areas were usually a focal point for pandemics originating in India, and, as could be observed in the 1899 epidemic, as one of the vectors for cholera's journey into Iran.

As such, for a variety of reasons Iran was ripe for the visitations of cholera; nonetheless, the question remains: why were these epidemics still occurring in the 1890s, at a time when the scourge of Asiatic cholera had largely been arrested throughout Western Europe and North America?[5] Why was it that, unlike the Western European powers, Iranian authorities could not halt the flow of the outbreak? The answer to these questions can be found in Iran's weak central administration and in its sanitary neglect and lack of medical facilities, which together with religious and cultural factors predisposed and perpetuated Asiatic cholera among the Iranian populace.

[5] Nevertheless, recent work by Snowden shows that epidemics of Asiatic cholera continued in Europe, well into the 20th century. Asiatic cholera in epidemic form also appeared in Hamburg in 1892; see Snowden 1995 and Evans 1987.

WEAK CENTRAL ADMINISTRATION

The Qajar dynasty (1796–1925) was marred by a feeble and hampered central government, which was essentially at the whim of the various "peripheral" power centers. Nasir al-Din Shah's (1831–1896) reign was not an exception. In the north, Russian and Ottoman hegemony and meddling in administrative matters, together with Turkoman and Kurdish raids, weakened his government's hold on the region. In central and southern provinces of Iran, the Bakhtiyari, Qashqa'i, and Khamsa tribal confederacies, together with British interests in the Gulf and Baluchistan regions, were wholly unsympathetic and even antagonistic toward any measure that would extend the central government's administrative hold and threaten their position. This weakness *vis à vis* the provinces was also perpetuated by the custom of assigning princes as provincial-governors or simply auctioning ministerial appointments to inept administrators. Although in theory these governors were representatives of the Crown and accountable to the Shah, in practice they were fairly autonomous. This abuse was sustained in part by virtue of Nasir al-Din's own dislike of bureaucracy and tendency toward a balance-of-power principle that rarely placed overwhelming authority in the hands of any one party. Consequently, any attempt by reform-minded premiers to increase the power of the central government met its demise at the hand of magnates and the European powers in the peripheries whose stronger influence in court circles overwrote ministerial authority (Bakhash 1978; Nashat 1982; Amanat 1997).

*The deficiency of the Iranian administration was also reflected in the delay of organized response to the crisis of epidemics in the 19th century. Indeed, it was only in 1868 that the first National Sanitary Council (*Majlis-i hifz al-sihha*) assembled in Tehran.*

The deficiency of the Iranian administration was also reflected in the delay of organized response to the crisis of epidemics in the 19th century. Indeed, it was only in 1868 that the first National Sanitary Council (*Majlis-i hifz al-sihha*) assembled in Tehran. The Council, headed by Dr. Joseph Desiree Tholozan, the Shah's chief physician, composed a report in which a summary of past epidemics was brought to light together with the need for sanitary and quarantine improvements as a means of preventing the future flow of cholera (Tholozan 1995). Although theoretically sound, the Council's proposals could never be executed owing to the lack of authority on the part of the central government to enforce intrusive and restrictive measures in the provinces. Furthermore, the failure of defensive implementation was also due to the Council's lack of mandate and to irregular meetings, which invariably only took place when a full-blown epidemic was already at hand. It was not until 1904, in accordance with the provisions of the 1903 International Sanitary Convention of Paris, that a regularly meeting Iranian Sanitary Council was inaugurated (Gilmour 1925). This paucity in regulation explains the inability to enforce quarantine measures in Iran during periods of crisis such as the 1889 cholera epidemic when "a quarantine station [that] had been established by the Persian Government was so contrived that it did not hinder at all the traffic carried on between Persia and Mesopotamia" (Dickson 1893–94).[6] Moreover, in a culture that condoned "tax-farming" as a means of acquiring revenue, it was deemed acceptable to auction off the administration of quarantines to the highest bidder. Hence, those who were appointed to supervise *cordons sanitaires* during periods of crisis usually managed them for personal profit, and orders issued by the central government were not always obeyed (Camposampiero 1893–94).[7] Ironically, the Government's weak authority sometimes compelled "peripheral" powers, such as the various regional tribes, to assume the management of sanitary measures and quarantines to protect their own people.

Dr. Camposampiero relates as an instance of the efficiency of *cordons sanitaires,* that when cholera prevailed at Mashad, the chiefs of the tribes of Bujnurd and Ghuskan, in the neighborhood of that city, interrupted all interaction between their camps and the infected places, and thus kept themselves free of the outbreak (Camposampiero 1893-94).

This administrative weakness *vis à vis* sanitation and response to epidemics was part of a larger "pathology," the symptoms of which expressed themselves in the urban sanitary decay that characterized many cities in Iran.[8]

URBAN SANITATION AND NEGLECT

The occurrence and intensity of Asiatic cholera in the Iran of the Qajar period refutes the commonly assumed link with 19th century urbanization and its associate the Industrial Revolution. Although an accurate population census of Iran in the 19th century is lacking, an estimate in 1867 puts the total population at 4 million, with a mere 850,000 souls inhabiting the principal cities.[9] Indeed, urbanization and the pattern of city growth observable in Western Europe did not occur in Iran until well into the 20th century. Even as late as 1925, only 2.5 million were urban dwellers, out of a population of about 11.8 million, indicating that the Iranians had kept the characteristic pattern of 21% in metropolitan settlements (Ehlers and Floor 1993). Furthermore, urban populations were not concentrated in any one Iranian city. Instead, masses were equally distributed among a number of regional centers. For example, in 1913, Tehran—Iran's capital and most populated city—boasted 350,000 inhabitants (Issawi 1976; Curzon II). Now, taking the 21% "urban-dwellers factor" together with an appraisal of the total Iranian

6 The inefficient quarantine enforcements were certainly not limited to the Iranian case. During his travel through Egypt from Mecca in 1886 Mirza Mohammad Hosayn Farahani tells us that: "When officials are posted to the quarantine, it is as if they [had been appointed] officials in charge of fleecing and plundering the pilgrims. One of the circumstances that makes this clear is that the authorities of the quarantine, especially the chief doctor, take something from the captains of the steamers so they won't cause any trouble: If someone dies during the two days stopped at the quarantine, they don't renew the period and do not delay the steamer; see Farahani 1990: 291.

7 On the concept of tax farming and the purchase of offices, Curzon tells us that "so long as the gift of office is largely determined by the strength of the purse, corrupt administration must prevail, and honest men will go to the wall." See Curzon 1892, I: 498.

8 The issue of urban decay was not unique to the Iranian context. Indeed, throughout the Middle East, sound urban planning was a prime concern that came to light following European models of urban and sanitary renewal; see Rosenthal 1980: 22.

9 The first national census of Iran was held in 1956; see Bharier 1968 and Issawi 1971: 28–29.

population in 1890 at nine million, we can safely estimate that the total population living in cities and large towns as late as the 1890s stood at about 1.9 million.

Obviously, with an overwhelming segment of Iranians leading a rural or sedentary life, the urban significance, with respect to the Iranian experience with Asiatic cholera, might be questioned. However, this issue is immediately resolved by the very nature of the "center-periphery" relationship in 19th-century Iran. Most importantly, villages, rural settlements, and even nomadic tribes, together with larger towns and cities were part of an organic system that depended on one another for survival. Owing to this mutual dependence, urban centers in Iran were the site for bazaars in which farmers and herders sold their harvest and cattle to feed the cities in exchange for the manufactured commodities of urban artisans, which they brought back to their tents and villages. As a result of its role, the bazaar became a regular icon of the Iranian urban landscape, ensuring frequent interaction between the "centers" and the "peripheries." This meant that when a cholera epidemic broke out in a town or city, the bazaars became centers of infection, through which peasants and nomads carried the disease to the surrounding villages and campgrounds (Clemow 1893–94).

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Trying to depict the urban sanitary condition during the Qajar era may seem like a gargantuan task in itself. Nevertheless, in a country of vastly contrasting climes and environments, which is mirrored by the variety of regionally determined designs of its urban landscape, the features of municipal sanitation (or lack thereof) remain remarkably similar throughout Iran. Tehran of the 1890s is a prime example of the unsanitary condition observable throughout urban centers in the Qajar era. As Curzon remarks: "That the city has yet much to do before it realizes the full aspiration of its royal Hausmann is evident as soon as we enter the gates" (Curzon 1892). By comparing Nasir al-Din Shah to Baron Hausmann, famed sanitarian and architect of Paris, Curzon's taunt was unwittingly appropriate. Indeed, although the city had undergone some reconstruction in 1870s, which included the widening of some streets and the inauguration of several parks, on the whole, Tehran remained a city devoid of sanitary planning or municipal maintenance (Nashat 1982). Dirty streets, stagnant and contaminated pools of water, and a suffocating atmosphere characterized its scorched summer months. Tehran's oppression reached such intolerable levels that it was commonplace for anyone who could afford it to escape the city for the cool shelter of the surrounding mountains, leaving behind the aromas of putrefying matter and the constant harassment of flies and mosquitoes (Polak 1865). Furthermore, with the exception of the cities of Isfahan and Rasht—which obtained their water exclusively from wells—highly unsanitary subterranean aqueducts, known as *qanats*, conducted the crucial municipal water supplies throughout most of Iran (Wulf 1968; Goblot 1979).

Since antiquity, *qanats* had been used as a method of securing water from distant places (See English, this volume). Their sheltering character allowed the water to traverse through warm climes with the least amount of loss due to evaporation. These channels were constructed by sinking vertical shafts every twenty or thirty yards and connecting them by tunneling (Gilmour 1925). Tehran's own water supply originated from streams and underground springs in the Shemiran slopes at the foot of the Elburz range to the north of the city. Departing from the aforementioned sources, the *qanats* conveyed water to the city, branching off among the important streets where they remained underground but very close to the surface. Once within the municipal boundaries, water from the *qanats* could be obtained by moving stone slabs that covered the channels traversing under the streets and alleys. Frequently nothing covered the *qanats* within city confines. In wealthier districts of Tehran, water was led to the houses through underground networks, whereas in the poorer neighborhoods, the water reached the surface and traveled in gutters on both sides of the street (Gilmour 1925). This water served the dual purpose of consumption and domestic usage; and hence, by its very nature and use the *qanat* system perpetuated infection among urban dwellers. Indeed, a chemical analysis of water, conducted in 1924, from six *qanats* as they entered Tehran revealed water of potable quality in only two cases. In three other cases the water purity was questionable and in one case the water was definitely unfit for drinking. These results were especially shocking due to the fact that these samples were taken from closed *qanats* before they were open to contamination (Gilmour 1925). This meant that even before entering the city, water purity had been pre-ordained, and protection from pathogens was not necessarily a correlate with income levels or neighborhood, since the same source which supplied the poor in the southern districts of Tehran also found its way into the city's wealthiest mansions. More than anything else, it was this system of water supply that was the main conveyor of the cholera epidemic, mainly due to the "fecal-oral" cycle of the infection, whereby the cholera bacterium had to be ingested by an unsuspecting host. As John Snow (1813–1858) had suggested in his investigations of outbreaks in England, more often than not it was the polluted drinking water of a community that was responsible for the outbreaks.[10]

[10] During the 1848 cholera epidemic, which claimed 53,000 victims in England and Wales, Snow published several pamphlets and papers (*On mode of communication of cholera*), in which he claimed that the disease was a specific water-borne infection that was distinct from other fevers. During the 1854 epidemic he was able to support his argument through two famous epidemiological investigations. The most famous of the two was the mapping of the occurrence of cholera in his own neighborhood of Soho and tracing the guilty party to a single contaminated well in Broad (now Broadwick) Street.He accomplished this by finding visitors who had drunk from the well and succumbed to the disease, and by showing that the workers at the local brewery, who had unrestricted access to beer as a prerequisite for their job, were relatively immune. His careful and detailed analysis convinced local aldermen that the well was the source of cholera and they removed the handle to the well's water-pump (see Bynum 1994).

Throughout Iran, even if the *qanat* water was uninfected before entering the cities, it had ample opportunities to get contaminated while traversing the urban streets. With the lack of proper sewage and waste disposal throughout Iranian municipalities, the cholera bacterium easily made its way into the drinking water (Morton 1940). In the city of Bouroudjird, for example, the household sewage drained freely onto the streets towards the middle of the city, where an immense pit received all the waste, which was subsequently left there to be sterilized by sunlight (Fuevrier 1894). Moreover, if the bacterium was not already in the water system through the thin porous pavement, the tradition of watering the roads for cleaning purposes would then introduce the infection into the thinly covered *qanats* and drinking gutters lining the throughways. Indeed, the drinking gutters, which supplied the poorer districts in Iran, were open to all kinds of contamination. In the city of Muhammareh, for example, the only form of sewage was a channel cut down the middle of each street, which was generally choked up except after rain. In another city, Shushtar, the streets became receptacles for domestic sewage, which was left on-site until rainwater washed the foul matter away. Obviously, open waterways were exposed to dirt and rainwater and the waste that was left on the streets, but where nature did not carry infection it was the inhabitants themselves who contaminated their drinking water directly. In Tehran, for example, it was not unusual to see children playing in the gutters or people washing their animals or dirty linens in them; in some cases the linens would be the clothes of a victim who had succumbed to cholera and hence strewn with fecal matter. More blatant forms of pollution came in the form of direct introduction of feces into the waterways. Indeed, the Persian word for latrine was *Kinar-i ab*, "the water's edge." Hence, it was not unusual to see children defecating in the gutters, which a little farther up were being used for drinking purposes or pre-prayer ablution. Furthermore, cemeteries were often built next to the very waterways that supplied drinking water to the community. In the city of Hamadan, for example, the municipality's largest cemetery was built next to the banks of the main waterway entering the city. This trait made municipal waterways highly compromised and open to infection especially via soil infection and "corpse washing" using the river's water.[11] To the untrained contemporary European mind, the universal disregard for sanitation might was passed off as a simple case of "oriental ignorance;" however, the lack of proper precautions found its source in cultural and religious beliefs of the Iranians which were at the very center of the popular conception of cleanliness (*nizafat*) and pollution (*nijasat*), doctrines, which, when put to the test,

[11] These characteristics also explain the reasons for the British Legation's private purchase of a *qanat*, which was completely subterranean (sometimes running up to two hundred feet beneath the surface) from its source in the mountains to the legation grounds in Tehran. Indeed, it can be said that it was this safe water source and proper quarantining that saved the British and American legations from outbreaks of cholera within their compounds. The British legation supplied the American legation with safe drinking water free of charge (see Pearson 1903).

proved to be more than effective in guarding the health of an urban population; however, it was Asiatic Cholera which proved to be the singular Achilles' Heel in Islamic conceptions of purity.[12]

RELIGIOUS AND CULTURAL PREDISPOSING FACTORS

When Dr. James E. Baker disdainfully observed that "Persians 'religiously' hold to the idea that running water cannot be defiled," he could not have known the irony of his statement (Baker 1886). Indeed, at the very root of the Islamic Iranian sanitary culture lay the belief that running water could be considered immaculate for rituals and consumption unless its color, taste, or smell indicated the presence of impurities. Furthermore, water from stagnant sources such as ponds, reservoirs, and wells was also considered pure, like running water, so long as its volume occupied at least one *korr* (350 liters), the religiously prescribed volumetric quantity that assured purity. Accordingly, to be considered clean, the water that was stored from *qanats*, in home reservoirs, also had to agree with the quantitative delineation of purity (Poonawala 1991). Consequently, basins were always guarded from dropping below 1 *korr*, which assured that the water was potable, no matter how long it had stood stagnant. This faith, rooted in the *hadith* (prophetic traditions) explains why Iranians did not conceptualize the idea of *jubs* or *qanats* as sources of infection and propagation of disease, for such a notion would have challenged their very system of beliefs. Indeed, the 19th century witnessed an almost obsessive concern with "ritual" purity or *taharat*. Indeed, the innumerable *fatwas* (edicts) and religious prescripts are an indication of the preoccupation of the *'ulama* with the subject of cleanliness and the influence of these opinions on the general public at this time.[13] Nevertheless, a minority of Iranians—such as Nasir al-Din Shah—did espouse the European conception of water-born infections and as a result they employed a *saqqa* (water-carrier), whose task was to ensure the drinking water's purity by bringing it from the source where the *qanat* first came to the surface.[14]

The same Islamic tradition that delineated the guidelines for water purity also required that Iranians copiously wash the bodies of the deceased before burial. This system, coupled with the staunch belief in the purity of running water, led many to wash the bodies of their loved ones who had died of cholera in *jubs* and streams which supplied the urban *qanats*. In addition, faith in the purity of running water also allowed graves to be dug right above the city *qanats* and close to other sources of drinking water, without any concern for pollution (Bell 1894). Unfortunately, faith in the purity of running or voluminous water, along with the religious obligation to wash the

[12] It should be recognized that even water polluted by the *cholera bacillus* in itself cannot give rise to illness since under normal conditions stomach acids should destroy the germs. However, prolonged periods of malnutrition and famine lower stomach acidity and breech the body's normally effective defense mechanisms. Famine and malnutrition were chronic problems in nineteenth century Iran and it should come as no surprise that cholera outbreaks paralleled periods of drought and dearth.

[13] Some examples of this genre are: Al-Bihbanani, Risala fi kayfiyyat wujub al-tahara (Manuscript: Sepahsalar 2487); Al-Ansari, al-Tahara (Ed. Tabriz, 1303); Al-Rashti, al-Tahara (Manuscript: Masjid-I Aízam 367). Even the late Imam Khomeini had a fascination (a common theme with the *'ulama* as we have seen) with the subject of ritual cleanliness and purity in daily life, see Khomeini, K. al-Tahara (Qom-Najaf, 1382–90).

[14] The father of Amin ul-Soltan, had started his career as the *Sakka Bashi* (chief water-carrier) of Nasir al-Din shah (see Feuvrier, *Trois Ans*: 187).

dead, would prove disastrous during cholera epidemics. The high casualty rates during Iran's encounter with these visitations are a testament to the role of the unsanitary condition of the urban water supply in perpetuating and abetting Asiatic cholera.

Although cholera's etiology made it principally rely on the intermediary of drinking water to be disseminated, the Shi'ite tradition of seeking entombment in the holy cities of Karbala and Mashhad gave Asiatic cholera in Iran the unique opportunity to continue to use a person as a vector for transmission, long after he or she had been "dead and buried."

> Even when they are buried, the bodies are not allowed to rest in peace. The richer families hold it a point of honor to lay the bones of their relations in some holy place—Kerbela [sic.], where Hussein was slain, or the sacred shrine of Meshed [sic.]. They therefore commit them only temporarily to the earth, laying them in shallow graves, and covering them with an arched roof of brickwork, which practice accounts for the horrible smell around graveyards after an outbreak of cholera. A few months later and long before tome has killed the germs of disease, the bodies are taken up, wrapped in sackcloth, and carried, slung across the backs of mules, to their distant resting place, sowing not improbably the seeds of a fresh outbreak as they go.
>
> (Bell 1894)

Essentially, these mule-driven caravans traveled from city to city in Iran, collecting the deceased and a small sum of money in exchange for a promise to the family of the departed that their loved ones would be buried in one of the Holy Cities (Mashhad or Karbala) for which they were bound. Often, the bodies were enclosed in an imperfectly nailed box, so as to facilitate transport, an operation that was accomplished by tying a pair of the coffins to the sides of a mule (Sheil 1856). The obvious result of this engagement was that caravans of stench and disease were continuously streaming across Iran, carrying and spreading infection at every halt. Sometimes the owners of the transports would decide to dispose of the corpse short of the promised destination so as to cut the costs of labor and conveyance. On these occasions, it is quite conceivable that the bodies were disposed of in rivers and streams, which might have also supplied drinking water of a town or village.[15]

Cholera in Iran did not always go hand in hand with what contemporary European observers labeled as a culture of unsanitary praxis. Sometimes, the pursuit of cleanliness, and the virtues of

[15] During the 1870 cholera epidemic, Dr. Dickson—chief physician to the British legation—credits the exhumation of bodies (victims of cholera) to be buried at a holy site, with the renewed outbreak of cholera in Iran. (Great Britain, The Public Record Office, Foreign Office, General Correspondence; Dickson to Granville, FO 60/326, no. 282).

bathing proved just as lethal as burial practices and the pollution of water. Indeed, the *hammam* (public bathhouse) in Iran became an important center for the propagation of cholera during times of epidemic. This condition came about for a variety of reasons, which included the customary location of the *hammams*, below the street level, so as to facilitate pumping and carrying water; a characteristic that also allowed sewage and garbage to have easy access to these locales (Gilmour 1925). Furthermore, the tubs in the *hammam* were usually filled with tepid water that was recycled from previous bathers, and it was not uncommon to see the sick or diseased bathing side by side with the healthy, especially since many traditional remedies for cholera recommended bathing (Baker 1886). Hence, not only did Iran's physical construct help spread cholera, but also a variety of cultural factors made people more predisposed to the disease. The only questions that remain, in this regard, are the factors for the limited frequency of outbreaks and the reasons for Iran is never becoming an endemic region for cholera.

CONCLUSION

For students of medical history, the Victorian era, roughly spanning from the 1830s to the closing years of the 19th century, is a period of prodigious innovation and advances in the medical sciences. This period marks the beginnings of the Christian and Muslim worlds' divorce from the Galenic ethos, which had dominated their medical practice for over two millennia. Essentially, the foundations of various disciplines of contemporary medical sciences were built in the 19th century, and no discipline characterizes this debut more than the field of epidemiology and public health.[16] Obviously, we should not confound our "modern" image of the epidemiologists with the Victorian "sanitary physicians," nor should we lead ourselves into believing that this "sanitary" outlook emerged overnight. Nevertheless, most historians of medicine would agree that the cholera pandemics of the 19th century were instrumental in the emergence of this new intellectual-scientific trend. Indeed, the sanitary-physician of the 19th century emerged in part as a result of active campaigns on the part of European governments to prevent the flow of epidemics into their lands. Moreover, these sanitary physicians, together with the active participation of their ruling administrations, took dynamic measures to change their environment and augment the sanitary standards of their citizens.

During the 19th century Iran was not isolated from these emerging intellectual trends in medicine. The *Dar al-Fonun*, or the Polytechnic College of Tehran, with its Europeanized medical school and Austrian instructors, is indicative of the change insofar as the

[16] For an in-depth exposition of medicine and public health in Victorian England, see W. F. Bynum's *Science and the practice of medicine in the nineteenth century,* Cambridge, Cambridge University Press, 1994. A more focused account of the foundations of epidemiological science in Victorian England is presented in David E. Lilienfeld, The greening of epidemiology: sanitary physicians and the London Epidemiological Society, (1830–1870), *Bulletin of the History of Medicine,* 1975, 52: 503–528 and A. Dodin and J. Brossollet, L'epidemie de cholera de 1832, ou la naissance de l'epidemiologie moderne, in *Hommage à Marcel Baltazard*, Paris, Institut Pasteur, 1972.

medical curriculum was concerned. The issue that remains perplexing is the seeming lack of Iranian impetus in putting new ideas dealing with sanitation and public health into practice.[17] This is a discrepancy, which, I propose, can be solved by comparing the Iranian experience with cholera with its European counterparts. Indeed, a corresponding look into the subject reveals that part of the European motivation in creating a "sanitary police" emerged out of the cholera's selectivity in that it impacted the lower ranks of European society more than its notable classes. The obvious repercussions of such discriminate casualties were that they bred an inherent suspicion and hatred of the "upper classes," which were not affected by the epidemics. European governments felt that in due course such resentments would lead to insubordination and rebellions, and in some cases such uprisings, due to cholera, were actually experienced. Hence, there was a very tangible self-preserving interest on the part of the European governments to institute change. Cholera in Iran, on the other hand, selected its victims on a much more democratic basis. Epidemics affected prince and peasant regardless of class or status; hence, the motivation to improve the foundations of public health was much less pressing. Obviously, this is but one symptom of a more general pathology within the Qajar government, which prevented it from instituting adequate sanitary measures.[18] Nevertheless, it gives us yet another perspective on the uniquely Iranian response, which emerged from its experience with the visitations of Asiatic cholera.

It should be reemphasized that Iran's experience with repeated visitations of Asiatic cholera, which included a distinct mode of transmission and mortality, indicates that pathogens and patterns of illness do somewhat legitimize boundaries and cartographic delineations. In essence this signifies that in as much as the cultures and national identities in the Middle East mirror the ecology and environment of that region, these distinguishing cultural and environmental features in turn give rise to unique physical and social responses to contagious diseases that further distinguish individual countries. The transmission of Asiatic cholera in 19th-century Iran, therefore, becomes a measure of that country's unique environmental and cultural identity. Consequently, Iran's central position on the Eurasian plateau, its unique practice of water husbandry, its predominantly Shi'i faith, together with a weak central administration during the 19th century, have direct bearing on Asiatic cholera's pathogenesis and transmission in that country.

[17] An active countrywide attempt at arresting the progress of epidemic diseases only occurs in the 1970s under the leadership of Dr. Joseph Desiree Tholozan, the Shah's French physician, and E'tezad al-Saltana, the Shah's staunchly conservative Minister of Science. For more on the roots of Iran's sanitary regime, see my upcoming article: Defending the Guarded Domain: Epidemics and The Emergence of an International Sanitary Police in Iran.

[18] Obviously, the lack of adequate state revenues and the decentralized "tribal" nature of Qajar polity were also great obstacles to the implementation of adequate sanitary measures. Homa Nateq gives a more conspiratorial reason for the administrative inaction to the threat of cholera by showing the epidemics as a "tool" used by the ruling class to distract the populace from administrative corruption and abuse. See Homa Nateq, *Mosibat-e Vaba va Balay-e Hokoomat* (Tehran: Nashr-e Gostareh, 1977).

[19] This distinct experience with illness can be seen in Iran's encounter with the 1918–1919 influenza pandemic. During Influenza's visitation, Iran had distinct patterns of co-morbidity and significantly higher mortality as compared to other countries that were gripped by the pandemic; see my upcoming article in the *Bulletin of the History of Medicine*, Compromised constitutions: the Iranian experience with the 1918–1919 Influenza Pandemic.

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Hydrostrategic Decisionmaking and the Arab-Israeli Conflict

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ABSTRACT
This paper examines the idea of hydrostrategic territory (that is, territory over which sovereignty has been sought politically or militarily *solely* because of its access to water sources) and its role in the establishment of national boundaries, warfare, and negotiations in the Jordan River watershed. It argues that although water resources constitute a critical factor in interstate tensions and relations in the region, they have never served as the sole determinant in strategic affairs. No boundaries have been drawn, no military strategies pursued, and no negotiating positions espoused solely on hydrostrategic grounds.

INTRODUCTION

"Water" and "war" are topics being assessed together with increasing frequency. Articles in the academic literature (Cooley 1984; Gleick 1993; Starr 1991; and others) and the popular press (Bulloch and Darwish 1993; World Press Review 1995) point to water not only as a cause of historic armed conflict, but as *the* resource which will bring combatants to the battlefield in the 21st century. Invariably, writings on "water wars" point to the arid and hostile Middle East as an example of a worst-case scenario, where armies have in fact been mobilized and shots fired over this precious resource. Elaborate "hydraulic imperative" theories have been developed for the region which cite water as the prime motivator for military strategy and territorial conquest.

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The argument is thus: water is a resource vital to a nation's survival, from its inhabitants' biology to their economy; the scarcity of water in an arid environment, often referred to as "water stress," leads to intense political pressures; the Middle East is a region not only of extreme political conflict, but also one in which states are reaching the limits of their annual freshwater supply; therefore, Middle East warfare and territorial acquisition *must* be related to the region's "water stress."

This paper examines in detail the link between water and land—the nature of "hydrostrategic territory"—in this "worst-case" water conflict between Arabs and Israelis. The central question is: in the absence of any other compelling strategic or legal rationale, does territory exist (a) over which sovereignty has been sought politically or militarily, or (b) which would be insisted upon in the course of current territorial negotiations, *solely* because of its access to water sources?

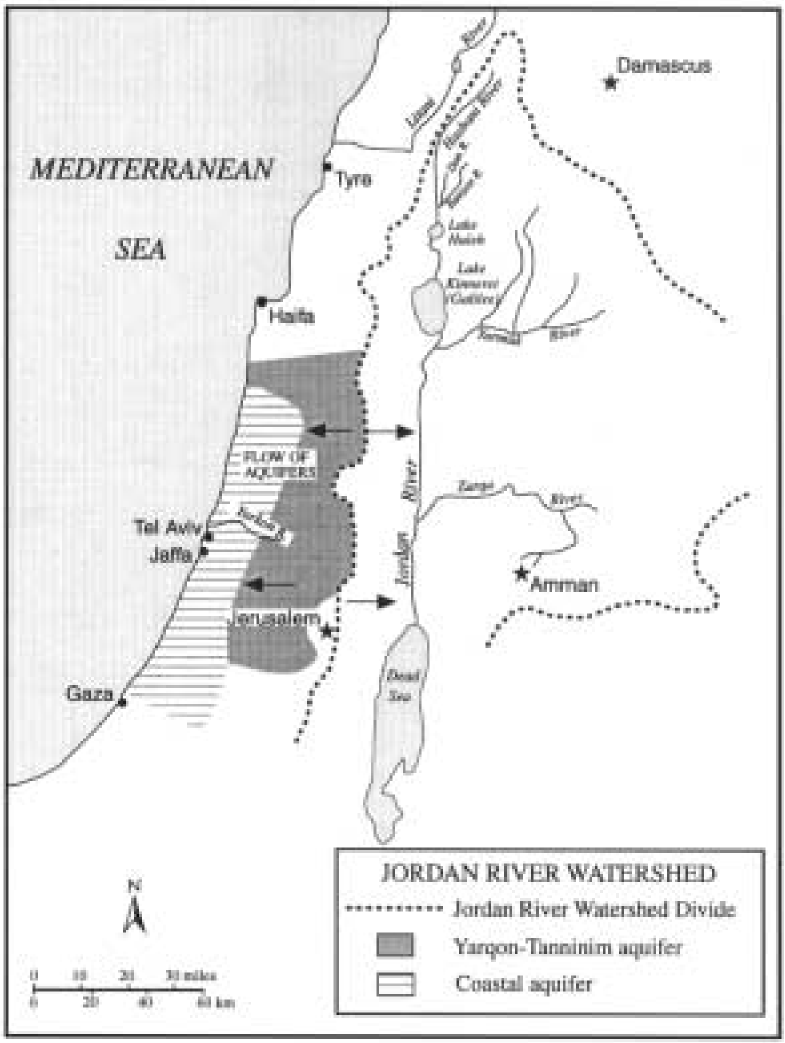

Figure 1 The Jordan River Watershed (Wolf 1995).

The approach is to subdivide the question as follows:

- Have boundaries been drawn historically on the basis of the location of water access?
- During warfare between competing riparians, has territory been explicitly targeted or captured because of its access to water sources?
- In the course of negotiations, has territory with access to water sources (but lacking any strategic component) been considered vital for retention by any of the riparians?

BORDERS, BOUNDARIES, AND HYDROSTRATEGIC TERRITORY

In order to answer these questions, it is necessary to distinguish "hydrostrategic" territory (that is, land surface which has strategic value solely on the basis of water resource access) from other territory under conflict.

Ratzel defines the difference between a border line and a border fringe: "the border fringe is the reality and the border line is the abstraction thereof" (cited in Prescott 1987). The term "boundary" has become more common for the line, while "frontier" and/or "border region" are used regularly to refer to the zone on either side of the boundary (O'Loughlin 1994). Prescott (1987) defines boundaries as "the line of physical contact between states" and identifies them as sources of both conflict and cooperation among states.

The link between the attributes of the border region and international conflict has been well documented. Ratzel emphasized the physical components of boundaries, arguing that states should establish strong military boundaries, including mountain slopes and the far banks of rivers (cited in Prescott 1965). The functional approach of political geography, as defined by Hartshorne (1950), Jones (1954), and others, describes the motives of state behavior; Douglass (1985) specifies security as the fundamental goal of a state: "security for its political system, its economic system and for its people...." Homer-Dixon (1991) offers a broad definition of security along similar lines, to include human physical, social, and economic well-being. If delineation of boundaries does not further these goals for states on both sides of the line, they themselves can become a cause of conflict. Waterman (1984) describes the hardships of the peoples of Ireland and Palestine brought about by the imposition of boundaries which insufficiently take geography into account. Cohen (1986) lists almost one hundred boundary disputes and describes the most important elements which contribute to them.

One problem is that many of these elements can be in opposition. As Tonkin (1994) points out, borders imply scarcity: "Borders now imply potential contestation and scarcity, a sense that territory is either in short supply or potentially valuable."

Water certainly is a source of boundary conflict. Prescott (1965) describes disputes over water bodies which mark or cross a boundary (including territorial waters) as the most common source of functional disputes, and both he and Bingham *et al.* (1994) describe such examples from around the world. In contrast, ignoring water in favor of other parameters of boundary delineation has also proved unwise. The boundary between India and Pakistan, for example, was drawn mostly on the basis of religious considerations, all but ignoring the dependence of populations on both sides on the waters of the Indus. Religion has been sufficient to unify either country (Donnan and Wilson 1994), and ignorance of the location of water has necessitated years of negotiations and elaborate engineering works to physically divide the river (Biswas 1992).

It is difficult to distinguish between military strategy, defined by one military officer as "from where are they shooting and from where will we shoot back" (cited in Wolf 1995), and "hydrostrategy," the influence of the location of water resources on strategic thinking. Rivers are invaluable barriers against tanks and troop movements and are also used to delineate boundaries. High ridges, ideal for military positioning, are also often local watershed boundaries. As Minghi (1963) points out, much thought was given to the relationship between boundaries and security particularly in the periods including the two world wars—times of intense boundary delineation. In 1907, Lord Curzon (cited in Prescott 1965) described the superiority of "natural" boundaries,[1] being dependent on physical geographic features, over "artificial" boundaries of latitude and longitude. Writing during World War I, Holdich (1916) linked the concept of security with boundaries, arguing that, whether it is natural or artificial, a boundary should act as a barrier which "must be made as secure as nature or art can make it."[2] Rivers, he argued, may make good boundaries (second to mountain ranges), provided "the channel is narrow in a rock-bound bed." Lyde (cited in Minghi 1963), arguing in 1915 that the prime function of a boundary was not as a barrier, but rather as "a feature which encourages peaceful international discourse," suggested that rivers made in fact the most desirable boundaries, providing "a maximum of peaceful associations."

Johnson (1917), Broek (1942), and others have pointed out problems unique to river boundaries, including the difficulty in accommodating geomorphic change and the fact that rivers often flow through heavily populated areas. With World War II, however, came the development of new military technology bringing a dimension to warfare which, along with a greater awareness of the importance of ethnic and economic relations between states, obviated the role of boundary-as-barrier (Spykman 1942, cited in Minghi 1963). The war also graphically contradicted Lyde's ideas on the boundary as an inducer of peace. With both arguments controverted, Jones (1945) concludes (not surprisingly) that rivers are especially troubling boundaries but that, "unfortunately, rivers probably [will continue to be] adopted as boundaries even though the geographer or engineer inveighs against them." Jones is also among the earliest observers to detail the conflict-inducing aspects

[1] Prescott makes the important point that Curzon differentiated between "natural" and what Ratzel and, later, Kjellen mislabeled as the geopolitically "Natural" frontiers, to which nations ought to strive. To avoid such confusion, Broek (1940) argues for the term "physiographic" boundary.

[2] Holdich also suggests that annexation of any territory against the will of its inhabitants is "a political blunder" (p. 499).

of international rivers, notably the difficulty in allocating the water of a shared river.

It is precisely these conflicting elements of water sources—their strategic value in the traditional sense, their functional value in a domestic sense, and their practical role in delineating boundaries—which inform the central questions of this paper. "Hydrostrategic" territory must then be operationally defined as that territory which has strategic value *primarily* because of its access to water resources for irrigation, drinking and/or electric power. This is distinct from strategic territory in a traditional military or political sense, including what Cohen (1986) calls "strategic water space," or water-related territory which provides traditional strategic value.

WATER AND BOUNDARIES

In this section, I seek to answer the first question posed in the introductory section: have boundaries been drawn historically in the Middle East on the basis of the location of water access?

BOUNDARY PROPOSALS AND DELINEATION: 1913-1923

After the first Zionist Congress in Basel, Switzerland in 1897, European Jewry began its efforts to gain the support of Ottoman or British authorities for a Jewish state in Palestine (which had been under Ottoman rule for 400 years). Even without commitments for independent nations, both Jewish and Arab populations began to swell in Palestine—the former in waves of immigration from Yemen as well as from Europe, and the latter attracted from other parts of the Arab world to new regional prosperity (Sachar 1969; McCarthy 1990). According to McCarthy (1990), Palestine had 340,000 people in 1878 and 722,000 by 1915.

During World War I, as it became clear that the Ottoman Empire was crumbling, the heirs-apparent began to jockey for positions of favor with the inhabitants of the region. The French held favor with the Maronite Catholics of Lebanon and therefore focused on the northern territories of Lebanon and Syria. The British, meanwhile, began to seek a coalition with (1) the Arabs from Palestine and Arabia, for military assistance against the Turks and (2) the Jews of Palestine, for both military assistance and the political support of Diaspora Jewry (Ra'anan 1955). As the course of the war became clear both the colonial powers and the local populations began to refine their territorial interests.

A detailed description of the lengthy process which led to the final determination of boundaries for the French and British mandates and informed the boundaries of modern Lebanon, Syria, Jordan, and Israel, is beyond the scope this paper.[3] The influence of

[3] Details of the transition can be found in the works of Ra'anan (1955), Sachar (1969, 1987), and Fromkin (1989).

Figure 2 Boundaries proposed for Palestine, 1916-1919 (Weizmann Letters 1968).

water resources along the Palestine-Syria border is described by Garfinkle (1994), and along the Palestine-Lebanon frontier by Hof (1985) and by Amery (1996). The following outline of events leading up to the Anglo-French Convention in 1923 emphasizes only certain decisions, and is based on the works mentioned above. The interested reader is referred to that literature for more detail.

The Zionist Position

The Zionists began to formulate their desired boundaries for the "national home" to be determined by three criteria: historic, strategic, and economic considerations (Zionist publications cited in Ra'anan 1955).

The Jews' historic concerns coincided roughly with British allusions to the biblical "Dan to Beersheba" area. The Zionists articulated minimum requirements which had to be supplemented with territory allowing military and economic security. Military security required desert areas to the south and east as well as the Beka'a Valley, a gateway in the north between the Lebanon Mountains and Mount Hermon.

Economic security was defined by water resources. The entire Zionist program of immigration and settlement required water for large-scale irrigation and, in a land with no fossil fuels, for hydropower. The plans were "completely dependent" on the acquisition of the "headwaters of the Jordan, the Litani River, the snows of Hermon, the Yarmuk and its tributaries, and the Jabbok" (Ra'anan 1955).

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In a flurry of communication between world Zionist leaders, the aspects of historic, strategic, and economic security became increasingly linked with the Jordan headwaters.

The guiding force on the boundary position of the Jewish side was Aaron Aaronson. In charge of an agricultural experimental station at Atlit on the Mediterranean coast, Aaronson's research focused on weather-resistant crops and dry-farming techniques. Convinced that the modern agricultural practices which would fuel Jewish immigration were incompatible with "the slothful, brutish Ottoman regime" (Sachar 1979), he concluded that Zionist settlement objectives required alliance with the incoming Allied Forces. Aaronson initiated contact with the British to establish a Jewish spy network in Palestine, which would report on Turkish positions and troop movements. Perhaps because of his training both in agriculture and in security matters, Aaronson became the first to argue for boundary delineation based specifically on future water needs. Aaronson's "The Boundaries of Palestine" (January 27, 1919, unpublished, Zionist Archives), drafted in less than a day, argued that,

> in Palestine, like in any other country of arid and semi-arid character, animal and plant life and, therefore, the whole economic life directly depends on the available water supply. It is, therefore, of vital importance not only to secure all water resources already feeding the country, but also to insure the possession of whatever can conserve and increase these water—and eventually power—resources. The main resources of Palestine come from the

> North, from the two mighty mountain-masses—the Lebanon range, and the Hermon....The boundary of Palestine in the North and in the North East is thus dictated by the extension of the Hermon range and its water basins. The only scientific and economically correct lines of delineation are the watersheds.

Aaronson then described the proposed boundaries in detail, as delineated by the local watershed (see Figure 2). He acknowledged that, with the exception of the Litani, the Lebanon range sends no important water source towards Palestine and could not therefore be claimed on a hydrological basis. It was the Hermon, he argued, that was the genuine 'Father of Waters' which could not be severed from (Palestine) without striking at the very root of its economic life."

Returning to the Litani, Aaronson argued that

> [it] is of vital importance to northern Palestine both as a supply of water and of power. Unfortunately its springs lie in the Lebanon. Some kind of international agreement is essential in order that the Litani may be fully utilized for the development of North Palestine and the Lebanon.

Aaronson's rationale and boundary proposals were adopted by the official Zionist delegation to the Paris Peace Conference, led by Chaim Weizmann. The "Boundaries" section of the "Statement of the Zionist Organization Regarding Palestine," which paraphrased Aaronson, read:

> The economic life of Palestine, like that of every other semi-arid country depends on the available water supply. It is therefore, of vital importance not only to secure all water resources already feeding the country, but also to be able to conserve and control them at their sources.…
> The Hermon is Palestine's real "Father of Waters" and [Palestine] cannot be severed from it without striking at the very root of its economic life.…Some international arrangement must be made whereby the riparian rights of the people dwelling south of the Litani River may be fully protected. Properly cared for these head waters can be made to serve in the development of the Lebanon as well as of Palestine (Proposals dated February 3, 1919, Weizmann Letters 1983, Appendix II).

Aaronson thought his ideas had been misrepresented in the official Zionist position, perhaps because he was not included in the final drafting. In an angry letter to Weizmann, he complained that the draft was "*a disgrace and a calamity*" (emphasis Aaronson's) and expressed shock that, for one of the delegates, "a 'watershed' is the same as a 'thalweg.' Incredible, but true..." (unpublished letter, February 16, 1919, Weizmann Archives).

In June of 1919 Aaronson died in a plane crash on his way to the Peace Conference and the Zionist proposals were submitted without revision. Nevertheless, the importance of the region's water resources remained embedded in the thinking of the Zionist establishment. "So far as the northern boundary is concerned," wrote Chaim Weizmann later that year, "the guiding consideration with us has been economic, and 'economic' in this connection means 'water supply'" (Weizmann Letters, September 18, 1919).

The Arab Position

The Arab delegation to the Peace Conference was led by the Emir Feisal, younger son of Emir Hussein of the Hejaz. Working with T. E. Lawrence, Hussein and his sons had led Arab irregulars against the Turks in Arabia and Eastern Palestine. After the war, Feisal had developed a relationship with Chaim Weizmann as both prepared for the Peace Conference. After a meeting in 1918, Feisal said in an interview:

> The two main branches of the Semitic family, Arabs and Jews, understand one another, and I hope that as a result of interchange of ideas at the Peace Conference, which will be guided by ideals of self-determination and nationality, each nation will make definite progress towards the realization of its aspirations (cited in Esco Foundation 1947).

Feisal also initially expressed support for Jewish immigration to Palestine, in part because he saw it as useful for his own nationalist aspirations. At a banquet given in his honor by Lord Rothschild in 1918, he pointed out that, "No state could be built up in the Near East without borrowing from the ideas, knowledge and experience of Europe, and the Jews were the intermediaries who could best translate European experience to suit Arab life" (Esco Foundation 1947).

In a meeting later that year, Feisal tried to enlist Weizmann's support against French policies in Syria. Weizmann in turn outlined Zionist aspirations and, "asserted his respect for Arab communal rights" (Sachar 1969). The two also agreed that all water and farm boundary questions should be settled directly between the two parties.

Feisal and Weizmann formalized their understanding to support each other's national ambitions on January 3, 1919, in a document which expressed mutual friendship, recognition of the Balfour Declaration, stating that:

> All necessary measures shall be taken to encourage and stimulate immigration of Jews into Palestine on a large scale, and as quickly as possible to settle Jewish immigrants upon the land through closer settlement and intensive cultivation of the soil. In taking such measures the Arab peasant and tenant farmers shall be protected in their rights, and shall be assigned in forwarding their economic development (original reproduced in Weizmann Letters), providing, Feisal hand-wrote in the margin, that Arab requests were granted. "If changes are made," he wrote, "I cannot be answerable for failure to carry out this agreement."

The Arab requests were spelled out in a memorandum dated January 1, 1919. Because the territory in question was so large—including Syria, Mesopotamia, and the Arabian Peninsula—so geographically diverse, and for the most part, well-watered, it is not surprising that water resources played little role in the Arab deliberations. Feisal requested the following (Esco Foundation 1947):

- that Syria, agriculturally and industrially advanced, and considered politically developed, be allowed to manage her own affairs;
- that Mesopotamia, "underdeveloped and thinly inhabited by semi-nomadic peoples, would have to be buttressed…by a great foreign power," but governed by Arabs chosen by the "selective rather than the elective principle;" and
- that the Hejaz and Arabian Peninsula, mainly a tribal area suited to patriarchal conditions, should retain their complete independence.

Two areas were specifically excluded: Lebanon, "because the majority of the inhabitants were Christian," and had their own delegates (Amery 1996), and Palestine, because its "universal character was left to one side for mutual consideration of all parties interested" (Esco Foundation 1947).

Once testimony was heard at Versailles, the decisions were left to the British and the French as the peace talks continued, culminating at San Remo in 1920, as to where the boundaries between their mandates would be drawn.

The French supported the Lebanese claim that the "historic and natural" boundaries of Greater Lebanon should include the sources

Figure 3 Disputed area, March–September 1919 (Hof 1985).

of the Jordan River (Sachar 1979), including the Galilee Region. They claimed that the Litani was needed for development in Lebanon, while the snows of the Hermon provided water for Damascus.

In 1919, the British first suggested the "Meinertzhagen Line" as a boundary (see Figure 2). Based mostly on British security requirements, this line was similar in the north to the Zionist proposals, and was rejected by the French for similar reasons. In September the British put forward the compromise "Deauville Proposal," which granted Palestine less territory than the Zionists sought, but still included the southern bank of the Litani and the Banias headquarters. At the time, Banias was thought (incorrectly) to be the biblical Dan, thereby allowing the British to remain true to their claim of Palestine "from Dan to Beersheba" (Hof 1985).

Finally, to best comply with French objections, the British proposed a border running north from Acre to the Litani bend, then east to Mount Vernon, which would increase Lebanese territory but leave the headwaters in Palestine (Ra'anan 1955).

Although the French rejected each of these proposals, Phillips Berthelot, the foreign minister and negotiator to an Anglo-French conference on the Mideast in December 1919, indicated that Prime Minister Clemenceau was insisting on the Sykes-Picot line, but that he was prepared

> to agree that one-third of the waterpower of the waters flowing from Mount Hermon southwards into the Palestine of the Sykes-Picot agreement should be allotted to the Zionists under an economic arrangement with France. The French could do no more than this (cited in Ra'anan 1955).

At the San Remo Conference in April 1920, an agreement was reached in which Great Britain was granted the mandates to Palestine and Mesopotamia, and France received the mandate for Syria (including Lebanon). During the remainder of the year, last minute appeals were made both by the British and the Zionists for the inclusion of the Litani in Palestine or, at the least, for the right to divert a portion of the river into the Jordan basin for hydropower. The French refused, offering a bleak picture of the future without an agreement and suggested, referring to British and Zionist ambiguity as to what was meant by a 'National Home,' "Vous barbotterez si vous le voulez, mais vous ne barbotterez pas à nos frais" ("You will flounder if you like, but you will not flounder at our expense." Butler and Bury 1958).

On December 4, 1920, a final agreement was reached in principle on the boundary issue which mainly addressed French and British rights to railways and oil pipelines as well as incorporating the French proposal for the northern boundaries of six months prior. The French delegation did promise that the Jewish settlements would have free use of the waters of the Upper Jordan and the Yarmuk, although they would remain in French hands (Ra'anan 1955). The Litani was excluded from this arrangement. Article 8 of the Franco-British Convention, therefore, included a call for a joint committee to examine the irrigation and hydroelectric potential of the Upper Jordan and Yarmuk "after the needs of the territories under French Mandate," and added that

> …in connection with this examination the French government will give its representatives the most liberal instructions for the employment of the surplus of these waters for the benefit of Palestine (cited in Hof 1985).

The final boundaries between the French and British mandates, which later became the boundaries between Israel, Lebanon, Syria, and Jordan, were worked out by an Anglo-French commission set up to trace the frontier on the spot. They generally circumvented settlements, divided territory on an ethnic basis (consistent with the wishes of the inhabitants), and retained the link between settlements and their agricultural land. The results were submitted in February 1922 and signed by the British and French governments in March 1923 (Ra'anan 1955; Hof 1985).

The frontier would run from Ras en-Naqura inland in an easterly direction along the watershed between the rivers flowing into the Jordan and into the Litani; the line was then to turn sharply north to include in Palestine a "finger" of territory near Metulla and the eastern sources of the Jordan.

Rather than include the Banias spring within Palestine as in the French proposal of six months prior, the border ran parallel to and 100 meters south of the existing path from Metullah to the Banias. The French insisted on inclusion of this road in its entirety to facilitate east-west transportation and communication within its mandate, as it was a stretch of the main route from Tyre to Quneitra. This northern border meant that the entire Litani and the Jordan headwaters of the Ayoun and Hasbani would originate in Lebanon before flowing into Palestine. The Banias spring, meanwhile, would originate and flow for 100 meters in Syrian territory, then into Palestine. Since Palestine had a promise of water use, and also access to the Banias Heights which overlooked the spring, the fact that the actual spring lay outside of the boundaries was not of immediate concern. Of the headwaters of the Jordan, however, only the Dan spring remained entirely within Palestine.

From the Banias, the border turned south toward the Sea of Galilee, along the foothills of the Golan Heights, parallel and just east (sometimes within 50 meters) of the Huleh Lake and the Jordan River. Rather than passing through the middle of the Sea of Galilee, the border ran 10m east of its shores (even if the level should rise because of a proposed dam), leaving the entire lake, the town of El-Hama, and a small triangle just south of the Jordan's outflow within the territory of Palestine. The latter two territories were already included in Zionist plans for water diversion and hydroelectricity generation. The arrangement was beneficial to Palestine's hydrostrategic positioning, and, although it was made mainly for administrative reasons, "to make customs inspection easier," it was also expressed that the development plans should proceed without international complication (Ra'anan 1955). Nevertheless, according to the agreement, fishing and navigation rights on the lake were retained by the inhabitants of Syria. Later, between 1948 and 1967, Syria claimed the shoreline as the *de facto* border, and argued for riparian rights to the lake on that basis.

At the Yarmuk, the border went eastward along the river, meeting up with the Sykes-Picot line into the Syrian desert and south of the Jebel Druze. The final agreement made no mention of joint access to French-controlled waters.

Administrative divisions would further convolute the boundaries along the Jordan. In May 1921, Churchill offered the Emir Abdullah reign over that part of the British Mandate east of the Jordan River. Transjordan became a semi-independent entity in 1923 and an independent kingdom in 1946. While the division was originally between administrative units under one authority—the British Mandate—the boundary, as defined by the center of the Jordan River, the Dead Sea, and Wadi Araba/Arava, would eventually become the international boundary between Israel and Jordan.[4]

Although the location of water resources had been an important, sometimes over-riding issue with some of the actors involved in determination of the boundaries of these territories, it is clear from the outcome that other issues took precedence over the need for water development. These other factors ranged from the geostrategic (the location of roads and oil pipelines) to the political (alliances and relationships among British, French, Jews, and Arabs) to the historical (how well versed one or another negotiator was in biblical geography).

Partition and Jewish Statehood: 1922-1948

During the 1930s and 1940s, water was a focus of several reports which tried to determine the "economic absorptive capacity" of mandate Palestine. In the absence of clear immigration policy, both Jewish and Arab residents of Palestine became increasingly frustrated, taking out their hostility on each other as well as on the British. Over time, the partition of Palestine into Jewish and Arab states increasingly became the most advocated option, first in an Anglo-American plan in 1946, and later, when Britain ceded the Mandate to the United Nations, in the U.N. Partition Plan of 1947.

[4] The boundary was originally defined as the location of the river in 1922. However, after the Jordan shifted 800 meters westward during the winter of 1927-28, the British high commissioner decided that the boundary would henceforth be the center of the water bodies mentioned, wherever they meandered. A similar shift in the streambed, and consequently in the boundary, occurred in the winter of 1978-79 (Biger 1994).

Figure 4 United Nations plan for the partition of Palestine, November 1947 (Sachar 1979).

In the case of partition the Zionists identified three areas that were essential to a viable Jewish state: the Galilee region with the Jordan headwaters, the populated coastal zone, and the Negev Desert, to absorb "the ingathering of the exiles." In the late 1930s, the Jewish Agency (the Zionists' pre-state governing body), sensing that partition was imminent, embarked on an intensive settlement program, building 55 farm communities between 1936 and 1939 (Sachar 1979). The northern Galilee was targeted in order to reinforce the projected boundaries and guarantee the inclusion of those portions of the Jordan headwaters left from the Mandate process.

The Zionist position on partition and the minimum territorial requirements for a viable Jewish state was increasingly influenced by Walter Clay Lowdermilk. In 1944 Lowdermilk, the director of the U.S. Soil Conservation Service, published a plan commissioned by the Jewish Agency. In contrast to the Ionides Plan of 1939, Lowdermilk asserted that proper water management would generate resources for four million Jewish refugees in addition to the 1.8 million Arabs and Jews living in Palestine at the time. He advocated regional water management, based on work of the Tennessee Valley Authority (TVA), to develop irrigation on both banks of the Jordan River and in the Negev Desert as well as construction of a canal from the Mediterranean to the Dead Sea to generate hydro-power and replenish the diverted fresh water (Naff and Matson 1984).

Referring to Lowdermilk's work, a 1945 *aide memoire* on Palestine described Zionist reservations on partition:

> With the sea in the West, the Jordan and the Power and Potash concessions in the East, the chief water resources in the North, and the main land-reserves in the South, any partition scheme seems bound to disrupt the country's economic frame, and wreck the chances of large-scale development (April 6, 1945, cited in Weizmann Letters).

At the same time, a 1944 study, "The Water Resources of Palestine," undertaken by Mekorot (the national water company for Jewish Palestine) described an "All-Palestine Project," for irrigation and hydroelectric development. The study included frontier adjustments which would be desirable for a basin-wide development scheme in Palestine.

It was suggested that the mandate border be moved upstream where it met the Hasbani, Dan, and Banias headwaters to allow for more effective drainage; eastward along Lake Hula to leave room for a conduit on the east side of the lake; and upstream along the Yarmuk to include an area of about 80 km^2 of Transjordan to develop a series of impoundments along the river (Mekorot Water Company, Ltd.1944). It should be noted that, although the report included plans to bring Litani water into the Jordan watershed, it was assumed that an agreement would have to be reached with the Lebanese government to do so. Lebanese territory was not included in the list of desirable frontier adjustments. It should be noted further that there is no evidence that any of the territorial suggestions of the Mekorot study were ever included in political decision making, nor were the proposed boundary modifications raised in subsequent negotiations.

Water and Boundaries—Conclusions

Prescott (1987) notes that the most common cause of boundary disputes can be found in the history of the boundary—especially where the "evolution" of the boundary is "incomplete." In answer to the question of water's influence on boundaries posed at the beginning of this section, it is clear that water sources have played a role, albeit one subservient to other concerns, in the delineation of international boundaries, first between the British and French Mandates, then between Israel, Lebanon, and Syria. In particular, the political and military policy makers of Israel had explicit interests in retaining the northern headwaters of the Jordan River, arguing for them in political arenas and reinforcing claims through settlement policy. The goal, however, was reached with only marginal success. While the headwaters of the Jordan originated in the territories of three separate entities, Israel had been successful in retaining riparian access to both banks of the Jordan River above the Sea of Galilee, and sovereignty over the entire lake. Yet it is also clear that once boundaries were agreed to in a legal forum in 1923, development plans were modified to fit the legal boundaries and *not* vice versa.

WATER AND WAR

The next aspect of "hydrostrategic territory" to be addressed is the relationship between military strategic thinking during wartime and the location of water resources. During warfare between competing riparians, has territory been explicitly targeted, captured, or retained because of its access to water sources?[5]

[5] The wars of 1956 and 1973 are not included because, in the author's judgment, they did not contain any hydrologic component.

THE WAR OF 1948

On February 2, 1947, Great Britain officially turned the fate of Palestine over to the United Nations. The U.N. Special Committee on Palestine recommended partition into two states but included a vehicle for joint economic development, "especially in respect of irrigation, land reclamation, and soil conservation."

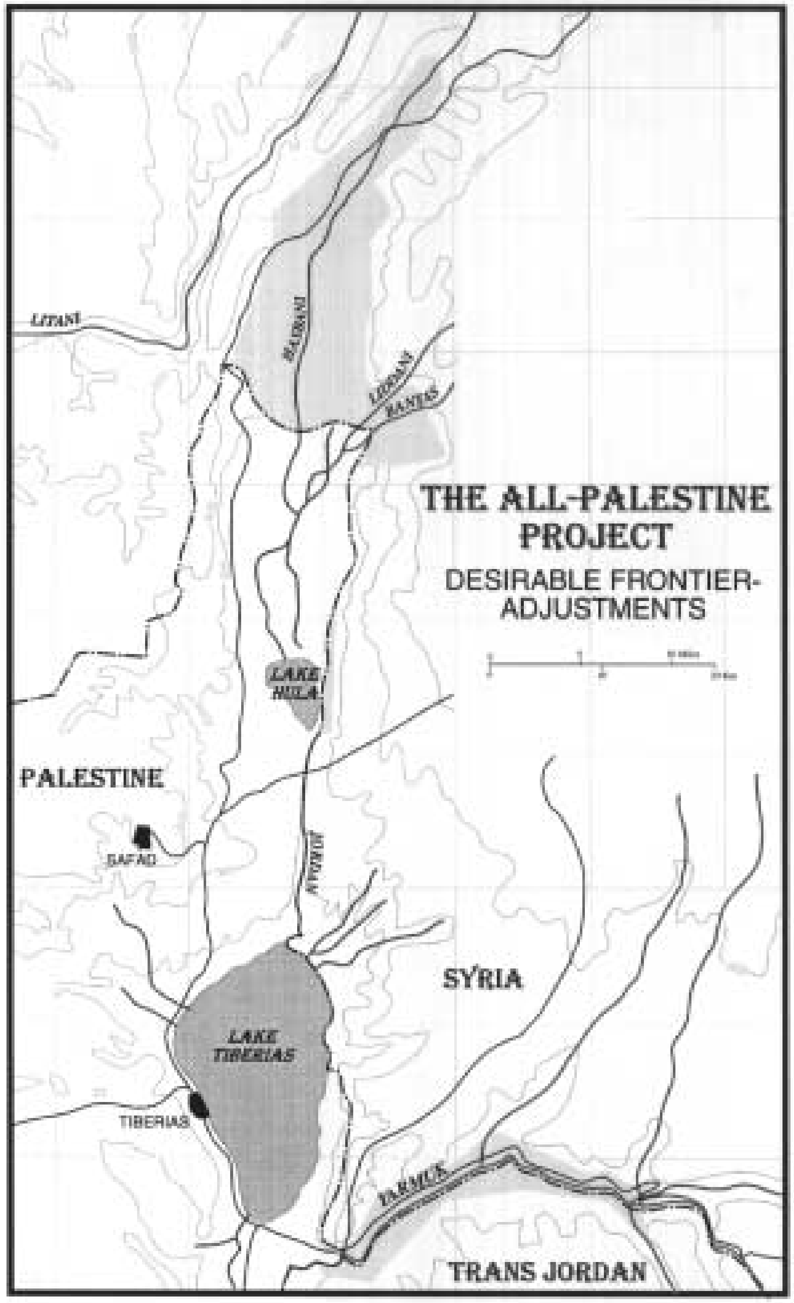

Figure 5 (Mekorot 1944).

The U.N.-delineated Arab and Jewish states are displayed in Figure 5. Jerusalem was to be an international city, and the Jewish state would pay an annual stipend of four million pounds to the

Arab state to reflect the more advanced agricultural and industrial position of the former (U.N. Resolution on the Partition of Palestine 1947, Chapter 4). The General Assembly approved the Partition Plan on November 29, 1947.

Though the Jewish Agency reluctantly accepted partition, the Arab states rejected it outright. When the British pulled out of Palestine in May 1948, Egypt, Jordan, Iraq, Syria, Lebanon and Saudi Arabia went to war against the new state of Israel. Maintaining the three aforementioned critical zones—the Galilee region with the Jordan headwaters, the populated coastal zone, and the Negev to absorb anticipated immigration—became the foci of the Israeli war effort.

Partition cost the Israelis three other strategic points along waterways, the repercussions of which would be felt through 1967.

As mentioned above, during the Mandate negotiations, the French had denied the Zionists the Banias Spring because an access road they needed crossed the waterway about 100 meters downstream. To guarantee access to the water, though, a small hill overlooking the stream, Givat Banias, had been included in Palestine. Second, the town of El-Hama, located on one of the few flat areas within the narrow Yarmuk valley, and an adjacent triangular area from the Yarmuk to the shores of the Sea of Galilee were included within Palestine territory, specifically to facilitate water resources development. Both of these areas were lost to the Syrians during fighting in 1948 (Sachar 1979). (Also, the Syrians crossed the Jordan River in the Huleh Lake/Daughters of Jacob Bridge region, an area targeted by water planners as the site of the first major Israeli reclamation project.) Finally, although the Israeli army had occupied a strip of Lebanese territory along the elbow of the Litani, they pulled back to the Mandate boundaries as part of the armistice agreement, in the unfulfilled hopes of gaining a peace treaty with Lebanon (Hof 1985).

The 1948 war added a new type of boundary to the region—the Armistice Line. While the boundary between the British and French mandates had the permanence and force of international law, the Armistice agreement which was signed separately between Israel and each of its neighbors was explicitly only a temporary military agreement (Hareven 1977). Negotiations continued in an unsuccessful quest for a permanent peace agreement culminating in Lausanne late in 1949 (Caplan 1993). Water was never mentioned during the Rhodes Armistice talks and was referred to only intermittently during the Lausanne Conference.[6]

The differences between permanent legal boundaries and the Armistice Line manifested themselves in how each boundary segment was treated by each combatant.

[6] The eighth point of the British Eight-Point Plan submitted in July 1949 was a call for "an Israeli-Arab agreement for sharing the waters of the Jordan and Yarmuk Rivers" (Caplan 1993).

The Israel-Lebanon Boundary

Israel had occupied Lebanese territory up to the Litani River, yet withdrew its forces to the international boundary as a result of the Armistice Agreement. Amery (1996) suggests that Israel's withdrawal was based on the belief that it could make peace with a Christian-led Lebanon, and that joint Lebanese-Israeli water resources development could proceed without territorial annexation (citing Berger (1965) as arguing that Israel would not have withdrawn from southern Lebanon had it not been convinced of these results).

The Israel-Syria Boundary

Syria occupied about 60 km^2 of Israeli territory during the war at three locations, as described above: (1) the Banias Springs area, (2) the Huleh Lake/Daughters of Jacob Bridge region, and (3) the triangle from El-Hama to the southeastern shores of the Sea of Galilee. During the Armistice talks, Syria agreed to withdraw from all of this territory, save Givat Banias and El-Hama, provided that the remaining territory would not be militarized by Israel. While both of these were included in Israeli water development plans, Israel did not push for their return, given the presumed temporary nature of the Armistice Line.

Neff (1994) suggests that Syria withdrew with the understanding that final borders, including final sovereignty of the three demilitarized zones (DMZs), would be negotiated in the future. Israel, in contrast, considered itself the legal sovereign of these areas, legal heir to the northern territory within the British mandate.

The Israel-Jordan Boundary

The pre-war boundary between British-mandate Palestine and Transjordan, delineated when Britain split Palestine in two in 1922, followed the middle of the Yarmuk River, the Jordan River, the Dead Sea, and Wadi Araba southward to the Gulf of Aqaba/Eilat (Biger 1994). After the war, Jordan claimed jurisdiction over the West Bank. Nowhere is the assumption that the Armistice Line was to be temporary more clear, however, than in the "Green Line" dividing the West Bank from Israel. While negotiations continued officially in Rhodes, Sachar (1979) describes secret meetings which took place directly between the Israelis and King Abdullah and his advisors at the king's winter palace. The agreement which was reached was informed not only by the location of the two armies at war's end, but also by the location of roads and railways, as well as hilltops and high ground for local strategic advantage. The line, drawn in green on a map at a scale of 1:250,000,[7] cut villages from their land, divided towns from the

[7] At that scale, the width of the line alone allowed for territorial ambiguity of 250m along the boundary (Biger 1989).

Figure 6 Rhodes armistice demarcation line, 1948 (Sachar 1978)

springs on which they relied, and occasionally split settlements in two (Biger 1989). As Biger (1989) points out, “in no case did the terms of agreement provide for continuing rights of access by inhabitants to their vital land and water resources.”

As a result of the 1948 war, the Jordan River was even more divided than it had been under the Mandates. The Hasbani rose in Lebanon with the Wazzani, a major spring of the Hasbani, situated only a few kilometers north of the Israeli border. The Banias flowed for five kilometers in Syrian territory before crossing into Israel. The Dan rose and remained within Israeli territory. The confluence of the three, the Jordan River, flowed along the Israeli-Syrian border, often through a demilitarized zone, until it reached the Sea of Galilee. The sea lay wholly in Israel, with the Syrian border ten meters from the eastern coast. The Yarmuk rose in Syria, then became the Syrian-Jordanian border until its confluence with the Jordan. South of the Sea of Galilee, the Jordan River formed first the Israeli-Syrian border, then the Israeli-Jordanian border below the confluence with the Yarmuk, finally flowing wholly into Jordanian territory and the Dead Sea, which was about one quarter Israeli and three quarters Jordanian. Groundwater was similarly divided, with the recharge zones of two springs on which Israel increasingly relied, the Yarkon and the Tanninim, originating in the Jordanian territory of the West Bank (see Figure 6).

THE WAR OF 1967

Water Resources and Background to the War

The legacy of the partition and the 1948 war was the division of the Jordan River in a manner so convoluted that unilateral water resources development, the only strategy possible among the hostile riparians, would lead inevitably to conflict. By the early 1950s, Arab states were discussing organized exploitation of two northern sources of the Jordan—the Hasbani and the Banias (Stevens 1965). The Israelis also made public their All Israel Plan, which included the draining of Huleh Lake and swamps, diversion of the northern Jordan River and construction of a carrier to the coastal plain and Negev Desert—the first out-of-basin transfer for the watershed (Naff and Matson 1984).

Jordan, in 1951, announced a plan to irrigate the East Ghor of the Jordan Valley by tapping the Yarmuk. At Jordan’s announcement, Israel closed the gates of an existing dam south of the Sea of Galilee and began draining the Huleh swamps, which lay within the demilitarized zone with Syria. These actions led to a series of border skirmishes between Israel and Syria which escalated over the summer of 1951 (Stevens 1965). In July 1953, Israel began construction

Figure 7 Jordan/Yarmuk river system (Medzini 1976).

on the intake of its National Water Carrier at the Daughters of Jacob Bridge north of the Sea of Galilee and in the demilitarized zone. Syria deployed its armed forces along the border and artillery units opened fire on the construction and engineering sites (Cooley 1984). Syria also protested to the U.N. and, though a 1954 resolution for the resumption of work by Israel carried a majority, the USSR vetoed the resolution. The Israelis then moved the intake to its current site at Eshed Kinrot on the northwestern shore of the Sea of Galilee (Garbell 1965).

Against this tense background, President Dwight Eisenhower sent his special envoy Eric Johnston to the Middle East in October 1953 to try to mediate a comprehensive settlement of the Jordan River system allocations.[8] Johnston's initial proposals were based on a study carried out by Charles Main and the Tennessee Valley Authority (TVA) at the request of the U.N. to develop the area's water

Figure 8 (Wolf 1995)

[8] For a detailed normative assessment of the Johnston framework, see Elmusa (this volume).

resources and to provide for refugee resettlement (Main 1953). Both Israel and a united Arab League Technical Committee responded with their own counterproposals. The Israeli "Cotton" plan included integration of the Litani River's flow into the Jordan basin, with a subsequent increase in allocations to Israel. The Arab plan rejected integration of the Litani and substantially reduced Israel's share as compared with the Main plan. Johnston worked until the end of 1955 to reconcile these proposals in a Unified Plan amenable to all of the states involved. In the Unified Plan, Johnston accomplished no small degree of compromise. Although they had not met face to face for these negotiations, all states agreed on the need for a regional approach. Israel gave up on integration of the Litani and the Arabs agreed to allow out-of-basin transfer. The Arabs objected, but finally agreed, to storage at both the Maqarin Dam and the Sea of Galilee so long as neither side would have physical control over the share available to the other. Israel objected, but finally agreed, to international supervision of withdrawals and construction. Allocations under the Unified Plan, later known as the Johnston Plan, included 400 million m^3 (MCM)/yr to Israel, 720 MCM/yr to Jordan, 35 MCM/yr to Lebanon, and 132 MCM/yr to Syria (Unpublished summaries, U.S. Department of State).

The technical committees from all sides accepted the Unified Plan, but continuing political support could not be garnered and the Plan was never ratified. Nevertheless, Israel and Jordan have generally adhered to the Johnston allocations and technical representatives from both countries have met from that time until the present two or three times a year at "Picnic Table Talks," named for the site at the confluence of the Yarmuk and Jordan Rivers where the meetings were held.

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As each state developed its water resources unilaterally, their plans began to overlap. By 1964, Israel had completed enough of its National Water Carrier that actual diversions from the Jordan River basin to the coastal plain and the Negev were imminent. Although Jordan was also about to begin extracting Yarmuk water for its East Ghor Canal, it was the Israeli diversion which prompted President Nasser to call for the First Arab Summit in January 1964, a meeting which brought together heads of state from the Mideast and North Africa specifically to discuss a collective Arab strategy on water.

The options presented at the summit were (1) to complain to the U.N., (2) divert the upper Jordan tributaries into Arab states (as had been discussed by Syria and Jordan since 1953), or (3) to go to war (Schmida 1983). The decision to divert the rivers prevailed at a second summit in September 1964 and the Arab states agreed to finance a Headwater Diversion project in Lebanon and Syria and to

Figure 9 (Wolf 1995)

help Jordan build a dam on the Yarmuk. They also made tentative military plans to defend the diversion project (Shemesh 1988).

In 1964, Israel began withdrawing 320 MCM/yr of flow from the Jordan water into its National Water Carrier and Jordan completed a major phase of its East Ghor Canal (Inbar and Maos 1984). In November 1964, the Arab states began construction of their Headwater Diversion Plan to prevent the Jordan headwaters from reaching Israel. The plan was to divert the Hasbani into the Litani in Lebanon and the Banias into the Yarmuk where it would be impounded for Jordan and Syria by a dam at Mukheiba. The measure would divert up to 125 MCM/y, thereby cutting by 35% the installed capacity of the Israeli Carrier and increasing the salinity in the Sea of Galilee by ~60 ppm (Unpublished memorandum, U.S. Central Intelligence Agency, May 1962). In March, May, and August of 1965, Israeli tanks attacked the diversion works in Syria. The final incident, which involved both Israeli tanks and aircraft on July 14, 1966, stopped Syrian construction.

These events set off what has been called “a prolonged chain reaction of border violence that linked directly to the events that led to the (June 1967) war” (Safran, cited in Cooley 1984).

Boundaries Following the 1967 War

The boundaries following the 1967 war, determined by an unsigned cease-fire agreement, have generally held until very recently.

The boundary between Israel and Lebanon, which was not involved in the war, remained the international boundary of 1923; the boundary between Israel and Syria extended well beyond the Armistice line and demilitarized zones of 1949 to include the plateau of the Golan Heights as far as Quneitra[9]; the boundary with Jordan returned past the Green Line of 1949 to the 1922 British Mandate division between Palestine and Transjordan along the Jordan River.

In addition to the territorial gains and improvements in geostrategic positioning which Israel achieved in the war, it also improved its hydrostrategic position. With the Golan Heights, it now held two of the three northern headwaters as well as high ground over much of the Yarmuk, together making the Arab Headwaters Diversion impossible. The West Bank provided riparian access to the entire length of the Jordan River and also overlay a major aquifer system which Israel had been tapping into from its side of the Green Line since 1955 (Garbell 1965). Jordan had endeavored to transport 70-150 MCM/y from the Yarmuk River to the West Bank, but given the results of the war, its plans were abandoned.

THE WAR OF 1982

In 1982, Israel mounted its second operation against the Palestinian Liberation Organization (PLO) in Lebanon. Its first offensive, named “Operation Litani,” was conducted four years earlier. Then, Israel had stopped its advance at the Litani River and had turned over portions of southern Lebanon to the South Lebanon Army (SLA) under the command of Major Sa’ad Haddad. Haddad

[9] There was some change along the Israel-Syria border as a consequence of the 1974 war. During that war, Syrian forces crossed westward past Quneitra but did not descend from the Golan Heights. Although the Israeli counter-attack extended east again across Quneitra, the town itself was returned to Syria following a 1974 Disengagement Agreement (Hareven 1977; Sachar 1979).

reportedly agreed to protect Israeli interests in the region, in particular to defend against attempted Palestinian incursions through the area to Israel. In addition, the militia is reported to have protected the Jordan headwaters of the Hasbani by closing some local wells and preventing the digging of others (Naff and Matson 1984). Some Israelis involved in these issues contest these reports. According to an Israeli officer who dealt with Haddad, extensively, the Lebanese major made perfectly clear to the Israeli threat, "We will cooperate with you, but there are two subjects which are taboo—our land and our water" (Wolf 1995).

In 1979, engineers from Mekorot, Israel's water planning agency, developed plans to divert from 5-10 MCM/y from the Wazzani springs for irrigation in Shi'ite southern Lebanon and in Israel. To allow the project to flow on gravity alone, a slight northward modification of the Israeli-Lebanese border, by about one kilometer, was considered (Wolf 1995). These plans were vetoed by Major Haddad.

In the 1982 war, the Litani was again the initially stated objective, but by July, Israeli forces had surrounded Beirut. After the invasion was launched by then Defense Minister Ariel Sharon, a "water hawk" who had frequently spoken of seizing the Litani, Israel captured the Qirawn Dam and immediately confiscated all hydrographic charts and technical documents relating to the Litani and its installations (Cooley 1984). Israel retreated from Beirut but retained a "security zone" of territory extending from the international boundary north to a bend in the Litani.

WATER AND WAR—CONCLUSIONS

Evidence of a "Hydro-strategic Imperative"

In recent years, particularly since Israel's invasion of Lebanon in 1982, the notion of a Middle East "hydraulic imperative" has been developed both in the academic literature and the popular press. The theory, which might be better termed the "hydrostrategic imperative,"[10] points to some combination of the following facts (see, for example, Davis *et al.* 1980; Stauffer 1982; Schmida 1983; Stork 1983; Cooley 1984; Dillman 1989; Beaumont 1991):

- Early Zionist lobbyists and planners, from Chaim Weizmann at the Paris Peace Conference in 1919, through the Hays and Cotton plans of the 1940s and 1950s, have advocated inclusion of either the Litani River within Israeli boundaries or of Litani water into the Jordan River watershed.
- The 1967 War had been precipitated by tensions over Israeli and Arab water diversion schemes, and the war itself had greatly strengthened Israeli "hydro-strategic" positioning.

[10] "Hydraulic" refers to the mechanics of water under pressure. "Hydrostrategic" as defined earlier, describes the link between the location of water resources and strategic decision-making.

- The 1979 Litani Operation left Israeli allies in control of the lower Litani river and the Hasbani headwaters.
- The 1982 Israeli invasion of Lebanon included capture of the Qirawn Dam and related data. Even after Israel's withdrawal, the "Security Zone" still leaves Israel in control of the area from Taibe and slightly north—the most likely site for any Litani to Jordan basin transfer.

Particularly during the years of Israeli occupation from 1982 to 1985, several analysts used this history to speculate about Israeli actions in Lebanon. Some predicted scenarios ranging from a simple diversion of the 100 MCM/yr available at the lower Litani and others conjectured a permanent occupation of the entire Beka'a Valley south of the Beirut-Damascus Highway which, along with the removal of Lebanese water infrastructure and the forced de-population of southern Lebanon, would allow diversion of the entire 700 MCM/yr flow of the Litani into Israel.[11]

Others have argued that Israel retains access to the Litani through its "security zone" because it is, in fact, covertly diverting water into the Jordan basin. According to John Cooley, "it was small wonder that the first Israeli diversion plans for the Litani have come into being" (cited in Soffer 1991). More recently, Beaumont (1994), has written that Israel "may well be stealing Lebanese water for its own use." Frey and Naff (1985), even while arguing against the imperative theory, do suggest that:

> Although water may not have been the prime impetus behind the Israeli acquisition of territory...it seems perhaps the main factor determining its retention of that territory.

Thomas Naff of the University of Pennsylvania later testified to Congress that "...Israel is presently conducting a large-scale operation of trucking water to Israel from the Litani River..." (U.S. House of Representatives 1990). Naff (1992) has since modified his position to argue that "water ... was instead trucked to units of the Israeli-supported Lebanese Army of South Lebanon in the same area as a reward for their cooperation."

Beaumont (1991) is among those who, building retroactively on the charges regarding Lebanon, now include the 1967 war as proof of water driving Israel's territorial "imperative:"

> To avoid each of the states (Lebanon and Syria) controlling their own water resources, Israel invaded southern Lebanon and the Golan Heights of Syria in 1967. The

[11] This last scenario is described in detail in Stauffer (1982).

pretext given was strategic reasons, but the control of the water resources of the area seems a more compelling and realistic reason.

Rebuttal to the Imperative

The theory that water has driven strategic thinking during wartime has been critiqued on political and technical grounds by Naff and Matson (1984), Wolf (1995), Soffer (1995), and Libiszewski (1995), as well as on economic grounds, by Wishart (1989). To examine the validity of a "hydrostrategic" imperative, two questions must be answered: (1) was the location of water resources a factor in the military strategy of Israel in 1967, 1978, or 1982 and, (2) is Israel now diverting water from the Litani River?

The 1967 War

It has already been noted that conflict between Syria and Israel over water resources contributed to tensions leading to the 1967 fighting, although the hydrologic aspect ended almost a year before the beginning of the war itself, which in the south was well away from sensitive water sources (with Egypt expelling the U.N. forces in the Sinai and blocking Israeli shipping to Eilat). The Sinai was the first front when war broke out on June 5, 1967, with the straits of Sharm-el-Sheikh being the primary objective.

The hydrostrategic locations over which Israel gained control during the war were on the West Bank, including the recharge zones of the Mountain Aquifer system and on the Golan Heights, including the Banias headwaters of the Jordan River.

Before the war, and even in its first days, Israel had agreed not to engage in combat with Jordan, as long as Jordan did not attack. Jordan did launch several artillery barrages in the first days of the war, though, which opened up the West Bank as the second front (Sachar 1979).

Finally, despite attacks from Syria, Defense Minister Moshe Dayan was extremely reluctant to launch an attack on the Golan Heights because of the presence of Soviet advisors and the consequent danger of widening the conflict (Slater 1991). For the first three days of the war, Dayan held off arguments from several of his advisors, including the CO of the northern command, David Elazar, to launch an attack on the Golan Heights. Finally, a delegation from the northern settlements, who had often experienced Syrian sniping and artillery barrages, traveled to Tel Aviv to ask Dayan to take the Heights to guarantee their security. Only then, on June 9, did Israeli forces launch an attack against Syria (Slater 1991).

In the taking of the Golan Heights, the aforementioned water sources were incidental conquests as Israeli forces moved as far east as Quneitra. The only exception was the conquest of the town of Ghajar, an Awali village which had no strategic importance in the military sense (it neither contained combatants nor was it situated in a strategic position). Ghajar does, however, directly overlook the Wazzani springs, which contribute 20-25 MCM/y to the Hasbani's total annual flow of 125 MCM/y. During dry summer months, the Wazzani is the only flowing source of the Hasbani. Moreover, Ghajar was the site of the projected dams for the Arab Diversion project.

Oddly, Ghajar was not even taken during the hostilities. During the fighting, Israeli troops stopped directly outside of the town since they believed Ghajar to be situated on Lebanese territory (and Israel did not want to involve Lebanon in the war). It turned out that the town *was* Syrian, having been misplaced on 1943 British maps. Cut off from the rest of Syria during the war, a delegation from Ghajar traveled to Beirut to ask to be annexed but the Lebanese were not interested. Three months after the war, another delegation traveled to Israel and asked that the village become Israeli. Only then did Israeli control extend north through Ghajar (Khativ 1988; interview, Khativ, October 1991). Only the village itself was included, though, and most of its agricultural land remained in Syria. Mekorot engineers did install a three-inch pipe for drinking water for the villagers from the Wazzani springs which, although literally a stone's throw from the village, was left under Lebanese control (interviews, Khativ, Paldi, October 1991).

Extensive literature exists on the detailed decision making in the events before, during, and after the 1967 war, but there is almost a complete absence of references to water, either as strategic targets or as propaganda by either side. See, for example, Institute for Palestine Studies (1970), which includes almost no mention of water; Brecher (1974), who includes chapters on both "Jordan Waters," and "The Six Day War," but documents no link; and Laqueur (1967, 50), who claims that, "(water) was...certainly not one of the immediate reasons for hostilities." Stein and Tanter (1980) do not mention water at all.

Hostilities of 1978 and 1982

The same absence of documentation is true for the Israelis' operations in Lebanon in 1978 and 1982 (see, for example, MacBride 1982). Israel's ally in southern Lebanon, Major Sa'ad Haddad, had made clear to Israel in 1979 that water was not to be discussed. It was Haddad, too, who quashed Israel's 1979 plans for a diversion of the Wazzani springs. Tamir (1988), a major general who helped outline Israel's strategic needs in 1967 and in 1982, described in detail the military strategy of the 1982 war. Here, too, references to water are conspicuously absent.

While the Israel Defense Forces planning branch does have an officer whose responsibilities include water resources, both the officer with those responsibilities during the 1982 war and Tamir (personal communications, 1991) insist that water was not, even incidentally, a factor in the war. When pressed on the subject, Tamir replied:

> Why go to war over water? For the price of one week's fighting, you could build five desalination plants. No loss of life, no international pressure, and a reliable supply you don't have to defend in hostile territory.

Even if water was not the immediate cause of the war, another question remains: does Litani water reach Israel? Despite the inherent difficulty in proving the absence of something, my answer, after investigating as closely as possible, is no. This conclusion is based on the following (discussed in more detail in Wolf 1995):

Even if water was not the immediate cause of the war, another question remains: does Litani water reach Israel? Despite the inherent difficulty in proving the absence of something, my answer, after investigating as closely as possible, is no.

1) The Litani River has a natural flow of about 700 MCM/y. A dam at Qirawn in the Beka'a Valley and irrigation and hydropower diversions completed in the mid-1960s reduce the lower Litani flow to 300-400 MCM/y (Kolars 1992). This lower section, flowing within kilometers of the Hasbani and the Israeli border, historically had presented the possibilities of diversions in conjunction with the Jordan system, and Israel has carried out seismic studies and intelligence reports to determine the feasibility of a Litani diversion (Naff and Matson 1984). These reports concluded that a diversion would be economically unattractive and, in any event, politically infeasible until cooperation could be developed with Lebanon (Wolf 1995). The Lebanese position was and continues to be that rights to Lebanese water should be retained for future Lebanese development.

2) Reports of a secret diversion tunnel were investigated by U.N. forces, as well as by members of the international press, to no avail (Soffer 1991). All relevant sources of spatial data indicate only two water pipelines crossing the Lebanon-Israel border previously mentioned—a three-inch pipe from the Wazzani springs in Lebanese territy to the town of Ghajar in Israel, and a ten-inch pipe from Israel into the Lebanese village of R'meish.

3) Hydrologic records show neither unaccounted-for water in the Israeli water budget after 1978 nor increases in the average flows of the Ayoun or the Hasbani, the most likely carrier streams for a diversion. Because of three years of drought, on October 14, 1991, the Israeli Water Commissioner asked the Knesset to allow pumping of the Sea of Galilee below the legal 'Red Line', the legal water level

below which the entire lake is in danger of becoming saline. On the same day, a field investigation showed that both the Ayoun and the Hasbani above the Wazzani springs were dry.

4) A hypothetical trucking operation is even more difficult to prove or disapprove. Both Mekorot officials (interview, Turgemon, October 1991), and Israeli military officers responsible for southern Lebanon acknowledge that witnesses may have seen Israeli military water trucks in southern Lebanon. Each has suggested that the most likely explanation is that the trucks were carrying drinking water from Israel to Israeli troops stationed in the "security zone." Israeli military code, they point out, insists that soldiers drink water only from official collection points, all of which are in Israel.

An officer who has acted as liaison officer between Israeli and South Lebanon forces doubts that anyone saw Israeli trucks filling at the Litani, pointing out that the 20-ton "Rio's" which are used to carry water could not make the grade of the military road which leads away from the Litani, if the trucks were full (interview, October 1991). Soffer (1991) has calculated that a cubic meter of water trucked from the Litani into Israel would cost about $4 to $10, as compared to about $1.50 for a cubic meter of desalinated water.

The Hydrostrategic Imperative—Conclusions

After closely examining the arguments both in favor and against a hydrostrategic imperative driving military and territorial decisionmaking, it is possible to answer the question posed at the beginning of this section: "Has territory been explicitly targeted, captured, or retained because of its access to water resources?"

I argue the following:

1) Water resources were not a factor for strategic planning in the hostilities of 1948, 1967, 1978, or 1982. By this I mean that the decision to go to war, and strategic decisions made during the fighting, including which territory was it necessary to capture, were not influenced by water scarcity or the location of water resources. The locations of water resources were not considered strategic positions (except in the purely military sense), nor were they a factor in retaining territory immediately after the hostilities.

2) There is no evidence that Israel is diverting any water from the Litani River, either by pipe or by truck. In fact, since 1985, when central southern Lebanon lost its own water supply, an average of 50,000 m^3/mo has been piped into that region from wells in northern Israel (Wolf 1995). As a consequence, it is difficult to view water as a rationale for Israeli retention of Lebanese territory.[12]

[12] Nevertheless, Amery (1993) has speculated that Israel will, at a minimum, pressure Lebanon to make Litani water available as a prerequisite to Israeli military withdrawal.

WATER AND NEGOTIATIONS

As noted above, years of warfare have obscured most of the original boundaries between Israel and her neighbors. The June 1967 war erased the boundaries determined in the 1949 armistice agreement on all fronts, with the exception of the line between Israel and Lebanon, in favor of unsigned ceasefire lines between the combatants. These in turn gave way to the lines of the Disengagement Agreement of 1974 on the fronts between Israel and Syria, and Israel and Egypt. The post-1967 years, and particularly the recent period of peace talks, have been characterized by a quest for stable boundary lines, taking into account the lessons of the past. The question which remains is how much of the quest for permanent boundaries is influenced by the location of water resources.

BOUNDARY PROPOSALS: STRATEGY AND HYDROSTRATEGY

The search for acceptable boundaries began immediately after the June 1967 war. For Israel, the guiding rationale was that territorial concessions should be balanced by security needs, defined differently depending on where one was situated on the political spectrum. For the Arabs, regaining *all* land captured during the war became the operative imperative, shadowing subsequent negotiations. In the survey of boundary proposals which follows, I exclude the extreme positions of either side—from a "Greater Israel" on one side to the elimination of Israel on the other—but rather describe those which incorporate the concept of territorial compromise in exchange for peace, as provided for in United Nations Resolutions 242 (1967) and 338 (1973).[13] Since Israel controls the territory and presumably will not withdraw unless its strategic and political goals are met in negotiations, this analysis focuses on studies which investigate Israeli interests in withdrawal.[14] However, Foucher's (1987) warning that, "in the case of the strategic debate over Israel, the West Bank and neighboring Arab states, one may have reason to consider that 'secure border' for Israel and 'security for all' are not synonymous concepts," should be borne in mind.

Immediately after the 1967 war, the Israeli government spelled out strategic needs (none of which related to water), which, if met, would result in its withdrawal from occupied territory. According to Moshe Dayan, the Golan Heights were negotiable even without a peace treaty, and, with such a treaty, so was the rest of the territory captured in 1967, save East Jerusalem (Slater 1991). This approach was met by the "three no's" of an Arab Summit in Khartoum in August 1967—no peace, no recognition, and no negotiations with Israel (Sachar 1979). As a consequence, Israel strengthened its position in the newly occupied territories through settlement activities: a

[13] These U.N. resolutions, the basis for peace negotiations between Israel and each of its neighbors, call for "the right of every State in the area to live in peace within secure and recognized boundaries," and "withdrawal of armed forces from territories occupied." Definite articles were purposely omitted in the latter clause (i.e. 'territories,' not 'the territories'), specifically allowing for some flexibility in boundary negotiations (see Julius Stone's forward to Blum 1971).

[14] I was not able to find many sources from an Arab perspective which dealt with the specifics of territorial compromise. Two exceptions are Kharmi (1994), who allows for Palestinian territorial adjustments in negotiations *provided* Israel reciprocates with a like amount of land from within green line Israel, and Falah (1995) who, with Newman, argues that a "good" boundary between Palestine and Israel would incorporate both internal and external perceptions of threat. Since neither study has an explicit hydrologic component, neither is described in detail here.

string of kibbutzim was established on the Golan Heights in 1967-68 from Senir, on Givat Banias overlooking the Banias headwaters, south along the ridge of the Heights overlooking the previously demilitarized zone, to Mevo Hama, adjacent to Hammat Gader with its access to the Yarmuk River. Senir and Hammat Gader were each situated in what had been until the war the demilitarized zone—territory which had been part of the British Mandate, but that Syria had occupied in the 1948 war, then had withdrawn from under demilitarized conditions as part of the 1949 Armistice Agreement.

The same strategy of holding conquered land as an inducement to peace talks was followed immediately after the 1982 war in Lebanon. In 1983, an Israeli-Lebanese agreement was signed which called for an Israeli withdrawal from all of Lebanon. The agreement was abrogated in 1984 however, and, consequently, Israel justifies its continued presence in the "security zone" (Tamir 1988).

The Allon Plan

As mentioned, Israel began to use settlement activity as a way of reinforcing its strategic interests immediately following the war of 1967. The Labor government which ruled Israel until 1977 adhered generally to guidelines devised by minister Yigal Allon to address Israeli security concerns.

The plan mainly emphasized the Jordan Valley and the eastern slope of the West Bank mountain range facing Jordan. It should be noted that the Allon Plan was neither endorsed nor ratified by any Israeli government, although it guided the Labor government's settlement policy until 1977.

Some Israeli settlements were established outside of the Allon proposals during the Labor years—a few reportedly to help protect Israel's groundwater resources on the northwest corner of the West Bank. As mentioned above, Israel had since 1955 been tapping into the Western sub-basin of the Mountain Aquifer (an aquifer whose recharge area occurs on the West Bank). Because of the disparate water table depths for this aquifer in the coastal plain and in the Judean hills (about 60m in the plain, 150-200m in the foothills, and 700-800m in the hills (Goldschmidt and Jacobs 1958; Weinberger 1991), and the resulting cost differences in drilling and pumping wells in these areas, this aquifer is especially vulnerable to over-pumping along a narrow westernmost band of the northern lobe of the West Bank, in the region of Galgilya and Tulkarm.

Some settlement plans for the late 1970s referred in part to this line, and about five settlements around Elkanna were reportedly sited in part to guarantee continued Israeli control of the water resources on its side of what would soon be referred to as a "red line" (Pedhatzor 1989; State of Israel memoranda, April-July 1977).

Figure 10 The Allon plan (Alpher 1994).

Post-1977 Boundary Studies

In 1977, the right-wing Likud party gained control of the Israeli parliament for the first time. As Israeli Prime Minister Menahem Begin was preparing for negotiations with Egyptian President Anwar Sadat, he asked the Water Commissioner at the time, Menachem Cantor, to provide him with a map of Israeli water usage from water originating on the West Bank, and to provide guidelines to where Israel might relinquish control, if protecting Israel's water resources were the only consideration.

Cantor concluded that a "red line" could be drawn beyond which Israel should not relinquish control, north to south following roughly the 100-200m contour line along both "lobes" of the West

Figure 11 West Bank groundwater (Shuval 1992).

Bank (see Figure 11). Israeli water planners still refer to this "red line" as a frame of reference (interviews, Golani, October 1991; Shmuel Cantor, December 1991), and it has occasionally been included in academic boundary studies of the region. This concept was later expanded by others to areas of the northern headwaters and the Golan Heights.

A brief description of those which mention water as a territorial imperative follows:

Cohen's "Defensible Borders"

Cohen (1986) explored "the geopolitics of Israel's border question," addressing possible boundary negotiations with a Palestinian political entity over the West Bank and with Syria over the Golan

Figure 12 (Wolf 1995)

Heights. His recommendations for boundary adjustments were considered from the perspective of defensible borders for Israel within the framework of territorial compromise, and included factors of a "strategic-tactical" and a "demographic-economic" nature. They included, explicitly, defensive depth, surveillance points, marshaling areas and corridors, water control, space for Israeli population and industrial growth, absence of dense Arab populations, and psycho-tactical space.

In describing the influence of the above principles, Cohen described how water might influence territorial compromise: Israel would need to retain sovereignty over the Banias-Har Dov-Hermon shoulder headwaters region, the Golan slopes east of the Upper Jordan, and the Golan Heights that overlook the Sea of Galilee and the Lower Yarmuk and its Raqqad tributary. On the West Bank, Cohen argued that Israel should annex the territory which extends until the "subterranean water divide," which he identifies as extending 2-6 km east of the Green Line.[15] Despite his acknowledgment that this territory includes Arab population centers, Cohen argued that the substantial geopolitical advantage that Israel would gain (presumably over and above the hydrostrategic considerations) would outweigh those concerns. Overall, for all the factors listed above, Cohen advised Israel to annex approximately 20% of the West Bank, 19% of the Gaza Strip, and 50% of the Golan Heights (see Figure 13).

[15] Cohen is probably referring to Cantor's "red line." The watershed divide is actually several kilometers inland along the ridge of the Samarian and Judean Hills.

The Jaffee Center's "Arrangements"

In 1991, the Jaffee Center for Strategic Studies of Tel Aviv University asked two researchers, Yehoshua Schwartz, the director of Tahal, Israel's water planning agency, and Aharon Zohar, also at Tahal at the time, to undertake a study of the regional hydrostrategic situation and the potential for regional cooperation. The result, a 300-page document titled, "Water in the Middle East: Solutions to Water Problems in the Context of Arrangements between Israel and the Arabs," was one of the most comprehensive studies of its kind (Schwartz and Zohar 1991). It examined a number of possible scenarios for regional water development, including possible arrangements between Israel and Jordan, Syria, Lebanon, Egypt, Turkey, Saudi Arabia, Iraq, and the Palestinians on the West Bank and Gaza. Scenarios were included both for regional cooperation and for its absence. Evaluations included hydrologic, political, legal, and ideological constraints. The impacts of potential global climatic change were also considered. The study showed, in the words of Joseph Alpher, the director of the Jaffee Center, "the potential beauty of multilateral negotiations" (interview, Alpher, December 1991).

Some of the findings of the study contradicted government policies at the time, however. In the sections on possible arrangements between Israel and the Palestinians, and between Israel and Syria, maps of the West Bank and Golan Heights included lines to which Israel might relinquish control of the water resources in each area, without overly endangering its own water supply. The line in

Figure 13 Cohen's "defensible borders" (Cohen 1986).

the West Bank, which was based on Cantor's "red line," suggested that Israel might, with legal and political guarantees, turn control of the water resources of more than two-thirds of the West Bank over to Palestinian authorities without threatening Israel's water sources from the Yarkon-Tanninim (Western Mountain) aquifer, although the authors advocated retaining control beyond the "red line." The same was true of more than half of the Golan Heights (see Figure 13).

These maps contradicted the position of the Ministry of Agriculture. Headed by Rafael Eitan of the right-wing Tsomet party, the Ministry's position was that, to protect Israel from threats to both the quantity and quality of its water, Israel had to retain political control over the entire West Bank.[16] On December 12, 1991, 70 copies of the report were sent throughout Israel for review, including to the Ministry of Agriculture. Calling the maps mentioned "an outline for retreat," Rafael Eitan and Dan Zaslavsky, whom Eitan had recently appointed Water Commissioner, insisted on a recall of the review copies and a delay in the release of the report. In January 1992, the Israeli military censor backed the position of the Ministry of Agriculture and, citing sensitivity of the report's findings, censored the report in its entirety.[17]

[16] Eitan's position, argued in full-page ads in the Israeli press, has little basis in hydrogeology, as discussed in Wolf 1995.

[17] When peace talks began in 1991, the document remained censored out of fear that it would reveal an Israeli negotiating strategy. At press, the document has not been made public.

Alpher's Proposals

Once negotiations began in 1991, boundary proposals took on new urgency. In one of the most comprehensive post-negotiation examinations of West Bank boundary options, Alpher (1994) both summarizes previous proposals for final boundary arrangements, including the recent "Third Way" and Sharon plans (neither of which have a hydrostrategic component), and offers his own. In defining Israel's requirements in a negotiated agreement, Alpher specifies Israel's needs according to nine parameters: security, water,

Figure 14 Alpher's "Water Boundaries" (Alpher 1994).

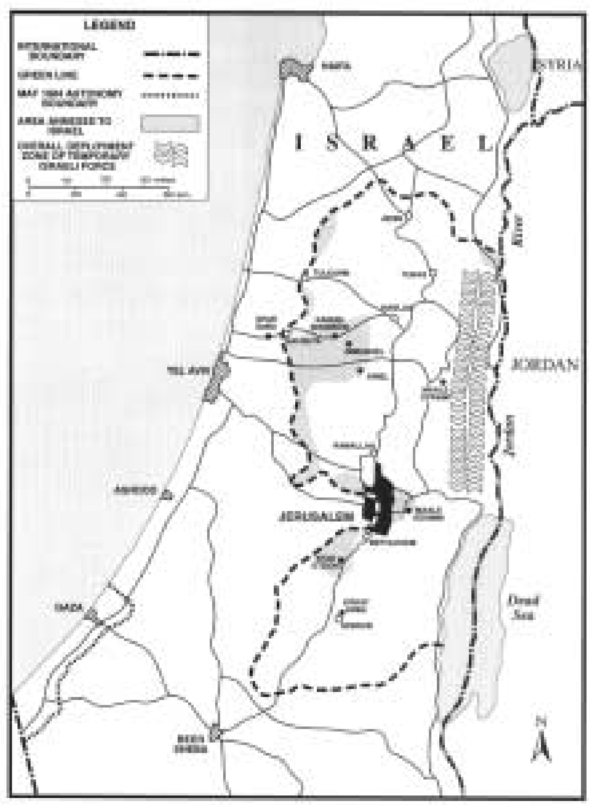

Figure 15 Alpher's "Final Boundaries" (Alpher 1994).

demography and politics, the "heritage dimension," the "historic dimension;" Hebron; Israeli Arabs and the danger of irredentism; "the economic dimension;" and the need to straighten the borderline.

Alpher relies on the unpublished Jaffee Center report of 1991 described above for his description of hydrostrategic territory.[18] He delineates West Bank territory which might be annexed to Israel in order to protect the Western sub-basin of the Mountain Aquifer, as defined first as Cantor's "Red Line"—the westernmost section of the northern lobe of the West Bank, and a region around Jerusalem.

Alpher notes that, while annexation would guarantee Israeli control of water resources, adequate supervision and control arrangements are possible without annexation—perhaps through the implementation of a joint water regime. He also points out that the territories of the West Bank which are vital for continued control over water management have already been heavily settled because of their importance with regard to security. Thus, he concludes:

> ...the water issue is not necessarily a decisive rationale for annexation. At the same time, to the extent that the water issue is juxtaposed geographically with additional vital issues such as security and demography, then it may be seen to further enhance an annexation solution.

Alpher finally seems to weigh in against annexation. In his final map incorporating all of the parameters he defines as crucial, *no* territory which was identified as being important for water alone is slated for annexation.

Bilateral and Multilateral Negotiations[19]

The Gulf War in 1990 and the collapse of the Soviet Union caused a re-alignment of political alliances in the Mideast which finally made possible the first public face-to-face peace talks between Arabs and Israelis, in Madrid on October 30, 1991. During the bilateral negotiations between Israel and each of its neighbors, it was agreed that a second track be established for multilateral negotiations on five subjects deemed "regional," including water resources. These two mutually reinforcing tracks—the bilateral and multilateral—have led, at this writing, to a treaty of peace between Israel and Jordan and a declaration of principles for agreement between Israel and the Palestinian Authority. Both have had a water component in terms of allocations and projects, but in *neither* has water had influence on the discussions over final boundaries.

[18] Alpher was director of the Jaffee Center when it commissioned the 1991 study.

[19] For a more detailed accounting of the agreements between Israel and Jordan the Palestinian Authority, see the text of the water components of the Israel-Jordan treaty and Oslo II, pp. 284-296 and Shamir's commentary, this volume.

Israel-Jordan Treaty of Peace

Israel and Jordan have had probably the warmest relations of any two states legally at war. Communication between the two has taken place since the creation of each, ameliorating conflict and facilitating conflict resolution on a variety of subjects, including water. As noted above, the so-called "Picnic Table Talks" on allocations of the Yarmuk have taken place since the 1950s and negotiations formulating principles for water-sharing projects and allocations have occurred in conjunction with, and parallel to, both the bilateral and multilateral peace negotiations.[20] These principles were formalized on October 26, 1994, when Israel and Jordan signed a treaty of peace, ending more than four decades of a legal, when not actual, state of war.

For the first time since the states came into being, the treaty legally defines mutually recognized water allocations. Acknowledging that "water issues along their entire boundary must be dealt with in their totality," the treaty spells out allocations for both the Yarmuk and Jordan Rivers and Arava/Araba groundwater, and calls for joint efforts to prevent water pollution. Also, "[recognizing] that their water resources are not sufficient to meet their needs," the treaty calls for ways of alleviating the water shortage through cooperative projects, both regional and international.

The peace treaty also makes some minor boundary modifications. As noted above, the Israel-Jordan boundary was delineated by Great Britain in 1922 and followed the center of the Yarmuk and Jordan Rivers, the Dead Sea, and Wadi Araba. In the late 1960s and 1970s, Israel had occasionally made minor modifications in the boundary south of the Dead Sea to make specific sections more secure from infiltrators. They had also done so on occasion to reach sites from which small wells might better be developed. In the last sixteen years, no modifications were made except on the rare occasion that one of these local wells ran dry and had to be re-dug. *All* of these territorial modifications were reversed and all affected land was returned to Jordan as a consequence of the peace treaty, although Israel retains rights to the water which comes from these wells. Moreover, a small enclave of Jordanian territory in the Arava is being leased back to Israel in 25 year increments.

One other area was similarly affected. In 1926, a Jewish entrepreneur named Pinhas Rutenberg was granted a 70 year concession for hydropower generation at the confluence of the Yarmuk and Jordan Rivers on land leased by TransJordan. The dam he built for that purpose was destroyed in the fighting of 1948 and the 1949 Armistice Line left a small portion of Jordan under Israeli control. This land was farmed by the kibbutz Ashdot Ya'akov, which was estab-

[20] For more details on the bilateral and multilateral talks on water, see Wolf (1995b).

lished in 1933. With the 1994 peace treaty, sovereignty of the land was returned to Jordan, who in turn leased it back to the Israelis, and Israeli kibbutzniks now travel into Jordanian territory regularly to farm their land.

Israel-Palestinian Declaration of Principles and Interim Agreement

On 15 September 1993, the "Declaration of Principles on Interim Self-Government Arrangements" was signed between Palestinians and Israelis, which called for Palestinian autonomy in, and the removal of Israeli military forces from, Gaza and Jericho. Among other issues, this bilateral agreement called for the creation of a Palestinian Water Administration Authority. Moreover, the first item in Annex III, on cooperation in economic and development programs, included a focus on:

> ... cooperation in the field of water, including a Water Development Program prepared by experts from both sides, which will also specify the mode of cooperation in the management of water resources in the West Bank and Gaza Strip, and will include proposals for studies and plans on water rights of each party, as well as on the equitable utilization of joint water resources for implementation in and beyond the interim period.

At approximately the same time, Israeli water managers discovered an additional 70 MCM/yr of available yield in the Eastern subbasin of the Mountain Aquifer—the only one of the three main West Bank groundwater units which was not being overpumped at the time. This probably did not hurt Jericho's choice as the first West Bank town to be given autonomy.

Between 1993 and 1995, Israeli and Palestinian representatives negotiated to broaden the interim agreement to encompass greater West Bank territory. On September 28, 1995, the "Israeli-Palestinian Interim Agreement on the West Bank and the Gaza Strip," commonly referred to as "Oslo II," was signed in Washington DC. The question of water rights was one of the most difficult to negotiate, with a final agreement postponed to be included in the negotiations for final status arrangements. Nevertheless, tremendous compromise was achieved between the two sides: Israel recognized the Palestinian claim to water rights, of an amount to be determined in final status negotiations, and a Joint Water Committee was established to cooperatively manage West Bank water and to develop new supplies. This committee also supervises joint patrols to investigate illegal water withdrawals—their first "action" was to discover and put a stop to illegal drilling in the area of Jenin in December 1995 (Israeline, December 20, 1995).

According to the agreement, Israeli forces are scheduled to withdraw from six Palestinian cities in order from north to south, and from 450 towns and villages throughout the West Bank. The final status of Israeli settlements in the West Bank has yet to be determined. *No* territory whatsoever was identified as being necessary for Israeli annexation due to access to water resources. The second and third cities scheduled for Israeli withdrawal—Tulkarm, and Kalkilya, fall well within Cantor's "red line" delineated in Israeli studies as being necessary to retain for water security.

Negotiations among Israel, Syria and Lebanon

As of this writing, water has not been raised in official negotiations between Israel and Syria.[21] Serious bilateral negotiations have only taken place since the fall of 1995 and, given the influence Damascus has on Beirut, Israel/Lebanon talks are not likely until Israel and Syria make more progress. Israelis had hoped to begin talks on water resources with the Syrians at a meeting in Maryland in January 1996, but the Syrians reportedly refused to broaden the scope (Israeline, January 24, 1996).

[21] In unofficial "Track II" discussions, water was the focus of meetings in which Israelis and Lebanese were present as early as 1993, and in which Israelis and Syrians participated in 1994. Participants at these meetings did not necessarily have official standing.

The basis for Israel/Syria negotiations is the premise of an exchange of the Golan Heights for peace. The discussions thus far have focused on interpretations of how much of the Golan, with what security arrangements, and for how much peace. The crux of the territorial dispute is the question of to which boundaries Israel would withdraw—the boundaries between Israel and Syria have included the international boundary between the British and French mandates (1923), the Armistice Line (1949), and the cease fire lines from 1967 and 1974.

The Syrian position has been an insistence on a return to the borders of June 5, 1967, while Israel refers to the boundaries of 1923. Although it has not been mentioned explicitly, the difference between these two positions is precisely over access to water resources. The only distinction between the two lines is the inclusion or exclusion of the three small areas which made up the demilitarized zone between 1949 and 1967 — Givat Banias, the Daughters of Jacob bridge area and the town of El-Hamma/Hamat Gader—a total of about 60 km^2. Each of these three territories were included in British Palestine specifically because of their access to the Jordan and Yarmuk Rivers and, since each is a relatively low-lying area with no strategic importance, their access to water is still considered paramount.

In fact, even before the Israel-Syria negotiations began, a flurry of articles has stressed the importance of water on the Golan

Heights. As mentioned above, Schwartz and Zohar (1991) advised Israeli retention of the Golan Heights west of the Jordan River watershed line in order to guarantee continued control of both water quantity and quality (see Figure 13). In a 1994 study, Shalev (1994), himself a retired general in the Israeli army, cites five other retired generals on the importance of Israeli sovereignty over the Golan to the protection of water resources. Even in his small sample, Shalev finds a range of military opinions, from those who suggest that Israel retain a physical presence on the Golan Heights, to those who advocate retention of at least the plateau above the Sea of Galilee, to those (such as former Chief of Staff Mordechai Gur) who argue that the water problem can be resolved politically in a peace treaty, and that the territory is not vital. Shalev concludes that Syria would not risk a war with Israel for water, especially since a diversion would take years to construct and would constitute a clear *casus belli*. It stands to reason, Shalev argues, that countries involved in water-sharing agreements would want to maintain them.

In the meantime, Schiff (1995), Tarnopolsky (1996), and others have argued in the popular Israeli and Jewish press that water's paramount importance may scuttle negotiations over the Golan, while Israeli politicians from the Labor party, including Prime Minister Shimon Peres and his Foreign Minister Ehud Barak, argue that while the land may be negotiable, the water is not (Jerusalem Post, January 6, 1996 and January 27, 1996).

Water and Negotiations—Conclusions

In answer to the question posed at the beginning of this section, "How much of the quest for negotiated boundaries has been influenced by the location of water resources?" the evidence seems to suggest: not much. This is not to say that water has not been an important topic in each set of negotiations—quite the opposite. The questions of water allocations and rights have been intricate and have been only partially resolved, and even so with great difficulty. Nevertheless, with the concluded negotiations between Israel and Jordan and the ongoing talks between Israel and the Palestinian Authority (and despite the quantity of studies identifying hydrostrategic territory and advising its retention) *no* territory to date has been retained simply because of the location of water. Solutions in each case have focused on creative joint management of the resource, rather than insistence on sovereignty.

In answer to the question posed at the beginning of this section, "How much of the quest for negotiated boundaries has been influenced by the location of water resources?" the evidence seems to suggest: not much. This is not to say that water has not been an important topic in each set of negotiations—quite the opposite. The questions of water allocations and rights have been intricate and have been only partially resolved, and even so with great difficulty.

The pattern which does seem to be emerging, however, is that water *in addition* to one or more other concerns, may justify retention of territory. For example, in the absence of any legal claims, security interests, or settlements, Israel withdrew from territory which it had occupied from Jordan—even those small portions which had hydrostrategic importance. What was important was an agreement on water management, not territory.

By contrast, Israel developed some settlements on the westernmost side of the West Bank to address security and demographic concerns *in addition* to protecting its water supply. While control of much of this territory is being turned over to the Palestinians, determination of the final status of those settlements has been postponed until the final round of negotiations. Again, the solution was found through agreements guaranteeing joint water management, precluding the need for annexation of territory.

These principles may be played out in negotiations between Israel and Syria as well. While Syria insists on the Armistice Line as it stood on June 5, 1967, Israel is arguing for boundaries based on the 1923 international division between the British and French mandates—the difference being three small areas of vital hydrostrategic importance. Based on the experience of other regional boundary delineations, Israel is likely to address hydrostrategic territorial concerns *in conjunction* with its legal claims.

CONCLUSIONS

Michel Foucher (1989) describes cross-border "realities and representations" thus:

> Border analysis does not only deal with space, but also with time. So boundaries can be considered as *time written in space*—not merely the past, but also a special relationship with that past which stands as an inevitable background to current geopolitical decisions.

I have sought to address in this paper the existence of hydrostrategic territory (that is, territory over which sovereignty has been sought politically or militarily *solely* because of its access to water sources) and its role in boundaries, warfare, and negotiations. Hydrostrategic behavior has occurred in the political realm but it has *not* occurred in the military realm.

Have boundaries been drawn historically on the basis of the location of water access? Beginning with the Paris Peace Talks in 1919 and ending with the 1923 mandate boundaries, the Zionist position clearly defined their future state in hydrologic terms, seeking as much of the Jordan Basin as possible, and occasionally some of the Litani as well. They were only marginally successful in achieving these goals, losing two of the three headwaters, but retaining most of the flow of the upper Jordan and all of the Sea of Galilee.

The watershed was further divided in the 1922 creation of Transjordan in territory east of the Jordan River, Dead Sea, and Wadi Araba/Arava. The Zionists attempted to reinforce their sovereignty of the headwaters region through settlement activity in the late 1930s, always within negotiated boundaries.

It seems clear that water was uppermost in the minds of planners and political decisionmakers, particularly among the Zionists, as boundaries were negotiated over the years. However, despite studies advocating the need for greater access to water through 1947, official adherence to sovereignty over such hydrostrategic territory has ceased each time negotiations over legal borders have been concluded.

During warfare between competing riparians, has territory been explicitly targeted, captured, or retained because of its access to water sources? This has been the most elaborately argued question in the literature relating water resources to Arab-Israeli relations, although it is too rarely investigated in detail. In contrast to the functionalists and advocates of a "hydrostrategic imperative," water-related territory seems actually to have played almost no role in Arab-Israeli warfare. Close examination of strategic planning and military decision making and tactics suggest no evidence at all that water was a factor in the hostilities of 1948, 1967, 1978, or 1982. The *only* instance in which territory was sought for access to water was a brief attempt by Israel in 1979 to move the boundary with Lebanon about a kilometer north to gain access to the Wazzani Springs—an attempt quickly vetoed by the local Lebanese commander.

In the course of peace negotiations, has hydrostrategic territory been seen as vital for retention by any of the riparians? Here, too, the answer seems to be no, despite a flurry of studies recommending Israeli retention of territory to protect its water sources. That is not to say that water has not been a difficult topic for negotiations between Israel and its neighbors—again, quite the opposite, but the debate has been over rights, allocations, and management, *not* over territory. Of territory identified in Israeli studies as being vital to the protection of Israel's water resources, *none* has been retained by Israel because of the location of water alone. This has been true of agreements completed as of this writing—the 1994 treaty of peace between Israel and Jordan, and the 1993 Declaration of Principles and the 1995 Interim Agreement between Israel and Palestinian Authority—where arrangements were made for joint management and sovereignty concerns were not highlighted.

Hydrostrategic territory *is* being insisted upon, however, in ongoing negotiations when at least one other compelling justification exists. Israel may point to demographic and/or security concerns over some Jewish settlements which were reportedly sited to protect Israel's groundwater resources, for example. And Israel's insistence that boundaries with Syria be drawn at the 1923 mandate line rather than according to the temporary 1949 armistice agreement is based on precedent and its interpretation of international law as well as on perceived hydrostrategic needs.

The facts show that water has had much less impact on the Arab-Israeli conflict than is increasingly argued, certainly in strategic, spatial, and territorial terms. As Libiszewski (1995) concludes in a thorough study of water and security in the Middle East,

> the Arab-Israeli conflict is not primarily a struggle "over water." The conflict is over national identity and existence, territory, as well as over power and national security.

In this context, water has played a minor role but only, it seems, in conjunction with one or more of these overriding imperatives. The true lesson of the Arab-Israeli experience seems not to be of water as exacerbator of conflict but rather, as the people in the region move from war to peace and the desire for sovereignty gives way to principles of joint management, of water as inducer to cooperation. As Lord Curzon (cited in Prescott 1987) said in 1907, "frontiers are indeed the razor's edge on which hang suspended the modern issues of war and peace."

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Water Agreements Between Israel and Its Neighbors*

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ABSTRACT
Israel signed a Peace Treaty with Jordan in October 1994, and the Oslo II Agreement with the Palestinians in September 1995. Both agreements address issues of water between the two parties to the agreement. The purpose of this paper is to review and discuss these agreements, so we can draw some lessons from them.

BACKGROUND: WATER IN THE MIDDLE EAST

Although the estimates differ somewhat, there is little doubt that Middle East water resources are being used to the limits of their availability. Some of the sources (particularly groundwater) are over-utilized; that is, current annual extraction exceeds average annual replenishment. Analyses in the professional literature uniformly indicate that there is an acute water shortage in the region.

The Middle East's population is growing (see Winckler, this volume), an ever-increasing percentage of it in the cities. Standards of living are rising, and with them unit water consumption rates. The product of these two increasing parameters—population and per capita water use—translates into rapidly escalating urban requirements for potable water.

Currently, agriculture utilizes approximately 70% of the freshwater in the Middle East. Although this percentage is somewhat lower in the more industrialized areas, agriculture is likely to remain the major water-consuming sector in coming decades. However, rising urban needs will require diversion of some potable freshwater resources away from agriculture to the cities. This will be accomplished in two main ways: improved water use efficiency and substitutions of reclaimed wastewater for irrigation and uses other than direct human consumption. The latter is compatible with the increasing production of urban wastewater. Meanwhile, maintaining the viability of agriculture in the region is desirable for a variety of reasons, among them food self-sufficiency and the preservation of rural pastoral lifestyle in the social fabric.

As freshwater utilization has reached the limits of its availability in Israel, the West Bank and the Gaza Strip, and Jordan, international tensions over scarce water have increased. Several attempts have been made to reach a water agreement in the region, the best known of which is the "Johnston Agreement," named after the American envoy Eric Johnston, who visited the region several times between 1953 and 1955 (see Elmusa, this volume, and Wolf, this volume). At the time his mission ended, Johnston had proposed

* Article includes text of water-related provisions of the Jordan-Israel Treaty and the Oslo II Agreement between Israel and the Palestinian Authority as an appendix.

three somewhat different versions of an agreement, one each to Syria, Jordan and Israel, with specified allocations for each. The basis for allocations in his proposals was agricultural use of water, calculated via the areas of arable land of each riparian. The Johnston agreement was never ratified. In later years, Amercian envoys Richard Armitage and Philip Habib made attempts to reach an agreement on water allocations between the regional parties, but were never successful.

Political, institutional, and economic constraints have hindered water quality protection in the region, resulting in threats to human health and the integrity of aquatic and terrestrial ecosystems. Re-use of treated wastewater for irrigation can contribute to the reduction of such hazards.

THE WATER PROVISIONS OF THE JORDAN-ISRAEL TREATY OF PEACE

Since the early 1980s, progress has been made on the ground between Israel and Jordan. Meeting in the field, close to the diversion point from the Yarmuk River into the Jordanian King Abdullah Canal (KAC, earlier known as the Ghor Canal), water experts from the two sides met to consider Jordanian requests for increasing the diversion into the KAC. Trustful and solid relations developed in what came to be known as the "Picnic Table Talks" (see Wolf, this volume), and Israel consented to alleviate some of the water shortage in Jordan by increasing the quantities diverted. This, however, did not change Jordan's position that it was entitled to more water from the Yarmuk, as well as from the Jordan, including from the Sea of Galilee. Jordan stood by the position that it is riparian to the entire Jordan River (from its headwaters in the Banias, Hasbani, and Dan springs) and saw Israel's diversion of water from the Sea of Galilee into its National Water Carrier as a breach of internationally accepted principles. Israel, on the other hand, maintains, as it did then, that Jordan is riparian only to that portion of the Jordan along their common border, and therefore has no legitimate claim to the Jordan River upstream of its confluence with the Yarmuk.

Jordan stood by the position that it is riparian to the entire Jordan River, from its origin, and saw Israel's diversion of water from the Sea of Galilee into its National Water Carrier as a breach of internationally accepted principles. Israel, on the other hand, maintains, as it did then, that Jordan is riparian only to that portion of the Jordan along their common border, and therefore has no part in the Jordan upstream from its confluence with the Yarmuk.

This was the situation when the two countries entered direct negotiations, following the procedure established in the Madrid peace conference of 1991. Many rounds of negotiations ensued, in Washington and later in the region. In the beginning, there were two Arab delegations to the Washington rounds: a Jordanian delegation with Palestinian participation, and a Palestinian delegation with Jordanian presence. (This resulted from Israel's refusal at the time to recognize the Palestinians as a separate entity.) Jordan delayed its agreement to the "Agenda" for the final peace talks until Israel and the Palestinians signed the Oslo I Accord on the White House lawn on September 13, 1993. The "Agenda" had been ready a year earlier, but was signed only the day after the Israeli-Palestinian agreement, at the State Department in Washington. This led to intensification of the negotiations, which moved to the region, and culminated in the Peace Treaty.

The state of belligerency between the two countries came to an end with the signing of the Peace Treaty, celebrated by a ceremony in the Arava/Araba Valley just north of Aqaba/Eilat, on October 26, 1994 (referred to herein as "the Treaty"). It is a comprehensive agreement, covering all areas of concern between the two countries, including water.

The agreement on water was one of the last issues to be concluded at all night meetings in the Jordanian Palace between the water negotiators—Dr. Munther Haddadin for Jordan and Mr. Noah Kinarti for Israel—with His Majesty King Hussein and Prime Minister Rabin working out the final details.

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GENERAL BACKGROUND AND THE JOINT WATER COMMITTEE

Article 6 of the Treaty states the principles relating to water, and Annex II details the "Water Related Matters." The agreement covers two distinct geographic areas, the first of which runs along the Jordan River from its confluence with the Yarmuk River to its confluence with Wadi Yabis at Tirat Zvi (the point at which the northern border of the West Bank meets the Jordan River), the second of which begins near the Dead Sea and extends down to the Red Sea at Eilat/Aqaba through Emek Ha'Arava/Wadi Araba.

The opening statement of Article 6 ("With the view to achieving a comprehensive and lasting settlement of all the water problems between them") stresses that this is a final agreement. Still, the negotiating parties each have recognized the need for future flexibility, and thus a Joint Water Committee (JWC) has been formed (Annex II, Article VII) as a permanent institution. The JWC is charged with implementing the Treaty and with resolving additional water-related matters which may arise subsequently.

The JWC consists of three members from each side. There is no third party involvement; however, Article 29 of the Treaty states that "Disputes arising out of the application or implementation of this Treaty shall be resolved by negotiations. Any such disputes which cannot be settled by negotiations shall be resolved by concilliation or submitted to arbitration." The JWC obviously comes under the supervision of their respective national leaders, via the relevant Ministers.

The Treaty establishes two JWC sub-committees, one each for the northern and southern areas (Annex II, Article VII.2). The northern sub-committee deals with matters relating to the Jordan/ Yarmuk, and the southern with groundwater in the Arava/Araba.

According to Article 6.3 of the Treaty "The parties recognize that their water resources are not sufficient to meet their needs. More water should be supplied for their use through various methods, including projects of regional and international co-operation." That is, the parties have recognized that by dividing the existing sources both will still face shortage, and thus endeavor not only to divide the "pie" but also to enlarge it. This is also an appeal to the international community for assistance in augmenting the region's water resources, as one of the so-called "fruits of peace."

The specific areas of cooperation, as outlined in Article 6.4, are: development of existing and new water resources, increasing of water availability, including regional co-operation on a regional basis, and waste minimization; prevention of contamination of water resources; mutual assistance in the alleviation of water shortages; information transfer; joint water research and development, and "review of the potentials for enhancement of water resources development and use."

WATER ALLOCATIONS, STORAGE, AND QUALITY PROTECTION IN THE JORDAN-YARMUK RIVER SYSTEM

The Agreement does not mention "water rights," but states that "the parties agree mutually to recognize the rightful allocations of both of them in Jordan River and Yarmuk River waters and Arava/ Araba groundwater, in accordance with agreed-upon acceptable principles, quantities and quality as set out in Annex II, which shall be fully respected and complied with" (Article 6.1). This indicates the pragmatic approach adopted by the parties; rather than insisting on what their respective rights might be according to the vague and somewhat contradictory international law on the subject, the parties agreed on specific water quantities, qualities, times and locations.

Allocations are taken up in Annex II, Article I. Israel is allotted flows from the Yarmuk River, specified for a "summer" period (May 15 to October 15) and a "winter" period (October 16 to May 14), with the remainder allocated to Jordan. To implement these allocations, "Jordan and Israel shall cooperate to build a diversion/ storage dam on the Yarmuk River directly downstream of the Adassiya Diversion/point 121." (Annex II, Article II.1.) Preliminary work in the location where the dam is to be constructed has been ongoing, but there is still no agreement on the precise location, design and operation, or environmental protection.

Israel stores in its system 20 million m^3 per year (MCM/y) of winter flows in the Yarmuk, to be returned to Jordan in the summer. This is done with a pipeline, 3.2 km long, "...from the Jordan River directly upstream of the Deganya gates on the river." (Annex II, Article I.2.a). The pipeline was constructed by Jordan, partly on Israeli territory, at its expense, and is operated by Jordan. Jordan pays Israel the operating costs of this system, and no compensation for the value of the water itself. A recent agreement by the Israeli Minister of Infrastructure Ariel Sharon resulted in an increase of 25 MCM/y to Jordan from this source.

Jordan is given allocations from the Jordan River: "Winter period – 16th October to 14th May of each year. Jordan is entitled to store for its use a minimum average of (20) MCM of the floods in the Jordan River south of its confluence with the Yarmuk" (Annex II, Article I.2.b). This is conditioned on the assumption that "Israel is entitled to maintain its current uses of the Jordan River waters between its confluence with the Yarmuk and its confluence with Wadi Yabis/Tirat Zvi" (Annex II, Article I.2.c). Agreement on how this translates into actual quantities has not been settled, and studies of potential for storage on the Jordan River have not been completed yet.

Annex II, Article I.2.d entitles Jordan to "an annual quantity of (10) MCM of desalinated water from the desalination of about (20) MCM of saline springs now diverted to the Jordan River." The brine from this operation cannot be discharged into the watercourses, as is the case with other low quality waters. "Jordan and Israel will each prohibit the disposal of municipal and industrial wastewater into the courses of the Yarmuk or the Jordan Rivers before they are treated to standards allowing their unrestricted agricultural uses." (Annex II, Article III.3.)

According to Annex II, Article I.3: "Jordan and Israel shall cooperate in finding sources for the supply to Jordan of an additional quantity of 50 MCM/y of water of drinkable standards. To this end, the Joint Water Committee will develop, within one year from the Treaty's entry into force, a plan for the supply to Jordan of the above mentioned additional water. This plan will be forwarded to the respective governments for discussion and decision."

This particular matter is one of the major outstanding issues on which the parties have not as yet reached a plan, two years after the expiration of the deadline. Jordan has insisted that it is Israel's responsibility to supply this water from its sources, and has repeatedly demanded that it be supplied from the Sea of Galilee. Israel's position was that the sources for this water should be found on both sides of the border, and that Jordan should pay the full price of developing and supplying it. The recent decision by Minister Ariel Sharon to supply an additional 25 MCM/y to Jordan from the Israeli system constitutes a deviation from this position. The first deliveries of those volumes were transferred to Jordan in the summer of 1998.

GROUNDWATER IN WADI ARABA/EMEK HA'ARAVA

This is the area between the Dead Sea and the port cities of Eilat/Aqaba. "… some wells drilled and used by Israel along with their associated systems fall on the Jordanian side of the border. These wells and systems are under Jordan's sovereignty. Israel shall retain the use of these wells and systems in the quantity and quality detailed in Appendix 1, that shall be prepared by December 1, 1994. Neither country shall take, or cause to be taken, any measure that may appreciably reduce the yields or quality of these wells and systems" (Annex II, Article IV.1)

Furthermore, "Israel may increase the abstraction rate from wells and systems in Jordan by up to (10) MCM/year above the yields referred to in paragraph 1 above, subject to the determination by the Joint Water Committee that this undertaking is hydrogeologically feasible and does not harm existing Jordanian uses. Such increase is to be carried out within five years from the entry into force of this Treaty" (Annex II, Article IV.3).

This inter-linking of water systems, allowing entry of one country into the territory of the other, should be viewed as an indication of the mutual trust and commitment that prevailed when the agreement was negotiated and concluded.

OBSERVATIONS AND COMMENTS

It must be stressed that the Jordan-Israel water agreement is a single component in a comprehensive peace treaty. What it accomplishes for each of the parties must be viewed in this light, and not in isolation.

The northern pipeline from the Jordan River in Israel to the KAC, built and operated by Jordan, and Israel's continued use and potential expansion of the groundwater in the Jordan in the south, are quite unique in international water agreements. This interlinking of water systems, allowing entry of one country into the territory of the other, should be viewed as an indication of the mutual trust and commitment which prevailed when the agreement was negotiated and concluded.

The Treaty is a permanent one. It is also fairly pragmatic and certainly complex, making it possible to present different perspectives on what it achieves for each side. This allows interested parties, on both sides, to characterize the agreement as either an achievement or a failure in domestic fora.

Protection of water quality and of the environment is an integral part of the Treaty. And yet, there is concern that while other parts of the Agreement have strong interests behind them (water users), the environmental interests may not have strong and specific interests to stand for them. It is therefore the role of the national authorities to make sure that the environment does not get short-changed.

The parties recognize the need to develop additional water, not merely to divide the existing sources.

The Treaty does not specify how shortages (in the Yarmuk and Jordan) are to be allocated between the sides; instead the task is left for resolution by the JWC.

Syrian involvement in the Yarmuk is an important factor. The construction of storage reservoirs on the Yarmuk and water uses from the Yarmuk in Syria have a critical influence on the discharge of the river remaining for Jordan and Israel. Any future agreement between Israel and Syria is likely to have a significant effect on the flows of the Jordan, and thus there is a possibility of having to decrease the quantities specified in Jordan-Israel Treaty, but also perhaps inspiring creative alternatives for increasing the quantities available to all parties in the Jordan basin.

Similarly, the agreement is likely to need adjustment when a final Israeli-Palestinian water agreement is discussed, for areas in the Jordan Valley and elsewhere in the West Bank.

THE PALESTINIAN-ISRAELI WATER AGREEMENT IN OSLO II

Oslo II is an interim agreement signed between the Palestinians and Israelis in September 1995, named with reference to "Oslo I," the initial Declaration of Principles which initiated the peace process in September 1993. Article 40 of the Agreement's Annex III, entitled "Water and Sewage," was initialed by the water negotiators—Mr. Nabil Sharif for the Palestinians and Mr. Noah Kinarti for Israel—in the early morning hours of September 18, 1995. It was the first portion of the overall Interim Agreement to be concluded between the two sides.

INTRODUCTION OF THE NOTION OF RIGHTS, GENERAL PRINCIPLES, AND THE TRANSFER OF AUTHORITY

While Jordan consented to discussing "allocations," the Palestinians succeeded in including in the Agreement an explicit reference to water "rights." The first substantive language of the water provisions of the Interim Agreement is as follows: "Israel recognizes the Palestinian water rights in the West Bank. These will be negotiated in the permanent status negotiations and settled in the Permanent Status Agreement relating to the various water resources" (Article 40.1).

The Interim Agreements' principles echo the Jordan-Israel Treaty's declarations on the necessity to augment existing reserves and to maintain existing uses (Article 40.2, 3a) and to prevent water quality deterioration (Article 40.3b, f). The Agreement notably adds language on sustainability (in terms of both quantity and quality) and on the factoring of interannual variability in hydrologic conditions (Article 40.3c,d). Wastewater reuse is introduced as a principle (Article 40.3f), as is avoidance of harm (Article 40.3h). Finally, the Agreement calls for coordinated operation, management, and development of water and sewage systems and insurance that the provisions of the Agreement are applied to all resources and systems, including those under private ownership or operation (Article 40.3g,i). "Coordinated" should be understood in this context as an alternative to "joint." "Joint" would mean joint ownership and management of a resource, and the nature of joint ownership must obviously be defined, for the principle to be made practical. "Coordinated" indicates that each side is sovereign in its domain, but agrees that certain matters (which have to be defined, to make the agreement practical) are managed together.

There is significant substantive language on regulatory and management authority which calls for the transfer by Israel (and, of course, the assumption by the Palestinians) of water and sewerage powers and responsibilities in spheres "related solely to the Palestinians, that are currently held by the military government and its Civil Administration" (Article 40.4). There are, nonetheless, caveats which postpone resolution (like other critical components of the peace process) until the final status negotiations, including "ownership of water and sewage-related infrastructure in the West Bank" (Article 40.5).

DATA ON THE MOUNTAIN AQUIFER

Schedule 10 of the Agreement places numerical estimates on the "utilization, extraction, and … potentials" of the sub-basins of the Mountain Aquifer, which it refers to as the Eastern, Northeastern, and Western Aquifers. (See Wolf, Figure 9, this volume.) The Eastern Aquifer is estimated to have an annual recharge of 172 MCM, of which 40 MCM (from wells) are utilized by Israelis, 54 MCM (24 MCM from wells and 30 MCM from springs) are utilized by Palestinians and an additional 78 MCM are "to be developed." The Northeastern Aquifer is estimated to yield 145 MCM, of which 103 MCM (from the Gilboa and Beisan springs, including wells) are utilized by Israelis and 32 MCM are utilized by Palestinians (25 MCM to users around Jenin and 17 MCM from the East Nablus springs). The Western Aquifer is estimated to have an annual recharge of 362 MCM, of which 340 are utilized within Israel and 20 MCM by the Palestinians. An additional two MCM from springs around Nablus is also to be utilized by Palestinians.

ADDITIONAL WATER

The Agreement states that "Both sides have agreed that the future needs of the Palestinians in the West Bank are estimated to be between 70 - 80 MCM/y" (Article 40.6), and then details the additional water to be provided to the Palestinians "during the interim period" (Article 40.7), some projects to be constructed by Israel, others by the Palestinians. The total quantity specified in these projects is 28.6 MCM/y, of which 5 MCM/y is dedicated to Gaza from the Israeli water system (Article 40.7.a.6, b.3), 17 MCM/yr "...to the Hebron, Bethlehem and Ramallah areas from the Eastern Aquifer or other agreed sources in the West Bank" (Article 40.7.b.2), and the remainder (6.6 MCM/y) from a number of specified sources and systems.

THE JOINT WATER COMMITTEE (JWC) AND A JOINT SUPERVISION AND ENFORCEMENT MECHANISM (JSET)

The Joint Water Committee provisions (Article 40.11-15, and Schedule 8) are far more detailed in the Israeli-Palestinian Interim Agreement than in the Jordan-Israel Peace Treaty. Although the Agreement does not specify the size of the committee (stating only that representation from the two sides must be equal in number), it is more specific as to the functions of the body (see Article 40.12.a-j and Schedule 8). Most significantly, all new water development in the area under jurisdiction must receive approval from the JWC from the planning stages onward (see Article 40.1.a-b, 2.d).

All JWC decisions are to be "reached by consensus, including the agenda, its procedures, and other matters" (Article 40.13). There is no reference to arbitration or other third party dispute resolution mechanisms, although the Committee is obviously entitled to seek advice or involvement by external entities, if it so agrees.

The Agreement also establishes enforcement arms of the JWC, termed "Joint Supervision and Enforcement Teams" (JSETs), to be comprised of at least two members from each side, with costs shared equally, to "monitor, supervise, and enforce Article 40 and [Schedule 9]" and granted extremely broad inspection and data collection powers (Article 40.17, Schedule 9.5.a-f.).

WATER RESOURCE PROTECTION AND SEWAGE SYSTEMS

The Interim Agreement requires the parties to "take all necessary measures" for the prevention of water quality deterioration and pollution, the protection of water and sewage systems in their own and the counterpart's jurisdictions (Article 40.21-24) as well as to reimburse the counterpart for "any unauthorized use or sabotage" to water systems under its responsibility (Article 40.24).

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OBSERVATIONS AND COMMENTS

It must be stressed that this is an *interim* agreement. As such, it may indicate a direction for the final status agreement, but is not binding for that stage.

Like in the Jordan-Israel Peace Treaty, this is but one part of an overall agreement. It should be viewed in this context, and not in isolation. As in the case of Jordan, the Interim Agreement is pragmatic. However, the leading statement deals with "water rights," which are then deferred to the final status negotiations.

The agreement is rather complex, making it possible to present different perspectives on what it achieves for each side. This enables interested parties, on both sides, to characterize the agreement in domestic settings as either an achievement or a failure.

The Agreement is more comprehensive than the Israel-Jordan Treaty with respect to monitoring and enforcement (as evidenced by the establishment of JSETs) and with respect to the specific functions of the joint oversight bodies.

Water and sewage are dealt with jointly, reflecting the danger which sewage poses to the environment and water resources, and its importance as a source of water for irrigation.

The agreement recognizes the need for both parties to develop additional water, not merely divide the existing sources.

The water agreements between Israel and its two neighbors–Jordan and the Palestinian Authority–will obviously have to be coordinated and brought in line.

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Appendix

Excerpted from the Treaty of Peace between the State of Israel and the Hashemite Kingdom of Jordan, signed October 26, 1994 on the Israel-Jordan border in the Arava/ Araba Valley:

ARTICLE 6

WATER

With the view to achieving a comprehensive and lasting settlement of all the water problems between them:

1. The Parties agree mutually to recognize the rightful allocations of both of them in Jordan River and Yarmouk River waters and Araba/Arava ground water in accordance with the agreed acceptable principles, quantities and quality as set out in Annex II , which shall be fully respected and complied with.
2. The Parties, recognizing the necessity to find a practical, just and agreed solution to their water problems and with the view that the subject of water can form the basis for the advancement of cooperation between them, jointly undertake to ensure that the management and development of their water resources do not, in any way, harm the water resources of the other Party.
3. The Parties recognize that their water resources are not sufficient to meet their needs. More water should be supplied for their use through various methods, including projects of regional and international cooperation.
4. In light of paragraph 3 of this Article, with the understanding that cooperation in water-related subjects would be to the benefit of both Parties, and will help alleviate their water shortages, and that water issues along their entire boundary must be dealt with in their totality, including the possibility of trans-boundary water transfers, the Parties agree to search for ways to alleviate water shortage and to co- operate in the following fields:
   a. development of existing and new water resources, increasing the water availability including cooperation on a regional basis as appropriate, and minimizing wastage of water resources through the chain of their uses;
   b. prevention of contamination of water resources;
   c. mutual assistance in the alleviation of water shortages;
   d. transfer of information and joint research and development in water-related subjects, and review of the potentials for enhancement of water resources development and use.
5. The implementation of both Parties' undertakings under this Article is detailed in Annex II.

ANNEX II

Pursuant to Article 6 of the Treaty, Israel and Jordan agreed on the following Articles on water related matters:

ARTICLE I: ALLOCATION

1. Water from the Yarmouk River
   a. Summer period - 15th May to 15th October of each year. Israel pumps (12) MCM and Jordan gets the rest of the flow.
   b. Winter period - 16th October to 14th May of each year. Israel pumps (13) MCM and Jordan is entitled to the rest of the flow subject to provisions outlined hereinbelow: Jordan con cedes to Israel pumping an additional (20) MCM from the Yarmouk in winter in return for Israel conceding to transferring to Jordan during the summer period the quantity specified in paragraphs (2.a) below from the Jordan River.
   c. In order that waste of water will be minimized, Israel and Jordan may use, downstream of point 121/Adassiya Diversion, excess flood water that is not usable and will evidently go to waste unused.
2. Water from the Jordan River
   a. Summer period - 15th May to 15th October of each year. In return for the additional water that Jordan concedes to Israel in winter in accordance with paragraph (1.b) above, Israel concedes to transfer to Jordan in the summer period (20) MCM from the Jordan River directly upstream from Deganya gates on the river. Jordan shall pay the operation and maintenance cost of such transfer through existing systems (not including capital cost) and shall bear the total cost of any new transmission system. A separate protocol shall regulate this transfer.
   b. Winter period - 16th October to 14th May of each year. Jordan is entitled to store for its use a minimum average of (20) MCM of the floods in the Jordan River south of its confluence with the Yarmouk (as outlined in Article II below). Excess floods that are not usable and that will otherwise be wasted can be utilized for the benefit of the two Parties including pumped storage off the course of the river.
   c. In addition to the above, Israel is entitled to maintain its current uses of the Jordan River waters between its confluence with the Yarmouk and its confluence with Tirat Zvi/Wadi Yabis. Jordan is entitled to an annual quantity equivalent to that of Israel, provided how ever, that Jordan's use will not harm the quantity or quality of the above Israeli uses. The Joint Water Committee (outlined in Article VII below) will survey existing uses for documentation and prevention of appreciable harm.
   d. Jordan is entitled to an annual quantity of (10) MCM of desalinated water from the desali nation of about (20) MCM of saline springs now diverted to the Jordan River. Israel will explore the possibility of financing the operation and maintenance cost of the supply to Jordan of this desalinated water (not including capital cost). Until the desalination facilities are operational, and upon the entry into force of the Treaty, Israel will supply Jordan (10) MCM of Jordan River water from the same location as in (2.a) above, outside the summer period and during dates Jordan selects, subject to the maximum capacity of transmission.

3. Additional Water

   Israel and Jordan shall cooperate in finding sources for the supply to Jordan of an additional quantity of (50) MCM/year of water of drinkable standards. To this end, the Joint Water Committee will develop, within one year from the entry into force of the Treaty, a plan for the supply to Jordan of the above mentioned additional water. This plan will be forwarded to the respective governments for discussion and decision.

4. Operation and Maintenance
   a. Operation and maintenance of the systems on Israeli territory that supply Jordan with water, and their electricity supply, shall be Israel's responsibility. The operation and maintenance of the new systems that serve only Jordan will be contracted at Jordan's expense to authorities or companies selected by Jordan.
   b. Israel will guarantee easy unhindered access of personnel and equipment to such new systems for operation and maintenance. This subject will be further detailed in the agreements to be signed between Israel and the authorities or companies selected by Jordan.

ARTICLE II: STORAGE

1. Israel and Jordan shall cooperate to build a diversion/storage dam on the Yarmouk River directly downstream of the point 121/Adassiya Diversion. The purpose is to improve the diversion efficiency into the King Abdullah Canal of the water allocation of the Hashemite Kingdom of Jordan, and possibly for the diversion of Israel's allocation of the river water. Other purposes can be mutually agreed.
2. Israel and Jordan shall cooperate to build a system of water storage on the Jordan River, along their common boundary, between its confluence with the Yarmouk River and its confluence with Tirat Zvi/ Wadi Yabis, in order to implement the provision of paragraph (2.b) of Article I above. The storage system can also be made to accommodate more floods; Israel may use up to (3) MCM/year of added storage capacity.
3. Other storage reservoirs can be discussed and agreed upon mutually.

ARTICLE III: WATER QUALITY AND PROTECTION

1. Israel and Jordan each undertake to protect, within their own jurisdiction, the shared waters of the Jordan and Yarmouk Rivers, and Arava/Araba groundwater, against any pollution, contamination, harm or unauthorized withdrawals of each other's allocations.
2. For this purpose, Israel and Jordan will jointly monitor the quality of water along their boundary, by use of jointly established monitoring stations to be operated under the guidance of the Joint Water Committee.
3. Israel and Jordan will each prohibit the disposal of municipal and industrial wastewater into the course of the Yarmouk or the Jordan Rivers before they are treated to standards allowing their unrestricted agricultural use. Implementation of this prohibition shall be completed within three years from the entry into force of the Treaty.
4. The quality of water supplied from one country to the other at any given location shall be equivalent to the quality of the water used from the same location by the supplying country.

5. Saline springs currently diverted to the Jordan River are earmarked for desalination within four years. Both countries shall cooperate to ensure that the resulting brine will not be disposed of in the Jordan River or in any of its tributaries.
6. Israel and Jordan will each protect water systems in its own territory, supplying water to the other, against any pollution, contamination, harm or unauthorized withdrawal of each other's allocations.

ARTICLE IV: GROUNDWATER IN EMEK HA'ARAVA/WADI ARABA

1. In accordance with the provisions of this Treaty, some wells drilled and used by Israel along with their associated systems fall on the Jordanian side of the borders. These wells and systems are under Jordan's sovereignty. Israel shall retain the use of these wells and systems in the quantity and quality detailed an Appendix to this Annex, that shall be jointly prepared by 31st December, 1994. Neither country shall take, nor cause to be taken, any measure that may appreciably reduce the yields of quality of these wells and systems.
2. Throughout the period of Israel's use of these wells and systems, replacement of any well that may fail among them shall be licensed by Jordan in accordance with the laws and regulations then in effect. For this purpose, the failed well shall be treated as though it was drilled under license from the competent Jordanian authority at the time of its drilling. Israel shall supply Jordan with the log of each of the wells and the technical information about it to be kept on record. The replacement well shall be connected to the Israeli electricity and water systems.
3. Israel may increase the abstraction rate from wells and systems in Jordan by up to (10) MCM/year above the yields referred to in paragraph 1 above, subject to a determination by the Joint Water Committee that this undertaking is hydrogeologically feasible and does not harm existing Jordanian uses. Such increase is to be carried out within five years from the entry into force of the Treaty.
4. Operation and Maintenance
   a. Operation and maintenance of the wells and systems on Jordanian territory that supply Israel with water, and their electricity supply shall be Jordan's responsibility. The operation and maintenance of these wells and systems will be contracted at Israel's expense to authorities or companies selected by Israel.
   b. Jordan will guarantee easy unhindered access of personnel and equipment to such wells and systems for operation and maintenance. This subject will be further detailed in the agreements to be signed between Jordan and the authorities or companies selected by Israel.

ARTICLE V: NOTIFICATION AND AGREEMENT

1. Artificial changes in or of the course of the Jordan and Yarmouk Rivers can only be made by mutual agreement.
2. Each country undertakes to notify the other, six months ahead of time, of any intended projects which are likely to change the flow of either of the above rivers along their common boundary, or the quality of such flow. The subject will be discussed in the Joint Water Committee with the aim of preventing harm and mitigating adverse impacts such projects may cause.

ARTICLE VI: COOPERATION

1. Israel and Jordan undertake to exchange relevant data on water resources through the Joint Water Committee.
2. Israel and Jordan shall cooperate in developing plans for purposes of increasing water supplies and improving water use efficiency, within the context of bilateral, regional or international cooperation.

ARTICLE VII: JOINT WATER COMMITTEE

1. For the purpose of the implementation of this Annex, the Parties will establish a Joint Water Committee comprised of three members from each country.
2. The Joint Water Committee will, with the approval of the respective governments, specify its work procedures, the frequency of its meetings, and the details of its scope of work. The Committee may invite experts and/or advisors as may be required.
3. The Committee may form, as it deems necessary, a number of specialized sub-committees and assign them technical tasks. In this context, it is agreed that these sub-committees will include a northern sub- committee and a southern sub-committee, for the management on the ground of the mutual water resources in these sectors.

Excerpted from the Israeli-Palestinian Interim Agreement on the West Bank and the Gaza Strip ("Oslo II"), signed September 28, 1995 in Taba, Egypt:

ANNEX III

PROTOCOL CONCERNING CIVIL AFFAIRS

ARTICLE 40

WATER AND SEWAGE
On the basis of good-will, both sides have reached the following agreement in the sphere of Water and Sewage:

PRINCIPLES
1. Israel recognizes the Palestinian water rights in the West Bank. These will be negotiated in the permanent status negotiations and settled in the Permanent Status Agreement relating to the various water resources.
2. Both sides recognize the necessity to develop additional water for various uses.
3. While respecting each side's powers and responsibilities in the sphere of water and sewage in their respective areas, both sides agree to coordinate the management of water and sewage resources and systems in the West Bank during the interim period, in accordance with the following principles:
    a. Maintaining existing quantities of utilization from the resources, taking into consideration the quantities of additional water for the Palestinians from the Eastern Aquifer and other agreed sources in the West Bank as detailed in this Article.
    b. Preventing the deterioration of water quality in water resources.
    c. Using the water resources in a manner which will ensure sustainable use in the future, in quantity and quality.
    d. Adjusting the utilization of the resources according to variable climatological and hydrological conditions.
    e. Taking all necessary measures to prevent any harm to water resources, including those utilized by the other side.
    f. Treating, reusing or properly disposing of all domestic, urban, industrial, and agricultural sewage.
    g. Existing water and sewage systems shall be operated, maintained and developed in a coordinated manner, as set out in this Article.
    h. Each side shall take all necessary measures to prevent any harm to the water and sewage systems in their respective areas.
    i. Each side shall ensure that the provisions of this Article are applied to all resources and systems, including those privately owned or operated, in their respective areas.

TRANSFER OF AUTHORITY

4. The Israeli side shall transfer to the Palestinian side, and the Palestinian side shall assume, powers and responsibilities in the sphere of water and sewage in the West Bank related solely to Palestinians, that are currently held by the military government and its Civil Administration, except for the issues that will be negotiated in the permanent status negotiations, in accordance with the provisions of this Article.
5. The issue of ownership of water and sewage related infrastructure in the West Bank will be addressed in the permanent status negotiations.

ADDITIONAL WATER

6. Both sides have agreed that the future needs of the Palestinians in the West Bank are estimated to be between 70 - 80 MCM/year.
7. In this framework, and in order to meet the immediate needs of the Palestinians in fresh water for domestic use, both sides recognize the necessity to make available to the Palestinians during the interim period a total quantity of 28.6 MCM/year, as detailed below:
   a. Israeli Commitment:
      1. Additional supply to Hebron and the Bethlehem area, including the construction of the required pipeline - 1 MCM/year.
      2. Additional supply to Ramallah area - 0.5 MCM/year.
      3. Additional supply to an agreed take-off point in the Salfit area - 0.6 MCM/year.
      4. Additional supply to the Nablus area - 1 MCM/year.
      5. The drilling of an additional well in the Jenin area - 1.4 MCM/year.
      6. Additional supply to the Gaza Strip - 5 MCM/year.
      7. The capital cost of items (1) and (5) above shall be borne by Israel.
   b. Palestinian Responsibility:
      1. An additional well in the Nablus area - 2.1 MCM/year.
      2. Additional supply to the Hebron, Bethlehem and Ramallah areas from the Eastern Aquifer or other agreed sources in the West Bank - 17 MCM/year.
      3. A new pipeline to convey the 5 MCM/year from the existing Israeli water system to the Gaza Strip. In the future, this quantity will come from desalination in Israel.
      4. The connecting pipeline from the Salfit take-off point to Salfit.
      5. The connection of the additional well in the Jenin area to the consumers.
      6. The remainder of the estimated quantity of the Palestinian needs mentioned in para graph 6 above, over the quantities mentioned in this paragraph (41.4 - 51.4 MCM/year), shall be developed by the Palestinians from the Eastern Aquifer and other agreed sources in the West Bank. The Palestinians will have the right to utilize this amount for their needs (domestic and agricultural).
8. The provisions of paragraphs 6-7 above shall not prejudice the provisions of paragraph 1 to this Article.
9. Israel shall assist the Council in the implementation of the provisions of paragraph 7 above, including the following:

a. Making available all relevant data.
b. Determining the appropriate locations for drilling of wells.

10. In order to enable the implementation of paragraph 7 above, both sides shall negotiate and finalize as soon as possible a Protocol concerning the above projects, in accordance with paragraphs 18 - 19 below.

THE JOINT WATER COMMITTEE

11. In order to implement their undertakings under this Article, the two sides will establish, upon the signing of this Agreement, a permanent Joint Water Committee (JWC) for the interim period, under the auspices of the CAC.
12. The function of the JWC shall be to deal with all water and sewage related issues in the West Bank including, inter alia:
    a. Coordinated management of water resources.
    b. Coordinated management of water and sewage systems.
    c. Protection of water resources and water and sewage systems.
    d. Exchange of information relating to water and sewage laws and regulations.
    e. Overseeing the operation of the joint supervision and enforcement mechanism.
    f. Resolution of water and sewage related disputes.
    g. Cooperation in the field of water and sewage, as detailed in this Article.
    h. Arrangements for water supply from one side to the other.
    i. Monitoring systems. The existing regulations concerning measurement and monitoring shall remain in force until the JWC decides otherwise.
    j. Other issues of mutual interest in the sphere of water and sewage.
13. The JWC shall be comprised of an equal number of representatives from each side.
14. All decisions of the JWC shall be reached by consensus, including the agenda, its procedures and other matters.
15. Detailed responsibilities and obligations of the JWC for the implementation of its functions are set out in Schedule 8.

SUPERVISION AND ENFORCEMENT MECHANISM

16. Both sides recognize the necessity to establish a joint mechanism for supervision over and enforcement of their agreements in the field of water and sewage, in the West Bank.
17. For this purpose, both sides shall establish, upon the signing of this Agreement, Joint Supervision and Enforcement Teams (JSET), whose structure, role, and mode of operation is detailed in Schedule 9.

WATER PURCHASES

18. Both sides have agreed that in the case of purchase of water by one side from the other, the purchaser shall pay the full real cost incurred by the supplier, including the cost of production at the source and the conveyance all the way to the point of delivery. Relevant provisions will be included in the Protocol referred to in paragraph 19 below.

19. The JWC will develop a Protocol relating to all aspects of the supply of water from one side to the other, including, inter alia, reliability of supply, quality of supplied water, schedule of delivery and off-set of debts.

MUTUAL COOPERATION

20. Both sides will cooperate in the field of water and sewage, including, inter alia:
    a. Cooperation in the framework of the Israeli-Palestinian Continuing Committee for Economic Cooperation, in accordance with the provisions of Article XI and Annex III of the Declaration of Principles.
    b. Cooperation concerning regional development programs, in accordance with the provisions of Article XI and Annex IV of the Declaration of Principles.
    c. Cooperation, within the framework of the joint Israeli-Palestinian-American Committee, on water production and development related projects agreed upon by the JWC.
    d. Cooperation in the promotion and development of other agreed water-related and sewage-related joint projects, in existing or future multi-lateral forums.
    e. Cooperation in water-related technology transfer, research and development, training, and setting of standards.
    f. Cooperation in the development of mechanisms for dealing with water-related and sewage related natural and man-made emergencies and extreme conditions.
    g. Cooperation in the exchange of available relevant water and sewage data, including:
        1. Measurements and maps related to water resources and uses.
        2. Reports, plans, studies, researches and project documents related to water and sewage.
        3. Data concerning the existing extractions, utilization and estimated potential of the Eastern, North-Eastern and Western Aquifers (attached as Schedule 10).

PROTECTION OF WATER RESOURCES AND WATER AND SEWAGE SYSTEMS

21. Each side shall take all necessary measures to prevent any harm, pollution, or deterioration of water quality of the water resources.
22. Each side shall take all necessary measures for the physical protection of the water and sewage systems in their respective areas.
23. Each side shall take all necessary measures to prevent any pollution or contamination of the water and sewage systems, including those of the other side.
24. Each side shall reimburse the other for any unauthorized use of or sabotage to water and sewage systems situated in the areas under its responsibility which serve the other side.

THE GAZA STRIP

25. The existing agreements and arrangements between the sides concerning water resources and water and sewage systems in the Gaza Strip shall remain unchanged, as detailed in Schedule 11.

SCHEDULE 8

JOINT WATER COMMITTEE

Pursuant to Article 40, paragraph 15 of this Appendix, the obligations and responsibilities of the JWC shall include:

1. Coordinated management of the water resources as detailed hereunder, while maintaining the existing utilization from the aquifers as detailed in Schedule 10, and taking into consideration the quantities of additional water for the Palestinians as detailed in Article 40. It is understood that the above-mentioned Schedule 10 contains average annual quantities, which shall constitute the basis and guidelines for the operation and decisions of the JWC:
   a. All licensing and drilling of new wells and the increase of extraction from any water source, by either side, shall require the prior approval of the JWC.
   b. All development of water resources and systems, by either side, shall require the prior approval of the JWC.
   c. Notwithstanding the provisions of a. and b. above, it is understood that the projects for additional water detailed in paragraph 7 of Article 40, are agreed in principle between the two sides. Accordingly, only the geo-hydrological and technical details and specifications of these projects shall be brought before the JWC for approval prior to the commencement of the final design and implementation process.
   d. When conditions, such as climatological or hydrological variability, dictate a reduction or enable an increase in the extraction from a resource, the JWC shall determine the changes in the extractions and in the resultant supply. These changes will be allocated between the two sides by the JWC in accordance with methods and procedures determined by it.
   e. The JWC shall prepare, within three months of the signing of this Agreement, a Schedule to be attached to this Agreement, of extraction quotas from the water resources, based on the existing licenses and permits.

The JWC shall update this Schedule on a yearly basis and as otherwise required.

2. Coordinated management of water and sewage systems in the West Bank, as follows:
   a. Existing water and sewage systems, which serve the Palestinian population solely, shall be operated and maintained by the Palestinian side solely, without interference or obstructions, in accordance with the provisions of Article 40.
   b. Existing water and sewage systems serving Israelis, shall continue to be operated and maintained by the Israeli side solely, without interference or obstructions, in accordance with the provisions of Article 40.
   c. The systems referred to in a and b above shall be defined on Maps to be agreed upon by the JWC within three months from the signing of this Agreement.
   d. Plans for construction of new water and sewage systems or modification of existing systems require the prior approval of the JWC.

SCHEDULE 9

SUPERVISION AND ENFORCEMENT MECHANISM

Pursuant to Article 40, Paragraph 17 of this Appendix:

1. Both sides shall establish, upon the signing of this Agreement, no less than five Joint Supervision and Enforcement Teams (JSETs) for the West Bank, under the control and supervision of the JWC, which shall commence operation immediately.
2. Each JSET shall be comprised of no less than two representatives from each side, each side in its own vehicle, unless otherwise agreed. The JWC may agree on changes in the number of JSETs and their structure.
3. Each side will pay its own costs, as required to carry out all tasks detailed in this Schedule. Common costs will be shared equally.
4. The JSETs shall operate, in the field, to monitor, supervise and enforce the implementation of Article 40 and this Schedule, and to rectify the situation whenever an infringement has been detected, concerning the following:
   a. Extraction from water resources in accordance with the decisions of the JWC, and the Schedule to be prepared by it in accordance with sub- paragraph 1.e of Schedule 8.
   b. Unauthorized connections to the supply systems and unauthorized water uses;
   c. Drilling of wells and development of new projects for water supply from all sources;
   d. Prevention of contamination and pollution of water resources and systems;
   e. Ensuring the execution of the instructions of the JWC on the operation of monitoring and measurement systems;
   f. Operation and maintenance of systems for collection, treatment, disposal and reuse, of domestic and industrial sewage, of urban and agricultural runoff, and of urban and agricultural drainage systems;
   g. The electric and energy systems which provide power to all the above systems;
   h. The Supervisory Control and Data Acquisition (SCADA) systems for all the above systems;
   i. Water and sewage quality analyses carried out in approved laboratories, to ascertain that these laboratories operate according to accepted standards and practices, as agreed by the JWC. A list of the approved laboratories will be developed by the JWC;
   j. Any other task, as instructed by the JWC.
5. Activities of the JSETs shall be in accordance with the following:
   a. The JSETs shall be entitled, upon coordination with the relevant DCO, to free, unrestricted and secure access to all water and sewage facilities and systems, including those privately owned or operated, as required for the fulfillment of their function.
   b. All members of the JSET shall be issued identification cards, in Arabic, Hebrew and English containing their full names and a photograph.
   c. Each JSET will operate in accordance with a regular schedule of site visits, to wells, springs and other water sources, water works, and sewage systems, as developed by the JWC.

d. In addition, either side may require that a JSET visit a particular water or sewage facility or system, in order to ensure that no infringements have occurred. When such a requirement has been issued, the JSET shall visit the site in question as soon as possible, and no later than within 24 hours.

e. Upon arrival at a water or sewage facility or system, the JSET shall collect and record all relevant data, including photographs as required, and ascertain whether an infringement has occurred. In such cases, the JSET shall take all necessary measures to rectify it, and reinstate the status quo ante, in accordance with the provisions of this Agreement. If the JSET cannot agree on the actions to be taken, the matter will be referred immediately to the two Chairmen of the JWC for decision.

f. The JSET shall be assisted by the DCOs and other security mechanisms established under this Agreement, to enable the JSET to implement its functions.

g. The JSET shall report its findings and operations to the JWC, using forms which will be developed by the JWC.

SCHEDULE 10

DATA CONCERNING AQUIFERS

Pursuant to Article 40, paragraph 20 and Schedule 8 paragraph 1 of this Appendix:
The existing extractions, utilization and estimated potential of the Eastern, North-Eastern, and Western Aquifers are as follows:

Eastern Aquifer:
- In the Jordan Valley, 40 MCM to Israeli users, from wells;
- 24 MCM to Palestinians, from wells; •30 MCM to Palestinians, from springs;
- 78 MCM remaining quantities to be developed from the Eastern Aquifer;
- Total = 172 MCM.

North-Eastern Aquifer:
- 103 MCM to Israeli users, from the Gilboa and Beisan springs, including from wells;
- 25 MCM to Palestinian users around Jenin;
- 17 MCM to Palestinian users from East Nablus springs;
- Total = 145 MCM.

Western Aquifer:
- 340 MCM used within Israel;
- 20 MCM to Palestinians;
- 2 MCM to Palestinians, from springs near Nablus;
- Total = 362 MCM.

All figures are average annual estimates.
The total annual recharge is 679 MCM.

SCHEDULE 11

THE GAZA STRIP

Pursuant to Article 40, Paragraph 25:

1. All water and sewage (hereinafter referred to as "water") systems and resources in the Gaza Strip shall be operated, managed and developed (including drilling) by the Council, in a manner that shall prevent any harm to the water resources.
2. As an exception to paragraph 1., the existing water systems supplying water to the Settlements and the Military Installation Area, and the water systems and resources inside them shall continue to be operated and managed by Mekoroth Water Co.
3. All pumping from water resources in the Settlements and the Military Installation Area shall be in accordance with existing quantities of drinking water and agricultural water. Without derogating from the powers and responsibilities of the Council, the Council shall not adversely affect these quantities. Israel shall provide the Council with all data concerning the number of wells in the Settlements and the quantities and quality of the water pumped from each well, on a monthly basis.
4. Without derogating from the powers and responsibilities of the Council, the Council shall enable the supply of water to the Gush Katif settlement area and Kfar Darom settlement by Mekoroth, as well as the maintenance by Mekoroth of the water systems supplying these locations.
5. The Council shall pay Mekoroth for the cost of water supplied from Israel and for the real expenses incurred in supplying water to the Council.
6. All relations between the Council and Mekoroth shall be dealt with in a commercial agreement.
7. The Council shall take the necessary measures to ensure the protection of all water systems in the Gaza Strip.
8. The two sides shall establish a subcommittee to deal with all issues of mutual interest including the exchange of all relevant data to the management and operation of the water resources and systems and mutual prevention of harm to water resources.
9. The subcommittee shall agree upon its agenda and upon the procedures and manner of its meetings, and may invite experts or advisers as it sees fit.

Toward a Unified Management Regime in the Jordan Basin: The Johnston Plan Revisited

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ABSTRACT
In 1955 an unratified agreement concerning future allocations and joint management of the Jordan River was reached between the Arab riparians and Israel through the meditation of the American special ambassador Eric Johnston. The author argues that this agreement, known as the Johnston Plan, is worth revisiting because it contains the essential ingredients for the resolution of any water conflict, such as provisions for allocations for each riparian and for the establishment of a joint commission. The author analyzes the Johnston Plan in light of current circumstances, assesses its weaknesses, and recommends certain modifications which would make the Plan attractive and feasible for the countries concerned.

INTRODUCTION

The conflict between Israel and the Arabs is not just about history and legitimacy, but also, of course, about land—perhaps the core natural resource of the region. The relative scarcity of water, and its importance in determining the value of some of the contested lands, has meant that it has been a site of conflict since the very beginnings of the Arab-Israeli feud. Because the main sources of the region's water are shared, any lasting peace between the Arab riparians of the basin and Israel will by necessity include agreements on water.

Through such agreements, the Arab riparians will presumably work to secure what they see as their fair share of the area's water resources, the bulk of which originate in Arab territory. Israel, on the other hand, is downstream of the two main disputed resources, the Mountain Aquifer and the Jordan River. The Mountain Aquifer is replenished primarily from the West Bank, and the Jordan River from Syria and Lebanon and, to a lesser extent, from Jordan. Israel and the West Bank contribute minor amounts of drainage area and water quantity to the headwaters and to the basin as a whole (Elmusa 1997). To compensate for its downstream position, Israel is unlikely to withdraw from the Golan Heights, southern Lebanon, and the West Bank without making arrangements for access to water. It has been the principal user of their waters, accomplished through direct or indirect control of the headwaters, i.e., through the occupation of the territory that holds them or through the assertion of its military power to halt projects it deemed inimical to its water supply. Under peaceful conditions, treaties would have to replace this form of control.

My focus here is on the Jordan River system which courses through, whether serially or contiguously (i.e. as a boundary), territories of Lebanon, Syria, Jordan, the Palestinians, and Israel. According to international water law, it qualifies as an international watercourse common to all five parties.[1]

In this paper, I will propose that future allocations and joint management of the Jordan River system be based on the Johnston Plan (JP). The Johnston Plan is an unratified agreement that was reached in 1955 between the Arab riparians and Israel through the mediation of the American special ambassador, Eric Johnston. It contains provisions for allocations for each riparian, diversion and regulatory schemes, and preliminary proposals for a joint commission— all of which are essential ingredients for the resolution of any water conflict. My main interest here is in the allocation provisions, but the possibilities for unified management will also be indicated. In addition, I will point out the principal weaknesses of the JP and suggest remedies. Whether, and which, riparians would agree to endorse the JP is anything but certain; I will examine this question by citing their individual responses to the JP and their hydrologic interests.

Before delving into the details of my main argument, however, I must mention the water agreements that have been reached in the course of the peace talks so far because of their ramifications for resolving the conflict in the future. The Jordan-Israel peace treaty (October 1994) contained what amounts to a water agreement, and so have the interim agreements between Israel and the Palestinians.[2] The Jordan-Israel agreement pertains principally to segments of the Jordan River system that the two states immediately share. A full accord on the basin would have to include Lebanon, the Palestinians, and Syria. The talks between Israel, on the one hand, and Lebanon and Syria, on the other, have all but come to a halt. The Palestinian-Israeli treaties contain partial, water-related arrangements for the interim period, or Palestinian self-governing period, and set out two main agenda items— namely, the equitable utilization of joint water resources and their joint management— for the "final-status" negotiations between the two sides. These negotiations commenced in May 1995, but have made little progress. They are scheduled to conclude on the eve of the year 2000 and to resolve the major issues of conflict between the two sides, especially borders, refugees, Jerusalem, the Israeli settlements in the West Bank and Gaza, and water.

AN OVERVIEW OF THE JOHNSTON PLAN[3]

Eric Johnston undertook his mission in 1953, to resolve the then escalating conflict in the Jordan basin between the Arab states of the Jordan basin and Israel, but his mission had two broader aims as well: (1) to "help Israel get on her feet" (Stevens 1965) including (at least tacitly) recognition of Israel by the Arab coun-

[1] The *convention on the law of the non-navigational uses of international watercourses*, United Nations General Assembly Report of the Sixth Committee convening as the Working Group of the Whole, A/51/869 11 April 1997, defines an "international watercourse" as "a watercourse, parts of which are situated in different states" (Article 2.b).

[2] For analyses of the Jordan-Israel water agreement, see Sharif S. Elmusa, The Jordan-Israel water agreement: a model or an exception? in Eugene Cotran and Chibli Mallat, *The Arab-Israeli accords: legal perspectives*, 1996. Boston: Kluwer Law International: 199-212; and Fredric C. Hof, The Yarmouk and Jordan Rivers in the Israel-Jordan Peace Treaty, *Middle East Policy* No. 4 (Spring 1995): 1-9. See also Shamir, this volume, which includes the texts of these agreements.

[3] The main arguments of this article were made in several chapters of Sharif S. Elmusa, *Water conflict: economics, politics, law and the Palestinian-Israeli water resources*, Washington, D.C., Institute for Palestine Studies, 1997. The JP has been examined in numerous publications, principally: American Friends of the Middle East, *The Jordan water problem*, Washington, D.C., 1964; Miriam L. Lowi, *Water and power: the politics of a scarce resource in the Jordan River basin*, London: Cambridge Univ. Press, 1993; Thomas Naff and R. C. Matson, *Water in the Middle East: conflict or cooperation*, Boulder, CO: Westview Press, 1984; Don Peretz, Development of the Jordan Valley, *Middle East Journal*, Vol. 9, No. 4, Autumn, 1995; Samir Saliba, *The Jordan River dispute*, The Hague: Martinus Nijhof, 1968; and Georgiana Stevens, *Jordan River partition*, Stanford, CA: Stanford Univ. Press and Hoover Institution on War, Revolution and Peace, 1965.

tries through regional cooperation; and (2) to resettle in the Jordan Valley those among the Palestinian refugees who fled to this region in the aftermath of the 1948 Arab-Israeli War. These aims, I believe, critically informed the size of the water allocations that the riparians received under the JP.

The Johnston Plan was the last, but truly not the least, of a series of plans for the development of the Jordan basin, starting in 1920 with the Anglo-French Convention. It should be recalled that before World War I, the Jordan basin area was part of the Ottoman Empire and was not subject to inter-state disputes. In a sense, we still are dealing with the consequences of the collapse of the Ottoman Empire and the break up of the region into individual "nation states." The Anglo-French Convention accorded priority of basin water use to Syria, which then included Lebanon and was to be made by the League of Nations in 1922 into a French-mandated territory. It gave Palestine, which was to fall under Britain's mandate, the residual flow.[4] The convention, however, did not assign specific quotas or chart a vision for the development of the Jordan River basin.

The first comprehensive survey in the Jordan basin and proposals for its development were contained in the 1939 Ionides Plan.[5] M.G. Ionides, then British director of development in Transjordan, was to my mind the most realistic and farsighted of the Jordan River planners. Ionides's assessment of the available water resources in the basin, for example, proved to be more realistic than those of John Hays and Walter Lowdermilk, whose figures turned out to be highly inflated. The inflation resulted from their mixing water and politics. The two engineers, Hays and Lowdermilk, were hired by the World Zionist Organization, which was trying to convince Britain to allow larger numbers of Jews to immigrate on the grounds that there was enough water in the country to support the numbers advocated by this organization. Additionally, Ionides argued that water development should be justified on an economic calculus, a view that we have come to appreciate recently after the realization that the limited water resources have been utilized inefficiently and that they need to be managed from the demand side.

A series of plans followed Ionides'. Two were devised by American engineering firms, Charles T. Main and Baker-Harza, at the request of the U.S., Jordan and UNRWA (the United Nations Relief and Works Agency in charge of rendering assistance to the Palestinian refugees). In the course of negotiations over the JP, these plans served as bases for proposals and counter proposals by the Arab riparians and Israel. They included a wealth of hydrologic

[4] Patricia Toye, *Palestine boundaries*, Vol. 3 London: Archive Editions; published in association with the International Boundaries Research Unit, Univ. of Durham, 1989, 232.

[5] M. G. Ionides, *Report on the water resources of Transjordan and their development,* Government of Transjordan, 1939. Highly informative excerpts from, and outlines of, each of the Jordan basin's plans, from Ionides's onward, are available in American Friends of the Middle East, *The Jordan water problem.*

data and competing diversion schemes, estimates of the irrigable area and irrigation water requirements in the Jordan basin, and water allocations.

Johnston, unlike the authors of the other plans, was not a technician drafting his own scheme. Instead, he sought to induce the Arab states and Israel to meet midway. His plan, sometimes also known as the Unified Plan, is both a synthesis of, and a compromise among, previous plans. It succeeded in bringing the positions of the riparians closer than any of the plans before it did, for, unlike these plans, it resulted from "give and take" by the two sides.

The JP was not formally ratified, although both sides accepted the water allocations or quotas *de facto*. This was because the Arabs would not entertain the recognition of Israel that a unified management regime would entail, without first resolving the Palestinian problem. Yet, although the JP was not ratified, it can be thought of, for reasons that will become apparent in the course of this text, as having become customary law in the basin, at least for Jordan and Israel.

The JP incorporated provisions and involved discussions of proposals germane to the following areas:

- Riparian water quotas, including quantities, basis of estimation, priorities of extraction, points of extraction, and spatial utilization (in and out of basin boundaries);
- Regulatory works, including diversion canals and dams and their location (see Figure 1);
- A joint management body, including international representation.

From an academic point of view, the JP has been used, for example, for the study of the Functionalist and Realist perspectives in international relations (Lowi 1993) to illustrate the inadequacy of the former as an approach to resolving the Arab-Israeli conflict. But it can also serve as a case study for the Communitarian perspective as well. Furthermore, it can amply demonstrate, for those who are interested in the "technology-society" relationship, how economical and political interests lurk behind what are presented as purely technical matters, from data to regulatory and diversion works.

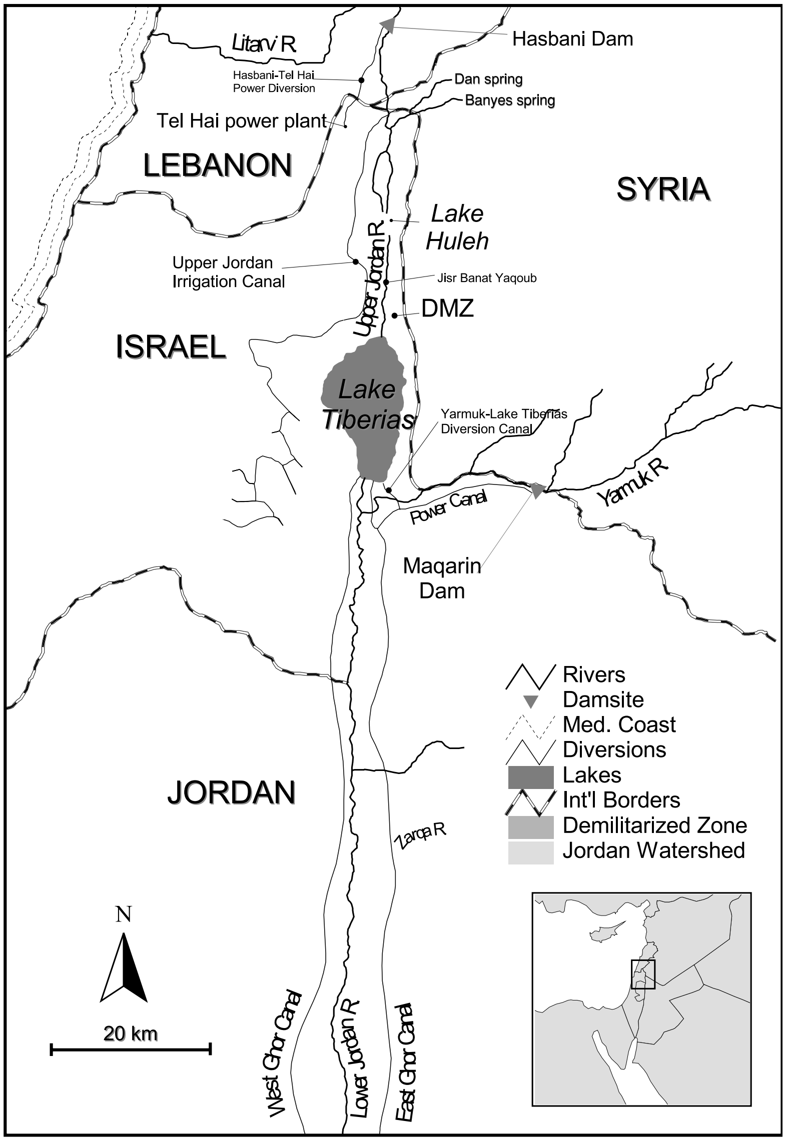

Figure 1 The Johnston Plan. Source: Saliba (1968).

QUOTAS

The quotas that were assigned to the four riparians from the Jordan River system (the West Bank was then part of Jordan), together with recent uses, are exhibited in Figure 2. These figures are cited by most scholars, including Israelis, as being those that were agreed upon between the Arabs and Israel at the end of Johnston's mission. The overall volume that was to be distributed among the riparians was an average of 1,273 million cubic meters per year (MCM/y).

Country	Quota (mcm/y)	Percent of total	Actual use (mcm/y)	Percent of total
Lebanon[a]	35	3	20	< 2
Syria[b]	132	10	200	17
Israel[c]	400	31	690	60
Jordan[d]	720	56		
East Bank[e]	505	39	250	22
West Bank[f]	215	17	0	0
TOTAL	**1,287**	**100**	**1,160**	**100**

Figure 2 Actual use versus quotas under the Johnston Plan in the Jordan River Basin.

Sources:
Based mainly on Ben-Gurion University of the Negev and Tahal Consulting Engineering, *Israel water study for the World Bank*, Washington, DC,1994; American Friends of the Middle East, 1964, *The Jordan water problem;* 1994, 26-7; Naff and Matson, 1984, *Water in the Middle East,* 41-42; Naff, 1991, Jordan River: average flows, 1985-1990, Philadelphia: University of Pennsylvania.

Notes:
[a] Both quotas and use from the al-Hasbani.
[b] Quotas: 90 from the Yarmuk, 22 from the Jordan, and 20 from the Banyas; actual use: all from the Yarmuk.
[c] Quotas: 375 from the Jordan, 25 from the Yarmuk; actual use: 550 from the Jordan and 70-100 from the Yarmuk.
[d] Quotas: 100 from the Jordan, 377 from the Yarmuk, and 243 from the western and eastern side wadis.
[e] Quotas: 297 from the Jordan and the Yarmuk and 206 from the side wadis; actual use: 130 from the Yarmuk and 120 from the side wadis.
[f] Quotas: 180 from the Jordan and the Yarmuk and 35 from the side wadis.

Percentages do not add up due to rounding.

The quotas for Israel were largely a residual; that is, Israel would not divert them until after the Arab riparians had tapped theirs. That meant they were not guaranteed quantities, owing to the fluctuation of rainfall. Assigning Israel a residual was in line with the 1920 Anglo-French Convention. Yet Israel fared much better under the JP than had British-mandated Palestine under the Anglo-French Convention. The quotas rewarded Jordan handsomely as well. The reason for the generosity of the JP allocations to Israel and Jordan undoubtedly lay in its broad goals, namely, "putting Israel on its feet" and re-settlement of Palestinian refugees in the Jordan Valley. Lebanon and Syria, in contrast, did not fare so well under the JP, although the convention had accorded them first priority of use.

For both Israel and the Arab riparians as a whole, the quotas were less than each side had demanded in the course of the negotiations, but Israel was allotted about one-third of the total allocations and the three Arab riparians received two-thirds.

How were the shares determined? They were calculated on the basis of the irrigable area within the Jordan basin. Agriculture at that time was considered the main vehicle of development and municipal and industrial use was still small.

The quotas—for convenience and economy, one assumes—were to be tapped according to the geographical location of the riparians on the system (see Figure 1). Lebanon was to get water from the al-Hasbani; Syria from Banyas, the upper Jordan, and the Yarmuk; Jordan from the Yarmuk, the lower Jordan and the side wadis; Israel from the two Lakes (al-Hula and Tiberias) and the Yarmuk. So while the aggregate shares did not account for geography or natural attributes, the disaggregated did. For example, Israel was to get only 25 MCM/y from the Yarmuk and 375 MCM/y from the upper Jordan, whereas Jordan was to get 377 MCM/y from the

Yarmuk 100 MCM/y from the lower Jordan, and 243 MCM/y from the side wadis.

One final point regarding the quotas is whether the JP permitted Israel to divert water outside the boundaries of the basin to the Negev and to the coastal plain, as it eventually did through its National Water Carrier (NWC). Some scholars have suggested that the Arab negotiators did eventually agree to Israel's demand for out-of-basin diversion, but there is no solid evidence to back them (American Friends of the Middle East 1964) The maximum that the Arabs might have agreed to was that Israel could only do so after the needs within the basin were satisfied. This conjecture makes sense because the water quotas were apportioned according to the irrigable areas of each riparian within the basin. If Israel was to divert water to irrigate land out of the basin, it would have compromised the basis of the allocations, opening the door for each riparian to claim it had large irrigable areas outside the basin and consequently needed more water than the JP's allotments. Clearly, compromising the allocation criterion would have rendered an agreement untenable.

That the Arab countries did not consent to Israel's out-of-basin diversion proposals is confirmed by Mahmud Riyadh, who served on the Arab Technical Committee that negotiated with Johnston and who subsequently became Egypt's foreign minister and secretary general of the Arab League. In a 1984 article he wrote: "We objected in principle to the use of the Jordan River outside the basin."[6] Riyadh justified the Arab position on the grounds that international customary law does not permit such transfer. In any event, the legality of Israel's diversion of Jordan River water out of the basin through the NWC remains an open issue, especially when the needs of the other riparians within the basin have not been met.

[6] Mahmoud Riyadh, Israel and the Arab water in historical perspective, in A. Farid and H. Sirriyeh, *Israel and Arab water*, Proceedings of an international symposium, Amman, Jordan, February 25-26, 1984; London, Ithaca Press, 1985; 12.

ENGINEERING WORKS AND JOINT COMMISSION

In addition to the quotas, the JP had provisions for the engineering works that were to be used for harnessing water from the river system and regulating its flow. There were also inconclusive discussions regarding the institutional framework for unified management of the basin.

The JP integrated the diversionary and regulatory works that appeared in plans after Ionides', and largely accommodated the Arab riparians' and Israel's demands. For Jordan, it suggested the diversion of water through two canals, as was originally proposed by Ionides. Only the canal on the east side, referred to as the East Ghor or King Abdullah Canal, was built; the western diversion, or West Ghor Canal, has yet to see the light of day.

The JP also proposed the construction of the Maqarin dam at the confluence of three Yarmuk River tributaries along the Jordanian-

Syrian border. Its site was first identified in 1951 by M.E. Bunger (author of the Bunger Plan), an American technician with the U.S. Technical Cooperation Agency (TCA), a forerunner of USAID. It is rumored that he spotted the site from an airplane on his way to the United States. The dam was to benefit Jordan and Syria with hydropower and irrigation water. It would have also allowed the two countries to store the Yarmuk River's water inside their own territories instead of in Lake Tiberias, as plans supported by Israel at first sought to do. Like the West Ghor Canal, the dam was never built. But the JP also gave Israel its own diversion scheme in addition to the drainage of Lake al-Hula and the contiguous marshlands—key Israeli demands.

Whereas the JP was specific on the quotas and engineering works, it did not say much about a unified management commission for the basin or the types of tasks and responsibilities it would undertake. This is a weak element of the JP, which would have to be remedied in any future negotiations. It seems that much time was spent on getting Israel to accept an international presence, namely the U.S. and the United Nations. The U.N. was fully involved in the scheme from the beginning through UNRWA, the United Nations agency in charge of dispensing assistance to the Palestinian refugees. And the U.S., of course, was the mediator and potential financier.

RESPONSES TO THE JOHNSTON PLAN

Let us now examine each party's response to the JP and what this might bode for the future.

OVERALL ARAB RESPONSE

Johnston was reported to have said that he felt that the parties accepted the allocations. But this view is not accepted universally. For instance, Mahmud Riyadh stated (Riyadh 1985) that the Arabs objected to the quotas, the out-of-basin transfers, and, as we shall see, to the use of Lake Tiberias as a storage facility for Yarmuk flood water.

There was probably no unified Arab position regarding the technicalities of the JP, and the disagreements were hidden by the Arab opposition to its political side, namely, recognition of Israel without a resolution of the refugee problem.

SYRIA'S RESPONSE

Syria appears never to have accepted the Johnston Plan. In the hydropolitical literature, emphasis has been placed on the political aspect of its rejection; it rejected the JP because it meant recognition of Israel and provided the means for strengthening Israel's economy. But we must also consider the possibility that Syria was not satisfied with the size of its quota. Syria is the largest contributor to the system both in terms of drainage area and flow. While it contributes more than 50 percent of the flow (Elmusa 1997), it was allocated only 10 percent of the divided flow. Although international water law and practice do not suggest that shared water should be distributed among co-riparians according to their relative contributions, upstream riparians generally consider the water originating in their territory to be theirs. Furthermore, in the Anglo-French Convention, Syria was to have priority in harnessing the water of the Jordan River system.

Today, Syria reportedly impounds 70–100 MCM/y more than it was allocated in the JP. It impounds the water behind a series of small dams built since 1967 on the numerous tributaries of the Yarmuk River, apparently using most of the water for irrigation. The irrigable area increased from what it was in 1955 because of the introduction of drip irrigation, which can accommodate the unfavorable topography of that area, unlike traditional furrow irrigation. In any future negotiations, Syria, I would conjecture, could be expected to demand more water than it was allocated under the JP. But Syria may not push its stream position as a basis for allocations too far because it is also downstream of its major source of water, the Euphrates River.

Although Syria did not approve the JP, it was keen on building the Maqarin dam. It had already signed an agreement for building it with Jordan in 1953, before Johnston began his mission. However, the two countries could not build the dam without Israel's approval. In 1987, the two countries revived the idea of building the dam, but in a nearby location, and dubbed the new proposed structure the Wihda (Unity) dam. Ultimately, Israel did not endorse the project, and the World Bank, in accordance with its long-standing policy of requiring the agreement of the concerned riparians in a situation of conflict, did not extend the loan to Jordan which it requested for financing this project. Whether the dam will be built or will be supplanted by alternative structures remains an open issue.

On a broader level, it is unclear whether Syria would favor a unified management commission for the basin. Generally, upstreamers do not seek joint management because it does not much promote their water-related interest. If Syria does accede to such an enterprise, it perhaps would do so for economic and political reasons that transcend water, but would at the same time attempt to obtain water-related concessions. It is up to Jordanian and Palestinian diplomacy to persuade Syria to uphold their JP shares. In fact, and although this proposition may seem far fetched, it might be in the interest of all the downstream riparians, including Israel, to

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help Syria in the Euphrates basin so that it might reciprocate in the Jordan basin. That would be more fruitful as a first step than putting forward projects for transporting water via so-called "peace pipelines" from Turkey down to the Jordan basin riparians.

ISRAEL'S RESPONSE

At the time of the negotiations, Israel demanded more water than it was eventually given by the JP. That, in part, was because Israel regarded the Litani River as part of the Jordan basin (Amery 1993). The idea of diverting water from the Litani to Israel goes back to the 1919 Paris Peace Conference, when Zionist leaders lobbied Britain and France to enclose a segment of the Litani River within the boundaries of what would become British-mandated Palestine. But the two powers, France and Britain, drew Palestine's boundaries in such a way that the Litani River in its entirety fell within Lebanon (See Wolf, this volume).

Israel actually invoked the JP in 1964 when it was about to inaugurate its National Water Carrier (NWC), and when the Arab countries, in response, decided to divert the headwaters of the Jordan through Syria and into Jordan. Prime Minister Levi Eshkol was reported to have said: "There are commitments in the world to us in the wake of the Johnston Plan. The accomplished fact, which was created by Johnston, created a certain situation."[7] He also was cited as having stated that the JP was "regarded as agreed to from an international point of view" (Farid and Sirriyeh 1985).

For Israel, the JP was without a doubt an achievement, giving it one-third of the water of the Jordan River system, even though mostly as a residual. Equally important, it secured the acknowledgment of the Arab countries that Israel was a co-riparian, which is tantamount to tacit recognition.

In spite of its endorsement of the Johnston Plan, Israel took advantage of its post-June 1967 control of the headwaters of the Jordan River and drew from the basin quantities in excess of its JP quota. The figures I have seen range from 200 to 300 MCM/y, or more than Syria's excess withdrawals. So, while both Israel and Syria have violated the JP quotas, Syria did not endorse the plan, whereas Israel acted expediently or pragmatically, depending on how one looks at the matter.

I am not sure what the official Israeli position on the JP is today, and how it differs between Labor and Likud. Raphael Eitan, the current minister of agriculture, traditionally the official wielding the most power in water affairs, reportedly invoked the JP when Jordan and Syria began talking about reviving the idea of the Maqarin dam[8] after Jordan grew frustrated with what it saw as Israeli procrastination on implementing their water agreement. Some of the JP's

[7] Press conference, 11 January 1965. Cited in *Department of state administrative history* (DSAH), vol. 1, chapter 4.H.2 (Johnson Administration), case no. NLJ 83-223, LBJ Library.

[8] *The Jerusalem Post*, 28 August 1996.

provisions also can be sensed in the Israel-Jordan agreement, although the JP was not cited in the text. For example, according to the agreement, Israel's withdrawals from the Yarmuk would be 25 MCM/y (Elmusa 1996), the same amount as under the JP.

I have not seen, however, any Israeli officials or publications endorse the JP. Moreover, a number of Israeli analysts, Elisha Kally and Arnon Soffer for example, have held that the JP has become passé owing to the changes that have occurred in the basin, including locations of scarcity and surpluses, the technical facilities, the political context, technology, winter and summer needs, and population growth. This is an arbitrary conclusion. It does not follow logically or practically from the changes enumerated by the authors, who, at any rate, fail to show how it does. It is self-serving because existing uses favor Israel. Furthermore, neither author analyzes the implications of the individual changes for the plan, except to conclude categorically that a new water sharing regime would have to acknowledge existing uses.[9]

True, the conditions for the basin's riparians have changed since the time of the plan, but the shifts have been more or less even for the main factors that drive water demand, notably population growth and urbanization. For example, Jordan received an influx of refugees from the West Bank as a result of the 1967 war and from the Gulf as a result of the 1991 Gulf crisis, and Israel received large numbers of Soviet immigrants in the late 1980s. Likewise, the Palestinian population has risen considerably now that Gaza, by virtue of coming under the jurisdiction of the Palestinian Authority, has become a riparian of the basin. Further, natural population increase in both Jordan and the West Bank has been even greater than in Israel, and also quite high in Syria. Only Lebanon's population did not multiply as much as the other riparians' thanks to the war-induced high emigration rates. In all, Israel's population comprised close to 17 percent of the basin's total in 1950 and less than 19 percent in 1992.[10]

With respect to a unified water commission, Israel seems to have objected to an international presence—the U.N. and the U.S.—during the Johnston mission. It is far from certain that Israel would welcome U.N. representation in the future, since Israel has been chronically at odds with this world body, evident in Israel's consistent effort to keep the U.N. at bay in the multilateral forums spawned by the peace negotiations. On the other hand, Israel could conceivably accede to a World Bank presence because this multilateral lending institution could also offer financial incentives for the development of the Jordan basin's water resources.

A more basic issue, however, is whether Israel would be interested in unified management at all. On the one hand, it may favor a

[9] Elisha Kally with Gideon Fishelson, *Water and peace: water resources and the Arab-Israeli peace process*, Westport, CT: Praeger, in cooperation with the Armand Hammer Fund for Economic Cooperation in the Middle East, Tel Aviv Univ, 1993: 33; and Arnon Soffer, The relevance of Johnston Plan to the reality of 1993 and beyond. In *Water and peace in the Middle East*, J. Isaac and H. Shuval, eds., Amsterdam: Elsevier; Studies in Environmental Science 58, Proceedings of the First Israeli-Palestinian International Academic Conference on Water, Zurich, Switzerland, 10–13 December 1992: 115–16.

[10] The author's estimate, based on figures from United Nations Environment Programme, *Environmental data report, 1993-94*, Cambridge, MA: Blackwell, 1994: 218-19. The following assumptions were made regarding the Palestinian population: Gaza was not included in the 1950 estimate; the West Bank and Gaza's population in 1992 was 2.4 million.

series of bilateral agreements with the other Arab riparians. Its hydrostrategic position (it shares segments of the Jordan River system with each Arab riparian) allows it to do that, whereas none of the Arab riparians enjoys this type of position. Such an arrangement would place Israel at the hub of the basin's management. Israel's interest in bilateralism may be buttressed by a reluctance on its part to be the only non-Arab member in a five-way commission, for fear of being outvoted if a voting system is used in decision making.

At the least, Israel would probably want to ensure that the decision making procedures do not allow the Arab riparians, should they take a joint stand, to decide on key issues. Whether this fear is well-founded is another matter; the history of the dispute suggests that the interests or the actions of the Arab riparians have not always been harmonious. Still, if the Arab riparians, particularly Syria, insist on a multilateral commission, Israel may have to go along. Furthermore, if Israel wants finally to be integrated in the region, it might not find a multilateral commission highly objectionable.

JORDAN'S RESPONSE

On the whole, Jordan favored the JP even when it opposed it on political grounds. Jordan's positive response is understandable. The Jordan River is its main water source and the JP granted it enough water to irrigate 50,000 ha in the Valley, the principal irrigable area in the country. As soon as the Arab world split into competing factions during the cold war, Jordan became identified as pro-Western, and signed agreements with the United States to initiate work on the East Ghor Canal. The United States itself had conditioned its aid to Israel and Jordan for projects in the Valley on their adherence to the Johnston Plan.

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In reality, however, Jordan was able to divert only around 250 MCM/y of its JP share, half from the Yarmuk channel and half from the side wadis that feed the Jordan river from its territory. According to its water agreement with Israel, Jordan may be able to harness a total volume from the basin equal to its JP quota if all the "additional water" it was allotted under the agreement—as estimated by its chief water negotiator, Munther Haddadin—materializes (Elmusa 1996).

Jordan cannot but be apprehensive about re-negotiating the JP allocations because it does not have the power to secure the original share and it is downstream on both the Jordan and Yarmuk rivers. These considerations would also make it interested in being a member of a unified commission for the management of the basin's waters.

THE PALESTINIAN RESPONSE

At the time of the JP, the Palestinians opposed it, but not because of water shares: they wanted the water, but they wanted it in Palestine. The quota that was allocated to Jordan and earmarked for the Valley's Palestinian and Jordanian farmers (the majority Palestinians), was generous—720 MCM/y—of which 477 was from the Jordan and Yarmuk channels and 243 from the lateral wadis. The Palestinian objection was to the idea of resettlement outside their original homes in Palestine. They did not accept the terms of the exchange, namely, Palestine for Jordan River water in the Valley.

In the meantime, Palestinian farmers had diverted small amounts of water directly from the river to irrigate farmland in its flood plain (the *Zawr).* In 1964, however, Israel shifted the water of the two main saline spring groups that fed Lake Tiberias into the lower Jordan River, rendering its water too saline for irrigation. But the *coup de grace* for Palestinian agriculture in the Valley was delivered in 1967 when Israel declared the Jordan River a closed military area and drove Palestinian farmers off.

Since the start of peace negotiations, the Palestinian reaction to the JP seems to have been mixed, even unclear. They have demanded a share of the Jordan River system based on the status of the West Bank as a riparian and have invoked the JP on several occasions, especially regarding the West Ghor Canal, which they hoped would be used to irrigate the Jordan Valley. In this regard, Israel's retention of the Jordan Valley—as many Israeli officials have reiterated—would vitiate the status of the West Bank as a riparian of the basin. Some Palestinian analysts, however, have claimed that: "the Revised Johnston Plan, which is still in effect today, neglected mention of the Palestinian people. Undoubtedly, this is one of the most blatant violations of the water rights of a region's indigenous peoples."[11]

True, the JP did not mention the Palestinians by name and they were not negotiators because the West Bank was part of Jordan. Nonetheless, one of the JP's core aims was to resettle Palestinian refugees in the Valley through the provision of land and water.

How much water was the West Bank allocated? A 1992 PLO report put the West Bank's share at 290 MCM/y (220 from the lower Jordan and 70 from the Yarmuk). Another report by a group of Palestinian water specialists, some of whom are or were members of the official negotiating water team, put it at 100 MCM/y, adding, without further elaboration, that "a rational allocation" would accord the Palestinians "at least 200" MCM/y.[12] Neither report indicates how the figures were arrived at.

I have proposed instead that the West Bank's share ought to be calculated as a percentage of Jordan's and in proportion to the

[11] L. Hosh and Jad Isaac, Roots of the water conflict in the Middle East, presented at the Conference on the Middle East Water Crisis: Creative Perspectives and Solutions, Univ. of Waterloo, Waterloo, ON, Canada, 8–22 May, 1992.

[12] Task Force of the Water Resources Action Program, *Palestinian water resources: a rapid interdisciplinary sector review and issues paper,* East Jerusalem: WRAP, 1994, 7.

irrigable area on the eastern and western banks of the Jordan Valley, as estimated in 1955 by the Chicago-based engineering firm Baker-Harza. The rationale behind this suggestion is that Jordan's share was allocated according to the water required for that irrigable area on both sides of the river. Calculated in this manner, the West Bank's share would be about 215 MCM/y (180 MCM/y from the river channel itself and 35 MCM/y from the side wadis). This amount is larger than what the Palestinian water specialists cited above regarded as "rational division." One would expect that the Palestinian negotiators would be keen on securing that quantity. It would also serve the Palestinian interest to take part in a unified management regime. In fact, any major revision of the JP is likely to be injurious to the Palestinians because they are in an even weaker position than Jordan, located in the utmost downstream position of the Jordan river system and having no control of any strategic part of it, not to speak of their overall meager power resources.

LEBANON'S RESPONSE

The Johnston Plan allocated to Lebanon 35 MCM/y, the least of all the riparians. This is commensurate not with its contribution to the Jordan River system, but with its irrigable area within the basin. Lebanon, like the other Arab countries, did not accept the JP in 1955 on political grounds. I have not seen much about Lebanon's position *vis-a-vis* the JP in recent years, except for one statement by the head of the Litani Commission, in which he demanded water for Lebanon from the Jordan basin on the basis of the JP.[13] In the final analysis, Lebanon's allocations cannot be reduced further in any future negotiations without rendering them meaningless.

Lebanon, although an upstreamer, would theoretically be willing to sit on a unified management commission because it lacks the military and economic power to impose solutions of its own and might benefit from international assistance to the basin if such aid were forthcoming. On the whole, however, Lebanon's position, as in other strategic regional matters, will be influenced by Syria's.

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[13] See interview with Fadi Qumayr, head of the Litani Project Commission, *Al Hayat,* December, 1994.

FINE-TUNING AND EXTENSION OF THE JOHNSTON PLAN

In its past form, the JP is an incomplete blueprint. It needs both extension to encompass new spheres and refinement of the allocation formula. For one thing, the plan did not speak to the question of water quality and protection. The environment was not a big issue at the time, and the JP had provisions, especially drainage of Lake al-Hula and the contiguous marshlands, that would be highly controversial today from an ecological point of view.[14] Yet the protection of water quality—which ultimately translates into quantity—would have to be a key element in any future accord. This issue has also been addressed in the Israel-Jordan water agreement, but the scope of the provisions needs to be widened to cover the rest of the river system.

Neither did the JP take into account the historic and ecological attributes of the Jordan basin. The basin is central in the history and myths of Muslims, Christians, and Jews. It is also a unique natural region, especially the Dead Sea. In fact, it is ecologically more pertinent to speak of the Dead Sea basin than the Jordan River basin. This inland lake is vulnerable to the reduction of the flow from the Jordan River, its primary feeder. It has dried up in its southern part and could shrink further in the future. Any schemes for the development of the basin, therefore, should consider not only the utilitarian, economic uses but the "instream" ecological, aesthetic and historic value of the river system and the Dead Sea.

[14] Draining of these two water bodies was opposed at the time by Syria on the grounds that Israel could not act unilaterally in an international basin and that some of the drainage canals would fall within the DMZ between the two states.

The JP, moreover, did not specify details regarding the structure and tasks of a joint management commission. Aspects of these were tackled in the Jordan-Israeli water agreement, but the tasks it named are only a fraction of what would be required for a commission managing the entire basin. Also, an international presence may be helpful at least at the start, especially in light of the rocky experience of the Jordan-Israel joint commission. An international party—such as the World Bank—can assist technically and financially to bridge gaps and resolve outstanding problems.

Additionally, the Johnston Plan quotas can benefit from refinement. The aggregate allocations, for example, could be broken down on a seasonal basis, as was done in the Israel-Jordan water agreement. Another improvement would be to state the quotas as percentages, in addition to fixed quantities, to account for the variations of rainfall and the concomitant water availability in the basin. A third modification would be to give Syria a choice between the water it impounds behind dams on the Yarmuk's tributaries and the water that the plan assigned to it from the Banyas and the Jordan rivers. If Syria opted for the latter, the dams could still be used to regulate the flow, and the downstream riparians would compensate Syria financially for this service.

The foregoing suggestions for improving the JP differ from saying that it is passé. They imply that the riparians should build on the JP, without discarding its basic allocations. Attempts to renegotiate an entirely new agreement and quotas are likely to be protracted, considering the mounting water scarcity in the area. Changing the quotas could only come at the expense of the Jordanians and Palestinians, the two vulnerable downstream riparians. While it may be possible to suppress the demands of these two riparians for a time, an enduring management regime must be equitable.

CONCLUSION

A water agreement in the Jordan basin is key for overall Arab-Israeli accommodation. In the Jordan River system, such an agreement can be built on the Johnston Plan. The JP is a synthesis of previous plans and a compromise between the Arab riparians and Israel; it may be said to have functioned as customary law in the basin, at least between Israel and Jordan, and by extension the Palestinians. The customary law status of the JP can be applied to the Palestinians because it was negotiated when the West Bank was first part of Jordan and then fell under Israeli rule.

The JP would have to be modified to include provisions for water quality control and instream value for the river system and the Dead Sea, largely absent in the historic JP. It would also have to fine-tune the quotas to accommodate seasonal uses and supply, as well as the water works built by some of the basin states.

The JP was not ratified in the past mainly because the Arab states of the basin would not accept its implicit recognition of Israel before resolving the Palestinian question. This condition no longer obtains; the Arab states have recognized or are willing to recognize Israel in exchange for returning Arab territories seized in 1967. The Palestinian refugee issue is also on the agenda of the final status talks between Israel and the Palestinian Authority, and its resolution depends only partially on water. In other words, only the "technical" aspect of the JP has to be re-negotiated. The stumbling block is likely to be the quotas, although the agreement on a unified management regime could present a formidable challenge as well.

Jordan, Lebanon and the Palestinians—the three vulnerable riparians—would be keenly interested in a JP-based agreement. The key to an agreement based on the Johnston Plan, however, is in the hands of the Israelis and the Syrians—Israel because it is the riparian with the greatest power resources in the basin, and Syria because it is the utmost upstreamer and the main water contributor to the surface waters of the basin.

SUMMARY OF RECOMMENDATIONS:
1) Extend provisions for water quality to river system at large; 2) Consider "instream" ecological, aesthetic, and historic value of the river; 3) Specify details of joint commission; 4) Refine quotas. The aggregate allocations, for example, could be broken down on a seasonal basis, as was done in the Israel-Jordan water agreement. Another improvement would be to state the quotas as percentages, in addition to fixed quantities, to account for the variations of rainfall and the concomitant water availability in the basin. A third modification would be to give Syria a choice between the water it impounds behind dams on the Yarmuk's tributaries and the water that the plan assigned to it from the Banyas and the Jordan rivers. If Syria opted for the latter, the dams could still be used to regulate the flow, and the downstream riparians would compensate Syria financially for this service.

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Section III: Nature and Culture

Cultural Ecology, Perceptions of Nature and the Advent of Monotheism in the Ancient Middle East: An Hypothesis

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ABSTRACT
The Middle East encompasses five ecological domains: (1) *the humid highlands* and their intermontane valleys, where rainfed farming was begun and permanent settlements were first established; (2) *the semi-arid steppes,* where the lesser amount and instability of rainfall made rainfed farming marginal but still provided vegetative resources that could be utilized by semi-nomadic pastoralists; (3) *the river valleys,* where irrigated farming was practiced in the floodplains and hydraulic works (including diversion canals and ponding basins) were developed; (4) *the seacoasts,* where fishing, seafaring, and maritime trade were practiced; and (5) *the deserts,* where a sparse population subsisted by hunting and occasional marauding, and eventually by becoming caravaneers conveying products such as herbs and spices overland from distant sources to centers of population. In each of these domains, a distinctive culture evolved, characterized by a specific set of precepts, beliefs, and rituals based on the deification and worship of the dominant forces of nature whose interplay seemed to govern the particular environment. In an exposition more fully elucidated in his forthcoming book *The natural history of the Bible: an ecological reading of the scriptures,* the author hypothesizes that it was the encompassing ecological experience of the ancient Israelites (who shifted from one domain to another in the early course of their history) that enabled them to perceive the overarching unity of all nature and therefore to begin worshipping a single God. The holistic perception of nature as an integrated domain governed by consistent principles was compatible with, and probably contributed to, the much later advent of modern science.

Much has been said and written in recent decades concerning the impact of human societies and their activities on the environment. Less attention is currently paid to the equally important influences of specific environments on the evolution of human societies and their distinctive cultures. People who live in the artificial environment of the city, sheltered from direct exposure to the natural elements, find it increasingly difficult to perceive how profoundly the ecology of each region must have shaped not only the material mode of individual and collective subsistence, but also the mental attitudes and spiritual perceptions of tribes and nations. Nowhere is this reciprocal influence more clearly apparent than in the Middle East.

The region called the Middle East encompasses parts of northeastern Africa and southwestern Asia. Ecologically, it spans the transition between the humid or semi-humid environment of southeastern Europe and the extremely arid environment of the great desert belt of the Sahara and the Arabian Peninsula reaching to the Thar in the Indian subcontinent. Significantly, it was in parts of this region that in the wake of the last ice age some ten thousand years ago, humans first made the momentous transition from nomadic scavenging, hunting, and gathering to regular husbandry of crops and livestock. Here they first domesticated plants and animals, established villages and cities, built temples and monuments, and organized nation states. Here they invented ceramics, metallurgy, mathematics, and writing. And here they conceived and enunciated universal ethical and religious ideals and codified them into laws.

The Middle East is, thus, the ancient cultural and spiritual home, indeed the birthplace, of Western Civilization.

The cultural history of the ancient Middle East is not a simple story of uniform steady development. Rather, it is an exceedingly complex process of fitful progress, beset by repeated crises and conflicts, in the course of which disparate societies co-evolved and repeatedly clashed. The complexity of that process can be related to the inherently variable and unstable environment within which it took place.

The variegated environment of this region consists, rather roughly, of five principal domains, each of which gave rise to a characteristic culture. The irregular distribution of these domains is such that they interlace with one another, thus forcing the cultures forming within them to interact continuously, both synergistically and antagonistically, in mutual dependence and rivalry. The five domains are: the humid highlands, the semiarid steppes, the river valleys, the seacoasts, and the deserts.

The first of these domains, the *humid highlands,* is the arc of upland ranges girding the Fertile Crescent on the northwest, north, and northeast (including the mountain ranges of Galilee, Lebanon, Taurus, and Zagros). These ranges face into the path of the cloud-bearing winds rolling in from the west and northwest, and therefore regularly receive a comparative abundance of rainfall. That rainfall gave rise to a profuse cover of herbaceous and woody plants, among which were native species of grain-bearing grasses and legumes, as well as of fruit-bearing trees and shrubs that provided the progenitors of the crops domesticated by the region's early farmers. This is, therefore, the domain of *rainfed farming.*

The second domain, namely the *semiarid steppes,* consists of the plains and hills that lie in the rainshadow of the humid highlands. Here rainfall is of lesser amount and regularity, so that rainfed farming is too hazardous to be practiced perennially. However, this domain does nevertheless provide vegetative resources which, though more sparse than in the humid domain, can be exploited by grazing animals. Indeed, this is the subregion wherein sheep and goats and other species of livestock were domesticated and herded by tribes of semi-nomadic pastoralists. Hence we call this the *pastoral* domain.

The third domain is that of the *river valleys* located in the semi-arid and arid zones. These valleys receive the excess waters (runoff) flowing from the various catchments of the humid zone. Because these flows originate in a different and often distant zone from the major river valleys, they are called "exotic." As such, they tend to be seasonally variable, with the flows being most copious during and immediately following the distinct rainy seasons. Some centuries following the initial domestication of crojƒ in the rainfed domain, farmers disaÎvered that they could import the seeds of those crops into the riverine domain and grow them successfully along the river banks and floodplains after the recession of the annual floods. In time, these farmers also learned to exercise greater control over the water supplies by diverting water from the natural river courses by means of artificial dykes, channels, and ditches. Thus arose the "hydraulic civilizations" of the ancient Middle East, which depended on *irrigated farming* for their subsistence.

In addition to developing distinctive material cultures, the societies that evolved in each of the domains also acquired characteristic perceptions of nature, which expressed themselves in specific sets of religious beliefs and practices.

The fourth domain, the *seacoasts,* or the littoral domain, consisted of the strips of land and water along the shores of the Mediterranean Sea, the Red Sea, and the Persian Gulf. Here the terrestrial and the marine environments meet and interplay to form a unique ecological zone, with a characteristic community of interlinked aquatic and land plants and animals. Humans who lived along these coasts tended to become fishermen, seafarers, and land-sea traders. Eventually, they developed such characteristic pursuits as glass making (using coastal sand), and dye making (from near-coasts sea snails). Some settled permanently at advantageous sites (such as islands, coves, and estuaries); while others developed a form of maritime nomadism characteristic of the Mediterranean "Sea Peoples," who combined coastal trading and raiding as means of subsistence.

The fifth domain was the *desert* domain, encompassing the vast dry lands that occupy the southern tier of the region. Here the sparse population continued for a long while to maintain an austere existence as nomadic hunters, gatherers, and occasional marauders who carried out incursions into the adjacent domains. Some also engaged in localized farming in isolated oases and others herded ungulents over the sparsely vegetated rangelands of the semi-desert. In time, the denizens of the desert domesticated the camel, that remarkable animal that has long been called the "ship of the desert." Henceforth, some became caravaneers, conveying goods such as medicinal, aromatic, and spice plants (along with gems, gums, and silk) from such distant sources as southern Arabia, eastern Africa, India, and central Asia to the centers of population along the Mediterranean.

In addition to developing distinctive material cultures, the societies that evolved in each of the domains also acquired characteristic perceptions of nature, which expressed themselves in specific sets of religious beliefs and practices. Their religions were based on recognition and worship of the dominant natural forces that, in effect, controlled their lives. And because the landscape of the region is so variegated, and the climate so unstable, the ancient inhabitants of the Middle East imagined the forces of nature to be in continuous conflict. Rainstorms alternated with searing desert winds, drenching floods with droughts, periods of plenty with repeated famine, as if the elements were at war. Hence, the early polytheistic religions were directed toward warding off the evil forces and propitiating the beneficent ones in a constant quest to attain a measure of security in a world that seemed so inherently unstable.

Rainfed farming societies coalesced from individual clusters of villages in separate valleys to form city-states in which a major city served as a center for a hinterland of farming communities. The chief gods of these communities were generally the rainstorm gods such as *Baal,* and an earth goddess, often named *Astarte.* Baal was depicted riding the clouds, and at whim or will, spewing forth or withholding his beneficence in the form of precipitation upon the reclining Mother Earth below, who would then respond with her abundant fecundity. The process of life was thus depicted as the mating of sky and earth. To elicit it, these societies would practice elaborate sacrificial rituals.

The pastoral societies tended to worship the brute and procreative prowess of dominant male animals, such as bulls or rams. As they too depended on seasonal rainfall, they often worshiped a combined pantheon of animal gods and rain gods.

The hydraulic societies appealed to riverine gods, believed to control the annual floods. In the case of Egypt, where the connection between the annual spates of the Nile and its sources in faraway Ethiopia was obscure, a popular river god was *Hapi,* portrayed in murals and sculptures as a rotund hermaphrodite with feminine breasts and masculine genitals, presumably having powers of self-generation. In Mesopotamia, where the threat of soil salination by rising groundwater was felt most acutely, the good river god was perceived to be countered by the lurking *Tiamat,* evil goddess of the briny subterranean waters.

The desert people naturally worshiped their own gods, among them the all-seeing god of the sun and the god or goddess of the moon, as well as the mysterious volcanic mountain gods who dwelt in the bowels of the earth and occasionally emerged from caves. These capricious gods with their pent-up power could lie dormant for long periods of time, only to awaken suddenly and cause the earth to tremble or the winds to kick up dust or even bring about a freak downpour.

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Finally, the coastal and island peoples worshiped the monsters of the sea (e.g., *Yam* and *Leviathan),* who had the power to roil the waters and either swallow the ships of the seafarers or smash them against the rocky shoals.

The societies in the various domains did not live in exclusive isolation. Rather, they were aware of, and influenced by, one another's cultures. The people of each domain often accepted the gods of other domains as minor deities alongside their own major gods. And when individuals or clans shifted from one domain to a neighboring one they generally accepted the supremacy of the gods that were relevant to their new domain (even while retaining an allegiance to their old gods—at least for a while).

One particular tribe, namely the Hebrews, appeared to deviate from the general pattern. As recorded in their collective diary, transmitted to us as the Hebrew Bible, they began during the early or middle part of the second millennium BCE. to traverse each of the regions domains. Originating in the eastern riverine domain of Mesopotamia, they embarked upon a venture of serial migrations. First they moved to the pastoral domain of eastern and southern Canaan, where they herded flocks of goats and sheep during the time of the Patriarchs. Some time later, in response to a severe and prolonged drought, they moved to the western riverine domain of Egypt, where—according to the story that remained indelibly imprinted in their ancestral memory—they sojourned for several generations. Next they left that domain at the time of the Exodus to enter into the desert domain of Sinai and the Negev, where they apparently wandered for some forty years. Finally, they emerged from the desert domain to reinvade the pastoral domain of southern Canaan and even to penetrate the rainfed domain of central and northern Canaan. As they entered the latter domains, they evidently encountered and clashed with another nation of invaders—the Philistines—an offshoot of the Sea Peoples who raided the coastal domains of the eastern Mediterranean at about the same time.

At this point, we offer what is admittedly only a conjecture. It seems plausible that the very fact of their inclusive ecological experience enabled the Hebrews, uniquely among their contemporaries in the region, to first perceive the notion of monotheism. Having sojourned in each of the domains and having shifted from one to another, assimilating elements of all the region's cultures, they could begin to coalesce the disparate deities into a concept of overarching unity.

At this point, we offer what is admittedly only a conjecture. It seems plausible that the very fact of their inclusive ecological experience enabled the Hebrews, uniquely among their contemporaries in the region, to first perceive the notion of monotheism.

The idea and ideal of a single omnipresent and omnipowerful force, a great common denominator unifying the entire realm of nature, was a radical departure from the prevailing pluralistic view. It could not have been a sudden, unanimous, and irreversible revelation. Instead, it must have been a painstaking process, first dimly perceived by a few and resisted by many and only accepted gradually after repeated advocacy by cultural and spiritual leaders in successive generations. We have abundant evidence of that process in the repeated exhortations and castigations by the Hebrew prophets against a nation all too prone to revert to the worship of the earlier naturalistic gods long seen as separate entities. The concept was eventually affirmed and carried forth by both Christianity and the Islam.

Eventually, however, the unified vision of nature took hold until it became the major ideological force that over time—much time—transformed the cultural foundation of the entire region, indeed of the entire world. Apart from its ritualistic or moralistic dimensions, which we associate with the practice of religion *per se,* achieving this unified vision was a precondition for the eventual development of a universalist science as a systematic common quest to understand nature as an integrated system.

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Gardens of Eden: Exotic Flora and Fauna in the Ancient Near East

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ABSTRACT
The idea of the garden began in the ancient Near East, in concert with the origins and development of agriculture, urbanism, and imperialism. From the start, exotic flora and fauna played vital roles in the world's earliest transformations of the natural environment, creating physical and metaphysical gardens of far-reaching significance. This paper examines selected aspects of exotica in Mesopotamia and Egypt, drawing together evidence from art, texts, and archaeology.

INTRODUCTION

Since earliest times, exotic flora and fauna have been integral components of the idea of the garden. As we cast our thoughts about nature and culture back across millennia to the ancient Near East, we see botanical and zoological gardens of every era replete with exotic plants and animals. There are, for example, the zoological firsts, bearing upon their striped and reticulated backs burdens of great social and political weight. The nineteenth century witnessed such firsts as the African animals brought to Antwerp and Berlin, evocatively installed in Egyptianizing pavilions as living testaments to colonial expansionism and to the triumph of order over the chaotic world (Hoage and Deiss 1996; Spongberg 1990). Then there were the first kangaroos in Europe, bred by the Empress Josephine in her gardens at Malmaison, as part of the Napoleonic imperialistic initiative in natural sciences (Chevallier 1993; Raby 1996). The year 1751 saw the first rhinoceros in Venice, an encounter for the Age of Enlightenment, didactic, and sometimes tiresomely pedantic, as shown in a "true portrait" by Pietro Longhi (Held and Posner 1971). In 1415, the imperial Chinese court examined its first giraffe (with some trepidation, judging from its handler's expression), as part of an ambitious African/Chinese trade agreement (Wilson 1992). About 800, the first elephant in northern Europe, one Aboul-Abas by name, made its way to Charlemagne, a gift from Harun al-Rashid to his counterpart in the West (Croke 1997). The citizens of Athens gathered to gape at their first tiger, presented in 323 BCE by Alexander's general Seleucus as a harbinger of the Hellenistic age (Ives 1996).

In the ancient Near East, for three thousand years before this Alexandrian tiger, exotic plants and animals were of considerable interest to royalty and private individuals. Some collected rarities out of intellectual curiosity, while others were motivated by potential economic rewards. Many rulers saw acquisition and display of exotic flora and fauna as effective ways to enhance prestige or to demonstrate imperial dominion over far-flung lands. Botanical gardens and zoos were often designed so that transplanted species could successfully establish themselves in their new environments. Specimens of exotic flora and fauna were prized as tribute offerings and suitable gifts for royalty. Certain non-native plants and animals were needed for the enactment of religious and other ceremonies. Finally, the controlled coexistence of exotic and indigenous flora and fauna in palatial and urban settings provided a powerful, living metaphor for mental maps of a more perfect world—the original gardens of Eden.

The present paper touches on selected aspects of this subject, drawn from my on-going, comprehensive investigation of the evidence from Mesopotamia, Egypt, and other areas of the Bronze Age world. My research has pursued three principal avenues of inquiry: exotica in art, texts, and archaeology. I have gathered over four hundred representations of exotic plants, animals, botanical gardens, and zoos. This wealth of artistic material raises the following questions, among others: How does the pictorialization of exotica demand new artistic solutions, instead of reliance on established conventions of rendering? What role does the introduction of exotica play in the stylistic development of narrative and landscape art? In what contexts are exotica situated geographically, so they serve as reliable maps of the hinterland and frontier? To what extent are depictions of exotica based on first-hand observation of species in their native habitats? What features of exotica become subsumed into a generalized thematic vocabulary denoting the strange or numinous?

Mesopotamian and Egyptian written sources abound with mention of non-native flora and fauna. My concern with textual material focuses on such issues as how exotic characteristics were described, the significance of exotica in figurative language, and the ways in which texts complement pictorializations, as captions or as parallel vehicles for ideological expression.

The archaeological record provides some evidence for the presence of exotic flora and fauna in the form of plant and skeletal remains, as well as excavated gardens and enclosures. The ancient Near East was home to three crucial, sequential developments in the relationship between nature and culture: (1) the domestication of plants and animals, and the start of agriculture; (2) the building of the world's earliest cities, with the concomitant first agrarian/urban dichotomies; and (3) the rise of the world's earliest empires and colonial powers. Within this context, my particular interest lies in defining archaeologically how exotic plants and animals played vital roles in the idea of the garden at its very beginnings.

EXOTICA IN MESOPOTAMIA

From nearly every period come Mesopotamian texts or representations pertaining to exotic fauna. In the Sumerian literary composition "The Curse of Agade," for example, the goddess Inanna describes the greatness of her city Agade, capital of the Akkadian empire ca. 2300 BCE: "Monkeys, mighty elephants, water buffaloes, and wonderful animals," she says, "jostle each other in the public squares" (Cooper 1983). In like manner, the royal Palm Court at Mari ca. 1800 BCE requested many exotic and rare animals, including Elamite cats, bears, and chamois (Wiseman 1983). Their desirability may be gauged by the fact that a chamois born en route to Mari was kidnapped by someone, though the mother animal arrived safely. Finicky animals like Mediterranean seals and dolphins were accompanied by their human handlers, who presumably were under strict instructions to see that their charges made it to their destination.

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As for exotic flora, "gardens enhance the pride of the city," says the Neo-Babylonian "Hymn to Ezida," especially those with unusual features (Wiseman 1983). Pleasure gardens and game parks with exotic specimens were maintained for king and populace. Several Sumerian texts describe how gods journeyed to visit certain temples to admire their gardens: Eridu, with its rare fruit trees and carp pools and Nippur, with its unusual palms and conifers (al-Fouadi 1969). Gardeners trained to care for these rare plants were much esteemed and well remunerated. Some exotic flora seem to have supplied the needs of perfume industries, temple rituals, and herbal pharmacopeia.

The most famous Mesopotamian gardens were one of the Seven Wonders of the Ancient World, the Hanging Gardens of Babylon. According to later sources, the Babylonian king Nebuchadnezzar (ca. 600 BCE) ordered artificial knolls, hills, and watercourses planted with exotic trees, shrubs, and trailing vines, all this effort so that his Median queen might be less homesick for her native mountains (Finkel 1988). Unfortunately, there is no archaeological evidence for these wondrous gardens. Many reconstructions at various locations in Babylon have been proposed, entailing such elements as vaulted supports, water wheels, terraces, and aqueducts. A recent study suggests that the Hanging Gardens may not have been at Nebuchadnezzar's Babylon at all, but at Sennacherib's Nineveh, ca. 700 BCE, where ingenious devices, forerunners of the Archimedes screw, raised water to several garden levels (Dalley 1994).

The Sumerian hero-king Gilgamesh is associated in symbolically important ways with indigenous and exotic flora and fauna. At the beginning and end of *The Epic of Gilgamesh*, he stands on the walls of his city Uruk, looking down at its rich gardens, part of his enduring legacy (Kovacs 1989). One of the epic's incidents involves cutting rare giant cedars and the dire consequences of that action. In a later episode, Gilgamesh travels in despair through darkness, searching for answers to his questions about death. He emerges into sunlight to find a garden of immortal jewels, with lapis lazuli foliage, carnelian fruit, and flowering clusters of semiprecious stones. A fictional letter composed centuries later as a school exercise has Gilgamesh request a shipment of rarities from an unnamed foreign king: thousands of black horses with white stripes, thousands of white horses with black stripes, and "anything precious, exotic, which I have never seen" (B. R. Foster 1995).

The Neo-Assyrian kings of the ninth to seventh centuries BCE elevated exotic flora and fauna to their greatest positions in the Mesopotamian imperialistic program (Aynard 1972; Curtis and Reade 1995; Reade 1983). During this period, relentless military campaigns extended Assyrian power from the Mediterranean to beyond the Zagros Mountains. Much of Assyrian art, especially palace wall reliefs, was propagandistic, intended to describe and commemorate events in distant places. In addition, the reliefs often served to depict plant and animal tribute from foreign lands, as well as their installation in botanical and zoological gardens that were the pride of kings.

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With Assurnasirpal II's building of a new palace and administrative center at Nimrud in 879 BCE, the acquisition of exotica escalated. Living tribute came to Nimrud from every quarter: monkeys, elephants, bears, rare deer, sea creatures. A major group of reliefs shows foreigners carrying luxury goods and prestige items, including a pair of leashed monkeys. The king himself actively sought out unusual specimens in the course of his military campaigns. As Assurnasirpal proudly writes, "I collected their herds, and caused them to bring forth their increase. From lands I traveled and hills I traversed, the trees and seeds I noticed and collected" (Wiseman 1983). No archaeological traces remain of what must have been extensive gardens, parklands, and animal enclosures at Nimrud.

Shalmaneser III, successor to Assurbanipal II, continued these patterns of acquisition and display, but sought to use exotica in art to greater narrative effect (Curtis and Reade 1995). Foreign topography, people, plants, and animals appear in more pictorially unified compositions, which visually confirmed their forcible integration into the Assyrian world. The embossed bronze bands made ca. 845 BCE for the massive wooden gates of a royal building at Balawat present Assyrian military and other enterprises, among them the royal visit to the source of the Tigris, or perhaps the Tigris Tunnel. The explorers wade through naturalistic grottoes, flares held high above the stream. The four sides of the ca. 825 BCE Black Obelisk bear register blocks showing tribute brought before Shalmaneser, including "camels whose backs are doubled," elephants, simians, and a single-horned creature, possibly a hippotamus. As on the Balawat Gate bands, exotica receive more sculpturally coherent treatment than they did in the essentially linear reliefs of Assurbanipal II.

A century later, Sargon II (721–705 BCE) founded a new capital city at Khorsabad, on the Khosr River north of Nineveh. According to his inscriptions, Sargon brought in skilled artists from Assyrian-held territories to embellish his palace (Curtis and Reade 1995). Perhaps due to their influence, the Khorsabad reliefs reflect a more sophisticated use of space, in which the Assyrians move with stylistic and personal assurance through landscapes rich in exotic flora and fauna. On panels depicting timber being transported by water, for example, wave and ripple patterns fill entire slabs, with exotic marine creatures swimming among the boats. Other scenes show Sargon's royal parks, complete with rare trees, elegant kiosks, and pleasure lakes. Assyrian hunting parties form overlapping friezes against a dense, controlled background of plants and animals.

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Sargon II's son and successor was Sennacherib (704–681 BCE), a king of exceptional vision. Early in his reign, he established a new capital at Nineveh. His "Palace Without Rival" featured rooms and courts decorated with sculptured panels unprecedented in their quantity and innovative quality (Russell 1991). For the narrative scenes, Sennacherib's artists filled whole slabs, as begun at Khorsabad, but here the layered divisions between foreground figures and background landscapes often disappear, resulting in more complex spatial and temporal relationships. Sennacherib's reliefs are the first internally consistent representations in Mesopo-tamian art, with exotica playing major roles in this development. In many instances, as in the marshland conquest scenes, they expand the pictorial field, while in others they afford cinemagraphically changing vistas undulating above and below the central narrative sequence, as in the throne room program of colossal winged bulls being quarried and transported. Not only are exotica rendered highly naturalistically, from the reeds bending in the current to the gnarled conifers clinging to wind-swept hills, but they also have become indispensible signifiers of Assyrian prowess.

Like his ancestors, Sennacherib used botanical and zoological gardens as important components of his reign's propagandistic message. To complement the "Palace Without Rival," Sennacherib's gardens were novel creations, inspired by the king's personal interest in hydraulics, botany, and animal breeding. As noted above, forerunners of the Archimedes screw brought water to intricately terraced gardens. Near Nineveh, Sennacherib reports that he "had a swamp made to control the flow of water, planted reeds there, and released herons, wild pigs, and other animals...the plantations were most successful; the herons which came from far away nested, and the pigs and others produced young in great numbers" (Wiseman 1983). Among the exotic trees in his orchards were ones "bearing wool," apparently a reference to cotton.

Some of Sennacherib's gardens still flourished in the reign of his grandson, Assurbanipal (668–ca. 631 BCE), whose reliefs at Nineveh include views of terraces with vaulted aqueducts, elaborate plantings, and pillared kiosks. If the Hanging Gardens were indeed Sennacherib's, these reliefs may afford an idea of their appearance. Other panels show Assurbanipal's own gardens and zoos, as well as foreign battles and lion hunts. Assurbanipal's sculptors seem to have been particularly interested in seeking fresh narrative possibilities. One is their increasing use of internal sequences as linking devices among multi-register panels. We follow, for example, a caged lion as it is released, springs forward, and is shot by archers. Another device is their insertion of cuneiform captions or epigraphs, especially into complex combat scenes filling huge slabs. A third involves their expanded understanding of the crucial importance of negative space in creating boundless potential for narrative statements.

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With these artistic means at their disposal, artists could rely less on exotica to provide the necessary temporal and spatial frameworks. Granted, Assurbanipal's botanical and zoological scenes contain exotica rendered with careful precision—vines twisting about trees, stems bending under the weight of lilies, deer trapped in taut nets. Yet the sense of situational, propagandistic immediacy is gone, replaced by confidence in the greater power of text and compositional manipulation. Historical events brought these developments to an end: fifteen years after Assurbanipal, Nineveh fell to the Medes, and the Assyrian empire was finished.

EXOTICA IN EGYPT

From the fourth millennium on, there was strong Egyptian interest in botanical and zoological life beyond the Nile Valley (Houlihan 1996; Hugonot 1989). Predynastic slate palettes and ivory handles of ca. 3100–2900 BCE depict exotic and fantastic animals, as well as living tribute or booty, though it is difficult to evaluate their commemorative significance. The earliest definitively historical texts pertaining to exotica record Old Kingdom expeditions to the Levant to obtain cedar wood. Reliefs from the funerary temple of the Fifth Dynasty pharaoh Sahure (ca. 2458–2446 BCE) depict the departure and return of such a venture, which also brought Syrian bears to Egypt. During the Sixth Dynasty, the young pharaoh Pepi II (ca. 2246–2152 BCE) requested a dancing dwarf or pygmy from the African land of Yam, for he desired this "more than the gifts of the mine-land or of Punt" (Lichtheim 1973). Harkhuf, the successful expedition commander, included Pepi II's letter of instructions in his autobiographical tomb inscription. The child-pharaoh was particularly anxious lest this special being, considered more exotic than human, fall overboard in the night.

Middle and New Kingdom pharaohs continued to sponsor the collection of exotica, especially as the Egyptian empire expanded southward into Nubia and northward into the Levant. The Eighteenth Dynasty pharaoh Thutmosis III (ca. 1479–1425 BCE), for example, conquered Megiddo and washed his weapons in the Euphrates. He commemorated one of his Syrian campaigns with a series of wall reliefs carved in side chambers near his Festival Hall at Karnak Temple (Beaux 1990). Nearly three hundred types of exotic plants, animals, and birds appear in these "Botanical Garden" reliefs, many of which are artistic creations meant to convey the idea of the unusual, even the bizarre, rather than any botanical or zoological reality. For that, gardens and zoos existed in the vicinity of the royal residences, certainly since the Old Kingdom. Those of Thutmosis III perhaps included four remarkable birds "that laid eggs daily," the first domestic chickens in Egypt (Houlihan 1996). On a Nineteenth Dynasty ostracon, an artist sketched a rooster, apparently drawn from life, possibly on a visit to a royal menagerie (Houlihan 1996). Rameses II (ca. 1290–1224 BCE) outdid Thutmosis III's exhibition of a large dead rhinoceros with display of a live one of prodigious size, whose measurements are given next to its representation (Houlihan 1996). At his new city in the Delta, to cite another example, the Twentieth Dynasty pharaoh Rameses III (ca. 1194–1163 BCE) designed a "sacred way, splendid with flowers from all countries" (Hugonot 1989).

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In literature, love poetry speaks of exotic trees planted as durable tokens of affection in the beloved's garden (Manniche 1989). Other love songs make liberal use of garden imagery, stressing the rich eroticism of perfumed flowers, shining pools, and ripening fruit (J. L. Foster 1974). Properly cultivated trees were metaphors for model behavior, as seen in "The Instruction of Amenemope," part of a peculiarly Egyptian literary genre (Simpson 1973). Yet gardeners themselves suffered poor reputations, objects of ridicule in caricatures and in "The Satire on the Trades" (Parkinson 1991), and targets of indignities to prove their innocence of pilfering, as recorded in a Demotic contract of the late first millennium BCE (Parker 1940).

The close Mesopotamian relationship between territorialism and exotica is similarly reflected in the tomb paintings and reliefs of numerous high-ranking officials of the New Kingdom. Many of these individuals seem to have directly participated in imperial activities.

Amenemhab, for instance, accompanied Thutmosis III to Syria, there encountering a herd of elephants: "I engaged the largest which was among them. I cut off his hand [trunk] while he was alive" (Davies 1940). On the lintel of his Theban tomb, Amenemhab fends off a giant hyenalike animal in a surreal landscape studded with fantastic plants reminiscent of those in the Karnak reliefs of Thutmosis III. The artist has supplied the visual counterpart to the narrative of heroic imposition of order upon a chaotic, non-Egyptian world.

Another of Thutmosis III's henchmen, Amenmose, went to Lebanon to collect tribute (Wreszinski 1923). His tomb artist emphasized the event's importance by painting it on a separate wall of the tomb. The tribute bearers are shown against a screen of cedars whose slender trunks are vertical stripes in the venerable Egyptian stylization of papyrus thickets, but instead of the expected umbels, here they are topped by ovoid, pointillistic crests. On the one hand, the exotic cedar forests are seen to conform to an ordered, familiar pattern under Egyptian domination, while on the other, the skillful inclusion of evocative details provides a particularized backdrop for effective narrative.

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Geographical orientation of exotic tribute played an important part in the development of New Kingdom tomb narratives. Representations of African flora and fauna appear on southern walls, while Levantine plants and animals are painted on northern walls. The tethered processions include elephants, bears, baboons, leopards, lions, antelopes, and monkeys, one of whom hitches a ride on the neck of a giraffe in the tomb of Rekhmire, vizier of Upper Egypt under Thutmosis III and Amenhotep II (Wilkinson 1983).

The middle colonnade of the Eighteenth Dynasty pharaoh Hatshepsut's funerary temple at Deir el Bahri, ca. 1450 BCE, contains an unusually complete program of wall reliefs depicting exotic flora and fauna (Herzog 1968; Kitchen 1971; Smith 1962). The subject is her expedition to Punt, probably located on the Horn of Africa, a destination at least since the Old Kingdom, but never before recorded in images. Egyptian ships sail southward to Punt on the south wall, while the formal announcement of their return is on the north wall. Six registers show Punt: its forests inhabited by exotic animals; its domed dwellings raised on stilts; its diminutive king and his amply proportioned queen; its natural treasures of ebony, frankincense, and myrrh.

Hatshepsut was justifiably proud of her idea to transplant myrrh saplings to Egypt to ensure a local supply of the costly material needed for incense and mummification. We observe a full narrative sequence, from the young trees carried aboard in Punt to the lush myrrh garden thriving in front of the temple at Deir el Bahri. In standard Egyptian practice, the trees are planted in rows and columns of pits filled with Nile alluvium (Hugonot 1989). Later pharaohs were less fortunate with their myrrh tree importations; perhaps the Puntites realized how competition would affect their market, and cannily cut the tap roots before balling them up (Dixon 1969).

In several important ways, the artists gave new life to Hatshepsut's repeated, propagandistic cliché: "Never was brought the like of this for any king who has been since the beginning" (Smith 1962). First, the renderings of the Punt exotica are highly naturalistic, implying a measure of first-hand observation, rather than reliance on the usual Egyptian recourse to hybridism, transference, or copying from pattern-books. In addition, the upper registers are wider and longer than the bottom ones, in part because the adjoining wall sloped inward in the Egyptian batter mode. This creates a subtle interplay between the lower village, with its ordered ranks of Egyptians, and the upper forests, with their towering trees, exotic animals, and raised huts seemingly lost in the foliage. Finally, the Punt exotica appear as sets of curvilinear shapes, a dramatic foil to the rectilinear formality of the Egyptian delegation. In the "Punt Colonnade," image and text combine to demonstrate how Hatshepsut's successful mission transformed the exotic forests of Punt into the ordered gardens of Egypt.

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CONCLUSIONS

This concludes our brief tour of physical and metaphysical gardens in the ancient Near East. Neatly enclosed, carefully tended, deliberately provided with exotic and indigenous species—these were the original Gardens of Eden (Delumeau 1995). It was in just such a garden that God planted the two most exotic trees of all: the tree of life, and the tree of the knowledge of good and evil.

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Between Paradise and Political Capital: The Semiotics of Safavid Isfahan

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ABSTRACT
In the late 16th century the Safavid Shah Abbas I established Isfahan as the capital of his empire. He designed a plan on a monumental scale in the garden fields south of the old Saljuq center, which integrated the river Zayendehrud into the formation of the new palatial city. The orthogonal intersection of the Chahar Bagh Avenue and the river created a *chahar bagh* (four garden) pattern on the scale of a city, which produced a synthesis between Persian and Islamic concepts of paradise, Turkic nomadic traditions of ritual and social uses of gardens, and the principle of a royal capital city. The symbolism and figurativeness of Isfahan within the frame of a *chahar bagh* cannot be completely separated from traditional notions of garden and paradise, but goes beyond the allegoric interpretation of religious or mystical references to Islamic paradise, bearing distinct iconographic and deliberate political connotations of empire. This paper is based on the hermeneutic analysis of Safavid gardens and contrasts traditional interpretations of Persian and Islamic gardens along the paradigm of paradise with an expanded definition of the political implications of paradise.

Have you seen Isfahan, that city like Paradise,
That holy cypress, that soul nourishing Eden;
That palace of the nation and that throne of government
That face of the seven spheres, that eye of the seven lands.[1]

PROLOGUE

The visual image of Isfahan has been inextricably shaped both by its architecture and its royal palace gardens. The city is acclaimed for the magnificence and splendor of its architecture, triumphant remainders of the Saljuq and Safavid empires. It has inspired generations of art historians, architects, archaeologists, artists, photographers, and tourists. Through city guides and coffee table books, Isfahan's architectural images were reproduced and proliferated into worldwide photographic effigies,[2] through which the domes and portals of the Safavid mosque *Masjid-i Shah*, the *Masjid-i Shaykh Lutf Allah*, the large plaza of the *Maidan-i Naqsh-i Jahan*, the palatial gardens of the *Bagh-i Hasht Behesht*, the labyrinth of the bazaar and the portico of the Saljuq *Masjid-i Jami*ʿ have been promoted as the epitome of Islamic architecture.

In the latter half of the 20th century the pressure for industrialization in Iran created new concerns, and the development of urban centers brought renewed attention to Isfahan. The acceleration of urban growth and modernization programs under the aegis of the White Revolution, the Shah's 1960 land reform and industrialization program, generated studies on urban development, city planning, road construction, municipal infrastructure, water supply, sewage treatment, and the preservation of historical architecture.

[1] Jamal al-Din Isfahani: *Divan-i Kamil*, ed. Vahid Dastgirdi, Tehran, 1320, p. 410.
Didi tu Isfahan ra an shahr-i khold-i Paikar
An sidr-yi muqqadas, an ᶜadn-i ruh parvar
An bargah-i millat va an takhtgah-i dawlat
An ruy-i haft 'alam an chishm-i haft kishvar.

[2] Among the most renowned of these are Wilfried Blunt's *Isfahan, pearl of Persia*, and Lockhart's *Persian cities*, London: Luzac and Co. Ltd. 1960, and the recent publication of photographs of Isfahan by Nasrollah Kasraian.

The need to combine the city's historical corporeality with modern urban development has directed the interests of historical research and archeological investigations toward the background and development of individual palaces, mosques, shrines and palatial gardens, with less emphasis on their wider urban context or the historical and environmental morphogenesis of the Safavid city.

The strategic location, abundant water supply and fertile land facilitated the expansion and development of Isfahan in the 17th century on an unprecedented scale. As Safavid capital, Isfahan provided a synthesis between the complex relations of cultural perceptions of land, political expressions of territoriality and royal self-representation which were articulated by the symbolic language of its gardens and buildings.

Garden and paradise are two themes which are inextricably attached to Isfahan and recur in associative descriptions as well as taxonomic distinctions. A closer examination of the layout of Safavid Isfahan shows an internal order, which is structured along the axial quadripartite pattern of a *chahar bagh* (literally four gardens) formed by the axes of the river Zayendehrud and the royal avenue *Khiaban-i Chahar Bagh.* This underlying urban plan or composition combined the principles of Turco-Iranian forms of city and Perso-Islamic and Timurid patterns of garden. It created a dialectic relation between garden and city, based on the implicit practical interdependence of the natural environment and the architectural semiotics of royal political representation.

The traditional metaphorical interpretation of the Qur'anic or Islamic paradise as the quintessential rationale behind Persian gardens is epistemologically insufficient to explain the interactive patterns between the religio-political system and the iconography of a garden on the scale of a city. The ostentatious, almost monumental layout of the new city suggests that it was not a coincidental pattern but deliberately planned by its founder Shah Abbas I (1587-1629). Poets and writers consciously chose the metaphor of paradise to celebrate Isfahan's beauty and extol its pre-eminence as imperial city. The ubiquitous contemporary insinuations and poetic allusions of Safavid gardens to the Garden of Eden as well as the literary comparisons of Isfahan as *khuld-i barin*, the eighth level and uppermost tier of paradise, keep them explicitly tied to the idea of paradise.[3] The implicit figurative connotation of Safavid Isfahan's quadripartite division along the four garden or *chahar bagh* model cannot be wholly separated from common religious notions of paradise either. Yet they reach beyond the allegoric interpretation of religious or mystical references to Islamic paradise, and bear a distinct political idiom. The textual and iconographic hermeneutics of royal Safavid

[3] The label of paradise for Isfahan has developed into a standard topos. Carl Ritter called it "die Paradiesische Stadt" in the early 19th century in *Die Erdkunde von Asien*, vol. VI, G. Reimer, Berlin, 1840, p. 21. The analogy has since proliferated as Isfahan's standard epithet.

gardens, and of Isfahan specifically, ultimately lead to a synthesis between the paradise paradigm applied by traditional interpretations of Islamic gardens and the political intentions of Safavid architectural and urban representation.

THE PROFUSION OF GARDENS AND THE PARADISE PARADIGM

Gardens and their associated cultural and practical principles were a major component of the new royal city laid out by Shah Abbas I in the late 16th century in the suburban fields between the old Saljuq city and the river Zayendehrud. Identified as an Islamic dynasty, both in religious and political terms, Qur'anic notions of paradise have been understood as both the guiding motive and principle behind Safavid gardens. The concept of "Persian garden" in traditional interpretations has become almost synonymous with "Safavid garden." In their dual Persian and Islamic traditions, the architectural, artistic, and iconographic expression of Safavid gardens has conventionally been interpreted as a metaphor of paradise, referring to both the Biblical and Qur'anic descriptions for paradise.[4] The Safavid garden has been seen as the apogee of the artistic temporal and human construction of the religious metaphysical paradisiacal garden of Islam.[5] The association of garden with paradise was strongly influenced by the pervasive images and epithets such as *Hasht Behesht* (the eighth paradise or eight paradises), *Bagh-i Jannat* (paradise garden), and *Bagh-i Eram* (terrestrial paradise), as well as evocations and metaphors in their inscriptions, poetry and mystical traditions.

Western writers, especially since the late 18th and 19th century, inspired by contemporary archaeological trends, excavations and the neo-classicist trends in Europe, both explored and re-enforced the logical sequence of pre-Islamic and Biblical notions of paradise. Since Xenophon's use of the word *Paradeisos* for the gardens of Cyrus the Great,[6] Persian gardens have been inseparably associated with their historical Achaemenid precedents, interpreted as terrestrial allegory of metaphysical, celestial Paradise. Early European travellers and explorers used the texts of Xenophon and other classical Greek writers as historical and literary reference, which were consulted and re-used by writers and travellers of the 18th and 19th century, who produced spirited descriptions of the scents, flowers, fruits and nightingales in Persia's gardens. "Alexander [the Great] is written to have seen Cyrus's tomb in a paradise," wrote William Temple in the 17th century, "so that a paradise among them seems to have been a large space of ground, adorned and beautified with all sorts of trees, both of fruits and of forest, either cultivated, like gardens, for

[4] For Qur'anic descriptions of paradise see e.g. surah 3, 16; surah 4, 14, 58, 123; surah 6, 100; surah 3, 42-48; surah 47,16; surah 55, 63-77; surah 56, 16-35. For a brief discussion of Quranic descriptions of paradise see: Marianne Barrucand: Gärten und gestaltete Landschaft als irdisches Paradies: Gärten im westlichen Islam, in: *Der Islam*, vol. 65, no. 2, 1988: 244-246. Biblical concepts of paradise are for example the Garden of Eden, Gen. 2, 1-14: profuseness and pleasure, Gen. 13,10; abundance of water, Ez. 47, 1-12; fertility, Os. 2, 2-24; celestial journey of Paul, 2 Cor. 12, 4; eschatological visions, Apc. 2, 7.

[5] Giovanni Curatola, for example, wrote, "with the Safavids the Persian garden paradise seems to reach its apex." In Garden and garden carpets: an open problem, in *Environmental design, water and architecture*, ed. A. Petruccioli, Aug. 1984: 92.

[6] Xenophon, *Oeconcomicus*. Paradeisos is derived from the Avestan *pairi-daeza*, meaning fenced in space, garden. For a more detailed examination of its etymology and transmission see Fauth: Der Königliche Gärtner, in *Persica*, no. VIII, 1979: 5–6.

shades and for walks, with fountains or streams, and all sorts of plants usual in the climate and pleasant to the eye, the smell, or the taste, or else employed, like our parks for inclosure and harbour of all sorts of wild beasts, as well as for the pleasure of riding and walking: and so they were of more or less extent, and of differing entertainment, according to the several humours of the princes that ordered and inclosed them."[7]

Traditional metaphorical interpretations of Persian or Islamic gardens have correlated the general orthogonal symmetry to God's perfection and transcendent purity. The straight lines have been seen to represent *tawhid*, divine unity, and sacred order between man and nature, in which order and harmony were expressed in mathematical regularity and unambiguous geometric patterns. The figure of the *chahar bagh* has been interpreted to denote the four quarters or directions of the universe. The orthogonal waterways have been seen to symbolize the four rivers of Eden;[8] the water as the Christian and Muslim symbol of moral and sacred purification, the fish as unequivocal symbol of life, the towering cypress trees, pointing to the metaphysical after-life, as symbol of death, and lastly, the garden as universal metaphor for the positive and symbiotic relation between man and nature, where water channels give replenishment, green trees render comforting shade, and fruit orchards extend pleasure and nourishment.[9]

The paradise paradigm as analytical interpretation for Safavid gardens has developed into a conventional and strongly established topos with few variations or attempts to expand the hermeneutics of the theorem or to explore the gardens' shape, function, and iconography in their historical context. A great deal of literature has been produced about the metaphysical and religious interpretations of the physical configuration of Safavid gardens. The general analytical approach to Persian gardens has classified them within their linear historic epochs, but the interdependence between garden and garden landscapes and the historical, cultural and political environment which produced them remains understudied. Research on Safavid gardens has primarily focused on the separate palatial gardens of Isfahan and others, such as the *Bagh-i Fin* in Kashan or the large garden complex of the *Bagh-i Shah* at Ashraf and Farahabad along the Caspian coast in Mazandaran. The driving ideas and the visions of the builders and architects, the meaning of spaces and architecture beyond the conventional and "terrestrial paradise," and the gardens' aesthetic and functional use, however, have been largely neglected. The method of describing the palatial gardens in an essentially kaleidoscopic juxtaposition, conveying their radiance, sensuality, and aesthetic expression, has not devoted enough atten-

7 William Temple: Upon the gardens of Epicurus, or, of gardening, in the year 1685, in: *Five miscellaneous essays*, ed. Samuel Holt Monk, Ann Arbor, University of Michigan Press, 1963, p. 8. For the trend and scope in the literary tradition of western approaches to garden history, and 19th and early 20th century uses of the classics see i.e. Sieveking, Albertus Forbes: *Gardens, ancient and modern*.

8 "A river flowed from Eden to water the garden. The first is named Pison and this winds all through the land of Havilah where there is gold. The gold of this country is pure; bdellium and cornelian stone are found there. The second river is named Gihon, and this winds all through the land of Cush. The third river is named Tigris, and this flows to the east of Ashur. The fourth river is the Euphrates." Genesis 2, 10–4. *The complete parallel bible*, Oxford University Press, 1989.

9 The most important studies, providing symbolic interpretations, and descriptive analyses with an emphasis on the internal sacredness and beauty of Isfahan's gardens are Hanaway's "Paradise on Earth: the terrestrial garden in Persian literature." Ralph-Pinder Wilson's "Persian garden: Bagh and Chahar Bagh," in: E. B. MacDougall and R. Ettinghausen, (eds.): *The Islamic garden*, Dumbarton Oaks, Washington, 1976; and Donald Wilber's *Persian Gardens and Garden Pavilions*, Charles E. Tuttle, Vermont, Tokyo, 1963. The most recent publication on historic gardens in Iran rehearses this inseparable connection as the book's *leitmotif* with the title *Persian gardens: echoes of paradise*. It portrays an intense and beautiful visual impression of historical Persian gardens within the framework of the paradise topos. Khansari, Mehdi; Moghtader, M. Reza; Yavari, Minouch *The Persian garden: echoes of paradise*, Mage Publishers, Washington D.C., 1998.

tion to the historical processes of their development, transformation, and relation to each other as a formation in a whole city or the interaction of the structural and metaphorical concept of garden and city, which is particularly evident in Isfahan.

The flourishing green countenance of Isfahan has earned it the designation "city garden," which has been used in a sensual and almost romantic sense.[10] In expressly visual descriptions, Safavid and Qajar Isfahan has been identified with the "profusion of gardens." [11] As one of the many travellers of the early 19th century described it, "the valleys and plains for many miles around Ispahan, are adorned with villages and plantations; and the first view which the traveller has on coming from Shirauz, of this great metropolis, is from an eminence, about five miles from the city, when it bursts at once upon his sight, and is, perhaps, one of the grandest prospects in the universe."[12] The European tradition of this description goes back to that of early depictions of travel authors like the physician and travel-explorer Engelbert Kaempfer (in Isfahan in 1684-85), Pietro della Valle (in Isfahan in 1619), Thomas Herbert (1628), Jean Chardin (1660s-70s), John Fryer (1677) and others. Without exception they invoked the impressive green resplendence after a journey through the dry, orche yellow, almost moon-like landscape of central Persia.

Sir Thomas Herbert, who sojourned in the city at the end of Shah Abbas I's rule, described Isfahan as "the metropolis of the Persian monarchy. Yea, the greatest and best built City throughout the Orient." He found that the city's gardens "challenge our attention; than for which grandeur and fragor, no City in Asia out-vies her. It incloses so many that at some distance from the city, you would judge it a Forest; so sweet you would call it a Paradize."[13] All sides of the city were "beautiful, from the richness of the plain, profusion of gardens and the domes and towers of mosques and palaces, rearing their heads from amidst verdant groves of poplars, sycamores, and cypresses of the most noble size;" reads J. S. Buckingham's description.[14] "Nothing can exceed in beauty and fertility, the country in the vicinity of Isfahan, and the first appearance of that city is very imposing. All that is noble meets the eye: the groves, avenues, and spreading orchards," wrote Sir John Malcolm a few years later.[15] The accounts offered a persuasive picture, which continues to be invoked by descriptions of Isfahan and its gardens today. Providing a sense of drama, they serve mostly as adornment to emphasize the extraordinary, without concern for the functional synthesis of garden and city expressed by the morphology of Isfahan.

The general symmetry and linear geometric patterns of Islamic and Persian gardens have often been contrasted with the "disorganized" and "unstructured" formation of the Islamic city. Although the

[10] Moghtader et. al. *Echoes of paradise*, p. 69; also see Haneda "The Character of Urbanization of Isfahan in the Later Safavid Period," *Pembroke Papers*, 4 (1996), pp. 369-88, reprinted in: Melville: *Safavid Persia*, p. 375.

[11] By J. S. Buckingham *Travels in Assyria, Media, and Persia, including a Journey from Baghdad by Mount Zagros, to Hamadan, the ancient Ecbatana, researches in Ispahan and the ruins of Persepolis*, 2 vols., Henry Colburn and Richard Bentley, 1830, p. 367.

[12] Kinneir, *Geographical memoir*, p. 112-3.

[13] Herbert *Some years travels*… pp. 153 and 158-9.

[14] In *Travels in Assyria,* vol. I, p. 367.

[15] Malcolm *Sketches of Persia*, London, John Murray, 1849, p. 129.

ecological and political symbiosis of Islamic suburban gardens and cities have been recognized, the innate principles and functions of the Islamic city and garden have conventionally been contrasted as implicitly antithetical.[16] The underlying formal structure of Safavid Isfahan incorporated an intentional quadripartite division with an inherent relation to the external urban expression of the city. The building of the new Safavid palace quarter created a dialectic affiliation between the old urban and new palatial center. Yet the development and expansion of the city, without the strict separation of the suburban gardens and the districts of the old center by a compact city wall, facilitated their gradual convergence.

Shah Abbas I's design of Isfahan was a pragmatic scheme, which aimed at a calculated synthesis of the practical and symbolic concept of garden and city and carried an implicit political dimension. The theme of garden was an essential exponent of Isfahan's Safavid morphology and internal rationale, which in its symbolic and political expression went beyond the phenotypical appearance.

HISTORICAL PARAMETERS OF THE SAFAVID CITY

Isfahan has been an important urban center since its origins as a military camp during Sassanian rule. Its enduring geo-strategic location, its agricultural advantages, and its facile and abundant supply of water from the Zayendehrud, (meaning the life-giving, the reviving, as well as the revived), enabled the city to develop into a leading metropolis. Isfahan's strategic position at the center of the commercial transit routes from China to the Ottoman empire and Europe, and the Persian Gulf to Russia, as well as the dual base of both agriculture and commerce, provided the essential pillars for its survival as urban center. This position determined the recurrence of a historical cycle of decline and prosperity, its repeated rise and fall from imperial to provincial capital.

Historically and architecturally Isfahan is most closely identified with the Safavids, but it had also been the political headquarters of the Buyids in the 10th and early 11th century, whose tenure, in spite of volatile political leadership, represented a period of prosperity for the city. Isfahan remained the center and political capital for most of Saljuq rule and regained this position five centuries later under the Safavids. The borders which outlined the domains of the Great Saljuqs placed Isfahan at the core of their empire's territories. Saljuq Isfahan's commercial and cultural prosperity reached its zenith during the reign of Malik Shah (1072-1092), when Isfahan also emerged as a leading center of Sunni theology. It was a period of internal architectural activity,[17] which produced several great royal gardens including the *Bagh-i Falasan*, the *Bagh-i Bakr*, the *Bagh-i*

[16] I.e. see Grandval in Moghtader: *Echoes of paradise*, p. 8.

[17] Malik Shah's vizier Nizam al-Mulk established the famous *Nizamiyya* in the quarter of Dardasht. Numerous official and private buildings, mosques and parks were built, including the *Bait al Ma'* (Water House), the *Qaleh-yi Shahr,* and the *Qaleh-yi Diz Kuh,* the *Masjid-i Jami'* and the *Saljuq maidan*, which after it was transplanted by the Safavid city at the turn of the 16th century, became known as the *Maidan-i Kuhneh*.

Ahmad Siyah, the *Bagh-i Dasht-i Gur* (Garden of the Wild Donkey's Plain).[18] The presence of the Saljuq government was contingent upon the economic and cultural prosperity of the city and many of the paradigms of Isfahan as a unique city, its geographical advantages, its fertility, its beauty, its sophistication, its tradition as a chief center of learning, culture and trade. Its famous epithet *nisf-i jahan*, meaning half the world, date to its position and aspirations as capital under Saljuq rule.

During Mongol rule Isfahan remained an influential city and commercial center, but it regained its political pre-eminence only with the Safavids. In the 17th century, at the height of Safavid territorial domination, the empire stretched from Mesopotamia, Gorjestan and Daghestan along the Qaraqum desert to the Sulaymaniya Mountains in the east. Its territory replicated the geo-political order of the Saljuqs, again placing Isfahan at the center of the empire's crossroads. By moving his court and the seat of government from Qazvin to Isfahan in 1597–98 Shah Abbas I (1587–1629) re-enforced Isfahan's geographical advantages and its commercial importance by making it the political capital of his empire. The scope of historicaal memory and presence of Saljuq records at the time of the Safavids has not been sufficiently documented but there is some association with the historical precedence and the role of Saljuq Isfahan in the 12th century. Iskandar Beg Munshi cited Kamal al-Din's eulogy of the Saljuq capital in praise of the architectural achievements of Abbas the Great in the early 17th century: "Isfahan is flourishing and the people happy, nobody has a recollection of an epoch like this."[19]

Shah Abbas I himself designed and planned the new city, south of the old Saljuq center, laying the new bazaar and royal quarter on the existing urban and suburban landscape.[20] There is only vague information about the landscape of pre-Safavid Isfahan, but earlier gardens had existed outside the central Saljuq city and the palace grounds of the *Bagh-i Naqsh-i Jahan* and a *dawlatkhaneh* located there were known since the 15th century.[21] Although there remained a certain dichotomy between the old and the new city, by the late 17th century, the Safavid quarter seemed to have coopted the old city physically as well as economically and politically. The Safavid city both engulfed the historic Saljuq district and through the junction of the bazaar and the *Maidan-i Shah* connected the new commercial and political center. The rapid growth of the city, the influx of human resources and money, the architectural expansion, as well as the introduction of artistic and political culture under Safavid rule thoroughly transformed the urban landscape. Shah Abbas' monumental layout of Isfahan, its architectural countenance

[18] E.G. Browne. pp. 567-610; and 849-887; in: *The Journal of the Royal Asiatic Society*, 1902, p. 597. (Summary of Mafarrukhi's *Kitab-i Mahasin-i Isfahan*.) Also see Honarfar Lotfollah: *Ganjineh*, p 57. For a list of names of other historic gardens see Alireza Aryanpour: *Pashuhesh dar Shenakht-i Baghhay-yi Iran*, p. 42.

[19] *Isfahan huram ast va mardum shad In chinin 'ahd kasi nadarad yad*. Munshi, *Tarikh*, p. 545.

[20] Abbas I's transferral of the new city away from the old Saljuq center is distinctly shown in Quiring-Zoche: *Isfahan im 15. und 16. Jahrhundert*, p. 200. Also see Mashashi Haneda, schematic reprint of Seyyed Riza Khan's 1923-4 map in: "The Character of Urbanization of Isfahan in the Later Safavid Period," *Pembroke Papers*, 4 (1996) 369-88, reprinted in Melville, *Safavid Persia*, pp. 369-387.

[21] The Venetian traveller Michelle Membré in the autumn of 1540 noted the beauty, the fine drinking water, and "many waters and gardens" outside the city, which he had still found enclosed by a mud wall. Membré, Michelle: *Mission to the Lord Sophy of Persia, 1539-1542,* transl. by A.H. Morton, School of Oriental and African Studies, 1993, p. 47. Also see Rosemarie Quiring Zoche: *Isfahan im 15. und 16. Jahrhundert*, pp. 36, 62 and 75. To the four gardens built by Malik Shah in Isfahan, see Mafarrukhi, al Mufaddal ibn Sad: *Kitab-i Mahasin-i Isfahan*, Matbu'at-i Majlis, Tehran 1993.

with his and his successors' palaces, mosques, bazaars, and extensive gardens within and without the city determined the physical and architectural profile by which Isfahan still continues to be identified at the dawn of the 21st century. Isfahan has acquired the title of 'Safavid city' and "anything that was to survive," as phrased by Bagher Shirazi, "was covered by Safavid color and forms."[22] As he points out, the Arabs, Buyids and Saljuqs who successively ruled the city had done the same, but none of their building and restructuring of Isfahan was as profound as that of the Safavids.

THE *CHAHAR BAGH* AND THE SEMIOTICS OF THE CAPITAL CITY

The physical layout of the post-Saljuq city was devised by Shah Abbas I with a "preconceived master plan."[23] Iskandar Beg Munshi reported that Abbas I, in the spring of 1598-97, after spending the winter in Isfahan, decided to implement the building plans for the city. He began with the building of the quarter of the *Bagh-i Naqsh-i Jahan*. After eighteen years the architects, engineers, builders, artist and craftsmen had completed the "sublime" buildings and gardens of the *Naqsh-i Jahan*, which were part of the shah's very own plan.[24]

A closer examination of Abbas the Great's ground plan of Isfahan south of the old Saljuq center reveals a transposition of the intersecting pattern of the walled Persian garden, with its clear quadripartite formation, the orthogonally intersecting water canals and an octagonal pool at the center of the channels' intersection.[25] Outlining the orientation of the royal city, the Zayendehrud created natural east west axis, crossed by the Chahar Bagh Avenue, which was divided by the *shah jub*, the main canal in its center and stretched from north to south. The direction of the Chahar Bagh Avenue with the center and sideway *jubs*, or water channels, was in this way used for the conscious re-construction of the quadripartite Persian *chahar bagh* on the scale of a city. It crossed the Zayendehrud over the Allahverdi Khan Bridge,[26] reaching from the *Darb-i Dawlat*, the gate of the royal precinct of the *Bagh-i Naqsh-i Jahan*, to the south side of the Zayendehrud as far as the garden of Abbasabad on the foot of the mountains, south of the city.[27] Albert de Mendelslo, who with Olearius was in Isfahan in 1637 under auspices of the Duke of Holstein's mission, described the "Tsarbagh" as the "King's Garden," which was divided by the Zayendehrud "so that it seems to make four Gardens of it."[28] Engelbert Kaempfer (1651-1716), who lived in Isfahan during the rule of Shah Suleyman for nearly two years also referred to this motive. "The royal avenue *Chahar Bagh*, i.e. four gardens," he explained, "derived its name from the fact that in conjunction with the

[22] Bagher Shirazi "Isfahan, the Old: Isfahan the New," in: *Iranian Studies*, vol. 7, part II, no. 3-4, 1974, p. 589.

[23] Bagher Shirazi, p. 588.

[24] Munshi 1955, pp. 544-545. Of the process of Abbas I's gradual move from Qazvin to Isfahan see Roemer 1974, p. 306-331 and Quiring-Zoche 1980, pp. 105-6. On the interdependence between the old section of the Saljuq city and the new Safavid part see Bagher Shirazi, ibid.

[25] On the structure and layout of Persian cities see Bonine 1979, pp. 208-224. Bonine emphasizes the functional aspect and technical necessity for irrigation of city structures. For a classification of the various types of gardens which have been generally subsumed under the model of *chahar bagh*, see Mahvash Alemi "Il Giardino Persiano: Tipi e Modelli," in A. Petruccioli (ed.)1994; idem: "Royal Gardens of the Safavid Period," in Petruccioli (ed.) 1997. Alemi questioned the view that the *chahar bagh* pattern manifests a strictly geometic quadripartite formation of gardens. Emphasizing the asymmetric elements in garden plans, she rejects the stereotyped symmetry and rigid axialities, concluding that the *chahar bagh* pattern does not correspond to a four part plan (Alemi 1986).

[26] Today it is mostly referred to as *Si-u-se-pul*. By contemporaries it was also called *Pul-i Chihil Chishmeh* or simply *Pul-i Chahar Bagh*. See Fryer, p. 296. Also see Honarfar Lotfollah *Ganjineh*, pp. 487–488.

[27] Munshi, p. 544. The garden was later known as the *Bagh-i Hizar Jarib*. Shahab Katouzian argues that the perpendicular axis between the Chahar Bagh and the Zayendehrud creates the synthesis between city and garden, the city's design being "based on the garden itself." "The Sense of Palace in Persian Gardens," in *Environmental Design*, Rome, 1 and 2, 1986, p. 47.

[28] de Mendelslo 1662, p. 331.

transverse intersecting river it partitioned the terrain into four garden areas. It begins behind the royal residence and stretches southwest in a straight and projecting line to the front side mansion and burgeoning Residence Hizar Jarib."[29] The layout of Isfahan itself embodied, hence, a garden with its implicit symbolism of the four realms of the universe, the metaphorical space of the king's domain. The *Khiaban-i Chahar Bagh* was one of the most acclaimed urban structures of the time. It was understood as the central axis through which the palatial city garden was articulated.[30] In his contemporary account Munshi particularly extolled the uniqueness of the Chahar Bagh Avenue. Kaempfer, too, emphasized the Chahar Bagh as the pivot of the city's layout. Like Herbert, who found the Chahar Bagh "remarkable in that abundance of green, broad, spreading, Chenor trees, yielding shade, and incomparable order and beauty," Kaempfer was impressed by the extraordinary size and height of the plane trees, which by the time he lived in Isfahan were about sixty years old, their luxuriant branches casting shade over the street, by forming a green portico or *Taq sabz* over the Avenue.[31]

In a brief paper about urban modernization and expansion, Baqher Shirazi emphasized the historic geographic premises of the Safavid construction of Isfahan. "For the first time in its history," he noted, "Isfahan received two quite distinct orthogonal axes of expansion: the natural east-west axis (the river Zayendehrud) was augmented by the artificial north-south axis (Chahar Bagh)." The existing old commercial center of Isfahan circumscribed the expansion of the new urban midpoint. To secure access to the first draw of irrigation water, the *dawlatkhaneh*, had to be situated south, closer to the banks of the river, and further west, toward the upstream direction of the Zayendehrud. While the growth and expansion of the Safavid city shifted the center away from the existing commercial town, causing the decline and decay of some of the old quarters, it overgrew and converged with the pre-Safavid city. Shirazi argued that the "main organic linear center," of the city persisted and the axes of the Zayendehrud and the Chahar Bagh Avenue remained chiefly the axes of the royal quarter: "nevertheless, they determined the total extension of the city in the centuries to come. The artificial north-south axis passed over the river on one of the most noble city elements," the Allahverdi Khan bridge.[32] The physical development of the city took place within the topographic delineation of Abbas the Great's city plan. "The implementation of the plan whose north-south extension was about six kilometers in length," recounted Shirazi, "imposed its geometric order on the immediately bordering new quarters, like Abbasabad and Julfa, while the expansion of other

[29] Kaempfer: *Aemontitatum*, Fasc. I, p. 172. It is quite possible that Kaempfer simply used de Mendelslo's explanation. The Safavid sources do not comment on the etymology of the name, for which the European literal tradition makes only a tenuous proof. Pinder-Wilson (1885) is cautious about the principle mentioned by Mendelslo and Kaempfer. MacDonald Kinneir thought the avenue's name being based on its structure, "so called from its connecting the upper and lower *Chahar Baug*, [...], which runs from the royal square to the foot of the mountains." Kinneir, *Geographical Memoir*, p. 112. Most architectural accounts and garden studies, however, ascribed its name to the four vineyards which Abbas I supposedly had to buy when he built the avenue. This was advocated by Curzon, *Persia*, vol. II. p. 38. Iskandar Beg Munshi mention's that four gardens were laid out at each side of the street. He does not indicate that these four gardens gave the street its name. Savory in the annotation of his translation of Munshi claims that this was the origin of the name. Munshi: *Tarikh*, p. 544, Savory: *History*, p. 724.

[30] Porter 1994, p. 26.

[31] Kaempfer: *Aemoenitatum*, Fasc. II, p. 287. Herbert, *Some years Travels*, p. 159 and Fasc. I, p. 173.

[32] Not the *Pul-i Khaju* as he wrote, which was the bridge connecting the Chahar Bagh Avenue. Bagher Shirazi, ibid., pp. 588–589.

quarters followed the organic growth of the old town and only picked up the direction of the plan."[33]

Safavid gardens are considered the pinnacle of Persian garden culture, but are distinctly influenced by the tradition of their historical antecedents. The form and function of Timurid gardens, which were used for military encampments and as sites for political and social activities, clearly recur in Safavid gardens.[34] Shah Abbas was born in Herat in 1571 where he lived until succeeding to the throne. The ground plan of Herat, whose urban profile had been extensively shaped during Timurid suzerainty, was divided into a very distinct quadripartite pattern. The Deccan city Hyderabad, which was planned in 1589 by Muhammad Quli Qutb Shah ten years before Abbas I's move to Isfahan, was based on an axial quadripartite pattern and founded on the garden suburb of Golkonda.[35] Shah Abbas I may not have seen Hyderabad, but he was definitely familiar with the idiom of the design of Herat. Terry Allan has argued that the "axial arrangement of the pavilions and gardens" west of the *Maidan-i Shah* was "derived directly from the organization of Timurid gardens." It was in the new city of Shah Abbas' Isfahan and the gardens of Babur's Kabul "that the memory of Timurid Herat lived on most vividly."[36]

There has been a conspicuous correlation between the construction of grand gardens and territorial expansion; Timur began to build the gardens at Samarkand as he increased his territorial control. The Mughal shah Akbar (1556-1605) constructed large gardens at the height of his rule, and Abbas the Great began to design and build his capital after ten years of continuous military confrontations with the Ottomans.[37] The growth of Isfahan as *Dar al-Saltaneh* (Abode of Royal Government or Kingship) of Abbas I went hand in hand with vital internal military reforms, leading to the lasting subversion of the Turcoman military aristocracy and the expansion of Safavid frontiers. Between 1596-98 he incorporated the vassal states of Mazandaran, Lahijan and Rasht and, in 1592, Gilan. In 1598-99, a year after making Isfahan the seat of government, Shah Abbas reconquered Herat and Mashad from the Uzbeks and expanded to Balkh, Marv, and Astarabad. In 1010/1601 he annexed Bahrain. In 1013/1603-04 he went to war with the Ottomans, in defiance of the humiliating 1590 peace agreement, and repossessed Azerbaijan, Nakhchievan, Erivan, with a major victory over the Ottoman troops in Tabriz. Further campaigns in 1607-08 restored Shirvan and Gorjestan under Iranian control. The territorial expansion and consolidation took place concomitantly to the increasing centralization of the political administration which made Isfahan the symbol of the rise of Safavid Iran.[38]

[33] Shirazi, ibid., pp. 588–589.

[34] E.g. Wilber1979, pp. 127–134.

[35] Hyderabad was also called Bhagyanagar, which is generally believed to be derived from the shah's concubine, a Hindu dancer called Bhagamati. Another explanation is that the original name was Baghnagar, meaning the City of Gardens, for which however contemporary documents do not exist. The axes of Hyderabad, like in Isfahan, were laid out from E-W and N-S. See Shah Manzoor Alam: *Hyderabad-Secunderabad*, pp. 23. Also see Annemarie Schimmel: *Deciphering the signs of God: a phenomenological approach to Islam*, Edinburgh University Press, 1994, p. 78. For a schematic map of Herat see Niedermayer and Diez: *Afghanistan*, Leipzig, 1924, which is reprinted in Gaube: *Iranian cities*, p. 45. Gaube argued in Isfahan "the new urbanistic concept introduced in Samarqand and Herat found its fulfillment." Ibid. p. 62. To both cities also see: Petruccioli: "Il Giardino come anticipazione dell città. Stoire parallele," in Petruccioli: *Il Giardino*, pp. 99-101.

[36] Terry Allan *Timurid Herat*, Ludwig Reichert Verlag, Wiesbaden, 1983, p. 55.

[37] See Roemer *Persien auf dem Weg in die Neuzeit*, pp. 310-312. Before the rise of Herat, Timur had named the quarters around Samarkand Sultaniyya, Shiraz, Bagdad, Dimashq, and Misr (for Cario) to indicate the supreme position of Samarkand as supreme city of his empire. see: Barthold "Herat unter Husein Baiqara," in *Abhandlungen für die Kunde des Morgenlandes*, XXII, 8, p. 11.

[38] "Symbol des Aufstiegs," as Roemer put it, in *Persien auf dem Weg*, p. 319.

Shah Abbas' decision to transfer his seat of government to the former Saljuq capital and re-develop the city was based on strategic, economic, and political considerations, as well as his personal liking of the city's climate; beyond this, it was an implicit reflection of his expansionist territorial goals and desire to create a specifically Safavid capital.[39] The relation between territoriality and royal gardens has been discussed in the context of Timurid and early Mughal gardens, which functioned as basis for conquest, the contention for a consolidated empire, places of exercise of power, and military and cultural domination.[40]

The reconstruction of Isfahan according to Abbas I's plan shows comparable intentions. The consolidation of his territorial ambitions, his growing political and military hegemony, the centralization of the empire's administration, and the avowal of the Safavid doctrine of kingship as the Shadow of God on Earth, *Zill al-allah fi al-arz*, were epitomized in his plans of the city of Isfahan. The fact that the bridge, which connects the lower with the upper Chahar Bagh Avenue, was built by and carries the name of Allahverdi Khan, the *sepahsalar*, (commander in chief), contains a clear reference to the territorial and hegemonic connotation of the city's design.

As has been pointed out by the many architectural studies, the *Maidan-i Shah* created and represented the spatial and physical nexus of the bazaar, the religious establishment and the government.[41] Most travelers have drawn attention to its commercial function, describing the many tents of fruit and vegetable sellers. Kaempfer recounted that in the 1680s the spaces of the lower floors around the four sides of the square's gallery were occupied by craftsmen and traders, while the upper floors were divided into small rooms for lodging which were also rented to foreigners, visitors and occasionally prostitutes.[42] Reports by later travellers about soldiers being housed on the rooms of the upper gallery alongside the square, and the para-military polo games, *chawqan*, played and practiced on the *Maidan* at the time of Abbas I, seem to indicate that in addition to its commercial and public use it also had a military function.[43] Its titles *Maidan-i Naqsh-i Jahan* or *Jahan Nameh*, insinuate an expansionist perspective which confirms the semiotics of power and conquest behind the architectural structure of the city.

It has been argued that Abbas I was essentially an "itinerant" ruler and the concept of capital city as "permanent center for government and administration did not apply to this phase of the Safavid state."[44] The success of his military and political objectives could not have been predicted in 1006/1597-98. Nonetheless he seemed clearly intent on creating Isfahan as his political headquarters and royal capital of a consolidated Safavid empire. The city and

[39] Isfahan had serious strategic advantages. It was closer to the eastern borders and the Persian Gulf than Qazvin or Tabriz and it was still close enough to the western frontiers, which occupied by Ottoman troops. Hafez Farmayan stresses the origin and tradition of Isfahan as an old Iranian city, and choosing Isfahan has capital was also sign of the Iranization of Abbas I's regime. Farmayan, Hafez F. *The Beginnings of Modernization in Iran: The policies and Reforms of Shah Abbas I 1587-1629*, Middle East Center: Salt Lake City: Utah, 1969.

[40] See e.g. James Wescoat "Babur and the Timurid Chahar Bagh, Use and Meaning," in: *Environmental Design, Mughal Architecture, Pomp and Ceremonies*, 9th year, no. 11; and idem, "Gardens vs. Citadels: The Territorial Context of Early Mughal Gardens, in MacDougal *Garden History*.

[41] See Haneda "The Urbanisation," in Melville *Safavid Persia*, p. 3.

[42] Kaempfer *Aemonitatum*, p. 170. Iskandar Beg Munshi describes the rooms along the Maidan as *chahar bazar-i Naqsh-i Jahan* or as *khanat-i havali-yi Naqsh-i Jahan* Munshi: *Tarikh*, pp. 830 and 836. Savory has simply translated them as "shops;" *History*, pp. 1037 and 1044.

[43] See Kaempfer's drawing of the *Maidan* where cannons and armament are spread out in front of the Ali Qapu and tents of small scale traders are set up only in front of the *Quisarieh*; *Aemonitatum*, between pp. 170 and 171. Showing the military use even more distinct is the drawing by Hofstedt van Ess, reprinted by Alemi, in *Il Giardino*, p. 52.

[44] Charles Melville "The Itineraries of Shah Abbas I," pp. 11-26, cited in Susan Babaie *Safavid Palaces*, p. 44.

the political administration grew despite the shah's repeated absences from the city on military campaigns. The grand scale of Isfahan's plan, his restorations of the existing bazaar and pragmatic efforts to invigorate the commercial life as well as the permanent establishment of the royal administration, all belay his intention of laying the groundwork for a capital city on a long term basis. Sir Thomas Herbert who witnessed its shape after the development of almost thirty years, compared its rise as capital and symbol of Safavid hegemony with the imperial supremacy of ancient royal palace cities like Babylon, Tauris, Persepolis and Nineveh. In a bulky eulogy he deliberated the city's idiom of power.

> "[...] Now royall Abas rules, Spahawn must rise.
> (Where Kings affect, there most men cast their eyes,
> There flock the people:) 'tis his power not thine
> Which hath eclipst their light, to make thee shine.
> Then use thy fortune so, that none from thence
> May with thy fall, or grudge they eminence."[45]

The Chahar Bagh Avenue, which formed the central axis of Abbas I's city plan, was lined with thirty gardens along its sides. It posed as the urban representation of the Safavid states' administrative and military backbone. "The vast expanse of territory which is divided into four areas by the intersection of the street and the river," explained Kaempfer, "is partitioned by walls into thirty gardens." "Shah Abbas the Great [...] has not only personally chosen the position of the palace complex and demarcated the extension of the city," explained Kaempfer, "but furthermore, was also supposed to have determined the size and the design of the described gardens, attuned to the surrounding terrain."[46] He was awestruck by the beauty of the small domiciles, surrounded by wide and unblemished walkways, trees, flowers, and clear water pools.[47] These gardens were given to the chief officials courts, who also had the first right to channel water for irrigation into their gardens.[48] Under Shah Sulayman's rule (1666-1694) they continued along the *Khiaban-i Chahar Bagh* after the four royal gardens, including the *Bagh-i Khargah*, the *Bagh-i Hasht Behesht*, the *Bagh-i Musaman* and the *Bagh-i Takht*. The owners of these gardens along the Avenue were the shah's chief officials, among them, the *Sufidar Bashi* (commander of the Safavid order), the *Qullar Bashi* (commander of the royal guard), *Qurchi Bashi* (commander of the cavalry), and the ˆ (quartermaster general).[49] Between the four royal gardens and the river were seven societal lots, including the *Takiyyeh-yi Ni'matullah* and the *Takiyyeh-yi Haidar*.[50]

[45] Thomas Herbert *Some Years Travel*, p. 153.

[46] Kaempfer *Aemontitatum*, Fasc. I, p. 198. Also see Honarfar, *Ganjineh, p.479-493.* Also see Baqer Shirazi ibid., p. 589. Masashi Haneda argues that it is not certain whether there were special quarters for the Jews and Indians. See "Urbanization of Isfahan," in Melville: *Safavid*, p. 386.

[47] Kaempfer *Aemoenitatum Exoticarum*: Politico-Physico Medicarum, Fasc. I, pp. 173–174.

[48] See Fryer *A New Account*, pp. 240 and 296.

[49] See Kaempfer's drawing of the *Bagh-i Naqsh-i Jahan*, and the Chahar Bagh Avenue, which shows all thirty gardens with the names of their owners. Reprinted from the Sloane collection of the British Library, in Mahvash Alemi "Gardens of the Safavid Period," in Petruccioli, *Gardens in the Time of the Great Muslim Empires*, pp. 82 and 83.

[50] Isfahan, like most Safavid cities, was divided into two zones between the order of the Ne'matollahis who controlled the eastern part of the city and held the Takkieh on the eastern side of the Chahar Bagh, and the Haydaris who commanded the quarters roughly along the west of the Chahar Bagh Avenue, and held the Takkieh on the western line of gardens. See Ansari: *Tarikh-i Isfahan*, pp. 97-98. For a general discussion about the background of the

Kaempfer also pointed to a historical continuity of which Abbas I, if not deliberately imitating it, must have been aware. "With the planning of the Chahar Bagh," expounded Kaempfer, "he was said to have directed the delineation with his own hands, which he proved himself as real and laudable descendant of the great Cyrus, who as may be read in Xenophon, took the design of gardens as a kingly occupation and who not seldomly planted plants and measured the rows of trees also with his own hands."[51] Thus, the city's internal rationale as well as its external representation states a direct link between kingship and the creation of gardens. The practical act of the shah himself mapping, planning and planting a tract of land is also expression of the royal control and ownership of territory.[52]

The Safavid garden and the city of Isfahan as a large example of such, had definite functional, symbolic, and aesthetic links to the Safavid state. The van of the royal garden was usually created by a palace, which was the governing point of the garden's structure. The palace and the garden created an organic unit with a gradual progression from the interior of the palace through a transitional narthex (*ivan* or *talar*) which is both part of the palace and the outdoors, leading into and also connecting the garden to the building. Akin to the classical palatial garden, the urban space devised by Abbas I through the crossing of the Chahar Bagh Avenue and the Zayendehrud was presided over by the royal quarter and *dawlatkhaneh*, the *Bagh-i Naqsh-i Jahan* on the northern end, and overseen by the *Bagh-i Hizar Jarib* on the southern end. It created the same relation between the central palace and government quarter and the city as existed between a palace and its surrounding garden, in which the palace constitutes the head and the focus of the system.

The architectural iconography of royal gardens, as much as it provided a space for pleasure and enjoyment, also articulated the domination over nature, including the control of land and water, the source of life and prosperity *sine qua non*. Traditional interpretations understood the use of water in pools and fountains as the obvious symbol of life. In the context of a more pragmatic rendition the use and display of water, and in the case of Isfahan the river as part of the city's *chahar bagh* pattern, recognizes the eternal interdependence of the organic relationship between the river, the city, and the surrounding country side and is a statement of the absolute royal guardianship over life and property.

Shah Abbas I had gradually turned most of the lands in Isfahan and its surroundings from *mamalik* (state lands) into *khasseh* property (land and estates owned by the crown). Rather than a reflection of the mere religious-metaphysical relation to nature, Safavid royal gardens, and Isfahan as a royal garden on the scale of a city, are a

Haydari and Ne'mati division see Hossein Mirjafari: "The Haydari and Ne'mati Conflicts in Iran" in *Iranian Studies*, vol XII, 1979, pp. 135–162. Kaempfer mentions that Shah Sulayman was a follower of the Haydaris.

[51] Kaempfer *Aemontitatum*, Fasc. I, p. 198. Iskander Beg Munshi does not mention the Achaemenids, but he does compare the Safavid gardens and palaces of Isfahan to Sassanian palaces, *Tarikh*, p. 545. For discussion of the image and role of Khavarnaq in Iranian epic literature see Renard: *Islam and the Heroic Image*, pp. 173 and 175.

[52] Also see: Wescoat, "Picturing an Early Mughal Garden," in: *Asian Art*, fall 1989, p. 76.

reflection of the socio-political aspects of the division, control, organization of land ownership and cultural production.

Isfahanis were always proud of the exceptional fecundity of Isfahan's earth, its bounteous river and good climate. The surviving notion of Isfahan being a place with special benison has its roots in Saljuq times. It was believed that Isfahan was at the center of the "fourth clime", which in the system of Ptolemaic cosmology was considered the best of the earth's seven astrological belts, each of which was presided over by a planet.[53] The location of Isfahan in this world system has been used to explain its outstanding fertility, and has played an important role in the justification of its eminence as a city and the attribution of its paradisiacal qualities. The city's epithet *nisf-i jahan* (half the world) as well as the name *Bagh-i Naqsh-i Jahan* (Garden of the World's Picture) of the palace complex, offers the notion of Isfahan at the center of the empire, and the world in imperial and religious terms. This suggests that Shah Abbas positioned his capital in a deliberate competitive self-definition with the world. The semiotics of the location and architecture implies a political, cultural as well as religious hegemony. Under Safavid patronage Isfahan developed into the foremost center of Shi'ite theology and orthodoxy in the Islamic world. Iskander Beg Munshi notes that Abbas I built the *Masjid-i Shah* intending to surpass the *Masjid-i Aqsa* in Jerusalem and the *Ka'ba* in Mecca, which is a clear statement of ambitions beyond the local or regional.

The quadripartite delineation of Safavid Isfahan also denoted the hierarchical order of the cosmos, pointing to the position of the world and the shah within it. The city was at once the creation and the reflection of the king's domain. Abbas I's conception of Isfahan perpetuated the function of garden as an allegoric and symbolic political order on multiple levels. It centered in the internal space of palace courtyards and from there expanded to the level of the walled palace and government gardens of the *Bagh-i Naqsh-i Jahan*, to the next level of the city with its axial center from where it extended to the level of the province, and after that to the expanse of the empire's domains. This pattern may be interpreted as perpetuating further from the territory of the empire, encompassing the realm of the globe and reaching from there to the metaphysical world of the universe to the seven spheres of heaven, to the *'arsh*, the throne or seat of God.[54]

The palaces and gardens of the later Safavids like the *Hasht Behesht*, the *Aineh Khaneh*, Shah Sultan Hussayn's garden of Farahabad, were mainly extensions to this fundamental structure. They reflected greater ostentation and a panoply of royal self-representation with a stronger emphasis on pleasure and enjoyment as opposed to the articulation of political and territorial aspirations, which is discernible in the earlier gardens, palaces and mosques of Shah Abbas I.

[53] See "Account of a rare manuscript History of Isfahan," described by E.G. Browne in: *The Journal of the Royal Asiatic Society*, 1902, pp. 414 and 419. Also see Hamdallah Mustawfi al-Qazvini *Nuhzat al Qulub*, transl. by Guy Le Strange, E.J. Brill, Leyden, 1919, pp. 55. For discussion of the theme of Iranian cosmology in literature see Renard *Islam and the Heroic Image*, pp. 79–80.

[54] See the diagram of J. Wescoat in "Gardens versus Citadels: The Territorial Context of Early Mughal Gardens," in MacDougall, *Garden history, issues, approaches, methods*, p. 347. John Renard pointed out how in the literary epic *sira* of Antar ibn Shaddad, "the hero's adventures unfold in a quadripartite world, each quarter of which constitutes the realm of an integral monarchy. The four realms are Byzantium; Sassanian Persia, with its capital at Ctesiophon, (Mada'in); the region of Hind and Sind [...]; and what one might call `greater Ethiopia.'" Renard, *Islam and the Heroic Image*, p. 169–70.

EPILOGUE: THE POLITICAL CIRCLE OF PARADISE

The figurativeness of Safavid Isfahan conveyed a pervading sense of a leading city, as cultural, political, religious and imperial center and the exclusive domain of the shah. The motives of political and dynastic self-representation in Shah Abbas' layout of Isfahan and the iconographic as well as textual references to paradise remain inextricably attached to Isfahan. Contemporaries consistently applied the metaphor of *khuld-i barin* or *khuld-i paikar* to the city. Rustam al-Hukama, chronicler and native of Isfahan, left no doubt that when Aqa Muhammad Khan Qajar conquered Isfahan at the end of the 18th century it was a city equal to the highest paradise, *khold-i barin*, despite the destruction caused by the tribal and civil wars of the 18th century. Yet, he not only intended to praise Isfahan's beauty and express his liking of its open and metropolitan spirit but also to underscore its political stature and superiority.[55]

In his research and publications about Mughal gardens, James Wescoat argues that Mughal gardens expressed a "denotation but not connotation of Islamic Paradise," that is, they "achieved the form, but not the meaning of paradise gardens."[56] This subtle but crucial distinction applies to Safavid royal gardens as well.

Aesthetically, Safavid gardens, like Mughal gardens, incorporated clear references to the pictorial imagery of Qur'anic paradise, but the builders' semiotic intent had also pragmatic goals with roots in the profane world, which was largely disinterested in the eschatologic implications of a metaphysical paradise in its essentially religious or theological meaning. Further readings of Safavid theological, scientific, and philosophical texts may yield more precise insights into the contemporary *weltbild* and the implications of cosmological models on political legitimacy as well as the relationship between paradise and political hierarchy.

Aside from the *Bagh-i Hasht Behesht* (The Garden of the Eighth Paradise) the names of the early palatial gardens laid out by Abbas the Great carry largely political-secular connotations which invoke size, status, and often their function, like the *Bagh-i Abbasabad* or *Hizar Jarib* (The Thriving Domain of Abbas or Garden of a Thousand Acres), *Bagh-i Naqsh-i Jahan* (Garden of the World's Picture), *Bagh-i Takht* (Garden of the Throne), *Bagh-i Khargah* (Garden of the Donkey), and those of simple ownership or cultivated fruit.[57]

Persian Islamic gardens have developed in a dialectic cycle of pre-Islamic Persian garden traditions and Islamic and Qur'anic notions of paradise, which derived their imagery of paradise from contemporary pre-Islamic and Persian traditions. The forms of Pre-Islamic Persian gardens have roots in the antecedent garden structures of Mesopotamian and Egyptian gardens and probably absorbed

[55] Muhammad Hashim Asif, Rustam al-Hukama *Rustam al-Tawarikh*, ed. Muhammad Mushir, Intisharat-i Amir Kabir, Tehran, 1352, p. 454.

[56] James Wescoat " From the Gardens of the Qur`an to the Gardens of Lahore," in *Landscape Research*, 20 (1) 1995, pp. 19-25.

[57] The *Bagh-i Hasht Behesht* was only built in 1670, by Shah Sulayman (1667–1694).

major structural, functional and aesthetic patterns from Assyrian Gardens of the 8th century BC.[58] The Safavids created a Shi'ite state and orthodoxy, whose theological system provided a direct basis of political legitimacy. At the same time, there are evident pre-Islamic Iranian traditions which surface in Safavid notions of divine kingship, with direct implications for politics and statehood. The Qur'anic or Islamic paradise as connection between both is not implausible, as Qur'anic images of paradise have roots in the pre-Islamic Persian and Mesopotamian traditions of worldly gardens. The concept of *chahar bagh* in the Safavid city garden of Isfahan thus has links to the metaphysical divine order of political power, which the Safavids deliberately insinuated.

The two interpretations, political-functional and metaphysical-sacred or theological, are not necessarily contradictory. If 16th and 17th century royal Persian gardens are analyzed as representative of royalty, reflection of kingship and territorial control, the theological aspect or divine inspiration of Safavid kingship has again a metaphysical and theological aspect, albiet with political consequences.

The allusions the Qur'an in Safavid gardens were less a reflection of the theological and eschatological meaning of the Qur'anic paradise. In the case of Isfahan, the *chahar bagh* pattern staged a nexus of pre-Islamic Iranian traditions of divine kingship and Shi'ite concepts of legitimacy. Safavid gardens, and Isfahan as a grand royal garden on the scale of a city, had very strong elements of regal self-representation. It was an expression of royalty, power, and a statement of political sovereignty as it was innately linked to the rise and fall of the Safavid empire. Its symbolism combined worldly political power with the theological mandate of monarchical authority, through which the Safavids aimed to balance divine kingship and Shi'ite legitimacy. This is based in the metaphysical world, where paradise is the domain or abode of God, the absolute and ultimate source of might and authority.

The form of the classical Persian garden was a deliberate *leitmotif* in Shah Abbas' location of the capital and the outline of the new part of the city. The organization of Safavid Isfahan represented a space of political consolidation, the epitome of centralization, expression of dynastic legitimacy and the primary center of exercise of power and territorial control. Isfahan was thus the quintessential royal garden and not only the geographic but also the allegoric midpoint of the Safavid empire, the *Maqarr al-saltaneh*, the royal city and residence of the shah, the highest abode of paradise, the definitive source and center of power.

[58] On the influence of Achaemenid and Sassanian Gardens see R. Pechère "Etudes sur les Jardins Iraniens," in *Les Jardins de l'Islam: Compte Rendu du 2`eme colloque International sur la Protection et la Restauration des Jardins Historique Organisé par l'Icomos et l'Ifla*, Granada 1973, pp. 19-25; David Stronach "Paterres and Stone Watercourses at Pasargadae: Notes on the Achaemenid Contribution to Garden Design," *Journal of Garden History* (special edition of "Site and Sight in the Garden, ed. by E. Kryder-Reid and D.F. Ruggles,) 1993. See also Mahvash Alemi "Der Persische Garten: Typen und Modelle," in *Der Islamische Garten*, Architektur, Natur, Landschaft, ed. Attilio Petruccioli, Deutsche Verlags-Anstalt, Stuttgart, 1995, pp. 39 and 41. Most important to the discussion of the relationship between kingship and garden during the Acheamenids and Sassanians is the article of W. Fauth "Der Königliche Gärtner" in *Persica*, no. VIII, 179, pp. 1–53.

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Rethinking the Islamic Garden

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ABSTRACT

A broader inquiry into the relationship among the garden's form, structure and meaning should aim to address two crucial issues: (1) the need for common ground in research which will organize the field and foster future scholarly work and (2) the importance of laying out an analytic method capable of shedding new light on the garden's formative process and in informing new urban development. This paper underscores how the garden has always played a crucial role in any anthropic process. It examines how the structural relationships among its components reflect other forms of settlement, such as the encampment, the royal palace, the city as an image of the king, and finally, the larger landscape. It suggests a new direction for further study based on two axioms: that there is a substantial continuity between different cultures in their appropriation of space, and that there are pertinent methodologies to retrace the garden's evolution.

PULLING THREADS

The wonders of Harun al-Rashid's garden described in *A Thousand and One Nights* have never existed. They were fictional hyperbole. But not everything is poetry and imagination. The renowned description recalls many gardens in *Dar al-Islam* from Samarra to Granada, Lahore, and Isfahan. Rather than depicting a single garden, it portrays an attitude toward the environment shared by the entire Islamic world: the taming and glorification of nature enclosed within four walls, juxtaposed with the hostile wilds of the outside world.

What is left of it? What is the impact of this philosophy in today's world? The first question has been answered by a vast scholarly body of work which can be seen as a collective effort to gather the information necessary to address the second, and more important issue.

Attention within European culture to the Islamic garden began in the 17th century, as part of a general discovery of the East. "The taste for Oriental culture and Islamic imagery, already present during the rococo," writes Paolo Portoghesi, "suddenly erupts in Europe. The new fascination for the exotic symbolized the emancipation from an academic classicism, the inspiration of which had, by then, almost completely dried up." The Islamic garden was one of the most seductive symbols of the new, exotic world—the place where the novel taste for space and decoration was most freely expressed.

Its influence can be seen in the Moorish decorations of Villa Torlonia, in Villa Melzi's casino, in the landscaping of the Stibbert garden in Florence and, most strikingly, in the Sezincote villa and in the Royal Pavilion of Brighton, England. By the 19th century, the infatuation with Islamic culture had become a glamorous fashion: it was extensively exhibited in World Fairs, chosen as the "official" architectural style of thermal resorts, and eagerly showed off first by the bourgeoisie and then by the masses. Its influence continued throughout the 19th and into the beginning of the 20th century, before the Modern Movement's disenchantment with it and its final oblivion.

Alas, much of this oriental contagion was born out of pure excitement for the new and unknown, based on a few exotic-looking objects and the enchanting, passionate accounts of travelers upon their return from the East. As a result, the Islam portrayed in Europe was merely an enthusiastic reinterpretation of a culture heavily filtered by the merchants of the time.

The first pragmatic studies on the Islamic garden didn't attract much attention. They came as late as the first quarter of the 20th century, produced by two researchers to whom much is owed for the diffusion in Europe of the history and form of the Islamic garden. C. M. Villiers-Stuart analyzed all Mughal gardens, although still captured by their exotic atmosphere and botanical species rather than by their spatial and structural layout; her romantic portrayal of ornate details was more reminiscent of Gertrude Jekyll's *Garden Ornament* (1918) and less of a methodological study. A more substantial contribution was offered by *Die Indische Garten* (1923) by the Baroness M. L. Gothein, who had already authored *Geschichte der Gartenkunst* (1913). For the first time, the Indian garden was studied as a structural whole within a specific context, examining it as a product of Indo-Muslim culture.

Overall, these two works laid the foundation for further Islamic garden studies. They were all the more precious for witnessing and reporting information at a time when the Civil Service, with great efficiency but mediocre preparation, restored Mughal gardens according to romantic models rather than according to original features. Also, at that time the possibility of unlimited substitutions of plants and trees had drastically complicated any botanical research on the original species. More than in architecture, where wounds and transformations can't mislead an expert eye, the original character of a garden can be erased: drastic changes often occurred in only one generation's time, completely altering previous forms and meaning. Scientific studies on vegetal fossils and seeds, or on the chemical composition of the terrain (like the ones undertaken in Pompeii) are still far from a reality in the Islamic world. In the end, the original literature, the iconographic archives and the survey of ruins have got to carry the day themselves.[1]

Scholarly interest in the Islamic garden has somehow revived in recent years, along with the passion for European gardens, and Italian gardens in particular. In the 1970s, however, the Islamic garden was still considered to be of marginal importance. Its study still showed a general lack of method. In *The landscape of man* (1972), S. Jellicoe dedicated a few superficial paragraphs to it; N. T. Newton (*Design of the land*, 1971) wrote two brief chapters on the Andalusian garden as part

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[1] However, accurate philological research can achieve unexpected results, such as Parpagliolo Shepard's identification and philological reconstruction of the Babur garden in Kabul (1972).

of a general historical introduction; F. Fariello's *Architettura dei Giardini* (1967) didn't reach any further.

A second generation of British scholars (Crowe and Haywood, J. Lehrman, E. B. Moynihan, D. Wilber, and many others) gets the credit for finally doing the dog's job: an unprecedented systematic survey, catalogue, and database of Islamic gardens existing to date, although many publications lack graphic evidence and, perhaps consequently, a careful spatial analysis. We had to wait until 1988 for the renowned work co-authored by C. Moore, W. J. Mitchell, and W. Turbull, Jr. to have an interdisciplinary reading of the most famous gardens and their underlying design ideas—a research approach of great nourishment and crucial importance.

However, it seems that, apart from scholarly research, we are slipping back to 19th-century World Fair trends: today the Islamic garden, perhaps less than Islamic architecture and decoration, is adopted as an easy model of an artificial pan-Islamism, centrifuging all forms and meanings within *Dar al-Islam*, and scattering them around the world with modern mass-media nonchalance. On one side, this process is made easy by the eclectic character of Islamic art, since the laws of Islam discipline daily life but avoid any strict regulation on art and architecture. Its art almost always joins sophisticated concepts with a vernacular tradition that, through a blend of craftsmanship's variations-on-a-theme and popular fantasy, cannot help but be eclectic. On the other side, Islamic art has never produced a precise code like Classical architecture, nor suddenly shifted taste, style, or fashion. Rather, it has always preferred to elaborate on its universal but multifaceted grammar, varying it by minimal changes and adjustments over time.

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All these elements further complicate research. In approaching a complex theme such as the Islamic garden, one of the first discoveries is that the idea of unity within diversity is, in reality, multilayered over centuries of seemingly unimportant mutations. The Islamic Garden, then, or gardens of the Islamic world? We can start addressing the question by outlining the archetypes belonging to three different pre-Islamic roots: the Arab, the Persian, and the Turkish—three concepts of nature, and consequently of space.

In Arab geographers' and travelers' reports, we note their excitement about tame and well-ordered nature, but also their lack of enthusiasm for the wilds. *Locus amoenus* coincides with *locus ferax*. But pleasure is possible only through contrast: if green gardens stand for paradise, hell wears the yellow sand of the desert. The concept of space in a culture evolved from the desert is by necessity based on protecting living space, thus transforming the enclosure into an archetypal sign of distinction—not only separation—between the nomadic and the sedentary, between oasis and desert, irrigated and arid land. There can be no dialogue between the two: the enclosure almost becomes a fortress under constant attack from the desert's symbolism-thirst, death, and evil spirits. Sheltered by high walls, the Arab can enjoy the perfumes and colors of his paradise in solitary sensual pleasure.

The pursuit of order in the Arab garden is taken to the extreme in Persia. Here a biaxial symmetry—although a third zenithal axis is always implied—is the means of drawing earth and cosmos together. Everything is organized according to this principle: the layout of architectural elements, the hierarchical organization of decorative symbols, even the practice of gardening. Sophisticated and passive, the Persian garden is a place for contemplation: "Persians don't walk in gardens as we do, but look at them from one viewpoint only," writes the 16th-century traveler and merchant Jean Chardin. Excluding the hectic commercial city by a well-defined enclosure, the geometrical order simul- taneously materializes and fosters the dreaming and making of love.

The Turkish world, settled in the high plains, is inspired by the wide open space of the prairies: a landscape to explore rather than contemplate. The garden becomes a resting spot in a never-ending journey. Its types and techniques, foreign to the nomadic world, had been imported from nearby Iran. The fundamental difference between the Arabs and the Turks can be exemplified by their opposite relationship between dwelling and garden—the first based on the introverted patio-house with the garden in the center, the second based on the hall between two gardens, open toward them on both sides.

Things were already intricate enough, but history shuffled the cards even more. The three different cultures influenced each other in a way apparently impossible to retrace. In the Abassid period, the Persians extended their domain to the whole Mediterranean, all the way to Gibraltar. After 1453, the Turks started dominating the same sea, as still evidenced by the periphery of Algiers and Istanbul, and by the Dalmatian coast of the Republic of Venice. On the other side, they met Iranian culture and, at the time of the Timurids, merged the static and centripetal conception of Iranian space not only with Turkish wide open spaces, but also with its dynamics and centrifugal exploration. What can we say when this synthesis met the Indian world, where the sense of time depended on agricultural seasons, and where traditional architecture had long been born in symbiosis with nature?

In approaching such a complex problem, it seemed legitimate to establish general classes in order to group phenomena. But this call for order led scholars to overgeneralize. Grimal's subdivision into park-garden and courtyard-garden, the first deriving from the Persians and the second from the Romans, is too generic not to be true, but can't be applied much further.[2] The classification suggested by M. Moynihan in

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[2] Both types almost always coexist, starting from the Samarra palaces to the imperial cities of Morocco. The second one often prevails, as for example in Grenada, but we can argue for the possible disappearance of the first type, especially during the great territorial transformations of the 19th century.

tomb-garden, palace-garden, and delight-garden is ambiguous and incomplete, the first group being the only one featuring specific characteristics.[3] On the contrary, although limited to a much smaller geographical area, M. Alemi's method seems more promising: he identified physical structures behaving according to specific rules under the poetic names of *pairidaeza, khiaban-i cahar bagh, bagh-i takht*, etc.

Along the lines of this last example, it seems valid to pursue a line of research capable of shedding new light on the evolution and structural organization of Islamic gardens. This study might start from a general inquiry into its perpetual, tangible traces: the mutual, never-ending relationship between garden and urban form.

GARDEN IN CITY FORM

The Islamic garden has always been an area of research essentially pursued by art historians. The obvious consequence is that it has been considered a specific, self-contained entity removed from its context—its surroundings, the city, and the environment. Along the same lines, reading the spatial qualities and structural layout of the garden, as well as the design ideas underlying it, cannot focus on the garden solely as an object, but ought to reach out beyond its boundaries to seek a larger set of relationships, a richer palimpsest where agriculture, garden, encampment, city, and territory recursively and mutually influence one another.

A 1984 conference in Genzano, Rome, entitled "The Garden as City, the City as Garden," started looking at the topic from that viewpoint. Among many examples from other cultures, the impact of orchards' patterns on urban morphology, or the influence of the garden on medieval city-building—considered an ideal urban laboratory for building with minimal means and methods—suggested how an interdisciplinary approach could widen the perspective of previous studies.

The structural relationship between the garden and its context should be analyzed from all possible viewpoints, both physical (at all scales, from the environment to the city) and metaphorical or allegorical (the relationship between the garden and the city as an image of the king).

THE GARDEN AND POWER

Despite regional differences, Islamic anthropic processes behave according to the same rules underlying governing the culture: on one side, religious imagery and hierarchy; on the other side, the necessity (and vanity) of expressing the power of the dominator.

[3] This type is characterized by a mausoleum located at the intersection of a simple or composite caharbagh, although the Taj Mahal in Agra is the most famous exception to the rule.

A famous article by Begley on the Taj-Mahal[4] demonstrates how emblems of power were an everyday Mughal obsession, and shows that the equation between architectural forms and celestial prototypes (always viewed in terms of the celebration of the deified image of the king) was the real spur to any architectural enterprise. What could not be stated by the orthodox Muslim, vicar of Allah, was left to the metaphor of stone. Playing continually on the ambiguity between Divine Throne and royal throne (an unbridled vanity) transformed tombs and monuments into symbols of glory and called for the laying out of gardens, replicas of the Qur'anic paradise, to exalt the figure of the holy demiurge.

The royal city is based on three recurrent key themes: first, gardens and palaces, merged together as places of heterodox pleasure; second, the importance of the court ceremonial; and third, the vast and complex system of gardens and palaces, sometimes taking the form of a labyrinth as if to express the idea of the king's divine and quasi-magical isolation.

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The world of the garden persists both in the royal palace and in the city. It endures through the structural relationship between garden and encampment, and by the bottom-up procession from the monumental entrance located at the lower level to the enclosure of the royal palace at the very top (as in the darbar of Agra). In the city, it persists in the pre-existent pattern of fields and orchards, as well as by the ever sought-after relationship between the garden and the city as an image of the king. The latter is best exemplified by the plan of the city of Hyderabad in the Deccan, founded by Sultan Quli Qutb Shah in 1591 on the banks of the river Musi with a cross-shaped plan designed by a Persian architect: as a response to an ideological program which prescribed the creation of a replica of the Paradise of the Qur'an, the archetypal form of the Persian garden (a vegetal metaphor for heaven) appeared as the most adequate solution.

In fact, besides the function of retreat from reality and protection from wild nature, the Islamic garden has generally aimed to represent, in more or less explicit form, the religious paradise. To complicate the play on imagery and metaphor, it also offers an allegorical sequence for the exaltation of royal power. Despite the difference between western and eastern Islam, the theme was always the same: in Spain and in Maghreb, the Sultan, vicar of God, exploited the association between the garden-of-paradise and garden-of-the-king as the aulic representation of their authority. In the east, in the Hellenistic tradition, conferring divine nature on the emperor transforms the garden into a royal hall for the theophany of the king. In both cases, the garden is the favorite symbol for the omnipotence of the king.

[4] See W. Begley, The myth of the Taj-Mahal and a new theory of its symbolic meaning, in *Art Bulletin*, March 1979, pp. 7–37.

But it is in Kashmir that the relationship between garden and city as image of the king is not only confirmed, but extended to the scale of the territory. Around Srinagar, Jahangir and his son Shahjahan started transforming the environment in order to mark their territory. It is significant how small the architectural intervention was compared to the great production of gardens which spawned, according to the sources, no fewer than seven hundred throughout the valley. The "royal enclosure" of Kashmir, then, becomes a systematic grand oeuvre of redesign of the landscape–an organic attempt to glorify the sacred image of the king. "The garden is the place of illusions where the king is venerated and where all proofs (though completely imaginary) of his infinite power have accumulated."[5] In these gardens, existent water sources are channeled and converge to pass under the throne where the king sits as the "distillate of the emanation of the Divine Being; a ray of sunshine illuminating the Universe; the subject of the book of perfection; the repository of all virtues."[6]

In Shalimar Bagh, for instance, the first terrace after the entrance built by Jahangir in 1619, dominated by a telar (a pavilion sheltering the throne), was the place reserved for the darbar (the public audience, the representation of the divine origin of the king) where the characteristic theatrical attitude of the Mughals prescribed a precise role for all. "When the king sits on the throne, all those present shall prostrate themselves and then remain standing in the place assigned on the basis of their rank, their arms crossed, receiving the light from the Divine Countenance... The firstborn prince shall be at a distance of one to four gaz from the throne... the second-born... sits a distance of three to twelve."[7] The diwan was decorated for the occasion, and illuminated for the king's solar and lunar birthdays, during various religious festivals, as well as to celebrate military victories.

On these occasions, the scenic venue was extended beyond the garden to embrace the entire lake. The second and third terraces are two typical caharbagh, completed by Shahjahan after 1630. The first is the private garden: again, according to a Kashmiri ritual, the king sits in the center of a square pool of water marked at its corners by four monumental plane trees. The second is the caharbagh of the zahane, featuring the magnificent Black Pavilion. A torrent, diverted into the garden, is a broad channel measuring six meters across, majestically flowing among plane trees and chenar (*Platanus Orientalis*). The enclosures of the terraces of Shalimar represent the correct layout for the performance of daily court life, based on a rigorous ritual yet extremely flexible in the use of space. It represents a model subjected to infinite variations and reinterpretations according to the same underlying principle.

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[5] Grimal, *Jardin des Hommes, Jardin des Rois*, in Traverses, 5/6, 1976, pp. 71-72.

[6] Abu'l Fazl 1877–86, vol. 1, p. 18.

[7] Abu'l Fazl 1877–86, vol. 1, p. 18.

GARDEN AND ENCAMPMENT

Garden and landscape interrelate through the intermediary form of the encampment. In this way they establish a fundamental relationship bound to affect, either consciously or unconsciously, the other acts of appropriation and settlement in the same territory.

The link between garden and encampment derives from the extraordinary mobility of the court, dictated by the need to strengthen the royal image throughout the country, control the political behavior of the population, and discourage possible sources of rebellion. But there were many other occasions for moving the court in grand style, from military campaigns to hunting parties and pilgrimages, as well as seasonal movements toward milder climates.

It is clear that the organization of the royal camp, required the highest level of administrative and logistic ability. The easiest and fastest way to settle in was to refer directly to established ways to lay out, organize, and subdivide areas. The natural way to do it was to rely on archetypal forms of appropriation of the environment in a way that were simultaneously capable of taming nature and expressing the hierarchy of the court. Within this set of parameters, the archetype per excellentia was the garden, because traditionally it addressed both issues. In fact in Mughal culture, according to the Timurid tradition, the garden combined the functions of contemplation and state ritual. It was also a place for feasts and receptions, fitting for celebrating the apotheosis of the King of Kings.

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The description of a camp given by Abu'l Fazl demonstrates the existence of a close functional relationship between the layout of the camp (derived from the garden) and that of the royal palace, in a blend of nomadic and sedentary culture. The world of the tent persists, however, in the forms of masonry architecture, the juxtaposition of courts and buildings, the pavilions, skylines, the mouldings and other decorative details, to the extent of justifying for the opulent palaces of the Mughals the description of "a camp in stone."[8]

How does the archetype of the garden evolve into palaces and new cities? And how can we retrace the process? Shalimar Bagh, for example, on the east coast of lake Dal, is a garden to discover step by step, one enclosure after the other. It is a royal garden. Typologically it refers to a scheme that, almost without exception, aligns in sequence the public ambits (*diwan-i 'am*), the semi-public ones reserved to the king and his court intimates (*diwan-i khass*), and the private ones (*harem*). This scheme is repeated in all palaces, and has a clear origin in the model of the Timurid encampment not only in its spatial layout, but also in its architecture and in the nomenclature directly taken from the tents. Even more strikingly, metaphor and reality often exchanged roles: in the long summer seasons, the garden's lawns became the ideal campground for the royal tents, decorated with red drapery, the symbol of the crown.

GARDEN AND URBAN DESIGN

The idea of the Oriental city as a puzzle of cramped houses around a maze of narrow streets and *cul-de-sacs*, surrounded by an indecent periphery oppressed by deafening traffic, is a misleading one. Before the transformation brought about by a fairly recent immigration process, Islamic cities had always been portrayed as a unique blend of nature and human settlement. Low building density was maintained in order to preserve a strong relationship with greenery. Vegetation prevailed. Even in the humblest house, the courtyard left room for a tree. Wide green spaces functioning as food reserves, orchards, and flower gardens formed a green belt between the city center and the walls. With the usual prosaic emphasis, European travelers described fabulous green oases for cities: Pietro della Valle saw Istanbul and Teheran as garden cities—the first dominated by cypresses, the other by plane trees; the Spanish ambassador Clavijo portrayed Samarkand as "... such an abundance of gardens and vineyards that when a traveler comes within sight thereof, all he sees is a great mass of greenery with the city in the center."[9]

Of course, emphasizing the symbiotic relationship between gardens and buildings in the urban fabric is almost trite. However, far from being either urban decoration or functional green lung, the garden has always played a generative role in city form. It seems of crucial importance to bring up the structural relationship between the two, where "structure" is viewed as an organic relationship of elements behaving according to a set of rules.

Ever since the last century, instead of interpreting tortuous lanes and *cul de sacs* as an impenetrable blend of the exotic, the unhealthy, and the horrid, a few scholars perceived the Islamic city in a totally different light, namely, as an extremely rational construction. In 1898, Shetalov remarked that the roads of Yazd, Iran, were traced according to a precise orthogonal scheme. The cities of Sabzavar, Kerman, Ardekan and, more confusedly, Tabas, were following the same principle. Along the same lines, Bonine noted how the urban grid of Mehrir (not far from Yazd) continued straight out of town toward the hills to the southeast. Although street networks were later interrupted by cul de sacs, the urban grid derived directly from the agricultural fabric, whose orthogonal pattern was generated by the cheapest and simplest irrigation technique: water was channeled at the base of the hills, then diverted to the arable area thus generating long rectangular lots (*kort*).[10]

Thus we can deduce that the morphology of Persian towns is linked to the development of a settlement (the original urban nucleus) within an irrigated agricultural system. In fact, we can note how the roads issuing from the urban gates of Yazd continued the

The idea of the Oriental city as a puzzle of cramped houses around a maze of narrow streets and cul-de-sacs, surrounded by an indecent periphery oppressed by deafening traffic, is a misleading one.

[8] See Petruccioli 1987, and in particular the first chapter.

[9] Translated from R. Gonzales De Clavijo, 1403–406 (1990).

[10] See M. Bonine, The Morphogenesis of Iranian Cities, in *Annals of the Association of American Geographers*, LXII, 9, 1979.

urban alignments and trajectories without any deviation induced by the need to link nearby towns or landmarks. The extramural fabric of fields, orchards and gardens, then, becomes an integral part of the city: it constitutes its original parcel. The relationship is taken to the extreme (and the axiom is best evidenced) in the urban huertas of Spain, and in the kitchen-gardens of suburban Maghreb.[11] The list of examples could be much longer, one for all the widespread urban plans conceived according to existent irrigation channels, or those cities whose survival literally depends on the constant flow of underground canals, as in the *foggara* of Gourara. [12]

In the so-called "Classical Islamic" period, before the devastating invasion of the Ilkhanids, the royal city developed through a serial repetition of large monumental complexes laid out according to the above-mentioned regular grid of agricultural origin: at the beginning, palaces were punctual elements within an endless sequence of square and rectangular gardens. We can distinguish three main variants: 1) gardens straddling a central thoroughfare, often continuing or slightly deviating from the axis of symmetry of the residential areas (i.e., the Balkuwara Palace in Samarra); 2) more seldom, gardens aligned in sequence (Ghaznavide of Lashkari Bazaar); and 3) an uninterrupted collage of gardens, adjoining linearly or perpendicularly according to simple symmetries (*i.e.*, in the Alhambra, the Courts of the Myrtle and of the Lions, and the Garden of Linfaraja and of the Partal).

Even after the Ilkhanid invasion of 1256, marking the end of the unity of Islam, the reappropriation of the territory in the image of the new emperor didn't destroy former fabrics, but reinterpreted the existent structural palimpsest of gardens and cities. The Persian caharbagh archetype-a square with four sides, four quadrants, four canals and four axes of symmetry-responded adequately to the renewed demand for centrality as symbol of power. Later on, the Tamerlane dynasty took up the same principle: the layout of the capital Herat is a square recalling a gigantic qual'e (fortified farm), with four gates giving access to four straight roads splitting the city in four sectors. Herat may be considered the culmination of experimentation with city form (further exemplified by Merw, Termez and Shahr-i Sabz,[13] and the reference for all following urban developments in the Deccan of India, ending with the layout of Shahjahanabad (Old Delhi) in 1638.[14]

But one of the most enlightening processes can be observed in the urban design of the Mughals after the invasion of Northern India (1526). The garden and the camp were the only forms available to the Mughals when they started redesigning Indian cities in the semblance of the new royal image. Refusing to adapt to the

[11] See Petruccioli 1985, in particular the chapter *Ambiente, acqua, agricoltura.*

[12] For a detailed study of the hydraulic systems of Saharan oases, see Laureano 1988.

existing fabric and the torrid Indian climate, they created exclusive settlements for themselves. Instinctively, design layouts were drawn from the garden. Neglecting the Indo-Muslim city of Agra on the right bank of the river, Babur decided to settle on the opposite side, building a regular pattern of gardens in the manner of those of Lahore and Dholpur, stretching for more than a kilometer, in which the idea of "monumentality" and "representation" of the new order was entrusted to the high, continuous stone plinth along the river. This pattern ended up establishing a framework for future urban development: Babur's successors strengthened the previous Mughal fabric by building the Red Fort and the Taj-Mahal, and further pursued the design of gardens along both banks of the Yamuna,[15] among which the outstanding example is the tomb-garden of I'tirnad-al Dawla. Furthermore, starting from the second half of the 16th century, the Mughal "gardens of delights" progressively turned to marble and sandstone palaces, rigorously retaining the order, rhythm and ratios of pre-existent gardens, the typical forms of the original pavilions, the hierarchical arrangement of the enclosures (*baradari*) and, despite the decrease of greenery, all the garden furnishings—fountains, pools, canals, and chadar.

GARDEN AND TERRITORY

To approach the relationship between garden and territory in the Islamic world, we may once more consider the Mughal gardens of Kashmir. They allow us to draw a more precise set of inferences, because the geographic isolation of Kashmir favored the maintenance of the same cultural archetypes over a long period of time. Thus, the Kashmiri garden represents a relatively uncorrupted typological process, one that allows us to draw similar deductions in more complex cultures.

"Kashmir is the garden of eternal spring, a safe (haven) for the palace of the King,"[16] wrote Jahangir about his trip to Srinagar. But what does that really mean? What can we infer from this apparently simple statement? First of all, reading between the lines, we can note how a one-line epithet blends together different, seemingly incompatible scales, and how their metaphors depict a set of peculiar spatial relationships: the 170 x 60 km valley of Kashmir becomes a single "garden," one of eternal flourishing beauty; then, it suddenly becomes one with the strong, opposite imagery of the safe haven, merging a vast valley and the architecture of a royal palace into a whole-a seemingly all-inclusive organic system. Analyzing the topography and spatial layout of its anthropic elements, we can note how Kashmir was to Hindu eyes a *ksetra*—a complex hierarchical system of holy places linked by pilgrimage circuits (yatra).[17] The

[13] See Pugacenkova 1978, which gives a diagram of the city's quadripartite layout.

[14] On Herat see Gaube 1979; Brandenburg 1977; Samizay 1989.

[15] See *Memoires* of Zehir-ed-din Muhammad Babur (1826, 1921). The chronology of the gardens along the left bank is still an open debate. Ebba Koch disagrees, for example, that the present Ram Bagh is of the Babur period. See Koch 1986, Notes on the Painted and Sculptured Decoration of Nur Jahan's Pavilions in the Ram Bagh at Agra, in *Facets of Indian Art* 1986. The same conclusion is reached, after stylistic analysis, for the Zahara Bagh: see Koch 1986, The Zahara Bagh (Bagh-i Jahanara) at Agra, in *Environmental Design*, 2, 1986: 3-37.

whole Indian subcontinent is structured according to a hierarchy of similar landmarks, within which ritual movement generates a hierarchy of pilgrimages to specific places. India is covered by a meshed pattern of these revered sites and the roads necessary to reach them, a pattern further subdivided into secondary systems according to a precise religious hierarchy. Everything, from the larger scale (the four corners of the continent) to the smaller subsystem (the single city) is structurally configured according to ritual movement and symmetrical references. Within such a system, the smaller unit always reflects the principle of the larger scale as an all-inclusive religious and cultural unity.

Returning to our example, the smaller unit—the city of Srinagar—is situated in such a way that the surrounding topography simultaneously suggests and strengthens the holiness of the place. Thus it is a matter of individuating the "sacred area" around Srinagar—those significant points that define its lines.[18] The ideal line connecting temples, linga, villages, orchards, vineyards, water sources, sanctuaries, gardens and tombs, defines the lines of this sacred space. Surprisingly, this line does not coincide with the ridges of the mountains overlooking the Fhelum valley, but marks the edge of the cultivated land, separating the artificial world of orchards, vineyards, floating gardens, and canals from swamps and forests. Mountains, then, are not the ideal walls of the king's haven! After all, it is not a coincidence that, in Brahman art, the *ksetra* is always represented as an enclosed garden.

The lines mainly contain an aquatic world. "The Gods approach the places which contain water and gardens," says the Bhavisya Purana (I.CXXX, 10)." The Gods reside close to the forests, rivers and mountains, streams and in the cities which are full of gardens" (I.CXXX, 15). In the 7th century Kadambari of Banabhatt, we find a description of a garden-palace featuring various devices for the collection and transportation of water, and pools for bathing. In the Rajatarangini, Kalhana mentions a garden founded by the king Jaysingh in 1150 in Kashmir (VII, 3360). Although we can't prove the existence in pre-Islamic times of formal gardens based on water sources instead of simple forests and lawns, everything seems to confirm it. We can imagine a continuous sequence of different gardens blending with the pattern of agricultural fields and orchards, sometimes floating on the lake to ultimately express a perfect synthesis of water and agriculture. Gardens, then, embody and foster that synthesis at the same time. They can be taken as the crystallization of the structural organization of that particular culture.

Extending our overview beyond Kashmir, the gardens of Persia, Central Asia, and India—supported by a philological reading of

[16] Nur ad-Din Muhammad Jahangir, Tucak-i Jahangiri, A. Beveridge, ed. (New Delhi: 1968, translated by A. Rogers), pp. 143–144.

[17] A scientific, although partial reconstruction of Srinagar's tirtha has been attempted by Stein 1899. Abu'l Fazl'Allami, the biographer of Mughal emperor Akbar, lists in the valley 45 shrines dedicated to Mahadeva, 64 to Vishnu, 3 to Brabama, and 22 to Durga; in 700 places he notes carvings of snakes as objects of devotion. See Abu'l Fazl'Allami, The *Ain-i Akbari*, translated by H.S. Jarret (Delhi, Oriental Books, 1978), vol. 2, p. 352. Also, 250 plans representing tirtha are kept in the Srinagar Museum, originally belonging to a manuscript by Pandit Sahibram, who died in 1872.

[18] This is also common to the Islamic world, as for example in the Haram around the Mecca; or to Western countries, as in the sacred hills around Varese, Italy.

their miniature representations—suggest a general process based on a progressive metamorphosis of water from a dynamic to a static state and, similarly, from open to enclosed form in the relationship of garden to environment. The formative process of the typical garden shows the prevalence of a hierarchy based on the longitudinal axis, marked by a waterline, which evolved from a marginal position (such as in Bagh-i Fin of Kashan) to an increasingly prominent location (as in the Babur garden in Kabul, where a line of water runs through fourteen terraces). As in the scenes portrayed in miniature paintings, in reality the original short perspective of the caharbagh is progressively extended, until it reaches outside the enclosure to include part of the surrounding landscape.[19]

Thus, the changing nature of the garden progressively marked a crossover from an idea of nature closed within the abstract scheme of the caharbagh to an organic representation of the relation between the garden and the landscape itself. Babur, founder of the Mughal dynasty, aimed to provide the territory with equidistant points of sojourn and recreation at Dholpur, Agra, Fathpur Sikri and even Sheikhupura, close to the site of the Panipat battle: the system was constructed through environmental-scale gardens connected by a welter of roads and hydraulic infrastructures which his successors ceaselessly strengthened and added to. The final aim was always the same: to gaze on the impossible model of a single great garden as large as the whole Empire.[20]

Symmetry, simplicity, metaphor: a simple canvas of design elements blending landscape and formal gardens pervades the entire modeling of the environment in the encampment, the palace, and the city. We have already discussed how palaces, having been turned into the administrative centers of a bureaucratic empire, were conceived in their layout as gardens through the intermediary stage of the royal encampment. These palaces further built up the structural grid, growing out of all proportion so as to house services, ministries, and the increasingly more complex activities of representation. But it is only in the valley of Kashmir, again, that the Mughal dynasty reached the goal of integrating the design of the garden into a larger territorial structure.

To conclude, Mughal geometric order ascends in a territorial grid capable of reaching beyond the regional scale. Similarly, the concept of the oasis of the Arab world projects the idea of enclosure to the scale of the whole territory. The Indian subcontinent has always been an incomplete system of hydraulic infrastructure and street networks, as well as services and gardens for the stopovers in the king's journeys, where each garden was itself a small-scale territory furrowed by canals and tree-lined paths—a constant set of relationships that has shaped the territory of today.

[19] In reality, the process is more complex. The garden comprises in itself a blend of different schemes, such as the double caharbagh witb a central axis cutting tbrough three terraces in the Shalimar of Lahore, or tbe deliberate acceleration of the water or abrupt level changes according to the existent topography, as in Kabul or in Kashmir. Also, we shouldn't forget how tbe tomb-garden, by far the most conservative type, persists until the 18th century with the same archetypal features.

[20] This territorial framework, based on an infrastructure system extended to all regions of the Empire, was homogeneous in theory but discontinuous in practice. The provincial governors vied with each other to endow the network witb caravanserai and resting places, to dig wells, plant gardens, shade main roads by planting endless lines of trees, and cross water courses by building bold stone bridges. An example of Mughal megalomania is the khiyaban, the great national boulevards. It seems that the idea of creating shady roads-a continuous oasis for tbe repose and protection of travelers, or a linear pergola at the scale of the whole nation-came to Jahangir. But kbiyaban existed at Samarkand, Qazvir, Tabriz, etc., albeit at a local scale. Royal caravanserai (padshahi seray) with a garden where the court could camp out, existed along all the main routes of the Empire. See R. Ch. Kak, Antiquities of Bhimbar and Rajauri, in *Memoires of the Archaeological Survey of India* (Calcutta: 1923: 14.

TOWARD INTERDISCIPLINARY RESEARCH

The relationships among garden, encampment, palace, and finally city and territory as the image of the king, open up new insights into the study, still in its infancy, of Islamic town planning. The outline above argues that, throughout Islam, a crucial aspect of the Islamic garden is the complex set of relationships it establishes at various scales, and how it serves as the basis for all human developments. The garden-territory nexus, then, may be seen not only as an aesthetic but, on the contrary, as a complex anthropic reality.

The numerous studies done by geographers, among them the fundamental work of Xavier de Planhol on anthropized landscapes, of Lambton on agriculture in Iran, of Sauvaigo on Mediterranean agriculture, and of Bisson on the oases as production areas, have always skimmed the theme of the garden. In an essay of at least fifteen years ago—*Dar al Islam, Architetture nel Territorio dei Paesi Islamici*—I tried in my turn to link Islamic settlements with the extraordinary infrastructures realized by those cultures for irrigation and agriculture. I also aimed to demonstrate how those functional works had much in common with the garden, aesthetics aside. In that same book, the environment is deliberately left aside (or seldom brought up) in order to focus on a narrower set of relationships. As the former arguments tried to evidence, it deserves a much more ample space. The field remains open for efficient ways to tackle the subject.

The outline above argues that, throughout Islam, a crucial aspect of the Islamic garden is the complex set of relationships it establishes at various scales, and how it serves as the basis for all human developments. The garden-territory nexus, then, may be seen not only as an aesthetic but, on the contrary, as a complex anthropic reality.

In approaching such a complex problem, it seems legitimate to establish certain categories in which to group single phenomena in homogenous classes, to define a chronological order, to examine their variants and how they affected the original categories. Furthermore, synchronic variants will class the differences introduced by the single designer within the general category. The analysis of these variants and their evolution will be referred to herein as the "typological process" whose aim is to retrace the crucial links between the garden and other forms of anthropic appropriation of the environment.

The multi-layered world of Islam seems to allow this approach only by cultural region. On the other hand, typological process may be an effcient way to undertake a study of the complex influences absorbed by Islamic cultures. For example, consider the city of Samarra, Iraq, capital of the Abassid empire from 836 until 892. A boundless city of enormous linear extension (a 35-km strip along the Tigris)[21] for the exclusive use of the Caliph, Samarra is a juxtaposition of Palatine cities according to typological schemes of various cultural matrixes, such as the Roman, Hellenistic, Byzantine, Sasanian, and Umayyad, dilated to the territorial scale. Typological analysis may show how this extraordinary case is far from being unique, and provide the methodological tools for retracing its apparently impenetrable evolution based on what exists today.

[21] On Samarra see J.M. Rogers, Samarra. A study in medieval town planning, in *The Islamic City*, A.H. Hourani and S.M. Stern, eds. London: Cassirer, 1970), and T. al-Janabi, Islamic archaeology in Iraq: recent excavations at Samarra, in *World Archaeology*, XIV, 1983: 305–327.

We can lay out a typological approach keeping in mind three fundamental issues: the meaning of type, the search for unity within the complexity of Islam, and finally the garden as the aesthetic distillate of agriculture.

We can define "type" as the ensemble of characteristics and tectonics that are common to a set of buildings, cities, and gardens in a precise geographical area and a precise period of time. But type, according to Saverio Muratori, is also a generative action *a priori*: it already exists in the subconscious of the designer, and it is an integral part of collective imagery, thus anticipating the act of building. In the entire Islamic world there is an archetypal form that has become almost synonymous with the Islamic garden, namely, the *Chahar bagh*, a system composed of two perpendicular axes intersecting and defining four equal quadrants sometimes featuring a monumental landmark (see Walcher, this volume, for a discussion of *Chahar bagh* as manifested in the Safavid capital of Isfahan). It is not important to argue about the origin of the form so much as to underline its universality, and start engaging in research on the process of its evolution.

Typological research could start from regional cultures and expand its overview to the whole Islamic world, as a consequence of the overlap between sacred topography in Hindu and Muslim cultures. In fact, we can argue that the appropriation of territory by the Islamic dynasties from Shams al-Din to Akbar occurred through a ritual refoundation based on the simple resacralization of venerated places and water sources. Thus, in spite of cultural and religious differences, there is a substantial continuity between Hindu and Muslim dynasties, as proved in the territorial management of the valley of Kashmir. Continuity, in any case, is confirmed by the toponymy, conserving an unmistakably Sanskrit origin.[22]

The garden is often regarded as a manifestation of refined beauty and intricate symbolism—essentially as an object. In reality, it is but the aesthetic distillate of an agricultural civilization, always playing a decisive role in any anthropic process. Of the three axioms, this last one, because of the continuity of its evolution in all cultures, may be the starting point for future interdisciplinary research.

[22] This is demonstrated by the recurrent ending in -pur, -mar, -khot in villages' names; -sar, -nambal, -nag in the names of lakes and swamps; -kul and -khan in the names of rivers and torrents.

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Section IV: Marine Environments

Middle Eastern Marine Environments: An Overview of Anthropogenic Impacts

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ABSTRACT
The seas that surround the lands of the Middle East have been significantly affected over the last century by human activities, including fishing, coastal engineering projects, and pollution from municipal, industrial, agricultural, and shipping sources. The impacts of these activities are only likely to increase in the future. Without coordinated, cooperative efforts by the nations involved, the seas of the Middle East are threatened with catastrophic change.

INTRODUCTION

The marine areas of the Middle East include four major basins: the Levant Basin (i.e., the Southeast Mediterranean); the Red Sea; the Gulf of Aden, the Arabian Sea, and the Gulf of Oman (which are more or less contiguous); and the Persian Gulf. Problems associated with anthropogenic change have increasingly affected the marine environments of the Middle East just as they have the world's other seas, but Middle Eastern seas also have to contend with problems and issues that are peculiar to, or especially acute in, the region. Among these features are:

- the Suez Canal, with its dense ship traffic and the huge amounts of crude oil, fuels, and petro-chemicals that are transported through all Middle East marine areas;
- biological issues specific to the two semi-enclosed basins of the region (i.e., the Red Sea and the Persian Gulf) including such special tropical biotopes as coral reefs; and
- inadequate regional and sub-regional cooperation in environmental matters, due to historical, political, and cultural reasons.

Numerous studies describe the changes in marine environments that have occurred throughout the Middle East during the past few decades (Ben-Tuvia 1985; Ben-Yami and Glaser 1974; Caddy 1993b; Caddy and Oliver 1996; Golik and Goldsmith 1986; Inman and Jenkins 1984; Nir 1989; Vadiya and Shenuda 1985). These changes include pollution and eutrophication as well as the side effects of certain engineering projects.

The main environmental problems in Middle Eastern marine environments today are:

- Pollution originating from municipal, industrial, and agricultural sources in densely populated areas with high population growth rates, e.g., in the southeastern Mediterranean;

- Coastal erosion and other effects of engineering projects;
- The question of fisheries sustainability;
- Conservation of marine and coastal biotopes and endangered species, as well as biota migration through the Suez Canal;
- Oil spills;
- Pollution due to shipping.

MUNICIPAL, INDUSTRIAL, AND AGRICULTURAL EFFLUENTS

These effluents, which are the most common and significant sources of marine pollution, often contain a wide variety of nutrients, untreated bio-wastes including bacteria and viruses, and pesticides and other toxins including heavy metals and assorted chemicals. They are on occasion abnormally acidic or basic relative to the marine environment that they enter. These effluents may trigger physical and/or chemical processes, including both those inherent in the existing marine ecosystem as well as those that can only happen in the presence of pollution. For example, certain effluents may result in the synergistic creation or transformation of poisonous materials and/or the re-accumulation of contaminants, with unpredictable and accumulative consequences, to which some species may be more sensitive than others (Patin 1992).

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Areas particularly affected by this sort of pollution can be found along the coasts of Israel and Gaza, the Nile Delta, the Gulfs of Aqaba and Oman, and the Persian Gulf. The situation is exacerbated by the fact that certain industrial interests, both from within the region and without, are often looking for locales where anti-pollution legislation is either weak or un-enforced in order to establish production facilities that would not be permitted under more stringent anti-pollution regimes (or would face high-cost investment in environment-friendly technology).

MARINE AND COASTAL FISH FARMING

Coastal and marine fish farms produce primarily organic waste, which can be especially detrimental to the ecosystems of semi-enclosed bays and inlets. Coastal fish farm effluents are mainly nutrients, but may also include misapplied chemicals (Berg and Lavilla-Pitogo 1996). Marine cage farms also produce effluents, although these are more readily dispersed because of their offshore location. In addition to waste feed and fish feces, marine cage farms may also introduce such undesirable elements as residual antibiotics and chemicals from disease and parasite treatments. Marine fish farming development in the Red Sea (Shehadeh and Feidi 1996) may lead to environmental damage, especially of coral reefs, if sites and culture practices are not chosen with care.

HOSTILITIES

Oil pollution, whether from accidents or hostilities, has so far occurred mainly in the Persian Gulf, where the world's most dramatic oil spill resulted from intentional Iraqi releases during the 1991 Gulf War. The Iraqis spilled an estimated eleven million barrels of crude oil into the Gulf, which spread quickly and affected hundreds of kilometers of coastline, mainly in Saudi Arabia. Cleaning efforts recovered an estimated 13% of the total. Contrary to a number of pessimistic forecasts, the Gulf environment managed to rebound rapidly from this disaster. Experience with this and other spills seems to indicate that warm, tropical marine ecosystems enable more rapid and effective decomposition of oil pollution than more temperate ecosystems, thanks in large part to intense solar radiation and the action of oil-degrading bacteria.

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FISHERIES

Fisheries play an important economic role in the Middle East, especially in the countries of the southern Arabian Peninsula and in Egypt (see Feidi, this volume). Although some of these resources are currently under pressure from excessive fishing and other anthropogenic factors, none of them are currently considered seriously overexploited (Caddy and Oliver 1996; Feidi 1996; Sanders and Morgan 1989). Since most of the fish stocks straddle the waters of more than one country, international and regional fishery management has an important role to play. In the semi-enclosed Mediterranean, fisheries have increasingly been affected by the combined effect of intensive fishing activities and persisting enrichment (eutrophication) due to runoff of nutrients and other polluting agents. Coastal pollution and the resulting eutrophication are playing a paradoxical role with respect to fisheries in oligotrophic seas (i.e. seas that are poor in nutrients and of low primary production). Although pollution is generally seen as something to avoid, the stable and even growing Mediterranean fish landings can only be explained in terms of man-made enrichment of its waters. This enrichment seems to be compensating for the reduction of nutrients that were once supplied by the Nile River but that were halted after the 1964 construction of the Aswan High Dam. Apparently, anthropogenic eutrophication is the main cause of the increasing landings in Mediterranean fisheries (Caddy 1993b, 1996). The sardine fishery offers a case in point.

Prior to the construction of the Aswan High Dam, this fishery produced 18,000 to 25,000 T/yr off the Nile Delta. After 1964, this fishery collapsed to 550 T in 1966. Since the 1980s, however, sardine and other small pelagic catches in Egypt's Mediterranean waters have rebounded to about 50% of the pre-Aswan period. Catches of some demersal fish have also grown significantly. These and other yield increases appear to be a result of anthropogenic enrichment rather than of the inadequate fisheries management that characterizes the region. Still, the relationship between eutrophication and fisheries should concern all Mediterranean countries, particularly in view of the ecological calamity that befell the Black Sea fisheries in early 1990s, which evidently was triggered and fed by man-made pollution, resulting in eutrophication, combined with a devastating intrusion of an exotic predatory comb-jelly (Zaitsev 1993; Caddy 1993; Ben-Yami 1994).

TOURISM DEVELOPMENT

Expansion of the tourist industry, as in the case of the recent rapid development along the coasts of the Gulf of Aqaba/Eilat, is quite a separate issue. Inadequate planning of tourist infrastructure, especially large hotels, can put severe strains on existing sewage treatment and disposal systems that were originally established to serve much smaller populations.

In semi-enclosed marine basins, all projects involving massive increase of the density of coastal population, whether permanent or transient, should be looked upon as components of one combined system. One way to assess eventual combined damage and at the same time to set limits on proposed tourism development is: (a) to assess the existing contribution to marine pollution in terms of person/day/pollution factors; (b) to assess the maximum sustainable pollution capacity throughout the affected marine area (approximate pollution carrying capacity (GESAMP 1986; Krom and Cohen 1991)); (c) to determine the additional number of person-days that the ecosystem affected can sustain without permanent damage to coral reefs, water clarity, etc., taking into consideration the existing and additional (planned) means of sewage treatment; and (d) upon such determination, to allow additional population in the various projects.

In areas such as the Gulf of Aqaba, this integrated approach would call for international cooperation, which has, of course, not always been easy for Israel, Jordan, and Saudi Arabia.

Although pollution is generally seen as something to avoid, the stable and even growing Mediterranean fish landings can only be explained in terms of man-made enrichment of its waters. This enrichment seems to be compensating for the reduction of nutrients that were once supplied by the Nile River but that were halted after the 1964 construction of the Aswan High Dam…still, the relationship between eutrophication and fisheries should concern all Mediterranean countries, particularly in view of the ecological calamity that befell the Black Sea fisheries in early 1990s, which evidently was triggered and fed by man-made pollution, resulting in eutrophication, combined with a devastating intrusion of an exotic predatory comb-jelly.

CORALS

In the Middle East marine environment, corals still abound and thrive. Coral reefs are sensitive biotopes, vulnerable not only to anthropogenic but also to natural stressors. Pollution (of any kind) and coral piracy can bring about, directly or indirectly, the degradation or death of a reef. Dead coral reefs are often found covered with sponge growth or algal turf, while multi-species bleaching of coral reefs, recently reported from the southern Persian Gulf (Dr. Roger Uwate—private communication), is the result of breakdown of the symbiosis between the corals and Zooxanthellae algae. Coral bleaching has been ascribed to several factors, most often to warming of the sea water. Seasonal floods carrying sediment that deposits on coral reefs are another natural cause for reef degradation. It remains to be seen whether proposed marine reserves will serve as an effective means for saving coral reefs (Russ 1996).

Pollution of any kind and coral piracy can bring about, directly or indirectly, the degradation or death of a reef… Coral bleaching has been ascribed to several factors, most often to warming of the sea water. Seasonal floods carrying sediment that overlays coral reefs is another natural cause for reefs degradation. It remains to be seen whether proposed marine reserves would be an effective means for saving coral reefs.…Pollution may reduce biodiversity and cause harmful genetic changes, especially in the sensitive ecosystems of coral reefs in the Red Sea/Indian Ocean system and the brakish and hypersaline lagoons in Egypt.

POSSIBLE EFFECTS OF MARINE POLLUTION

In seas with low natural productivity, such as the Red Sea and the Mediterranean, eutrophication may initially enhance marine organism populations, but it may also later lead to major environmental damage and even to collapse of whole ecosystems. Pollution may reduce biodiversity and cause harmful genetic changes, especially in the sensitive ecosystems of coral reefs in the Red Sea/Indian Ocean system and the brackish and hypersaline lagoons in Egypt. Algal and medusae blooms linked to pollution may reduce water clarity and threaten other marine organisms as well as the tourist and recreational industry in coastal areas, such as the Levant Basin and along the shores of the Sinai Peninsula. Another danger from pollution is the concentration of heavy metals or other toxic substances in seafood. Special attention must be paid to the presence of such contaminants as mercury and cadmium in the run-off from existing and developing industries in the region (Enserink *et al.* 1991; Simpson 1981; Talbot 1989; Nogawa 1984). Countries of the Middle East have a joint interest in protecting their waters from pollution, in particular from non-biodegradable contaminants. Cooperative regulation and enforcement on the part of the littoral states would benefit the environmental health of the Middle East's marine basins (i.e., eastern Mediterranean; Red Sea; Gulf of Aden, Arabian Sea and Gulf of Oman; and the Persian Gulf). The Persian Gulf in particular is ecologically vulnerable to the actions of its littoral states as well as the riparians of the Tigris-Euphrates river basin whose waters flow into the Gulf.

MIGRATION, BIODIVERSITY, AND EXOTIC SPECIES

In some areas of the Middle East, native marine life faces not only exposure to pollution and destruction of feeding and breeding habitats, but also the added risks of competition due to intentional or accidental introductions of exotic organisms. Examples of this include diseases and their carriers, such as the new Noda virus which is the cause of viral encephalopathy in seabass, a fish cultured in the area, or the viruses that have been plaguing shrimp farms in southern Asia. Introductions and immigrations of exotic wild and farmed species may affect biodiversity in the marine ecosystem. Indeed, this phenomenon has long been an issue in the Mediterranean, where numerous migrants from the Red Sea have been continually settling in the Levant Basin in niches occupied by native species (Golani, this volume; Ben-Tuvia 1978, 1985; Ben-Yami and Glaser 1974; Golani and Ben-Tuvia 1989). More recently, for example, in the Gulf of Aqaba, the Mediterranean gilthead seabream raised by Israeli cage farmers in Eilat have already found their way into the wild.

COASTAL CONSTRUCTION

Coastal and other marine construction is often detrimental to the coastline, low delta areas, and in-shore biotopes, both in biological and physical terms. Too often the damage done by such construction could easily have been predicted and avoided. Unfortunately, steadily increasing real estate values in heavily populated coastal areas have often led developers to disregard the environmental costs of their work.

Additionally, engineering projects influencing the flow of major rivers may lead to ecological damage of the marine environment downstream, as in the Nile Delta-Suez Canal area and below the Shatt al-Arab (Inman and Jenkins 1984; Vadiya and Shenuda 1985). Especially conspicuous has been the coastal erosion in Egypt in the wake of the Aswan High Dam construction.

Poorly planned harbors, marinas, and similar projects, both already completed and still in the planning stage, have become or may yet become ecological calamities. In Israel, these include the Ashdod harbor and the marina at Herzlia. Also, the coast of Gaza is already heavily eroded due to the rather small structures existing there (Golik and Goldsmith 1986). Any major construction, such as a deepwater harbor, especially if based on sea walls or breakwaters protruding seawards, would certainly substantially accelerate the coastal erosion, endangering not just the beaches, but also coastal roads and residential areas (Nir 1989). Such at-risk sites may in fact be developed by innovative, alternative solutions, such as offshore harbors connected with the coast by bridges allowing free flow of water.

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SHIPPING

Pollution generated by shipping, notably oil tankers, (particularly along the shipping lines leading to and from the Suez Canal, the Straits of Bab al-Mandab, the Gulf of Oman, and Shatt al-Arab) contaminates both the sea and coastlines. This pollution is partly caused by the flushing of ships' bilges and oil and fuel tanks at sea, and partly by jettisoned waste and litter, some of which is practically indestructible plastic (Golik and Gertner 1989). Much of this pollution arrives at beaches in the form of tar-like products and as ordinary garbage. Frequently, marine animals may swallow plastic bags and other containers or fasteners, while others may become entangled in this waste with potentially fatal consequences. The Suez Canal alone carries some 20,000 vessels that transport about 14 % of the world's trade. This includes 2,500 oil tankers. The average amount of crude oil passing daily through the Suez Canal is approximately 800,000 barrels. The Canal has been deepened recently to 17.5 meters, which makes it navigable by all but the largest oil tankers. The load of the oil traffic on the Canal seems, however, to be subsiding owing to increased use of the Suez-Mediterranean Pipeline (SUMED) and to a lesser degree the Trans-Israel Pipeline (TIP). Because the oil to and from these pipelines is carried by ships, the transfer of oil into and out of the pipelines may in fact increase the risk of spills.

Apart from Persian Gulf oil, the crude-oil load of the Suez Canal also derives from local production which is centered on the Gulf of Suez basin. Further development of oil refineries and petro-chemical industries has been projected in Egypt.

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FUTURE RESEARCH NEEDS AND COASTAL ZONE MANAGEMENT

In all areas, but especially in enclosed and semi-enclosed bays, gulfs, and lagoons, there is a need for "preventive" research and surveys. One objective for research is the assessment of their capacity to absorb waste originating from human activities (GESAMP 1986), with special attention to heavy metals and other toxic substances. This research should include the water at all levels, the sediments, and the flora and fauna (Caddy 1993). Routine monitoring and regular scientific research represent an essential condition for rational decision-making and should be introduced in all marine areas to prevent unpleasant surprises, including environmental effects due to global warming (Everett 1995) and ozone depletion (Baker 1991) on especially sensitive ecosystems.

At the same time we should bear in mind the widely discussed limitations of environmental sciences, both in terms of the reliability of environmental capacity assessments (Krom and Cohen 1991) and forecasting of the influence of natural and man-caused changes on whole ecosystems and their separate components.

Undoubtedly, the world-wide movement toward integrated coastal zones management (ICZM), which appears increasingly essential in view of the multiple users of coastal waters, beaches, and related resources, will also arrive in the Middle East. Coastal development and protection are largely a national issue related to environmental degradation of shores, including coastal lakes and lagoons, mangrove areas, beaches, and coral reefs. This issue may become international where major coastal construction projects in one country may cause beach degradation in another, or where pollution originating in one country is contaminating beaches and inshore waters of its neighbors.

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CONCLUSION

In view of the high rate of population growth, industrial and tourism development, and crude oil production and transportation, problems in the marine environment of the Middle East will increasingly require national attention and international cooperation among neighboring countries. In some areas, such as the Persian Gulf, the Gulf of Aqaba, and the southeastern Mediterranean, whole marine ecosystems may collapse without such cooperation. Efforts toward the establishment or reinforcement of such cooperation must continue despite the often tense political situations in many of these regions.

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Impact of Red Sea Fish Migrants through the Suez Canal on the Aquatic Environment of the Eastern Mediterranean

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ABSTRACT
The invasion of Red Sea organisms through the Suez Canal, known as "Lessepsian migration" (after Ferdinand de Lesseps, the Frenchman who directed the canal's construction), has profoundly modified the ecosystem of the Eastern Mediterranean. This migration, the result of major man-made changes in the area, has given us a unique opportunity to study the process of invasion and colonization by tropical biota of a sub-tropical region populated by temperate biota. The present research on Lessepsian fish focuses on three major areas: 1) identifying the characteristics distinguishing colonizer species from closely related non-colonizer species in the Red Sea; 2) assessing the colonizer populations' responses to the new environmental conditions; and 3) studying the impact of the Lessepsian migration on the Eastern Mediterranean ecosystem.

INTRODUCTION

No zoogeographic marine area of the world has been affected more by man-made changes than the eastern Mediterranean. Two major projects have heavily influenced the Levantine marine ecosystem: the construction of the Suez Canal, completed in 1869, and, to a lesser extent, the Aswan High Dam. The dam, which became fully operational in 1964, resulted in the cessation of fluvial sedimentation and nutrients to the Mediterranean, leading to a sharp decrease in fish populations, mainly sardines (Aleem 1972); as a result, the Egyptian purse seine fishing industry today takes only 10% of the pre-dam catch. The Suez Canal, however, has had an even more significant and lasting impact.

The opening of the Canal in 1869 has zoogeographic and ecological ramifications far beyond those envisioned by its designers, who only intended to provide a quick trade route from Europe to India and the Far East.

The opening of the Canal in 1869 has had zoogeographic and ecological ramifications far beyond those envisioned by its designers, who only intended to provide a quick trade route from Europe to India and the Far East. Stretching from Port Said in the north, the Suez Canal continues southward for 162.5 km, crossing Lake Timsah and the Bitter Lakes on its way to the city of Suez and the Gulf of Suez. For most of its length, the canal is quite narrow, only 200–300 m, and very shallow, 10–15 m. The canal connects two major bodies of water, the Red Sea and the Mediterranean, which differ fundamentally both faunistically and hydrographically. The main abiotic difference between the two regions is the temperature regime, which is stable in the tropical Red Sea but experiences wide fluctuations in the subtropical Mediterranean. The fauna of the Red Sea is of tropical Indo-Pacific origin, while that of the Mediterranean is mainly of temperate Atlantic origin. In the wake of the opening of the Suez Canal, each sea was exposed to invasion of organisms from the other sea. However, the vast majority of migrational movement has been from the Red Sea to the Mediterranean. This influx of biota from the Red Sea into the Mediterranean has been termed "Lessepsian migration" (Por 1978), in recognition of Ferdinand de Lesseps, the engineer and spirit behind the creation of the Suez Canal. The minor migration in the opposite direction is known as "Anti-Lessepsian migration." This phenomenon encompasses all major taxa. It is interesting to note that in all studied taxa, the percentage of Lessepsian migrants in the Levant is quite high: 7.1% of Polychaeta (Ben-Eliyahu 1995); 22.9% of decapod crustaceans (Galil 1992); 9.4% of Mollusca (Barash 1992) and 13.2% of fish (Golani 1996). Among all taxa, the study of fish is advantageous, since their taxonomy is well known and, due to their commercial importance, constant information on quantitative and qualitative changes of migrant and native populations is available through the local fisheries (Golani and Ben-Tuvia 1995).

The fauna of the Red Sea is of tropical Indo-Pacific origin, while that of the Mediterranean is mainly of temperate Atlantic origin. In the wake of the opening of the Suez Canal, each sea was exposed to invasion of organisms from the other sea.

The phenomenon of Lessepsian migration provides a unique opportunity to investigate, on a large scale, processes of migration, invasion and colonization, processes which usually occur over a geological time scale.

Lessepsian fish research commenced shortly after the opening of the Suez Canal, with the monitoring of fish species in the canal itself (Keller 1882; Tillier 1902). Until the late 1970s, the vast majority of studies were limited to reporting new arrivals and creating inventories of migrant species (Ben-Tuvia 1966, 1978). In the 1980s and 1990s, a wider approach has been taken, emphasizing quantitative and qualitative ecological analyses (Ben-Tuvia 1985; Golani and Ben-Tuvia 1995). The present research on Lessepsian fish focuses on three major areas:

- identifying the characteristics distinguishing colonizer species from closely related non-colonizer species in the Red Sea;
- assessing the colonizer populations' responses to the new environmental conditions; and
- studying the impact of the Lessepsian migration on the Eastern Mediterranean ecosystem.

WHAT IS A SUCCESSFUL LESSEPSIAN FISH MIGRANT?

It has been observed in many taxa that some species have a high dispersal and colonization ability while other closely related species with similar ecological requirements do not. In the Red Sea, there are a number of fish families with several species, of whom only a few have established populations in the Mediterranean.

For example, there are 14 Goatfish (Mullidae) species in the Red Sea (Goren and Dor 1994), but only two, *Upeneus moluccensis* and *U. pori*, have migrated to the Mediterranean. Similarly, there are 15 species of Squirrelfishes (Holocentridae) in the Red Sea but only one colonizer in the Mediterranean, namely, *Sargocentron rubrum*.

The question of how to distinguish a potential colonizer was first approached by Elton (1958). In the mid 1960s, Baker and Stebbins (1965) and MacArthur and Wilson (1967) were among the first to study this problem in a multidisciplinary manner. In the Red Sea, their approach was utilized in the study of mollusc migrants (Lavee 1983; Lavee and Ritte 1994). Selander and Kaufman (1973) noted that there are great differences between invertebrates and fish concerning their response to changes in the environment. In the current study, criteria which distinguish the successful colonizer were examined in four critical areas. The goatfish family (Mullidae) was the subject of this multidisciplinary approach. The four factors chosen for examining the correlation to successful colonization were:

- genetic variability;
- breadth of trophic niche;
- life history strategy; and
- relative importance in the fish assemblage in the source site (Red Sea).

GENETIC VARIABILITY

Since the conditions in the target area differ from those prevailing in the source area, the colonizer must respond rapidly to changes encountered in order to establish a sustainable population. Theoretically, an adequate response to the new selective pressure demands high genetic variability, so that within the given wide genetic repertoire, the appropriate genotype can be found, become dominant, and thus lead to successful adaptation. Five non-colonizer species of Mullidae, *Mulloides flavolineatus*, *Parupeneus forsskali*, *P. rubescens*, *P. macronema* and *Upeneus subvittatus*, were compared to two mullid colonizers, *Upeneus moluccensis* and *U. pori*. Genetic variability was tested by electrophoretic examination of allozymes; the results revealed no correlation between genetic variability and success in colonization (Golani and Ritte 1993). These results confirm the general findings of Gray (1986) and Barrett and Richardson (1986). However, Parsons (1983) claimed that examination of specific allozymes responsible for adaptation to new environmental conditions and facilitating success in colonization would reveal differences between colonizers and non-colonizers.

TROPHIC NICHE BREADTH

The theoretical basis for examination of this factor resembles that for the previous factor, genetic variability, namely, that species which feed on a wide variety of food types (termed "generalist feeders") will be better potential colonizers. Species with a narrow trophic niche breadth ("specialist feeders") are less likely to find appropriate food in the new area. The feeding habits of three non-colonizer mullids, *Mulloides flavolineatus*, *Parupeneus forsskali* and *P. rubescens*, were compared to that of the colonizer *Upeneus pori* (Ben-Eliahu and Golani 1990). No correlation was found between trophic niche breadth and success in colonization.

LIFE HISTORY STRATEGY

This factor is defined as the sum total of demographic features that determine the species' fitness. MacArthur and Wilson (1967) developed a model, by which a continuum of life history strategy is determined. One end of the continuum represents the "r-strategist," which is characterized by rapid growth rate and a high reproductive potential (which is expressed by a high intrinsic rate of increase, early sexual maturity, small body size, a short longevity and usually only one reproductive season). On the other end is the "K-strategist," which is characterized by the opposite features. MacArthur and Wilson (1967) and Safriel and Ritte (1980) predicted that r-strategists would be better colonizers. Their reasoning was based on the hypothesis that smaller populations have greater probability of random extinction. Since the pioneer group of invaders is usually small, not more than a few individuals, the invaders must have the ability for rapid population growth in order to avoid extinction. Moreover, in the case of invaders who perceive their new environment as unpredictable in contrast to the source environment to which they have been long adapted, the invaders are prone to ecological catastrophes that are liable to decrease their population, leaving a very small number of individuals.

In the case of invaders who perceive their new environment as unpredictable, in contrast to their source environment to which they have been long adapted, the invaders are prone to ecological catastrophes that are liable to decrease their population, leaving a very small number of individuals.

The association between life history strategy and success in colonization has been studied also in the family Mullidae. Table 1 summarizes demographic data on goatfishes in the source area of the Red Sea, obtained by Golani (1988) and others. From the data it can be concluded that the two colonizer species are indeed "r-strategists" as compared to the non-colonizers. However, Golani (1988) postulated that in the particular case of the eastern Mediterranean, which is a heterogeneous ecosystem as compared to the Red Sea, the r-strategists had an advantage in colonizing this unpredictable environment. Therefore, r-strategists are not necessarily always better universal colonists. For example, the rivers of North America are dominated by typical K-strategist (mainly Cich lidae) colonizers (Stauffer 1984).

Relative importance in fish assemblage in source site

It is evident that, in order for colonization to be successful, there must be some similarity between the environmental conditions of the source habitat and that of the target habitat. This overlap must be within the range of tolerance of the colonizer. Golani and Ben-Tuvia (1989) showed that the habitat in the eastern Mediterranean that is the most prone to Lessepsian colonization is shallow sandy or muddy substrates. The closest equivalent to this Mediterranean habitat in the Red Sea is the sandy shore. Examination of the fish assemblage in the Red Sea sandy shore revealed that the dominant species in this assemblage were Lessepsian migrants, who inhabited this habitat throughout all their life stages (Golani 1993 a). It was therefore concluded that dominance in the equivalent source habitat constitutes pre-adaptation to success in colonization of the Eastern Mediterranean by Lessepsian fish migrants.

Table 1 Some demographic data of colonizing and non-colonizing goatfishes (Mullidae) from the Red Sea and other native sites.

	COLONIZERS		NON-COLONIZERS			
	U. mol.	*U. pori*	*M. fla.*	*M. van.*	*P. for.*	*P. hep.*
Spawning season	Apr.- Dec.[a]	Mar.-Apr.	Mar.-Aug.	May-Sep.[c]	—	—
Size at benthic settlement (mm, SL)	45.0[b]	27.2	50.0	—	50.0	—
Age at first reproduction (month)	12[b]	9	36	—	24	—
Size at first reproduction (mm, SL)	104[b]	61	130	—	115	—
Maximum attainable size (mm, SL)	170[b]	135	328[c]	363[c]	230	444[e]
Growth rate coefficient	0.303[b]	0.663	0.213[c]	0.160[c]	0.261[d]	0.208[e]

[a] - Southern Red Sea (Ben-Tuvia 1968) [b] - Hong Kong (Lee 1974) [c] - Gulf of Aqaba (Wahbeh 1992)
[d] - " " (Wahbeh and Ajiad 1985) [e] - " " (Al-Absy and Ajiad 1988)
U. mol. = Upeneus moluccenis, U. pori = Upeneus pori, M. fla. = Mulloides flavolineatus, M. van = Mulloides vanicolensis, P. for. = Parupeneus forsskali, P. hep. = Parupeneus heptacanthus.

RESPONSE TO THE NEW ENVIRONMENT

Once the colonizers have established a population in the target area, they are presumably isolated from their source population and are exposed to new selective pressures which may result in phenotypic and genotypic changes in the new population (Parsons 1982). In order to test this hypothesis, a comparison was made between the source and target populations. Golani (1990) compared specimens from the source (Red Sea) and target (Eastern Mediterranean) populations of seven species of Lessepsian migrants. In most species, the spawning season was shortened in the Mediterranean, presumably due to the constraints of the colder temperature regime. In some species, changes were noted in some meristic counts, namely, number of dorsal and anal rays, number of lateral line scales and number of vertebrae. All these changes have been attributed to the prevailing temperature during spawning season (Golani 1990; also see Lindsey 1988).

Almost half of the catch of trawl fishery in the Mediterranean coast of Israel can be attributed to Lessepsian migrant species.

Golani and Ritte (1993) compared allozymes of source and target populations of two Lessepsian fish migrants, *Upeneus moluccensis* and *U. pori.* No discernible genetic differences were found. It should be noted that this method of allozyme analysis is rather crude and is not sufficiently sensitive to discern small alterations. Current techniques such as DNA sequencing are able to detect minute changes and it is in this direction that research should progress.

Diet adaptations were studied in several species of Lessepsian migrants. As anticipated, the feeding habits of colonizers remained generally similar to those of the mother population. Some small differences were noted; for example, *Upeneus pori* feeds in the Mediterranean upon a wider size range of prey. The algal composition of the diet of the two rabbitfish, *Siganus luridus* and *S. rivulatus*, was altered in the Mediterranean. However, lack of quantitative data on trophic resources in both the source and target areas prohibits a determination of whether these changes are the result of selectivity or availability.

IMPACT OF LESSEPSIAN MIGRANTS ON THE EASTERN MEDITERRANEAN

A total of 54 Lessepsian fish species have been recorded to date (Golani 1996), representing 37 families, of which 13 are new to the Mediterranean (Table 2). Out of these 37 families, 25 are represented by only one species; 8 by two species; three families by three species and one family (Clupeidae) by four species. The Lessepsian fish species constitute 13.2% of the total number of ichthyofauna in the Levant. These species have a qualitative and quantitative importance beyond their percentage in the composition of the local ichthyofauna; more than half of the species have become common in

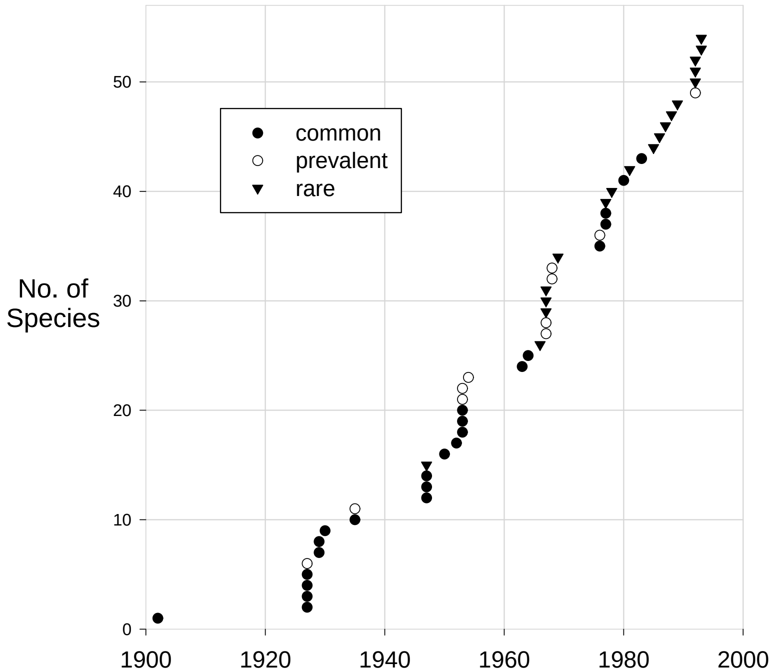

Figure 1 Cumulative count of Lessepsian migrant species as a function of the year of first record.

the eastern Mediterranean and at least 18 species contribute to the local fishery. Almost half of the catch of trawl fishery in the Mediterranean coast of Israel consists of Lessepsian migrant species (Golani and Ben-Tuvia 1995). It is difficult to determine precisely the percentage of Lessepsian migrants in the catch of other fishing methods, but it is estimated to be considerable.

There is a clear east-west gradient in the distribution of Lessepsian migrant species in the Mediterranean. There are 54 Lessepsian migrant fish species along the Levantine coast. This number gradually decreases along the gradient westward, up to the coasts of Tunisia and Sicily. Thirty Lessepsian migrant fish species inhabit the southern coast of Turkey and 32 inhabit the Mediterranean coast of Egypt. Only four Lessepsian species have been found along the southern coast of Italy, and no Lessepsian species have been found in the western basin of the Mediterranean.

From Table 2 and Figure 1, a clear correlation can be seen between the year of first record of individual Lessepsian migrant species in the Mediterranean and each species' current abundance along the Mediterranean coast of Israel. In general, those species that appeared earlier are currently more abundant. Although date of first record is not identical with the actual first arrival of a Lessepsian species to the Mediterranean, it is reasonable to assume that the chance of a species being collected and recorded increases with

Table 2 List of Lessepsian fish migrants. * - new family to the Mediterranean; IP - inshore-pelagic, M - muddy, P - pelagic, R - rocky, S - sandy, V - vegetation; Abundance: + - rare, ++ - prevalent, +++ - common; 1st Year of Record - year of first record in the Mediterranean; BS - beach seine, N - trammel and gill nets, PS - purse seine, T - trawl.

Family	Species	Habitat	Abundance	1st Year of Record	Commercial
DASYATIDAE	*Himantura uarnak*	S&M	++	1955	T
CLUPEIDAE	*Dussumieria acuta*	PS	+++	1953	IP
	Etrumeus teres	P	+++	1963	PS
	Herklotsichthys punctatus	IP	+++	1976	PS
	Spratelloides delicatulus	IP	+	1978	—
CONGRIDAE	*Rhynchoconger trewavasae*	M	+	1993	—
MURAENESOCIDAE*	*Muraenesox cinereus*	M	+	1982	—
SYNODONTIDAE	*Saurida undosquamis*	S&M	+++	1953	T
EXOCOETIDAE	*Paraexocoetus mento*	P	++	1935	PS
BELONIDAE	*Tylosurus choram*	P	+	1963	—
HEMIRAMPHIDAE	*Hemiramphus far*	P	+++	1927	PS
	Hyporhamphus affinis	P	+	1967	—
ATHERINIDAE	*Atherinomorus lacunosus*	IP	+++	1902	—
HOLOCENTRIDAE*	*Sargocentron rubrum*	R	+++	1947	N
SCORPAENIDAE	*Pterois miles*	R	+	1992	—
PLATYCEPHALIDAE*	*Papilloculiceps longiceps*	S	+	1990	—
	Platycephalus indicus	S	++	1953	—
	Sorsogona prionota	S	+	1947	—
SERRANIDAE	*Epinephelus coioides*	R	+	1969	—
	Epinephelus malabaricus	R	+	1969	—
TERAPONIDAE*	*Pelates quadrilineatus*	S	++	1970	—
	Terapon puta	S	++	1976	—
APOGONIDAE	*Apogon nigripinnis*	R	+++	1947	—
SILLAGINIDAE*	*Sillago sihama*	S	+++	1977	PS
RACHYCENTRIDAE*	*Rachycentron canadum*	P	+	1986	—
CARANGIDAE	*Alepes djedaba*	S&IP	+++	1927	BS&PS
LEIOGNATHIDAE*	*Leiognathus klunzingeri*	M	+++	1931	—
LUTJANIDAE*	*Lutjanus argentimaculatus*	R	+	1977	—
MULLIDAE	*Upeneus moluccensis*	S&M	+++	1947	—
	Upeneus pori	S&M	+++	1950	T
HAEMULIDAE	*Pomadasys stridens*	S	++	1969	—
SPARIDAE	*Crenidens crenidens*	S&V	++	1970	N
	Rhabdosargus haffara	S	++	1992	—
PEMPHERIDAE*	*Pempheris vanicolensis*	R	+++	1979	—
MUGILIDAE	*Liza carinata*	S&IP	+++	1971	BS&PS
SPHYRAENIDAE	*Sphyraena chrysotaenia*	P	+++	1930	T&PS
	Sphyraena flavicauda	P	+	1992	—
LABRIDAE	*Pteragogus pelycus*	S	+	1992	—
BLENNIDAE	*Petroscirtes ancylodon*	S	+	1989	—
GOBIIDAE	*Monishia ochetica*	S	++	1927	—
	Oxyurichthys papuensis	S	+++	1983	—
	Silhouetta aegyptia	S	++	1991	—
CALLIONYMIDAE	*Callionymus filamentosus*	S	+++	1953	—
SIGANIDAE*	*Siganus luridus*	V	+++	1964	N
	Siganus rivulatus	V	+++	1927	N&PS
SCOMBRIDAE	*Rastrelliger kanagurta*	P	+	1971	—
	Scomberomorus commerson	P	+++	1935	N&PS
CYNOGLOSSIDAE	*Cynoglossus sinusarabici*	S	++	1953	—
MONACANTHIDAE*	*Stephanolepis diaspros*	R&V	+++	1927	—
OSTRACIIDAE*	*Tetrosomus gibbosus*	S&V	+	1988	—
TETRAODONTIDAE	*Lagocephalus spadiceus*	S	+++	1953	—
	Lagocephalus suezensis	S	+++	1977	—
	Torquigener flavimaculosus	S	+	1987	—
DIODONTIDAE*	*Chilomycterus spilostylus*	S	+	1993	—

population growth upon arrival to the target area. Therefore, date of first record may be used as a baseline for initiation of a species' colonization. There are several explanations for this correlation. First, the longer the time elapsed since colonization, the better the opportunity to establish large, flourishing populations; in addition, the species may have undergone further adaptation to the new habitat during these years. Second, these species may have had a superior colonization and competitive ability that allowed them to arrive first into the Mediterranean and closely thereafter establish a population. Another explanation may be that the increase in ichthyological studies in the last few decades has revealed more first records, some of which may represent abortive colonization events which would not have been detected prior to the use of intensive research methods. It is interesting to note that the vast majority of species recorded since 1970 have been rare (see Figure 1); however, five species (*Herklotsichthys punctatus*, *Sillago sihama*, *Pempheris vanicolensis*, *Oxyurichthys papuensis*, and *Lagocephalus suezensis*) recorded in the late 1970s are very common in the eastern Mediterranean. There is no obvious common feature between these five species, yet together they constitute an exception to the pattern of gradual building of population size.

The success of Lessepsian migrant fish species in colonization of the Eastern Mediterranean has often been explained as the exploitation of unsaturated niches. For example, the success of the two herbivore siganids *Siganus luridus* and *S. rivulatus* was attributed to their entering temperate waters of the Mediterranean where there were scarcely any herbivores (Lundberg and Golani 1995). Similarly, the lack of nocturnal species facilitated the success of the colonization of three nocturnal Lessepsian migrants: *Sargocentron rubrum*, *Apogon nigripinnis* and *Pempheris vanicolensis* (Golani and Diamant 1991). One might conclude that penetration and colonization should be easier for species whose families have no or very few representatives in the target area; conversely, one might assume that species whose families are well represented by species in the target area would have a high resistance to confamilial colonization. Figure 2 offers four categories according to the percentages that the Lessepsian migrants represent among all species in a particular family in the Levant, as well as the composition of each category by the number of species in each family. In thirteen families, all species are Lessepsian migrants and in another eleven families, 50% or more are Lessepsian migrants. However, there are thirteen other Lessepsian migrant species which have succeeded in penetrating and colonizing the Mediterranean, despite many indigenous confamilial species already inhabiting the Mediterranean.

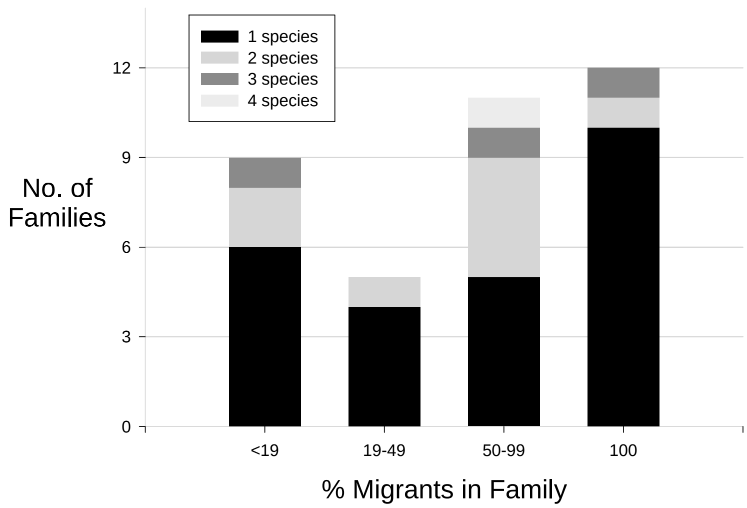

Figure 2 Percentage of Lessepsian migrant species in their families in the Mediterranean, with further breakdown according to the number of Lassepsian species per family.

There are very few studies which directly investigate the impact of Lessepsian migrants on the autochtonous species. The difficulty lies mainly in the lack of information available from the period prior to invasion. The method of investigating this relationship should be the study of the ecological requirements of closely related species (Ben-Yami and Glaser 1974). Such an investigation was conducted by Golani (1994) on Goatfishes (Mullidae), in which there are two migrant species, *Upeneus moluccensis* and *U. pori*, and two indigenous Mediterranean species, *Mullus barbatus* and *Mullus surmuletus.* A similar study (Golani 1993b) was conducted on Lizardfishes (Synodontidae,) which has a single Lessepsian migrant, *Saurida undosquamis*, and an indigenous species, *Synodus saurus.* The family Sphyraenidae was also studied (unpublished material). In all three families, the feeding habits of the colonizers and the local species were remarkably similar and niche partitioning was presumably accomplished along bathymetric axes. Among the goatfishes (Mullidae), the colonizer species occupied a shallower sector, while an opposite trend was observed among the lizardfish (Synodontidae). It is difficult to determine whether the colonizers displaced the local species or whether the latter occupied the same bathymetric niche prior to its confamilial's colonization. An examination of the bathymetric distribution of local species in those areas where colonizers have not penetrated will be of no avail in determining this question, since there are many other environmental factors which on one hand may be affecting the local species and on the other hand may be preventing the entrance of colonizer species.

It is important to note that no local species has disappeared since the study of Lessepsian migration. Nevertheless, there are two cases which deserve further study. The indigenous meager *Argyrosomus regius* was once one of the most common commercial species in Israel. Since the 1980s this species has almost completely disappeared in local catches, while simultaneously, the Lessepsian migrant narrow-barred Spanish mackerel *Scomberomorus commerson* has dramatically increased its population. Both species are piscivores and may utilize a similar niche. Similarly, the Lessepsian dragonet *Callionymus filamentosus* is one of the most common by-catch species in local fisheries. The other three confamilial indigenous species, who also occupy a similar shallow habitat, have almost disappeared from local catch. The only indigenous dragonet still being collected is *Synchiropus phaeton*, which inhabits much deeper waters (150–300 m).

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Fisheries Development in the Arab World

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ABSTRACT
Arab fisheries resources, including the coastal waters of the Arab states, inland waters, and aquaculture potential, are an important sector for development. If rationally and scientifically exploited, fisheries could play a role in meeting increased food demand, and in activating the economies of the region, possibly surpassing oil exploitation by being a renewable and self-replenishing resource.

INTRODUCTION

Marine waters border the Arab countries on all sides: the Arabian Gulf on the east, the Atlantic Ocean on the west, the Mediterranean Sea on the north, and the Indian Ocean on the south. In addition to these, the Red Sea and various gulfs, rivers—mainly the Nile, the Tigris, and the Euphrates—and the natural and man-made lakes constituting inland water resources afford the Arab countries very important potential for fisheries. The Exclusive Economic Zone (EEZ) expands Arab marine waters to rich international fishing grounds. Engaging in aquaculture activities in marine and inland waters, as well as better exploitation of the available fisheries resources, would create a more sound and more beneficial fishery industry. It could become one of the main pillars of Arab economic activities, of no less importance, in some countries, than the fishery industry in the economy of major fishing nations such as Japan and Norway.

Prior to the discovery of oil in some Arab states, fish had traditionally been an important source of animal protein, particularly along the coastal areas. Increasing incomes from oil, providing higher purchasing power, made other protein sources available, causing diversification of protein intake and reducing fish consumption. In recent years, however, due to various economic and social reasons, demand for fish and its consumption in fresh or processed form have risen to some degree. On the whole, consumers have begun to turn to cheaper foods, often consuming traditionally unmarketable fish products, developing new uses for fish by either diversifying preparation methods or accepting imported products previously unknown locally.

Fish marketing opportunities are increasingly opening up in the Arab states. Such an increase in the demand for fish products may be met either from better exploitation of fisheries resources or through the importation of quantities that may not be obtained from local sources.

Fishing and fisheries contribute more than any other animal production activity to protein intake in most of the developing regions of the world, including most of the Arab states, and are important for the food security of many coastal populations. By all accounts, many wild marine and freshwater resources are on the decline.

THE ISSUE OF FISHERIES GLOBALLY

In past decades the rapid growth of the exploitation of fisheries resources has taken its toll: during the 1950s and 1960s, the global catch from commercial fishing grew three times faster than the world population. Production growth was slower afterwards; currently, as global fishery production (catch and aquaculture) averages 100 million tons (MT) per year (113 MT in 1995, a record so far), per capita supplies are on the decline. These trends have an obvious impact on prices: during the last decade seafood prices have risen almost 4%/yr on average, rendering a traditionally inexpensive source of protein much less accessible to the poor.

Blame for the depletion of aquatic resources has been placed mostly on two factors:

- The development of excess fishing capacity with respect to existing fish stocks and their natural growth rates; and
- the deteriorating condition of fish stocks due to the pollution of sensitive aquatic systems, both freshwater and marine.

Small-scale fisheries in developing countries have generally played a minor role beyond their communities, although the pressure of growing local demand has occasionally contributed to the over-exploitation of coastal waters.

The development of fishing capacity has taken place mostly in the large-scale (industrial) and medium-scale fishing sub-sectors. Since the early days of international development assistance, the main objective of fisheries development projects has been to increase fishing efficiency and income levels through motorizing boats, improving gear, and in harbor development and other infrastructure facilities. The sector and its manpower have grown, drawing workers from rural to urban areas.

At the same time, large numbers of small-scale fishermen have had no access to that assistance, finding it increasingly difficult to survive in an overexploited environment. From this perspective, the crisis of fisheries has been a crisis of livelihoods.

The implications go far beyond dwindling fish stocks available to small-scale fishermen. Globally, fishing provides the main source of income for about 100 million fishermen and their families, the majority of them among the world's poorest. They are among the one billion people—nearly a fifth of the global population—for whom fish is the main source of animal protein. The scarcity of fisheries resources is leading to clashes between neighbors as fishing fleets stray across maritime borders after depleting stocks in their own waters.

It is estimated that 85% of the world's fish harvest is still caught in the wild, although the practice has reached the limits of sustainability in many areas. This, in part, is because the means of exploitation have become so efficient. Fishing fleets use sonar, radar, aircraft and satellites to track shoals. Winches and motors and drift nets typically trap more than 18 tons of fish. This enables trawlers to increase not only catches but the by-catches—species that are netted but are unwanted and consequently discarded.

The issue of discards is a very disturbing one since it results in a very large wastage of fisheries resources . FAO estimates that 18–39 MT of fish per year may be discarded at sea to catch about 50 MT of fish suitable for human consumption.

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PRESENT STATUS OF ARAB FISHERIES

FISHERIES BOUNDARIES

The geographical boundaries of the Marine Statistical Areas as classified by FAO place Arab waters in the following areas:

AREA 34: East Central Atlantic, Mauritania, and Morocco

The most dominant fisheries of Area 34 consist mainly of rich resources of hake, crustaceans (shrimps and lobsters), cephalopods (octopus, cuttlefish, and squid), small pelagics (sardines, mackerels), and tunas (big-eye and yellowfin). Rich demersal resources are also present. This area is the largest contributor to Arab fish landings.

AREA 37: Mediterranean Sea, Morocco, Algeria, Tunisia, Libya, Egypt, Gaza (Palestine), Lebanon, and Syria

Area 37 is generally considered medium to poor with regard to fish productivity. The western parts of this area have small pelagics, with its main fishery consisting mostly of sardines and anchovy, as well as a modest population of demersal species. The central parts, while rich in demersal and small pelagic species, suffer from over-fishing in such areas as the Gulf of Gabes in Tunisia, for example, while other waters bordering Libya are under-exploited. The eastern portions consist of poorer fisheries fished by much smaller boats than those of the central and western portions. Palestinian fisheries off Gaza have in recent years dropped from about

4,000 T/y to about 1,000 T/y as a result of the reduction of the fishing limits from 20 km to 12 km from the shore. This has also caused the reduction of the number of fishermen from 13,000 in 1980s to the current estimate of some 1,500 or so.

Area 51: North Western Indian Ocean, Egypt, Sudan, Djibouti, Somalia, Yemen, Comoros, Saudi Arabia, Jordan, Iraq, Kuwait, Bahrain, Qatar, United Arab Emirates, and Oman

Area 51 is an extremely varied area consisting of the Red Sea, the North Arabian Sea, several gulfs, and the northern parts of the Indian Ocean. The Red Sea is considered of poor productivity (outside of the Gulf of Suez, which is actually over-fished) and its fisheries resources consist of quantities of small pelagics, jack, and some demersal and crustacean resources. The fisheries of the Arabian Gulf and Gulf of Oman are modest in their production of small pelagics, demersal species and crustaceans. Some areas, especially in the Gulf of Oman and the north Arabian Sea, could withstand further exploitation of their resources. Only the shrimp resources are highly exploited. The Gulf of Aden is considered a fish-rich area and is underexploited, the fisheries consisting of mostly small pelagics (sardines and anchovy) and several high-value demersal species. Crustaceans resources and cephalopods are also available and could withstand further exploitation. The unexploited resource of mesopelagic fish in the Gulf of Aden as well as in the Gulf of Oman, estimated to be not less than 1.5 - 2 MT, is another resource which offers potential. Finally, the southern part of Area 51, waters bordering Somalia, is considered rich in small pelagics (sardines) as well as a good resources of demersal species, tunas and crustaceans.

In addition to the traditional and conventional fisheries, a wide variety of seafoods, such as abalone, bivalves, crabs, sea cucumbers, jelly fish, sea-unicorn and sea turtles, are available in Arab waters. It is possible that some of these species may be nationally exploited for export purposes once the expertise for their processing and marketing becomes available, as long as the harvest of endangered species is still strictly prohibited.

The coastlines of the Arab states total 23,000 km, and span a continental shelf area of 608,000 km^2. Inland waters are estimated to have an area of about 7.2 million hectares of marshes, water reservoirs, rivers and lakes.

Latest FAO fisheries statistics on the Arab world indicate that in 1995 fish production from marine and inland waters including aquaculture was 2 MT or about 1.8 % of global catches. The 1994 fish landings from all sources were 1.9 MT amounting to 1.7% of the world catch of 109 million tons, i.e., a rise in landings of about 1.1 %

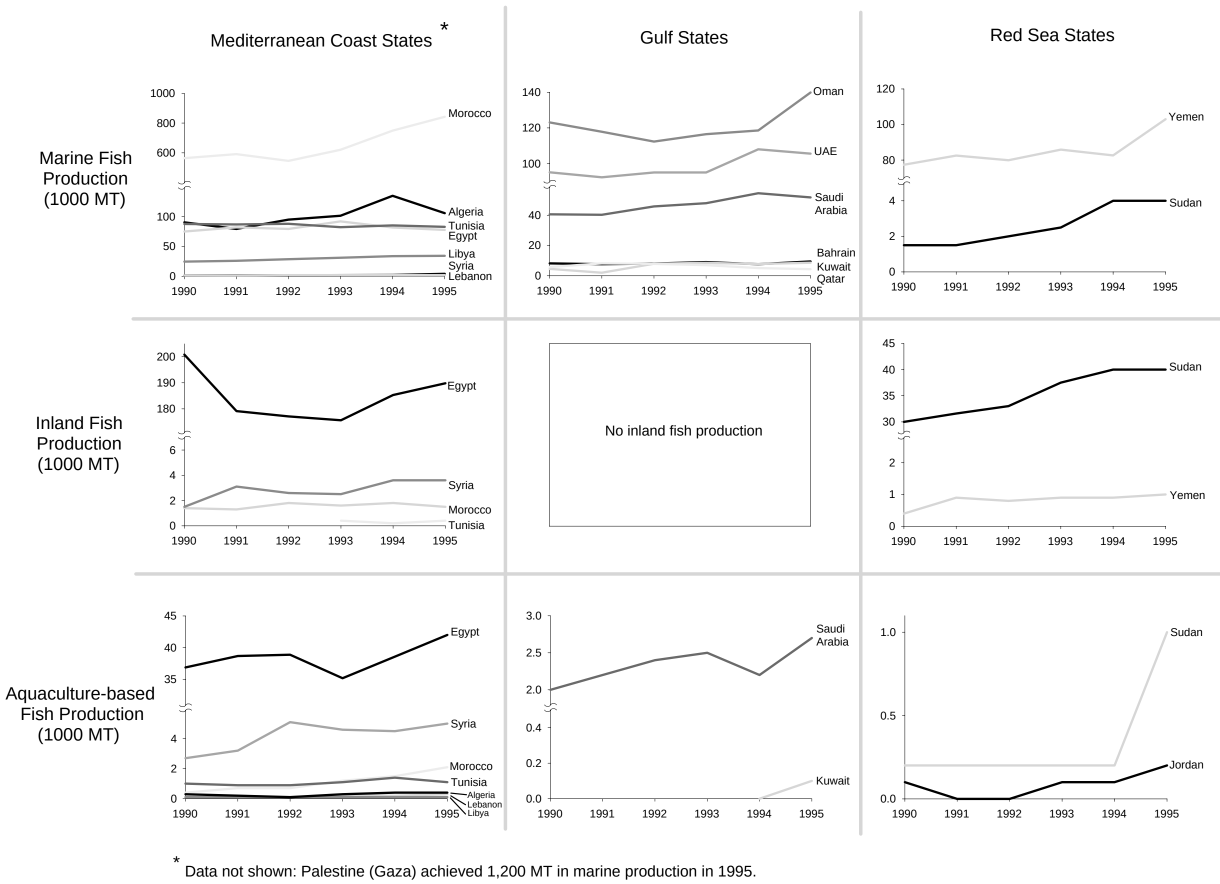

Figure 1 Fish Production of Arab states from 1990-95. Source: FISHDAB.

from all sources over the period of 1990–1995.

Marine and inland catches over a period of six years have fluctuated slightly but maintained an increasing trend (see Figure 1).

With regard to the contribution of aquaculture to Arab fisheries resources in both marine and fresh waters in 1995 the total production reached 69,000 MT. Aquaculture is a relatively new source of fish in the Arab states but has made significant progress since 1984 increasing by about 68% in roughly a decade. It is significant to note that the practice of aquaculture in Egypt, Iraq and Syria for many years has been contingent upon the availability of fresh water. In recent years, aquaculture has been initiated in several countries where fresh water is very scarce, such as Kuwait, Saudi Arabia, Bahrain and United Arab Emirates (Figure 1).

CLASSIFICATION OF FISHERIES RESOURCES

Fisheries resources may be classified into four main areas:

EXCLUSIVE ECONOMIC ZONE FISHERIES

The introduction in the mid-1970s of Exclusive Economic Zones (EEZs) and the adoption in 1982 of the United Nations Convention of the Law of the Sea provided a new framework for the management of marine resources. The new legal regime of the oceans gave coastal states rights and responsibilities for the management and use of fishery resources within their EEZs. However, many coastal states, including several Arab countries, continue to face serious challenges, lacking experience and financial and physical resources to achieve greater benefits from the fisheries within their EEZs.

Subsequently, the FAO Committee on Fisheries (COFI), at its Nineteenth Session in 1991, called for the development of new concepts which would lead to responsible, sustainable fisheries. As a result, the International Conference on Responsible Fishing, held in 1992 in Mexico, requested FAO to prepare an international Code of Conduct to address these issues. The outcome of this Conference was an important contribution to the 1992 United Nations Conference on Environment and Development (UNCED), particularly Agenda 21. Afterwards, the United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks was convened, to which FAO provided important technical back-up. In November 1993, the Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas was adopted.

As a result of these developments, the Code of Conduct for Responsible Fisheries, adopted in October 1995 by the FAO Conference, provided a necessary framework for national and international efforts to insure sustainable exploitation of aquatic living resources in harmony with environmental management activities. It has also brought about a significant change in the conditions under which fisheries are carried out on a world wide basis. The extent of national EEZs and the nature of jurisdiction claimed differ from country to country, but in the majority of cases the zone extends 200 nautical miles offshore and in all cases jurisdiction over fishery resources is included.

All Arab states, albeit in ranging degrees, may have access to fisheries resources in their EEZs. However, it is not yet clear what benefits the Arab states can gain from fish resources available in their EEZs. The only extension of jurisdiction by Arab states of possible benefits to their fisheries is in the fishing areas of the countries bordering the east central Atlantic Ocean (Mauritania and Morocco) and the northwest Indian Ocean (Oman, Yemen and Somalia). However, although extension of jurisdiction by these countries over the fish resources in their EEZs provides an opportunity for more effective development and national management of fisheries based on the stocks available, realization of that opportunity depends on the solution of a number of difficult problems.

MARINE FISHERIES

The fisheries of the Arab Middle East and North Africa are quite heterogenous as a result of wide geographical spread. They may be classified into two broad categories based on vessel size, gear types and species targeted.

HIGH SEAS (OFFSHORE) FISHERIES

In large fish-producing countries such as Morocco and Mauritania, the category is characterized by a large modern mechanized fleets with vessels equipped with freezing, storage and other facilities capable of up to three months of operation at sea at a stretch. These vessels operate beyond the 20 mile fishing zone and their catches are almost exclusively destined for export. This is capital intensive activity requiring large investment, often beyond the reach of most private local fishermen. It is an export-oriented sub-sector of high-value species, such as cuttlefish, octopus, squid, shrimp and tuna. The fleets operating in this fishery are largely fleets from Spain and Portugal operating in most instances under license or joint ventures. Their catches are of high value, but they are not, in most cases, reported as catches of the countries bordering the waters where fishing operations take place.

COASTAL FISHERIES

Within this category, two sub-groups are usually considered: intermediate and small scale (artisanal) fisheries.

Intermediate Fisheries

This sub-group is characterized by vessels of 25 meters or less, operating up to 20 miles off shore, mostly targeting pelagic species, sardines and mackerels in particular. Because an important proportion of the production of this category goes to canning and, to a lesser extent, fish meal and fish oil industries, they are sometimes referred to as "industrial fisheries." The average share of these fisheries is 15–20%.

Small Scale Fisheries

This sub-group is characterized by a fleet of small motorized boats, 5–6 m in length, of small catching capacities equipped with various kinds of traditional fishing gear. Fishermen composing this group are scattered all along the coastlines of Arab states. Their numbers are high and much of their fishing is subsistence fishing for local markets, families and clans. The official statistics of their catches are not recorded systematically and therefore lack reliability. The species they target are mostly demersal, near shore species and crustaceans (mainly shrimps) where they exist. The average share of coastal fisheries in the Arab world fish landings has been estimated at 80-85%.

Inland Fisheries

Inland fisheries resources are those landed from the various inland water bodies, which are estimated to cover about 1.5 million km^2. The major states where these are available are Egypt, Sudan, Iraq and Syria. These include lakes, rivers, marsh lands, swamps, reservoirs, and natural and man-made lakes. The lakes in the Egyptian Delta region are the main fish production water bodies in addition to Lake Nasser in the south, Lake Qarun, and the River Nile. In Sudan, the main inland fisheries are in the Blue and White Niles in addition to the main stem of the Nile. Iraq's main fisheries are located on the Tigris and Euphrates Rivers as well as some man-made reservoirs. Other rivers with smaller size fisheries exist in Syria, Lebanon, Jordan, and Mauritania.

Most of the inland fisheries in the Arab states are characterized by subsistence fishing to meet immediate food supply needs of populations living in the vicinity of the water bodies. Any excess to their food needs is sold to the local markets. The major problems facing these rivers are:

- reduced volumes from upstream diversions and flood control; and
- compromised water quality from pollution.

Aquaculture

Aquaculture's global importance grows each year because of population growth and the fact that the natural fisheries resources may have reached their maximum sustainable yield. The Arab world is no exception. Many states with freshwater resources, such as Egypt, Sudan, Iraq and Syria, have practiced aquaculture for many years. Other countries where freshwater is scarce are engaging in mariculture activities, farming fish along their coastlines (such as in Tunisia, Morocco, Saudi Arabia, Kuwait and Bahrain). The U.A.E. and Oman have also established research centres with the aim of developing mariculture in their waters.

In 1995, fish from aquaculture reached a production level of 68,000 MT, 4% of total fish catches in the Arab region, valued at about

$300 million. Production in 1984 was only about 22,000 MT valued at only $59 million. The 1995 level represents an increase of 67% in quantity and 95% in value (Figure 1).

The main species farmed are those indigenous species which are popularly accepted in the individual Arab countries. In Egypt and Sudan *Tilapia* is farmed and is also being introduced for farming in Saudi Arabia where Egyptian and Sudanese minorities live. Groupers and rabbitfish are farmed in the Gulf Cooperation Council States (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and U.A.E.), and shrimp farming has been attempted along the Egyptian coast of the Red Sea. There are also experimental projects aimed at developing the commercial cage farming of sea bass and sea bream in Egypt, begun in 1990 in Port Said in the east and Mersa Metrouh on the Mediterranean coast in the west. When research studies on fish farming become feasible, and as the technologies and know-how become readily available, fish from aquaculture production is expected to expand substantially.

With a coastline stretching for about 23,000 km, the Arab region offers considerable possibilities for fish farming both in inland and marine waters. It remains to be seen, however, whether aquaculture production of fish will substantially increase fish supply in the region and significantly reduce either the supply/demand gap or dependence on imports.

FISH CONSUMPTION AND PREFERENCES

Average *per capita* fish consumption in the Arab world in 1995 was about 6.6 kg, compared with the world average of about 13 kg/y.

Per capita fish consumption among the Arab countries is highest in the United Arab Emirates (51.1 kg/y) followed by Oman (36.7 kg/y) Bahrain (16.93 kg/y) Mauritania (16.6 kg/y) Qatar (16.5 kg/y) and Morocco (15.4 kg/y). All other Arab states are well below the international average, with some as low as less than 1 kg/year, as in Lebanon and Syria.

Fish consumption in the region as a whole has some distinctive characteristics:

- Fish consumption is highest in coastal countries where fish are comparatively abundant, the population is low, and fish represent an important part of the national diet.
- All other Arab states generally have a low consumption rate. This is mainly due to low production levels, high populations, and shortage of hard currencies to import fish as a supplement to local supplies. The coastal areas in several such countries have very high consumption levels, e.g., Somalia and Yemen, but remote inland populations may consume negligible amounts.

- Fish consumption patterns have changed somewhat in some of the countries having a substantial foreign labor population, notably the oil-producing countries. This is due to the increased import of non-traditional species to satisfy new consumer demands, the introduction of new fish preparation methods, changes in eating habits, and innovations in product forms.

The list of preferred locally produced seafood species includes shrimp, lobster and cuttlefish, caught mostly in the waters surrounding the Arabian Peninsula and Algeria, Morocco, and Mauritania. However, as local market demand in the region is limited, such species are largely exported due to their high international market prices.

Generally, fish consumption is affected by conditions and systems of marketing, distribution, and transport and, to a minor extent, by tribal, traditional, and social attitudes. Fish consumption thus presents a complex pattern, ranging greatly between countries and within different areas in the same country or subregion.

FISH RESOURCES POTENTIAL

The fisheries statistics of FAO indicate that total fish catches from all Arab sources during 1995 was about 2 MT. However, fishery statistics issued by the Arab Organization for Agricultural Development (AOAD) indicate that Arab fish landings in the same year were 10% higher. The discrepancy in reported figures implies that statistics require harmonization in order to arrive at a more reliable and accurate database.

However, considering the potential of all the marine waters that border the Arab states, it is believed that the marine fish total caught from Arab waters is higher than that which is actually reported. This assumption is made on the belief that there are many foreign fishing vessels operating, legally or illegally, in Arab fish-rich waters such as those off Morocco, Mauritania, Somalia, and Yemen, and the catches made are not recorded as catches from these waters. These catches are estimated to be about 1-2 MT. In other words, actual fish landings from Arab marine resources may be in the range of 3-4 MT per annum.

In the absence of strict surveillance, monitoring, and control of the fisheries resources of the fish-rich countries, it is difficult to substantiate and document the actual fish volumes caught from Arab waters. It is well known that there are several joint ventures between Arab states and foreign companies, but the extent and volume of their actual operations are not publicly known or documented.

The 1993–94 negotiations between Morocco and the European Union (EU) over fishing rights in Moroccan waters offer a case in point. During the negotiations European fleets did not operate in Moroccan waters. Catches by the local fishermen jumped to a record high of 40 MT/d during May-November 1995. Morocco's territorial waters have an abundance of sardines, mackerel, squid, octopus, tuna, hake seabream, and shrimp. Moroccan fishermen feel that the foreign fleets are a threat to their domestic resources and feel they can better exploit their own fisheries themselves. During negotiations, the coastal fleet was catching up to five MT/d, which is still only half the record of the seventies (possibly due to the effects of indiscriminate over-fishing by the foreign fleets) but above the one MT/d maximum catch during the presence of foreign fleets.

Morocco, in its consideration of the future beyond the year 2000 when the renewed agreement with the EU expires, has embarked on an investment plan to reshape its fishing industry. It has earmarked over $200 million to upgrade installations industry-wide as part of a long-term goal to exploit its rich waters without foreign intervention. The fisheries authorities' objective for the year 2000 is to achieve yield on an annual sustainable basis ranging from 1.5 to 2.5 million tons. Production objectives are 1.5 MT/y, up from the 1994 production of 752,000 MT/y, and 846,000 MT/y in 1995. The Moroccan authorities are also establishing another fisheries research centre and imposing longer fish conservation periods to protect the stocks. The rehabilitation of several ports and fleet servicing facilities are part of the upgrading process.

FISH TRADE

TRADE TRENDS

Although the collection and dissemination of fishery statistics has generally improved over the last few years in several Arab countries, information on fish trade within each country is still not sufficient. For example, it is not well established how much of the total fish production is marketed. Subsistence fishing is practiced to a considerable extent in the region, especially in the countries bordering the Arabian Peninsula and along the shores of inland lakes and rivers, especially in Iraq and Egypt. Therefore, it is assumed that a considerable portion of total production is consumed by the fishermen and their families.

Marine catches constituted about 84% of total catches in 1995. Quantities not consumed locally by the coastal population are mostly cured and exported. In the last few years, foreign fish and fishery products have also been exported. These exports should not be interpreted as a genuine surplus as there is probably a strong potential demand for fish in the interior, which in some countries lacks accessibility due to poor communications and transportation.

Exports in 1995 are mostly attributed to expanded fishing activities off the coast of Mauritania (14% of the total) possibly by foreign fleets and trans-shipment of foreign fish. Morocco has also shown a substantial increase in canned fish product exports (61% of the total).

Most countries of the region are importers of some quantity of fish. Egypt is the largest importer (28% of the total) followed by Saudi Arabia (25% of the total). Apart from the imports to Egypt, other major import items include canned and foreign products and some high-value fish preparations (especially for the Gulf countries).

It might be expected that the Arab region would be a net exporter of fish and fishery products. However, when excluding Mo-

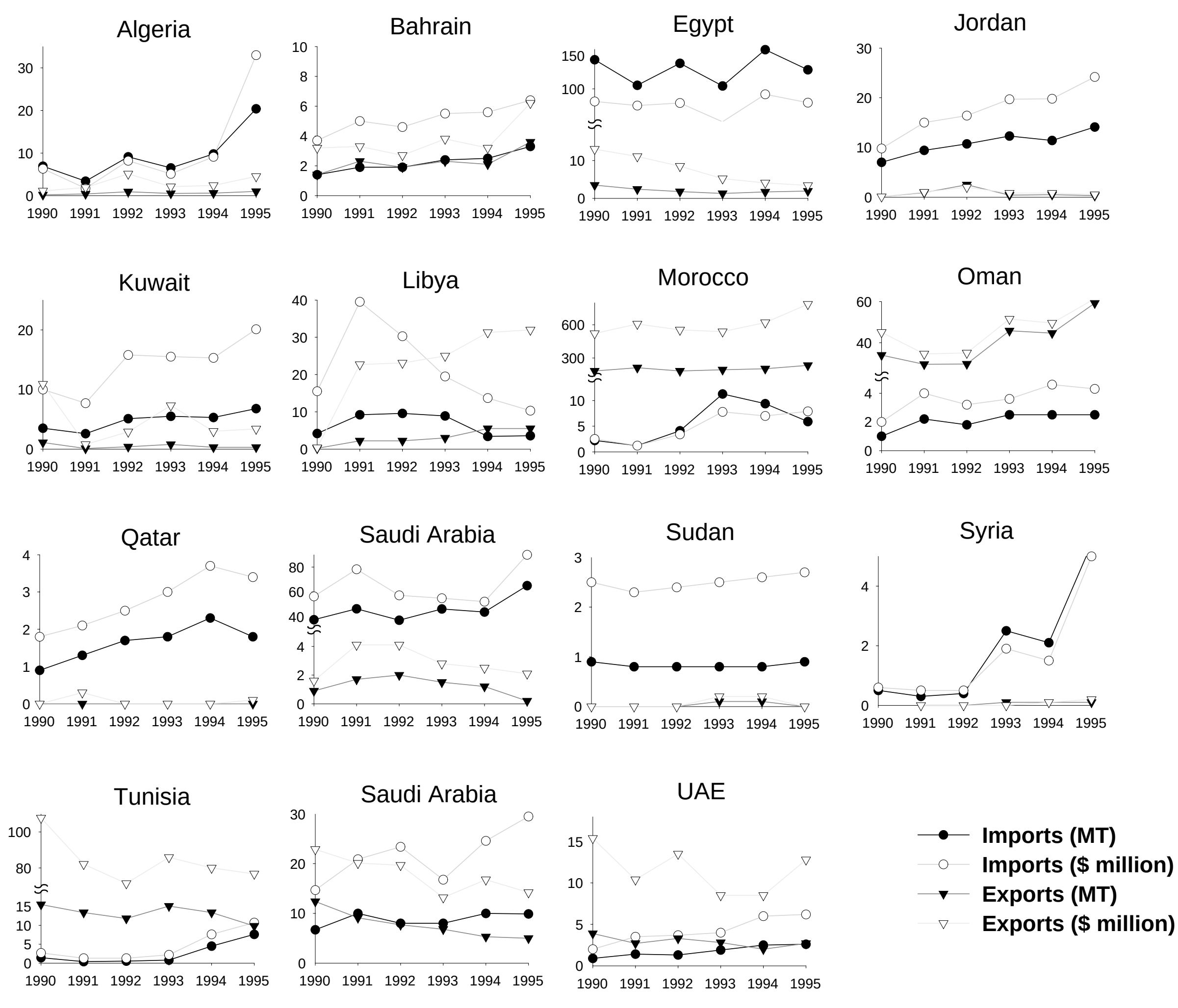

Figure 2 Imports and exports of fish and fishery products of select Arab states as a function of time, broken down by weight and monetary value.

rocco and Mauritania, the total for other countries classifies them as net importers. It should also be noted that the exports from Mauritania are predominantly small pelagic species caught mostly by foreign fishing vessels off the territorial waters and similar fish species caught and canned by Morocco. Exports by other exporting countries are mainly high valued demersal species, crustaceans and cephalopod species, mostly for export outside the region (Figure 3).

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TRADE CONSTRAINTS

Shortage of dependable information on demand and supply, prices and price fluctuations, as well as buyers and sellers in most of the countries, has been a major factor adversely affecting the growth of Arab trade in fish and fishery products. Coupled with this is the dearth of technical know-how and trained manpower, together with inadequate infrastructure. Attempts at product development, product and market diversification and value addition have been quite

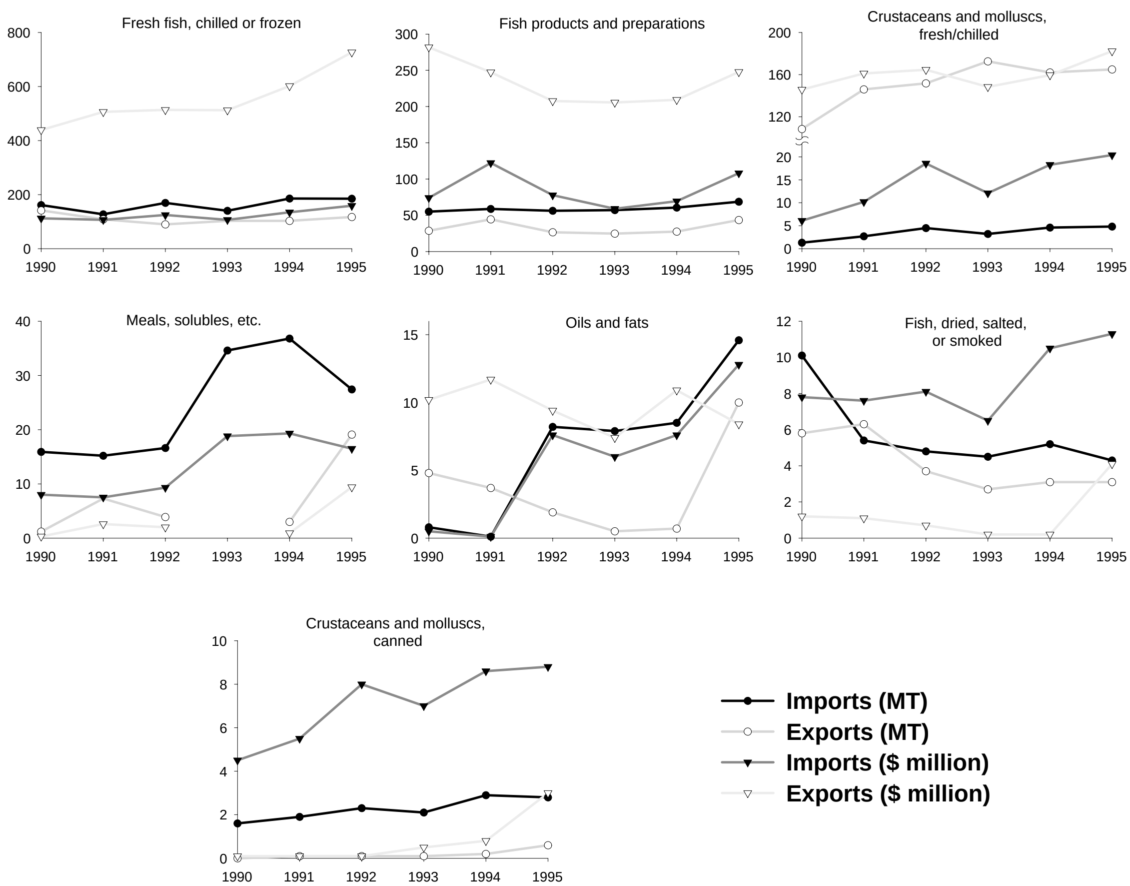

Figure 3 Total imports and exports of Arab states by seven commodity groups. Source: FISHDAB. Includes Mauritania, Comoros Islands, Djibouti, and Somalia in addition to those countries listed in Figure 1.

limited in scope and results, in spite of improvements in recent years.

Lack of regular and direct flights linking the production and consumption centres both within and outside the Arab world has restricted trade in fresh fish, while irregular shipping facilities hamper smooth flow of frozen fish from one port to another. Moreover, though some of the countries in the Arab world are among the richest in the world, there are also several countries that are not so fortunate. This has resulted in insufficient communication facilities even between neighbors. Due to such problems, the share of intraregional trade in fish and fishery products in the total import-export trade within the Arab region is also quite negligible.

Another trade constraint is associated with canned small pelagics, a major export item. It is estimated that the GCC countries together consume between 25,000 and 30,000 MT of canned fishery products per annum. Despite the growing demand, a major share of these imports are not from Arab exporters of the same commodities. At times, countries such as Tunisia and Morocco are stuck with quantities of canned products for want of buyers. Moreover, the installed capacity utilization in these two countries is quite low, often due to lack of orders. In some Arab countries, the general pattern of trade linking producers to buyers is based exclusively on a few traditional products, depending on a few traditional buyers and sellers. In other countries, where there is a wish to diversify products, enter new markets and increase trade, producers and processors suffer from acute lack of up-to-date information on such vital matters as product requirements and specifications, the required processing technology, quality standards, current prices, and marketing opportunities and trends, all of which leads to the misapplication of production capacity, loss of potential profits, loss of foreign exchange, and reduced employment opportunities.

MAJOR TRADE MARKETS

The Arab world is most likely to continue to be a major importer of fish and fishery products in the years to come. This is in spite of the efforts made to increase indigenous production. Some of the items available in this region, such as cephalopods, crustaceans, molluscs and high-value demand species, will have to be exported to markets elsewhere due either to little domestic demand or the quest for hard currency earnings.

The major importer among of the Arab states is Egypt, with 129,000 T valued at $79 million imported in 1995 or 46% of all Arab fish imports. Egyptian imports are mostly frozen small pelagic species of sardines and mackerels which are consumed by the low income section of the population at subsidized rates. The next major market is the six GCC states, which as a combined market area imported a total of 89.3 thousand tons valued at $153.7 million and in 1995 led by Saudi Arabia as the main importer of the GCC states and second from the Arab countries (Figure 2).

Irrespective of the varying size of markets and the corresponding levels in quantity and value of imports, the consumption pattern as well as marketing channels in the GCC states have many things in common. All the GCC countries are characterized by close socioeconomic and linguistic links as well as population growth trends. With the implementation of a free trade area and free movement of nationals, funds and goods, and the liberalization of wholesaling and other marketing activities, the importers, distributors, and wholesalers, in general, have benefited immensely.

The average expatriate population in the GCC countries is estimated at 45% of the total population. Consumer preferences among the expatriates is very often different from that of the nationals. Thus, fish and fishery products imports fall into two categories: chilled/fresh fish, as well as canned and dried products preferred by the native population and items like frozen fish in demand among the expatriates.

With regard to exports, the major Arab exporter is Morocco, with exports totalling 233,900 MT in 1995 or 61% of total exports, valued at $786.5 million. Most of these exports are canned small pelagic fish species to markets in Europe, some of which are re-exported to the Arab markets. Mauritania is the second largest exporter, with 55,000 MT, or 14%, valued at $167.3 million. The main exports are cephalopods, Japan being the most important importer. Also Italy, Spain, France and Germany are importers of Mauritanian demersal fish species. African countries import small pelagic species from Mauritania.

ROLE OF INFOSAMAK CENTRE IN DEVELOPING ARAB FISH TRADE

One of the most visible impediments to enhancing inter-regional trade in fish and fishery products and consequently a better exploitation of Arab fisheries is the fact that this sector has not in the past been given the priority it deserves in some of the Arab countries. The Centre for Marketing Information and Advisory Services for Fishery Products in the Arab Region (INFOSAMAK), which was established in Bahrain in 1986 as a link in the FAO worldwide Fish Marketing Information Network, has played a major role in providing fish trade promotional services.

INFOSAMAK services help raise the level of awareness and importance of the sector. Inter-country trade has benefited in both value and quantity by the information made available by INFOSAMAK. The market information service is an efficient and productive mechanism for fish trade information and collation. With respect to market promotion, the ability of INFOSAMAK to match buyers and sellers has been productive.

Investment opportunities in the field of Arab fisheries has also been one of INFOSAMAK's promotion and identification services. It undertook pre-feasibility studies on behalf of investors which led to the strengthening of contacts with Arab national and regional institutions and organizations who are potential investors in the fisheries sub-sector.

INFOSAMAK has proven to be an important regional service and an active participant in the Arab international fish marketing sub-sector. Its establishment has boosted the development of the Arab fish trade.

DEVELOPMENT PROSPECTS AND CHALLENGES

Total fish landings attributed to the Arab states from marine and inland resources have stagnated during the last few years at about 1.7 MT/y. Aquaculture, a newly developed resource, added about 60,000 MT in 1993. Although an increase in production from capture fisheries is possible and will probably occur in response to intensified fisheries activities, it is very unlikely to keep pace with population growth if the most sought-after and most easily caught fish are to be maintained as supply to the local domestic markets. The challenge here is organizing and stimulating production from fish resources so that per capita supply of fish as food does not decline.

In order to meet this challenge, proper management of available resources is required by the fisheries authorities in the Arab states. Maintaining efficient measures of monitoring and controlling these resources is essential. When applied properly and effectively, these measures could mitigate the effects associated with over-fishing of the major fisheries resources. The measures include building the capability to enforce laws against poaching in the territorial waters and high seas under national jurisdiction, banning fishing methods which are a threat to the resources, and finding a balance in the multi-purpose use of coastal resources to ensure a sustainable and optimum supply of fish. (Coastal fisheries at present provide Arab states with over 85% of their fish landings). In other words, the stock-damaging experience of the "shrimp-rush" of the 1960s in the Arabian Gulf by foreign fleets should not be allowed to take place again.

In aquaculture, the challenge here lies in the fact that it has not yet fully taken hold in the Arab states. In order to sufficiently develop aquaculture, governments and research institutions concerned will need to increase and improve research that could be applied inland and along the coastlines. Involvement of the private sector and industry to identify research needs and priorities is essential. Research in aquaculture must address improvements in technologies, contribute to a reduction in the cost of production, and consider the increasing need to ensure that aquaculture is environmentally safe and that farming indigenous and popularly-demanded species as well as possible introducing new species can be achieved without endangering the local ecology.

Fisheries statistics is another challenge that needs to be met. Much of the recorded data and information on the sector is incomplete, inconsistent, and outdated. Concerted efforts are needed to improve and develop the methods of data compilation, documentation, and analysis which are essential to making proper management decisions. Provision of upgraded data should be the responsibility of all concerned governments in the region, to optimize appropriate exchanges of economic, commercial, and biological data.

Training and upgrading of the fisheries workforce poses another serious challenge to the development of the fisheries sector. Training on the various aspects of fisheries management administration and technology is required. Attention should also be given to the strengthening and establishment of fisheries training institutions. This challenge will prove to be an essential contribution and, in some cases, has already had a major impact on a country's fisheries development. When fisheries resources have a human resource base adequate for supporting more efficient national exploitation and increasing that exploitation, the result is better job opportunities for those who receive training. Experience has shown that a national institution designed to meet national scientific training needs can make a bigger contribution than a regional institution, which cannot satisfy all the different needs of the various countries of the region. Regional training institutions would be effective, however, if established in a region where the countries involved have common fisheries resources, similar experiences, and homogeneity in the exploitation of their fisheries, as exists in the GCC countries.

CONCLUSIONS

The Arab states' fisheries sector can be a much better contributor to the economic development of the Arab countries and could provide increased benefits to the Arab peoples. Enhancing fisheries production would increase food supplies to help avert shortages in animal protein, give support to food security measures, and reduce imports (which are a drain on hard currencies). It could open job opportunities to rural and urban populations, raise the standard of living of small-scale fishermen, and develop rural areas and fishing communities. Furthermore, with increased and enhanced fisheries activities, fisheries industries would improve the utilisation of fish landings, develop value-added products, and promote marketing, distribution, and inter- and intra-regional trade.

However, to embark on such activities, considerable improvements to the sector have to be implemented. These improvements require initiatives by the governments of the region to give higher priority in their national development plans to their fisheries sector. Public investment in fisheries infrastructure and services has to be increased to create an encouraging environment for potential private investors. Fisheries research must be encouraged in marine and inland fisheries and aquaculture in order to bring about better management of resources including measures for resource conservation. The new internationally recognized Code of Conduct for Responsible Fishing is an opportunity which the Arab states may seize upon in order to achieve increased benefits from their own resources.

There are various challenges to the Arab states which have to be met in order to achieve the desired results. Fisheries should not by any means be considered a side- or marginal activity and should be given sufficient support and protection measures to allow the gradual growth and development. Fisheries development is, by its very nature, a long term activity, and development projects or programmes often require considerable time until they start to bear fruit.

In the past few years marine fisheries in many areas, Arab waters included, have achieved their maximum sustainable yield. However, future concentration of development should be in the rational exploitation of some marine areas offshore and in the EEZs, as well as in maximizing benefits from joint ventures with foreign fishing fleets by negotiating better terms. Furthermore, the small-scale fisheries sector should have greater emphasis, and aquaculture, in fresh and marine waters, should be a major growth area.

Finally, it cannot be over-emphasized that, for the Arab states, fisheries are vital for the food security and economic livelihood of a major portion of the population. Fisheries productivity and renewability are dependent on both high-quality management and a high quality natural environment. Therefore, better management of currently over-exploited stocks, cautious utilization of under- or non-harvested marine and fresh water resources, expansion of acquaculture, and improvements in post-harvest utilization are prerequisites for the development of Arab fisheries.

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LIST OF ABBREVIATIONS AND ACRONYMS

AOAD	Arab Organization for Agriculture Development
COFI	Committee on Fisheries
EEZ	Exclusive Economic Zone
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GCC	Gulf Cooperation Council
GLOBEFISEI FAO	Fish Marketing and Information Data Bank
INFOSAMAK	Centre for Marketing Information and Advisory Services for Fishery Products in the Arab Region
U.A.E.	United Arab Emirates
UNCED	United Nations Conference on Environment and Development

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Assessment of Damages to Commercial Fisheries and Marine Environment of Fujairah, United Arab Emirates, Resulting from the Seki Oil Spill of March 1994: A Case Study

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ABSTRACT
Historically, about half the oil transported through the global marine environment has come through the Arabian Gulf and the annual input of oil to the gulf's marine environment is skewed toward sources connected with marine transport. As a case study, we assess the damages from an oil spill caused by a collision between the crude oil tankers *Baynuna* and the *Seki* on 30 March 1994. The collision released approximately 16,000 metric tons (MT) of light Iranian crude oil into the coastal waters of the Emirate of Fujairah, United Arab Emirates. Under the sponsorship of the Government of Fujairah, we analyze the effects on commercial fisheries and marine environment of Fujairah resulting from the spill. This analysis was the first comprehensive natural resource damage assessment conducted in this area. The major difficulty was to establish the economic damages associated with the environmental contamination and fisheries declines. We adapt an established compensation schedule to the UAE situation. Information on the amount and type of oil spilled, the amount of oil recovered, the season, the habitats oiled, the resources exposed, and the sensitivity of the resources is then used to establish the economic value of losses associated with environmental contamination and fisheries decline.

INTRODUCTION

Oil currently supplies about 40% of the world's energy, and recent estimates suggest that the Middle East has over 65% of world's petroleum reserves (World Resources Institute 1996). The countries bordering the Arabian Gulf produce almost 6 billion barrels (bbl) or 798 million metric tons (MT) of oil a year, about 27% of the world's production in 1993 (World Resources Institute 1996). Historically, about half of the oil transported through the global marine environment has come through the Arabian Gulf (Gupta *et al.* 1993).

Besides the dramatic and well-publicized catastrophic oil spills, a substantial amount of oil enters the marine and coastal waters of the Arabian Gulf and the Gulf of Oman from a variety of other sources: ballast water discharges, fueling spills, platform blowouts, pipeline leaks, and spills from tanker and barge accidents. Natural seeps also constitute a significant contribution.

Little information is available on the magnitudes of inputs from these more routine sources, and what estimates are available differ by orders of magnitude (e.g., Oostdam 1980; Linden 1990; Sorkoh 1992; Literathy 1993; Price 1993). Transported oil constitutes a more significant source in the Gulf than in other parts of the world because of this region's importance as a shipping route to the West (Sheppard *et al.* 1992; Price 1993). For example, an estimated 400,000 to 750,000 mt of ballast water and other oily water discharges from tanker and ship traffic enter Gulf waters annually (Linden 1990; Price 1993). A single pipeline spill in Kuwait released over 15,000 bbl (about 2 000 MT) to marine waters (Linden 1990). Assuming a tanker spill equivalent to the *Seki* oil spill occurs every four years, the annual oil input is 4,000 MT from tanker accidents. About 14 tanker accidents of various kinds occur annually in the Arabian Gulf and at least 13% of these release oil (Linden 1990). For comparison, spills released about half a million bbl (67,000 MT) during the Iraq-Iran War (Price 1993). The world's largest oil spill occurred during the 1991 Gulf War and released 3.81 to 8.1 million bbl (500,000 to 1,100,000 MT) into the northern Arabian Gulf (Sauer *et al.* 1993).

Tankers carry oil from the Arabian Gulf, with 20,000 to 35,000 individual tanker passages per year through the Strait of Hormuz (Price 1993). Hundreds of tankers can be seen anchored off Fujairah on the East Coast of the United Arab Emirates (UAE) awaiting passage into the Arabian Gulf. In this area on 30 March 1994, two tankers, the *Baynuna* and *Seki,* collided, and the *Seki* released about 16,000 MT of light Iranian crude oil into the coastal waters of the Emirate of Fujairah. Spills such as this differ from chronic releases in that a large amount of oil contaminates a limited area in a short time period. This acute contamination is certainly more discernible and its effects, while difficult to demonstrate, are certainly made more evident through the acute toxicity of high oil concentrations and through the increased attention given them compared to the chronic exposures.

This paper treats the *Seki* oil spill as a case study to draw some lessons for both science and policy concerning the assessment of damages from such spills. Before reviewing the events of *Seki* and discussing the results of our assessment of spill damages, we offer some background on the region's environment.

THE MARINE ENVIRONMENT OF THE GULF REGION

The waters of the Arabian Gulf have several unique features, described well in Sheppard *et al.* (1992) and concisely in Sheppard (1993). First, this geologically young region has an enclosed shallow sea with a low flushing rate (i.e., 3 to 5.5 years). Second, although the climate is arid, there is a marked seasonality with hot summers and cool winters. Heating and chilling events are common. Third, the excess of evaporation over rainfall leads to high salinity. Salinity, especially in the southern part of the Gulf, is often above 40 points per thousand (PPT) and may reach to 70 PPT in embayments. Fourth, with most of the Gulf less than 60 m deep (and therefore within the photic zone), benthic production contributes strongly to the high biological productivity reported for the Arabian Gulf.

The region's climate subjects its living marine resources to high natural stressors (Sheppard 1993). The reef areas of the Gulf can experience temperature maxima approaching 36 °C and seasonal differences ranging up to 25 °C. Many species are living at the limits of their tolerances to temperature and salinity. This situation has led to questions of whether the biota of the region may be more vulnerable or more resistant to pollutants, or are some mixture of vulnerable and resistant species. Fish kills following *shamals* (cold winter winds) and red tides and coral bleaching following temperature extremes are examples of consequences of such natural stressors.

The region's high temperatures and high concentrations of oil-degrading microbes also produce a strong weathering environment for spilled oil. Much of the volatile and more toxic components of oil spilled in the region evaporate within hours (h) or days. Indeed, about half of the oil spilled in tropical waters is expected to disappear within 24 h (Gupta *et al.* 1993). After the first 24 h, oil disperses through a variety of physical and chemical processes and also begins to degrade. Ultimately, oil that is not degraded can remain as asphaltic layers within beach sediments or become tar balls. For example, studies of beaches contaminated during the Gulf War Oil Spill also found relict asphalt pavements derived from the Nowruz oil spill in 1983 (Hayes *et al.* 1993). Tar balls can be found commonly on the Gulf's sea surface (Gupta *et al.* 1993), sometimes at depth (Gupta *et al.* 1993) and on many, if not most, gulf beaches (Price *et al.* 1987; Badawy and Al-Harthy 1991; Sheppard *et al.* 1992). Despite this strong weathering environment, oil that is sequestered in certain environment compartments can remain relatively unweathered. Recently, Randolph *et al.* (1997) found beach sediments heavily contaminated during the Gulf War Oil Spill were still toxic to amphipods some 30 months after the spill (Randolph *et al.* 1997).

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The region's critical habitats are well described by Sheppard *et al.* (1992), and the list in Table 1 is expanded from Price *et al.* (1993). Here as elsewhere, critical coastal habitats are often also the ones vulnerable to oil and other disturbances. While Price (1993) lists oil pollution as potentially degrading to the Gulf's coastal habitats, he considers coastal infilling and development as potentially more destructive.

The important living resources of the Gulf include fisheries, birds, sea turtles (both green and hawksbill), and dugongs (sea cows) (Price *et al.* 1993). The region's oil and gas are of course

Table 1 Critical coastal habitats in the Persian/Arabian Gulf (expanded from Price *et al.* 1993)

HABITATS	IMPORTANCE AND COMMENTS
Mangroves	Nursery area for fish and shellfish
Seagrasses	Direct food for dugong, sea turtles, some urchins and fish; indirect food for many other marine species; nursery area for fish and shellfish, especially shrimp
Coral areas	Principally patch reefs; true coral cays around offshore islands; food and shelter for resources supporting artisanal/commercial fisheries
Tidal flats	Major energy and nutrient input to marine system
Tidal flats w/algae mats	Habitat with most injury from 1991 Gulf War oil spills
Rocky reef fisheries	Food and shelter for resources supporting artisanal/commercial fisheries
Carbonate rock platforms with microalgae	Nursery areas for shrimp and pearl oyster spat

the major non-living resource, but increasingly important is clean seawater for desalination. During the Gulf War, substantial effort was directed at preventing oil from reaching the intakes of desalination plants. In July, 1997, diesel fuel spilled from a grounded barge in Sharjah, UAE entered the intake of a desalination plant, contaminating the water supply of an estimated half million people.

The coastal and offshore waters of Fujairah support a rich and diverse fish fauna, including many species of reef-associated fish, seasonally abundant large pelagic species, and small schooling fish

FUJAIRAH AND ENVIRONS

The spill environment is Fujairah, which contains most of the eastern UAE coastline bordering the Gulf of Oman. The Gulf of Oman is just south of the Strait of Hormuz, and seawater from both the Arabian Sea to the south and the Arabian Gulf to the north circulates through it. The shoreline north of the port of Fujairah is characterized by coarse- and fine-grained sandy beaches interspersed by rocky headlands and occasional mixed sand and cobble shores, with occasional boulders. Bedrock outcrops of sedimentary rocks are common in several locations, particularly in the lower intertidal zone. The tidal range (vertical distance between mean high and low tide) along the Fujairah coast is about 2 m. Depending on the slope of the shore, the intertidal zone (the area between the mean high and low tide lines) may be anywhere between a few meters to more than 200 m wide. The shallow nearshore area contains mixed substrates. Rocky reefs and coral reefs are common throughout the area.

The coastal and offshore waters of Fujairah support a rich and diverse fish fauna, including many species of reef-associated fish, seasonally abundant large pelagic species, and small schooling fish (Sheppard *et al.* 1992). These fish support moderate to large local commercial and artisanal fisheries of substantial economic value to the people of Fujairah. These fisheries are based in several fishing ports along the east coast of the UAE. Ministry of Agriculture and Fisheries (MAF) statistics indicate that 1993 fish landings along the east coast of the UAE totaled ~29,300 MT, with a value of 227,577,000 Dirhams (about $62 million).

These shallow coastal waters support abundant marine life, particularly in association with coral reefs. Small nearshore islands are important habitats for marine birds and sea turtles. There is a growing tourist industry based on the warm, sunny climate, sandy beaches, and nearshore reefs of Fujairah. All these natural resources and the commercial interests they support were adversely impacted by the *Seki* oil spill.

A SHORT HISTORY OF THE *SEKI* OIL SPILL

On the evening of 30 March 1994, the crude oil tanker, *Seki*, fully loaded with Iranian light and heavy crude oils, was moving slowly south-southwest about 9.6 km off the port of Fujairah, UAE. The *Baynuna*, moving in ballast, attempted to pass in front but instead collided with the *Seki*. The bow of the *Baynuna* penetrated to a depth of 6 to 7 m into the *Seki*'s No. 1 port cargo tank, which contained a light Iranian crude oil (American Petroleum Institute [API] gravity 33.9 at 60 °F).

An estimated total of 16,000 MT (~18.7 million liters [L]) of crude oil escaped. Booms deployed around the *Seki* failed to contain the oil, and the oil slick spread away from the vessel, initially carried offshore by winds. However, on 2 April, the winds changed, and oil began drifting in a northwesterly direction toward the coast north of the port of Fujairah. On 2 April, large amounts of oil came ashore on the Fujairahan coast between Lu'lu'iyah and Rul Dibba (Figure 1). Approximately 30 km of coastline from about Al Bidhiya northward to about Ras Dibba were oiled initially. However, oil washing off the shore with each tide tended to be driven northward by the prevailing winds, oiling additional shoreline. Some of the coastline of the Musadam peninsula of Oman, north of Fujairah, was also oiled. Booms deployed across the entrance to the fishing ports of Dibba Fujairah and Dibba Sharjah prevented many but not all the slicks from entering the ports themselves.

The spill response was organized and managed by the Fujairah Port Authority. Small skimmers were deployed shortly after the spill to recover oil from the sea surface. Approximately 813,600 L of oil was recovered (about 4% of the amount spilled). Cleanup of oil on the shore was initiated in early April by local contractors. However, efforts were halted after it was learned that the oil had penetrated deeply into the sandy shoreline sediments. Cleanup resumed in late August and continued until the end of the year. The cleanup contractors from Saudi Arabia and France removed an estimated 10,000 cubic meters (m^3) of oil-contaminated sediments for offsite disposal.

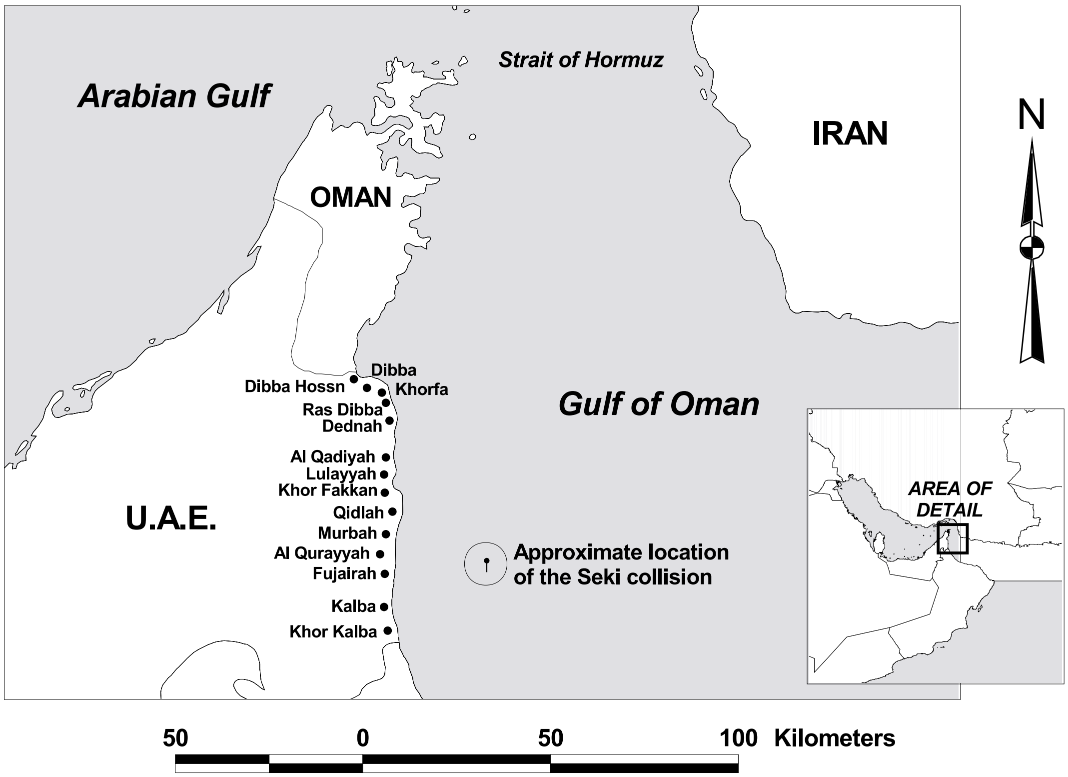

Figure 1 Map of the spill region.

DAMAGE ASSESSMENT

There is general agreement the *Seki* spill caused substantial harm to the marine environment and natural resources of the UAE's East Coast. A large number of damage claims for business interruption and losses were filed against the potentially responsible parties on behalf of the people of Fujairah. However, these business loss claims did not cover all the injuries sustained by natural resources and the people of Fujairah who depend on the resources for a livelihood. Commercial fisheries in nearshore waters are important to the economy of the Emirate of Fujairah, which sponsored our assessment of the damages to its fisheries and marine environment resulting from the spill.

Our assessment principally involved:

- determination of the extent to which resources of concern (e.g., commercial and artisanal fishery resources) were exposed to the spilled oil;

- determination of the extent to which the resources or resource uses sustained injury (i.e., reduced fishery catch) as a result of exposure to the spilled oil;
- determination of the extent to which the resources and resource uses recovered over time; and
- economic valuation of the injured resources or resource uses.

In July 1995, at the request of the Government of Fujairah, the Battelle Memorial Institute performed a preliminary study to determine whether additional scientific investigations would facilitate an improved assessment of the effects of the *Seki* oil spill. Battelle's feasibility report (Neff *et al.* 1995) indicated that there was evidence of environmental degradation along more than 30 kilometers (km) of shoreline and of localized degradation in shallow subtidal areas attributable to the spill. Also, data available from the MAF at the time indicated that decreased fish catch rates were evident and strongly associated with the spill. To assess more fully the potential exposure of fish and the extent and implications of the decreased catch rates, Battelle recommended the chemical analysis of archived beach, subtidal sediment, and fish samples, and more detailed examination of fisheries information.

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This subsequent more detailed assessment (Pearson *et al.* 1996) was also sponsored by the Government of Fujairah and included an exposure assessment, an injury assessment, and an economic evaluation. The Exposure Assessment documented the exposure of marine habitats and bottom fish from fishery areas along the coast of Fujairah to crude oil from the *Seki.* The injury assessment included a quantitative description of the reduction of fish catches from fishing ports in the spill area relative to reference areas. Information gathered by interviews with east coast fishermen and fish landings data from the MAF were evaluated. MAF data on market price and sales were also examined. An analysis of marine climate examined possible alternative explanations for fishery declines. The damages assessment used information from the exposure and injury assessments to establish economic damages.

EXPOSURE ASSESSMENT

The exposure assessment consisted of several interrelated iterative steps which accomplished the following:

- confirmation of the release of oil from a known source;
- identification of the exposure pathways from the source to resources at risk; and
- demonstration that the resources at risk and their environment actually were exposed to the released oil or to its byproducts.

The major results were as follows:

Clearly, the *Seki* released a substantial amount of oil that subsequently contaminated the marine environment of Fujairah. The observations of International Tanker Owners Pollution Federation, Ltd. (ITOPF), Centre de Documentation de Recherche et d'Experimentation sur les Pollutions Accidentelles des Eaux (CEDRE), U.S. National Oceanic and Atmospheric Administration (NOAA), and Wimpey Environmental confirmed that a substantial amount of crude oil was released from the tanker *Seki* following its collision with the *Baynuna* on 30 March 1994. A large amount of the spilled oil reached and contaminated the shoreline of Fujairah (CEDRE 1994; Wimpey Environmental 1994a, b).

The results of Battelle's chemical fingerprinting analysis (Sauer *et al.* 1993; Sauer and Uhler 1994) of shoreline and offshore sediments in April and May 1994 confirmed that the shoreline and offshore sediments were contaminated with crude oil, the source of which was unequivocally identified as the *Seki.* Some samples contained oil from other sources. The *Seki* oil persisted in the marine environment for at least 19 months after the spill.

The fisheries resources were exposed to *Seki* oil at the time of the spill. Fish samples collected by trap from the oil spill path off Ras Dibba a few days after the spill were moderately to heavily contaminated (42 to 478 parts per billion [ppb] total polycyclic aromatic hydrocarbons [PAHs]) with crude oil residues analytically linked to the *Seki.* With a large majority of the samples having tissue burdens of PAHs above 100 ppb, the evidence for recent high exposure of demersal bottom-dwelling fish is strong. The observed levels were high compared to other spills (Pearson *et al.* 1996).

Some PAH exposure of fisheries resources was detectable 19 months after the spill, but its lower magnitude suggested that recovery from contamination was occurring. Nineteen fish samples collected by traps from spill path areas and a reference area off the Fujairahan coast in November 1995 contained much reduced concentrations of total PAHs (4 to 32 ppb). Concentrations were highest in tissues of fish from Al-Ghais Station 2, south of Ras Dibba, an area of heavy contamination during the spill. Concentrations were higher in fish from the other two oil spill path stations than in fish from the reference station off Fujairah City.

Other evidence of continuing exposure was equivocal. Analyses of the P-450 enzyme and 7-ethoxy resorufin O-deethylase (EROD) activity in the fish samples collected by traps in November 1995 showed slightly elevated levels at all stations. These levels suggested recent exposure of demersal fish along the Fujairah coast to contaminants that induce the enzyme activity. Without more information, including an adequate baseline, further interpretation of the enzyme data beyond a general indication of recent exposure was not possible.

EXPOSURE ASSESSMENT DISCUSSION

The observation of subtidal oil and the confirmation that it derived from the *Seki* was unexpected. After the Gulf War oil spill, subtidal oil contamination was observed by Michel *et al.* (1993), who found no evidence of sinking oil and argued for a mechanism in which oil stranded on beaches sorbed to particles that sank when subsequently eroded from the beaches. A similar mechanism for the transport of *Seki* oil into subtidal areas is plausible.

Bottom-living fish from the spill path were exposed to and became contaminated with crude oil from the *Seki* shortly after the spill. Some fish from the most heavily contaminated area of the spill path may still have been slightly contaminated 19 months after the spill. However, limited sampling did not allow estimation of the full extent of exposure and contamination.

INJURY ASSESSMENT

Our injury assessment focused primarily on commercial fisheries resources. The examination of fisheries information included interviews with fishermen, analysis of the MAF landings data, and analysis of the MAF market data. In addition, an analysis of the marine climate was performed to examine alternative hypotheses for the declines in fish catch rates.

FUJAIRAHAN FISHERIES

East coast fishermen deploy a combination of gear types and change those combinations seasonally as the target species change. Fujairahan fishermen in small outboard boats (*tarrads*) use nets (drift and set), traps (*gargurs*), and hook-and-line to capture pelagic and demersal fish. Larger diesel-powered dhows (*lanshs*) deploy primarily traps for demersal fish, but do some net and hook-and-line fishing for pelagic and demersal species. *Lanshs* usually fish deeper waters than *tarrads.* In the winter and early spring, shore-based *tarrads* also engage in a beach seine fishery for sardines (*Sardinella* spp. and *Stolephorus* spp.), which are sun-dried for fertilizer and export. Demersal fish species account for approximately 40% of the landings along the East Coast of the UAE. However, pelagic migratory species are generally the most valuable fish harvested, in terms of unit value per fish, along the Fujairahan coast. Fishing occurs year-round, with the largest landings in the winter and spring, and the smallest landings in July and August each year.

During the spill, a fishing ban was declared that caused fishermen to lose from 20 to 40 days of fishing. At the time of the spill, the sardine fishery had already concluded. Upon return to fishing, fishermen targeted pelagic and demersal fish.

FISHERMEN INTERVIEWS

Information from fishermen concerned changes in catch rates, fishing grounds, and/or gear selection during and after the spill. We were most interested in the success that fishermen experienced after they returned to fishing when the ban was lifted. In November 1995, we interviewed fishermen and boat owners in focus group settings in the ports of Fujairah, Dibba, Kalba, Khor Kalba, Dibba Hosn, and Dadnah. The major results of the interviews were as follows:

- It is incorrect to assume that fishermen only fish off the coast near their home port. Most fishermen fish along the entire UAE East Coast.
- All fishermen reported that they were affected by the spill to some extent, mainly due to loss of catch.
- Fishermen reported that fish stocks were reduced, and that only recently (after almost two years), they appear to be recovering in diversity, but not yet in quantity.
- Fishermen in some areas, such as Dibba Hosn, Dibba Fujairah, and Dadnah, which received heavy oil contamination, reported that decreased catches were continuing and that oil or tar still occurred on their traps.

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According to the fishermen interviewed, market prices at Fujairah were reduced for 6 months to one year after the spill, due mainly to public reluctance to buy fish from the east coast that were believed to be contaminated. The market recovered, and several fishermen believed that market price fluctuations in November 1995 were within pre-spill range.

ANALYSIS OF FISHERIES LANDINGS DATA

We examined the catch records to assess whether any change in fishing success occurred after the spill. Our analysis focused on the fishing success or catch rate once the fishermen returned to fishing, rather than on the number of days of lost fishing resulting from the fishing ban. The rationale for such focus is that while lost fishing days were already claimed as direct damages, the effects of the spill on fishing success and the fisheries resource had not yet been examined.

The fish landing records showed that the fishing strategies differ among the ports and by season within each port. Pelagic species are seasonally abundant and are generally targeted with specific gear types in the fall and winter months. This pursuit of pelagic fish can lead to some high catches at particular times and ports. There is also a basic fishing strategy conducted year-round at several ports that employs a mixture of traps and handlines. This strategy produces mostly demersal fish with some specific species of pelagic fish. Khor Kalba, an unoiled port, and Dibba Hosn and Dibba Fujairah, oiled ports, target demersal fish with traps. Our analysis examined the pelagic and demersal fish groups separately.

The analysis of fish landings yielded the following findings:

Catch patterns, in particular at Khor Kalba and Fujairah fishing port, did not show a significant change in the catch rate (kg/boat/trip) for pelagic species (Table 2).

Patterns in the catch rates for demersal species did show an abrupt and substantial decrease at oiled area ports of Dibba Hosn and Dibba Fujairah in April and May 1994 that was not seen at unoiled area ports of Khor Kalba or Fujairah. For Dibba Hosn, the monthly mean catch rates for demersal fish fell from 128 kg/boat/trip in the pre-spill period to 22 kg/boat/trip in April and May 1994 (Table 2). After September 1994, the demersal fish catch rate at Dibba Hosn was 51 kg/boat/trip. (This post-spill average may have been an underestimate, because the dataset for Dibba Hosn lacks data for the winter months when the highest demersal and other catches are normally expected.)

The decrease in catch rates of total species and demersal species at Dibba Hosn in April and May 1994 were about 63% and 83%, respectively, of their average rate at Dibba Hosn before the spill. For Dibba Fujairah, catch rates for total species and demersal species in May 1994 decreased by about 80% and 77%, respectively.

The catch rates for Dibba Hosn appear to have recovered by fall 1994, but because there are no data available to us from Dibba Fujairah after May 1994, we cannot say when the catch rates there recovered.

Table 2 Catch rates at Khor Kalba and Dibba Hosn in the Emirate of Fujairah, and indicators of statistical significance.

	Pre-spill (kg/boat/trip)	During spill (kg/boat/trip)	Post-spill (kg/boat/trip)	F statistic	P-value
KHOR KALBA (unoiled)					
Total species minus small pelagic	295	56	144	3.4	0.062
Pelagic species	93	14	40	2.0	0.166
Demersal species	152	33	69	3.2	0.072
Demersal and mixed species	186	40	96	3.0	0.085
DIBBA HOSN (oiled)					
Total species minus small pelagic	262	36	95	3.7	0.074
Pelagic species	115	14	36	2.9	0.115
Demersal species	128	22	51	5.6	0.030
Demersal and mixed species	136	22	52	5.7	0.029

ANALYSIS OF MARKET DATA

From data on the prices (Dirhams/kg) and quantities (kg) of fish sold in the Fujairah fish market, several findings were evident:

- In the two months (April and May) immediately following the spill, the average daily quantities of fish sold in the Fujairah market decreased for all categories except for shark and mollusks/crustaceans.
- The quantities sold in the market appear to have recovered in September 1994, but not fully to pre-spill conditions.
- Market prices showed little fluctuation when grouped by species classes.

Average daily total market value, the summed products of the prices and the quantities sold for all species, fell in the two months following the spill. Because the prices did not change substantially, the reduction in total market value was likely a function of the decrease in quantity rather than a decrease in price.

Based on the analyzed data, the Gulf of Oman did not show significant deviations from the long-term average oceanographic climate for the region in and around the time of the spill.

The fishermen reported that prices were reduced immediately following the spill, but this information was not supported by the analysis of data from the Fujairah market.

From these data, it is not clear whether the decrease in quantity of fish sold in the market was due to the fishing ban, reduced catch rates, the perception that fishing would not be worthwhile, or some combination of these elements.

OCEAN CLIMATE ANALYSIS

We examined available physical oceanographic data to determine whether there was any evidence that special ocean climate changes occurred at the time of the spill that could confound interpretation of the fisheries data. The data used came from two sources: 1) The Global Temperature-Salinity Pilot Project (GTSPP) database and 2) the Comprehensive Ocean-Atmosphere Data Set (COADS) Release 1a. The monthly mean sea surface temperature for all 6 years of the GTSPP data and the COADS long-term means and standard deviations demonstrated that the year 1994 did not significantly deviate from the long-term regional means. Based on the analyzed data, the Gulf of Oman did not show significant deviations from the long-term average oceanographic climate for the region in and around the time of the spill.

INJURY ASSESSMENT DISCUSSION

The decreased catches, especially for the bottom-dwelling fish, were strongly associated with the *Seki* spill. The catch rates were not only abruptly and substantially low at ports in the spill area immediately after the spill, but were also decreased compared with other ports with similar fishing strategies outside of the spill area.

Attributing the decreased catches to the *Seki* oil spill is reasonable. As mentioned by MacAlister, Elliott, and Partners (1995), such abrupt change is unlikely to be a seasonal change, which would have been more gradual. Further, recovery occurred by the fall of the year the spill occurred. Such rapid recovery is consistent with a decreasing exposure and argues strongly against overfishing as the cause of the decreased catch rates. There is no evidence of a dramatic change in ocean climate during or after the spill; therefore, major oceanographic changes were not likely to be involved. Moreover, the finding that the pelagic catch rates showed little change associated with the spill also argues against a change in ocean climate as a cause of the decreased rates. Although a change in fishing grounds could have led to decreased catch per unit effort, the fishermen reported no change in their grounds. Instead, they continued to fish over broad areas of the east coast.

The spill events could have led to the decreased catches in several ways. The reduced catch could have been a result of reduced numbers of traps and nets from lost gear. As an alternative or in addition to decreased amounts of gear deployed, the gear could have been functioning less effectively. The fishing strategy most clearly affected was that employing traps and handlines, both of which use bait. Decreased effectiveness of baited gear could have been due to decreased response of the fish to the bait, or to decreased numbers of fish due to avoidance of "oiled" areas. Decreased chemosensory responses in fish and shellfish in the presence of oil and avoidance of oil-contaminated sediment by commercial fish and shellfish have both been experimentally demonstrated (Weber *et al.* 1981; Pearson *et al.* 1981, 1984; Pinto *et al.* 1984; Martin *et al.* 1992). The work of Martin *et al.* (1992) is noteworthy, because their conclusions are based on a field experiment in which salmon homing, which requires the salmon's sensing the odor of homestream water, was transiently disrupted at hydrocarbon concentrations between 1 and 10 ppb.[1] Although it is not known which of these alternatives led to the decreased catches, all are plausible, and all were derived from the spill events.

A consistent story emerged from the fishermen and the landing reports, even though there were some discrepancies between them. Both the market data and the fish landings data indicated that there were fewer fish caught and sold in the two months immediately following the spill. Demersal fish were the component of the catch with both observed contamination and a clear decrease in number. Further, the fishermen in some areas, such as Dadnah, which were

[1] These concentrations do not refer to total organic carbon (TOC) but instead to a mixture of mono- and diaromatic organics intended to mimic the high solubility components of Prudhoe Bay crude oil. See Martin *et al.* (1992).

not sampled for the MAF landings records, continued to report decreased catches and the existence of oil or tar on their traps. Attributing the decreased catches to the spill is reasonable, given the observations, but the available data were too limited in amount and kind to give more than a rough indication of the extent of the effects on the fishermen.

While the available catch rate and economic data suggested that decreased catch rates encountered upon return to fishing resulted in losses in net revenue to an "average" fisherman operating in the two months following the spill, we do not know how many fishermen actually suffered such an effect. Also, because the MAF landings data are a sampling of a portion of the fishermen from only some of the ports, we have no data to extrapolate the effect of the decreased catches to all the potentially affected fishermen. Another approach to estimate the monetary damages derived from injury to the fisheries was needed.

While the available catch rate and economic data suggested that decreased catch rates encountered upon return to fishing resulted in losses in net revenue to an "average" fisherman operating in the two months following the spill, we do not know how many fishermen actually suffered such an effect.

ECONOMIC DAMAGES ASSESSMENT OF FISHERIES AND ENVIRONMENTAL INJURIES BY THE COMPENSATION SCHEDULE APPROACH

To estimate the economic value of the injuries (i.e. damages) from the *Seki* oil spill to the fisheries and marine environment of the UAE East Coast, we used procedures based on the Washington State Marine Oil Spill Compensation Schedule (Geselbracht and Logan 1993; Washington Administrative Code Chapters 173-183), and applied them to the circumstances of the spill and to the UAE environment. The Washington schedule was developed to estimate comprehensive environmental damages when actual data on injuries are sparse and cannot be obtained without inordinate expense, when restoration of the resources is not technically feasible (and thus cannot be used to estimate monetary damages), or when data gaps or other circumstances do not permit adequate compensation to the resource trustees. All of these conditions applied in the case of the *Seki* spill. The schedule approach was thus well-suited to the *Seki* oil spill situation, where there was clear evidence of widespread contamination of the marine environment and of effects on marine resources, especially fisheries, but incomplete data on the distribution of oil among habitats and ecosystem components, and inadequate data to determine the full extent of fisheries injuries and their linkage to economic effects. Moreover, using the schedule enables estimation of damages not only for the obvious injuries to commercial fisheries, for example, but also for those to other environmental components that we were not able to study directly.

The Washington schedule requires as inputs:

- the amount and characteristics of the oil spilled that determine the severity of effects,
- the resources exposed and their sensitivity, and
- the actions taken by the spiller—primarily, recovery of the oil (Geselbracht and Logan 1993).

The schedule applies general and expert knowledge of the resources and oil characteristics to arrive at coefficients between $1 and $50/gal of oil. Coefficients for a series of ecosystem components are multiplied by the number of gallons spilled, and the products are summed to give a total comprehensive environmental damage assessment. We derived coefficients for habitat, commercial fisheries, sea turtles, marine birds, and environmentally-based recreation following the compensation schedule approach and using expert knowledge of UAE marine fisheries and environment. The result of this effort was a total comprehensive damage assessment that was distinct from other damages resulting from business interruption and other disruptions and costs. We believe this assessment to be the first of its kind in the Gulf Region.

ECONOMIC DAMAGES ASSESSMENT METHODS

The Compensation Schedule has two main components: resource vulnerability scores and oil effects scores (Geselbracht and Logan 1993; Washington Administrative Code Chapter 173-183). Geselbracht and Logan (1993) provided resource vulnerability ranking formulas for seven ecosystem components: habitat, marine birds, marine fisheries, shellfish, salmon, marine mammals, and recreation. We did not develop scores for shellfish, salmon, and marine mammals. The shellfish caught in the UAE are primarily crabs and mollusks captured in traps along with demersal fish. Because the shellfish are caught with the demersal fish and because no effect was evident on shellfish, we elected not to develop a separate scoring for shellfish. Because there are no salmon and marine mammals are of low occurrence off the east coast of the UAE, we did not develop scores for those categories.

The evidence discussed in previous sections made it clear that contamination and degradation of both intertidal and subtidal habitats had occurred and that there were impacts on fisheries and fisheries resources beyond interrupted fishing or gear loss. The formulas provided by Geselbracht and Logan (1993) were used to score habitat and commercial fisheries. Because sea turtles occur as juveniles feeding along the coast in the spill area, and because turtle mortalities were observed during the spill, we developed a formula modified from the marine mammal formula of Geselbracht and Logan (1993) and applied that formula to estimate damages for marine turtles. Because marine turtles are endangered and protected by law in the UAE, we followed Geselbracht and Logan (1993) in multiplying the score for the sea turtles by a factor of 1.5. This endangered species factor was applied only to the score for turtles. Because marine birds are often one of the most heavily impacted ecosystem components during an oil spill, we used the formula of Geselbracht and Logan (1993) to assign a score for them. Since the beaches and reefs of the east coast provide opportunities for recreation that would be obviously impaired by oil contamination, we used the approach described in Geselbracht and Logan (1993) to develop a formula specific to the affected areas. This recreation score compensates for the impact of oil contamination on the recreational potential of the environment in the oiled area, and is separate from and in addition to specific economic losses suffered through business interruption (e.g., cancelled reservations).

Using the Washington Schedule we calculated damages for the *Seki* spill. The schedule requires the scores to be assigned based on seasonal values, and we assigned scores for the spring season based on the early spring occurrence of the spill. Input values for vulnerability scoring range from 5 (most sensitive or most important) to 1 (least sensitive or least important) and were derived by a group of scientists with oil spill and UAE experience. For example, because weathering of oil is higher in the UAE than Washington state, the persistence scores used were lower than those that would have been assigned for Washington. Also, a highly valuable habitat, such as mangrove stands, was assigned a score of 5 because of its high biological productivity and its role as nursery and feeding grounds for fish and other wildlife. Using tables for the nonlinear relationship between raw and scaled scores, the raw scores produced by applying the formulas to the input values were scaled to provide a final score between 1 and 5.

The habitat types used in scoring were derived from data presented in the Wimpey Report (Wimpey Environmental 1994a) and are specific to the *Seki* spill area. To obtain the distribution of oil among the habitats, we assumed that the oil was distributed among the intertidal habitats in proportion to their observed occurrence in the spill area, as presented by Wimpey Environmental (1994a). For the distribution of oil among the subtidal habitats, we assumed that the oil was evenly split between hard and soft substrata, and among the hard substrata evenly split between coral and rocky reef habitats. Without data from a systematic subtidal survey, this assumption is the most conservative. Although there was clear evidence that oil reached the subtidal habitats, the precise extent of subtidal oiling was not known. Consequently, we used two scenarios in estimating the damages. The first scenario assumed that 15% of the spilled oil reached the subtidal habitats, and the second assumed that 25% did. Based on evidence from other spills and the oil characteristics, we doubt that more than 25% of the spilled oil reached subtidal habitats. Local expert knowledge was used to develop values for the importance of the habitat and other inputs.

For marine fisheries, we developed scores for small pelagic, pelagic, and demersal fish, because these three groups showed clear differences in seasonal abundances, stock conditions, oil sensitivities, and importance to fisheries and the environment. The scores for the three groups were then combined into one composite score for marine fisheries.

For each recreational category, we estimated the proportion of coast where recreation could occur and derived an attribute score for that activity. The products of the coastline length and attribute scores were then summed and scaled to fall between 1 and 5 for the final vulnerability score.

Following Geselbracht and Logan (1993), oil effects rankings were developed for three aspects of injury: 1) acute toxicity, 2) mechanical injury, and 3) persistence. Using the API gravity for light Iranian crude oil of 33.84 and following Geselbracht and Logan (1993) and Washington Administrative Code Chapters 173-183, we assigned an acute toxicity ranking of 2 (out of 5), a mechanical injury ranking of 3, and a persistence ranking of 3. The amount of oil spilled was assumed to be 4,949,952 US gal (~18.7 million L), and the amount recovered, 214,935 US gal (~814,000 L).

The calculation of damages followed the formula of Geselbracht and Logan (1993). For each resource, the vulnerability scores, the oil effects scores, and the number of gallons spilled (less the number of gallons recovered) were multiplied according to the formula. The total environmental damages were then calculated as the sum of the damages for the five components: habitat, marine fisheries, marine, turtles, marine birds, and recreation.

ECONOMIC DAMAGES ASSESSMENT RESULTS

Depending on the assumptions concerning the amount of oil reaching the subtidal habitats, the estimates for the total comprehensive environmental damages for habitat, commercial fisheries, sea turtles, marine birds, and marine-based recreation ranged between $48,680,946 and $48,930,581 (Table 3).

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Habitat injury had estimated damages of $5,393,505, assuming that 15% of the oil reached the subtidal and $5,643,140, assuming 25% reached the subtidal (Table 3). The difference in damages

Table 3 Summary of environmental damages from the *Seki* spill as calculated by the Marine Oil Spill Compensation Schedule, assuming different amounts of oil reaching subtidal habitats (Pearson *et al.* 1996).

Category	15% reaching subtidal	25% reaching subtidal
Habitat	$5,393,505	$5,643,140
Marine fisheries	$15,665,931	$15,665,931
Marine turtles	$10,718,795	$10,718,795
Marine birds	$9,482,011	$9,482,011
Recreation	$7,420,704	$7,420,704
TOTAL	**$48,680,946**	**$48,930,581**

between the two scenarios for the amount of oil reaching the subtidal habitats was less than 1% of the total comprehensive damages. About 49% of the intertidal zone of the coastline affected by spill was rocky, whereas the remainder was primarily sandy. Highly valued and oil-sensitive habitats, such as mangroves and mud flats, were not found in the oil spill area. If such valued habitats had been oiled, the damages for habitat injury would have been substantially higher.

The category with the largest estimated damages was marine fisheries (Table 3). Based largely on their seasonal presence, relative commercial importance, and other factors, the demersal fish had the highest vulnerability, followed by the pelagic, and then by the small pelagic. Because of their threatened and endangered status, marine turtles had estimated damages in the vicinity of $11 million.

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ECONOMIC DAMAGES ASSESSMENT DISCUSSION

The application of the Compensation Schedule provided an estimate of the total comprehensive environmental damages for five natural resource services known to be contaminated and affected by oil from the *Seki* oil spill. It enabled the estimation of damages in a situation in which clear evidence of contamination and of effects on the environment and fisheries existed, but in which the data to link oiling and environmental effects to their economic value losses were inadequate or incomplete.

The results of the schedule approach were consistent with the observed effects and prevailing values. For example, marine fisheries had the highest estimated damages and were resources with clear effects and high value (Table 3). The fisheries damages estimate was about one quarter of the annual value of the east coast fisheries. Marine turtles had high estimated damages because of their threatened status. Damages for habitat injury were lower than expected. However, these estimated damages were reasonable in hindsight because *Seki* oil did not reach the most sensitive or most important habitats, such as the mangrove stands in Khor Kalba to the south of the spill area.

There is still some uncertainty about the estimate of habitat damages, because we do not know the proportion of spilled oil that reached the subtidal habitats. *Seki* oil did reach the subtidal, but without a systematic survey of sediment contamination, we know neither the amount that reached the subtidal nor its distribution there. However, even a high-end estimate of 25% of the oil's reaching the subtidal only increases the estimated damages by about $250,000 (Table 3). The marine fisheries damages overshadow those for habitat injuries.

CONCLUSION

Lessons can be drawn from the *Seki* oil spill for both science and policy concerning oil spill damage assessments. The first is that although the assessment was hampered by incomplete data, the compensation methodology worked to produce damage estimates that are, in our opinion, reasonable. Fingerprinting analysis proved successful and necessary for demonstrating the contamination of the marine environment by *Seki* oil and exposure of demersal fish. The fisheries data provided strong evidence for the occurrence of effects but, while adequate for the management purposes for which the fisheries data are routinely collected, did not enable estimation of the full spatial or temporal extent of fisheries effects. The linkage of the fisheries effects to their economic damages could probably not have been made without an approach similar to the one we took. Similarly, the linkage of contamination of the coastal habitats to economic damages could not have been possible without the compensation schedule approach.

Lessons can be drawn from the Seki *oil spill for both science and policy concerning oil spill damage assessments. The first is that although the assessment was hampered by incomplete data, the compensation methodology worked to produce damage estimates that are, in our opinion, reasonable.*

To improve the compensation schedule approach in the Arabian Gulf and Gulf of Oman, we recommend that the coastal habitats be classified and mapped in detail. The emerging Geographical Information Systems (GIS) is ideal for such a task. We believe that an oil spill compensation procedure developed in more detail for the region would enable rapid calculation of damages without large or time-consuming studies. Such a schedule is appealing from several policy perspectives, and its more frequent and widespread use would enhance its value as a deterrent to less than full attention to oil spill prevention.

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Global Climate Variations Over the Past 250 Years: Relationships with the Middle East

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ABSTRACT
We analyze recent global temperature reconstructions over several centuries in time based on calibrations of temperature patterns against global networks of long instrumental and "proxy" data (natural archives such as ice cores, corals, and tree rings), focusing on long-term climatic variations in the Middle East. The pattern of global warming of the past century does not show a strong influence in this region. Instead, patterns of natural low-frequency variability appear to dominate the region. One of these patterns is associated with the well-known "North Atlantic Oscillation" and leads to changes on interannual and decadal timescales. Another distinct pattern appears to relate to influences of low-frequency variability in the North Atlantic ocean circulation and overlying atmosphere circulation, and describes changes that are predominantly multidecadal in timescale. This latter pattern is especially important in predicting possible climate change scenarios in future decades in this region.

INTRODUCTION

Documenting the patterns of large-scale climate variability during the past several centuries is important to understanding the significance of long-terms trends and low-frequency variations in the global climate. Once such large-scale patterns of variability are established and statistically verified, they can provide a context for understanding the variations present in particular regions of the globe, including those regions of importance in the history of human civilization. Unfortunately, there is no instrumental climate data available on the century and longer timescales of interest in this context. However, widespread networks of high-resolution proxy climate indicators and the few very long instrumental and historical climate indicators available several centuries back can be combined into a global "multiproxy" network that can potentially be used to describe annual global temperature patterns during past centuries. Here we analyze climatic variability back to the mid-18th century based on the multiproxy-reconstructed global surface temperature patterns of Mann *et al.* (1997a). We focus here on the variations in the Middle East region and its relationship with larger-scale patterns of climate variability. We can thus examine in detail the relationship between Middle Eastern climate and global climatic variations several centuries back in time.

DATA

The reconstructed surface temperature patterns of Mann *et al.* (1997) are based on the multivariate calibration of globally distributed annual resolution proxy climate indicator network. The network includes (see Figure 1, left) the collection of annual resolution dendroclimatic, ice core, ice melt, and long historical records used by Bradley and Jones (1992) combined with other coral (Lough 1991; Quinn *et al.* 1993; Dunbar *et al.* 1994), dendroclimatic (Jacoby and D'arrigo 1989, 1990; Briffa *et al.* 1992), and long instrumental (Jones and Bradley 1992) records. The available instrumental records are formed into annual mean anomalies relative to the 1902-1980 reference period, and gridded onto a 5 degree by 5 degree grid, consistent with the instrumental gridpoint data described below. This provides 11 temperature gridpoint records, 12 precipitation gridpoint records, and 3 station surface pressure gridpoint records dating back to 1820 or earlier.

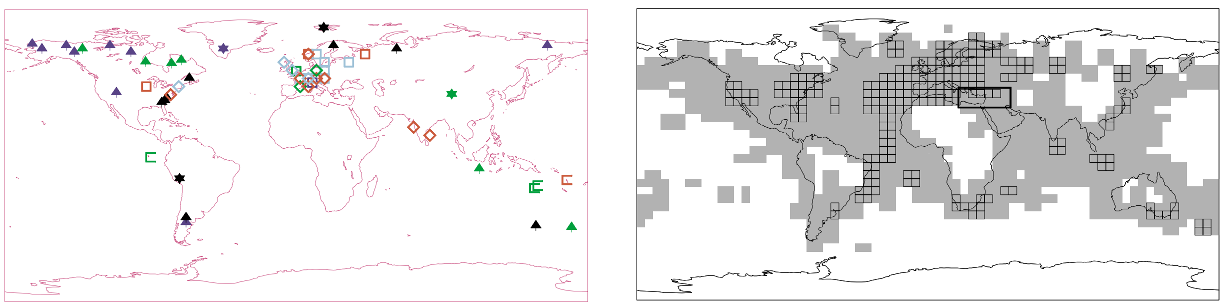

Figure 1 Data used in this study. (left) Distribution of annual resolution proxy indicators used in this study. Dendroclimatic reconstructions are indicated by "tree" symbols, ice core/ice melt proxies by "star" symbols, coral records by "C" symbols. Long historical records and instrumental "gridpoints" series (see text) are shown by squares (temperature), or diamonds (precipitation or surface pressure). All 58 sites (62 records) available back to 1820 are shown, with records dating back to at least 1820 (red), 1800 (blue-green), 1750 (green), 1600 (blue), and 1400 (black) shown with different colors. Certain sites (e.g., Quelccaya ice core) provide multiple proxy indictors (e.g., multiple nearby cores, and both d^{18}o isotope data and ice accumulation). (right) Distribution of the (1082) nearly continuous available land air/sea surface temperature gridpoint data available from 1902 onward indicated by shading. The blue squares indicate the subset of 219 gridpoints with nearly continuous records extending back to 1854 that are used for verification. Northern Hemisphere (NH) and global (GLB) mean temperature are estimated as areally-weighted (i.e., cosine latitude) averages over the Northern hemisphere and global domains respectively. A Middle Eastern ("MNET") surface temperature index is constructed from the gridpoints available over the large-rectangular box shown in that region.

The instrumental temperature anomaly data (Figure 1, right) used to train the proxy dataset span the interval 1902-1993 and are taken from a gridded combined land air and sea surface temperature dataset of Jones and Briffa (1992). Although there are notable spatial gaps, this network covers significant enough portions of the globe to estimate a global mean ("GLB") temperature, and enough of the Northern hemisphere and of the extreme eastern equatorial Pacific to construct highly faithful estimates of both the Northern Hemisphere mean ("NH") temperature series, as well as certain indices of particular importance (e.g., the "NINO3" index important in the context of the El Niño phenomenon). A box including all gridpoints in the region 30N to 50N latitude, 20E to 40E longitude is used to construct a Middle Eastern ("MNET") temperature index. An instrumental estimate of the North Atlantic Oscillation (NAO) taken from Hurrell (1995) is also made use of in our analysis.

MULTIPROXY CALIBRATION

Multiproxy networks appear to provide the greatest opportunity for large-scale climate reconstruction (Bradley and Jones 1993; Hughes and Diaz 1995) and climate signal detection (Mann *et al.* 1995; Barnett *et al.* 1996). While limitations (e.g., dating errors) in the individual proxy indicators must be carefully accounted for in constructing an appropriate multiproxy network (see Mann *et al.* 1997a), the mutual information contained in a widely distributed set of independent climatic indicators can more faithfully capture the consistent climate signal that is present, reducing the compromising effects of biases and weaknesses in the individual indicators.

The reconstructions of which we make use (Mann *et al.* 1997a) are based on a calibration of such a multiproxy network against widespread instrumental surface temperature data of the 20th century. Multivariate statistical calibration approaches have previously been applied to proxy climate data for local or regional climate reconstruction, particularly in the field of dendroclimatology (see e.g., Fritts *et al.* 1971; Cook *et al.* 1994). Related statistical methods have more recently been applied to the problem of interpolating sparse early instrumental climate observations through training them against the dominant large-scale patterns of variability isolated in shorter, but more widespread recent climate fields (Kaplan *et al.* 1997). Our approach to long-term climate pattern reconstruction combines these traditionally distinct applications. We first decompose the instrumental training data into its dominant patterns of variability, and subsequently perform a multivariate calibration of the climate proxy indicators against the time histories of these different patterns. In doing so we make a number of important assumptions. We assume (1) that the indicators in our multiproxy trainee network are linearly related to one or more of the instrumental training patterns. In the relatively unlikely event that a proxy indictor represents a truly local climatic phenomenon which is uncorrelated with larger-scale climatic variations, or represents a highly non-linear response to climatic variations, this assumption will not be satisfied. We further assume (2) that a relatively sparse but widely distributed sampling of long proxy and instrumental records may nonetheless sample most of the relatively small number of degrees of freedom in climatic patterns at interannual and longer timescales. Regions not directly represented in the trainee network may nonetheless be indirectly represented through teleconnections with regions that are. Finally, we assume (3) that the patterns of variability captured by the multiproxy network have analogs in the patterns we resolve in the shorter instrumental data. This latter assumption represents a fairly weak "stationarity" requirement—we don't require that the climate itself be stationary. In fact, we expect that some sizeable trends in the climate may be resolved by our reconstructions. We do, however, assume that the basic *spatial patterns* of variation that the climate has exhibited during the past several centuries are similar to those by which it has varied during the past century. Studies of instrumental surface temperature patterns suggest that such a form of stationarity holds up at least on multi-decadal timescales, during the past century (Kaplan *et al* 1997). The statistical cross-validation exercises we describe later provide the best evidence that these key underlying assumptions are reasonable.

We isolate the dominant patterns of the instrumental surface temperature data through principal component analysis (PCA) (Preisendorffer 1989). PCA provides a natural smoothing of the temperature field in terms of a small number of dominant patterns of variability "empirical eigenvectors" that describe 20th century temperature variations. Each of these eigenvectors is associated with a characteristic spatial pattern or "Empirical Orthogonal Function" (EOF) and its characteristic evolution in time, or "principal component" (PC). The first 5 eigenvectors describe a fraction (*ß* = 0.27, or 27%) of the total multivariate variance ("MULT") in the raw data, 90% of GLB, 85% of NH, 67% of NINO3, and 76% of the detrended ("DETR"), interannual-to-multi-decadal timescale variability in NH. The first 40 eigenvectors, for comparison, describe nearly all of the GLB and NH annual mean variance, about 90% of the NINO3 annual mean variance, and 73% of MULT. The rank of the eigenvectors orders the fraction of variance they describe in the standardized data (1=12%. 2=6.5%, 3=5%, 4=4%, 5=3.5%). The first eigenvector describes a modest 12% of the full spatiotemporal variance in the dataset, but a majority of variance in GLB (88%) and NH (73%) estimated temperatures. This eigenvector is associated with the significant global warming trend of the past century. The second eigenvector describes 8% of the multivariate data variance, and is associated with much of the ENSO-scale variability, describing 40% of the variance in the NINO3 index. This eigenvector exhibits a modest negative trend. The third eigenvector describes much of the traditional NAO pattern (verified through correlation analyses described later), with opposed centers of warm and cold anomalies in and neighboring the North Atlantic. The fifth eigenvector is associated with variability centered in the Atlantic basin exhibiting significant multi-decadal variability (see Kushnir 1994; Mann and

Park 1994,1996). Figure 2 shows the EOFs for eigenvectors 1, 2, 3 and 5. (The verification exercises described briefly below and in detail in Mann *et al.* (1997a) indicate that the fourth eigenvector can not be skillfully resolved by the present multiproxy network). The associated PCs are shown along with their reconstructed counterparts ("RPC"s) below. Note that both EOFs 3 and 5 have large projections in the Middle East. Indeed, as discussed below, these two independent patterns compete for influence on Middle Eastern temperature variations.

As described in detail by Mann *et al.* (1997a), we calibrate the multiproxy data network against these empirical eigenvectors at annual mean resolution during the training (1902-1980) interval. This multivariate calibration provides a transfer function that can be applied to the multiproxy network to reconstruct temperature patterns before the calibration interval on an annual basis, with a spatial coverage dictated only by the spatial extent of the instrumental training data. The statistical skill of the temperature reconstructions is established through independent cross-validation or "verification" exercises. Verification statistics were determined based on two

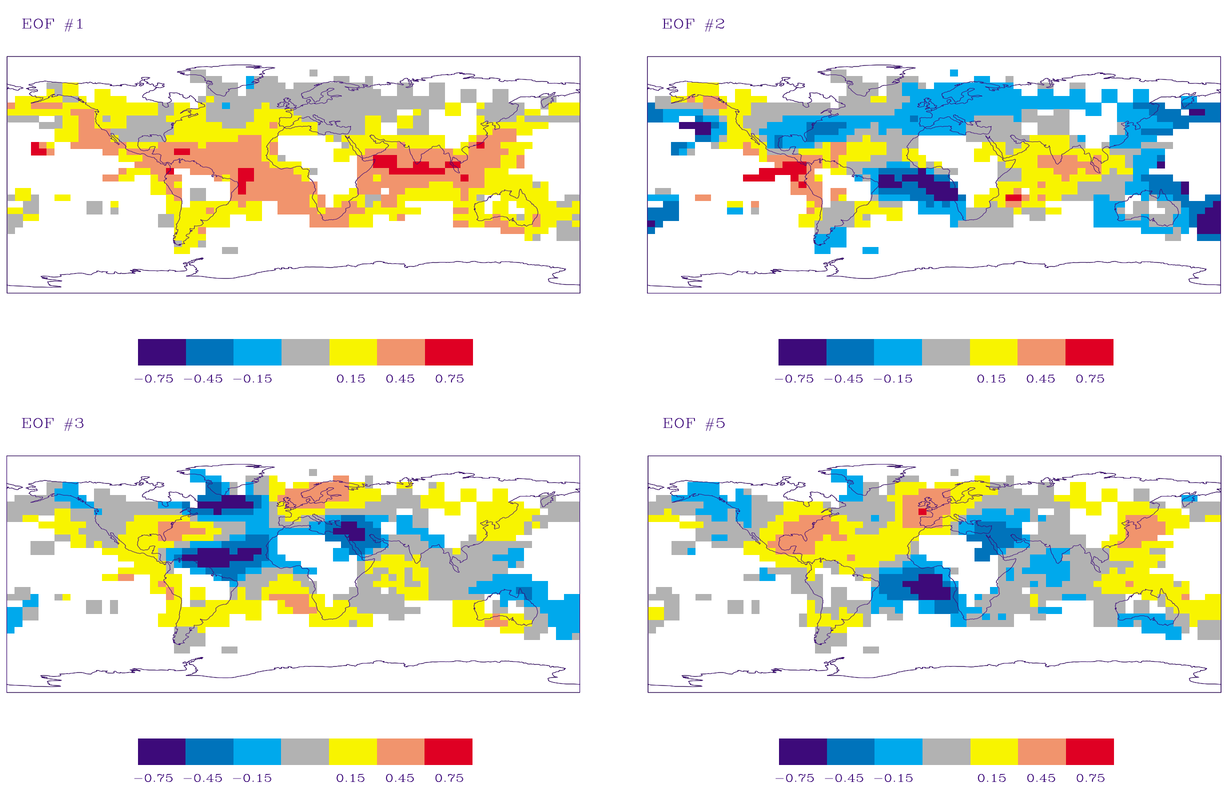

Figure 2 EOFs of the leading eigenvectors (#'s 1,2,3,5) of the global temperature data from 1902-1980 retained in the analysis. The EOFs are renormalized to remove the areal weighting factor which tends to diminish the amplitudes of the pattern at higher latitudes.

distinct verification datasets described by Mann *et al.* (1997a). Here we will discuss the results from one of these verification datasets, the sparse subset of the gridded data (M' = 219 gridpoints) for which independent values are available from 1854-1901 (see Figure 1, right). NH and GLB verification statistics are computed, as is the multivariate ("MULT") gridpoint level verification statistic.

A sequence of multiproxy calibration experiments were performed in which progressively lower rank eigenvectors are retained. Sensitivity to the exclusion of certain intermediate rank eigenvectors was also investigated. While calibration described variance increases monotonically with increased retained eigenvectors, an optimal subset of eigenvectors can be isolated which maximizes the verification described variance. In this study, that subset corresponds to only a handful of the highest ranked eigenvectors. We also test the network for sensitivity to the inclusion or elimination of particular trainee data (e.g., instrumental records, the Northern treeline dendroclimatic indicators of North America, and tropical coral records). The technical results and details regarding calibration/verification are described by Mann *et al.* (1997). These experiments demonstrate that the multiproxy network appears able to capture much of the variance that can potentially be described by the modest retained set of eigenvectors generated by cross-validation exercises. Although more widespread proxy data are available, the network used here is intentionally sparse, illustrating the principle that skillful pattern reconstruction can be performed with a relatively sparse trainee network. More widespread proxy networks should allow an increasingly large number of eigenvectors to be skillfully retained, and a consequently increased fraction of described variance. The patterns of calibration and verification *ß* for the full reconstructed patterns are shown in Figure 3.

In Figure 4, we show the comparison of the raw and reconstucted MNET temperature index during the 1902-1980 calibration interval. The match is excellent, with a correlation of $r = 0.5$ between the raw and reconstructed series ($r^2 = 0.25$) and a value of *ß* = 0.17 for described variance. Note that the values for this coarse-averaged regional index are better than for the individual gridpoints making up the index because of the large-scale optimality of our EOF-based reconstruction approach. Although the 1854-1901 verification dataset poorly samples the rectangular region used to construct the MNET index, the verification *ß* values for the gridpoints which are present are with one exception statistically significant at the 99% level, albeit negative—the impact of quality problems with the instrumental data themselves before the 20th century is unknown and

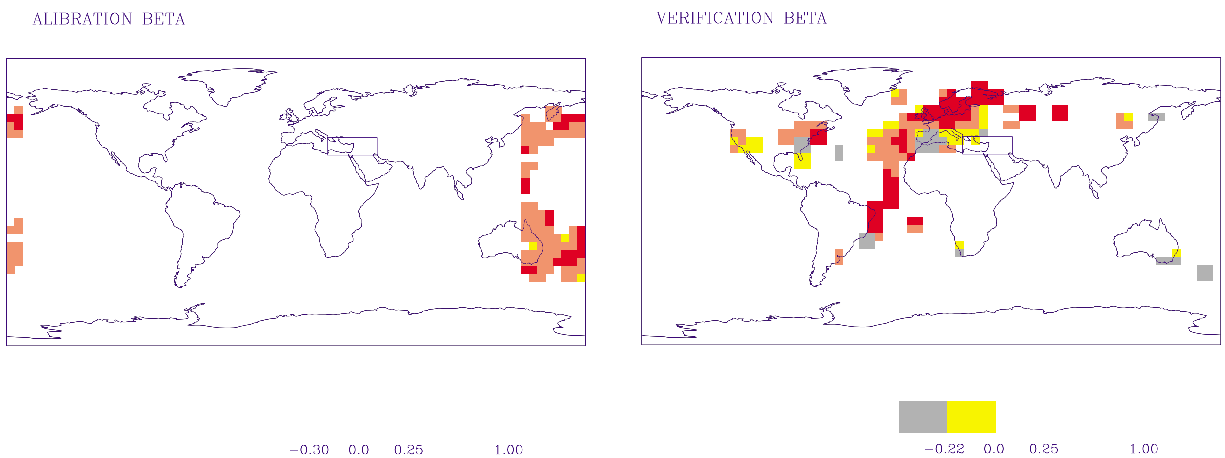

Figure 3 Spatial patterns of calibration (left, based on 1902-1980 data), and verification ß (right, based on 1854-1901 data) (bottom). Values that are insignificant at the 99% level are shown in gray, while negative, but 99% significant values are shown in yellow, and significant positive values are shown in two shades of red.

may artificially degrade the apparent skill of the reconstructions. We thus believe the reconstructed MNET index to be quite faithful.

TEMPERATURE RECONSTRUCTIONS

The reconstructions discussed below are derived from the optimal eigenvector subsets for the period 1760-1980 as described by Mann *et al.* (1997a), reconstructed with EOF #s 1,2,3,5. To illustrate the effectiveness of the proxy pattern reconstruction procedure, we show as an example (Figure 5) the raw, EOF-filtered, and reconstructed temperature patterns for a year during the calibration interval (1941).

It is clear that the proxy network in this example is capable of resolving much of the structure that is resolved by the 4 EOFs themselves used in calibration. Figure 6 shows the 4 reconstructed princi-

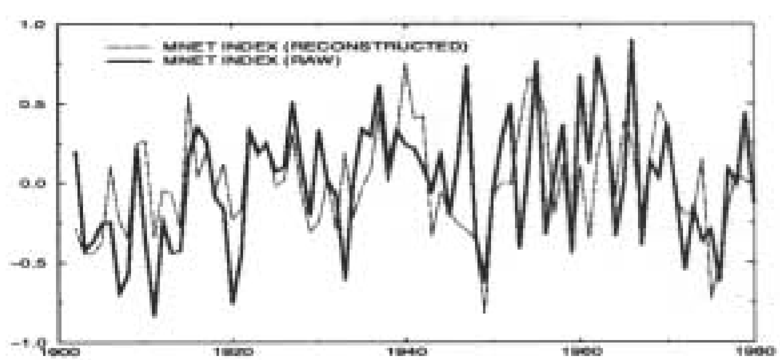

Figure 4 Comparison of raw and proxy-reconstructed MNET index during the 1902-1980 calibration interval.

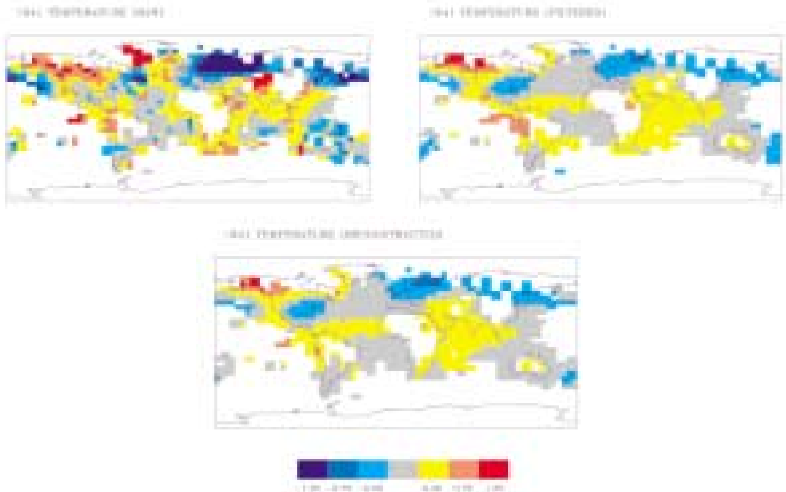

Figure 5 Comparison of the proxy-based spatial reconstructions of the anomaly pattern for 1941 vs. the raw data. based on (upper left) raw and (bottom) proxy-reconstructed data. Anomalies (relative to 1902-1980 climatology) are indicated by color scale, with lighter shading corresponding to warm anomalies and darker shading to cold anomalies. Noteworthy is a warm event in the tropical Pacific, and presumably associated teleconnections over the Pacific/ North American sector, as well as substantial cool anomalies over Eurasia. The major features of this year are captured, albeit highly "smoothed" by the filtering of the pattern by the small number of EOFs (#s 1,2,3,5) used in the reconstruction procedure. The comparison of the multiproxy reconstruction with the equivalently eigenvector-filtered raw pattern (the "target" for reconstruction) is excellent. during the 1902-1980 calibration interval.

pal components ("RPCs") #s 1, 2, 3, and 5 (the associated spatial patterns were shown in Figure 2).

The positive trend in RPC 1 during the 20th century is clearly exceptional in the context of the long-term variability in the associated pattern, and indeed describes much of the unprecedented warming trend evident in the NH reconstruction. Equally interesting is the negative trend in RPC 2 during the past century which is also anomalous in the context of the longer-term evolution of the associated pattern. The recent negative trend is associated with the modest long-term cooling trend in the eastern tropical Pacific (superimposed on warming associated with the pattern of eigenvector #1) which may be a modulating negative feedback of global warming (Cane *et al.* 1997). The third eigenvector exhibits much of the NAO signature in the data. The fifth eigenvector exhibits notable multi-decadal variability throughout both the modern and pre-calibration interval, associated with the wavelike trend of warming and subsequent cooling of the North Atlantic this century that has been discussed elsewhere (Kushnir 1994; Mann *et al.* 1994, 1996; Schlesinger and Ramankutty 1994) and longer-term multi-decadal oscillations in that region detected in a previous analysis of proxy climate networks (Mann *et al.* 1995). This variability may be associated with ocean-atmosphere processes related to the North Atlantic thermohaline circulation (Delworth *et al.* 1993, 1997). Table 1 shows the correlations between the MNET index, the NAO, and the four reconstructed principal components of this study.

Middle Eastern climate is known to have a significant relationship with NAO on inter-annual timescales (see Cullen and Demenocal 1997). This is certainly substantiated in Table 1. However, of particular interest here are the patterns of variation influencing the region on longer timescales as well. The correlations also show that a distinct pattern of variation associated with EOF 5 has considerable influence on Middle Eastern temperature. The long-term trend in the reconstructed NH series exhibits a a general period of coolness through 1850, and warming thereafter. In Figure 7, we show the reconstructed NH series along with the MNET index. Although there are some broad similarities, MNET does not track NH on the longer timescales. In particular, the marked NH warming of the 20th century is not evident in the MNET index, although there is multi-decadal variability as described below. This difference appears to be associated with multi-decadal cool periods in the Middle East associated with the pronounced multi-decadal variations in RPC 5. These variations favor negative temperature anomalies in MNET during the early and late 20th century, offsetting times at which the global warming trend and its weak projection onto the region was most rapidly accelerating.

A comparison of the power spectra (Figure 8) of the MNET series, RPCs 3 and 5, and the NAO provides considerable insight into the natural of the patterns of variability influencing Middle East temperatures on different timescales.

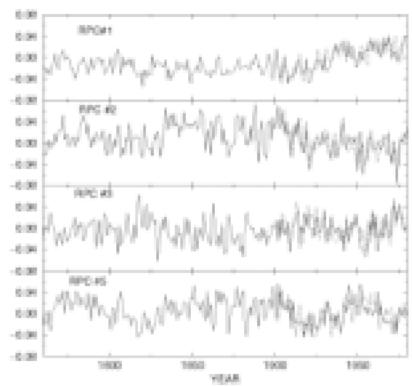

Figure 6 Reconstructed Principle Components ("RPCs") 1, 2, 3, 5 used in the climatic reconstructions.

Table 1 Correlations of RPCs with NAO and MNET indices over two different periods of time during the reconstructed 1760-1980 time interval.

RPC	r(NAO)	1864-1980 r(MNET)	1760-1980 r(MNET)
1	-0.28	0.26	0.28
2	-0.06	-0.30	-0.18
3	0.41	-0.63	-0.68
4	-0.09	-0.32	-0.26

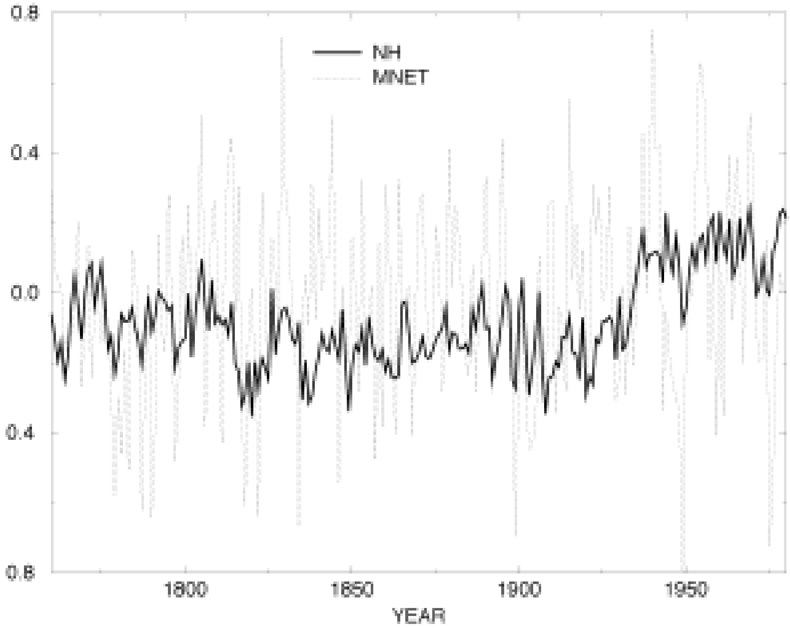

Figure 7 Reconstructed Northern Hemisphere mean (NHEM) temperature series along with reconstructed MNET index.

It is evident that the MNET temperature index exhibits enhanced power (which is statistically significant) in the "multi-decadal" frequency range of $f = 0.01$-0.02 cycles/year (50-100 years period) as well in the decadal $f = 0.05$-0.1 (10-20 years period) frequency range. These spectral peaks are most pronounced in the longer 1760-1980 data interval. This is distinct from the behavior of the NAO which, although displaying a secular peak during the past century (i.e., a near-zero frequency trend isolated in the above figure), does not exhibit significant decadal or multi-decadal spectral peaks. The long-term multi-decadal variability *is* a robust feature of the North Atlantic climate (Mann *et al.* 1995) which appears unrelated to the NAO, and in fact nearly orthogonal to it, probably associated with the response of atmosphere to multi-decadal changes in surface heating by the ocean (Kushnir 1993; Mann and Park 1994, 1996). These multi-decadal variations appear to be associated with a stochastically-excited eigenmode of the coupled ocean-atmosphere system (Delworth *et al.* 1993; 1997). This relationship is also shown in Figure 9. The multi-decadal variations in MNET have a close relationship with intervals during which the RPC 5 (associated with the pattern EOF 5) favors warming (negative) or cooling (positive) in the Middle East. In contrast, the inter-annual/decadal variations in MNET have a closer relationship with episodes during which the RPC 3 associated with NAO-like pattern EOF 3 favors warming (negative) or cooling (positive) in the region.

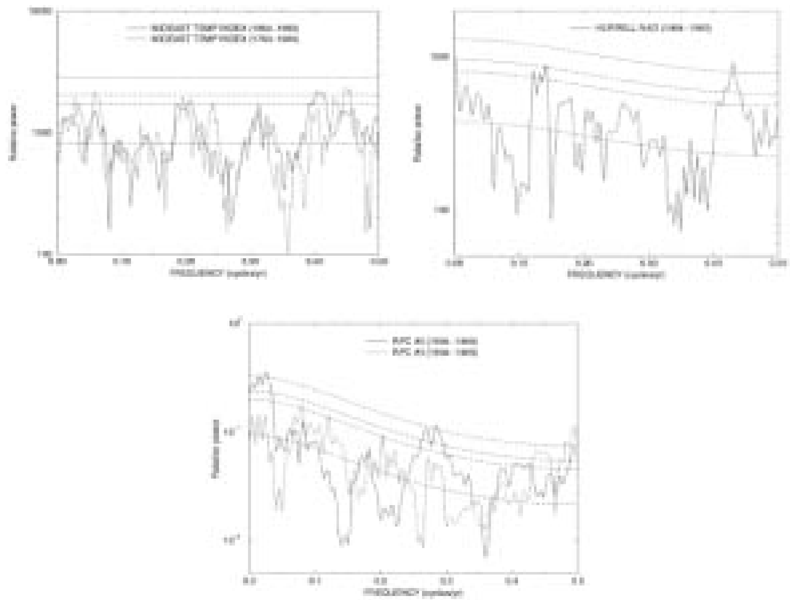

Figure 8 Power spectra for (upper left) reconstructed Middle/Near Eastern "MNET" temperature index, (upper right) NAO index, and (bottom) RPCs 3 and 5. The spectra are based on the multitaper method, with best red noise median power levels and 90%, 95%, and 99% confidence levels (dashed) lines estimated by the robust method of Mann and Lees (1996).

In Figure 10, we show some example patterns for different reconstructed years.

The warm MNET year 1760 appears to have been associated with a particularly prominent NAO-type pattern superimposed on the otherwise cool multi-decadal period. 1783, a strong El Niño year (Quinn and Neal 1992) exhibits, by contrast, a prominent negative MNET temperature anomaly. A (weaker) negative MNET anomaly is also observed during the very strong (Quinn and Neal 1992) El Niño year 1878 shown. Analysis of ENSO variability in these reconstructions is discussed in more detail elsewhere (Mann *et al.* 1997b). The pattern of 1816 shows anomalous cooling throughout much of the globe (even relative to this generally cold decade) but with a quadrupole pattern of warmth near southern Greenland and the Middle East, and enhanced cold in the eastern United States and Europe. This latter pattern is indeed consistent with the anomalous atmospheric circulation associated with the North Atlantic Oscillation (NAO) pattern observed in empirical (Kelly *et al.* 1996) and model-based studies (Kirshner 1995) of the atmospheric response to volcanic forcing. This latter pattern is evident in neither the following nor preceding year, and is likely associated with the large

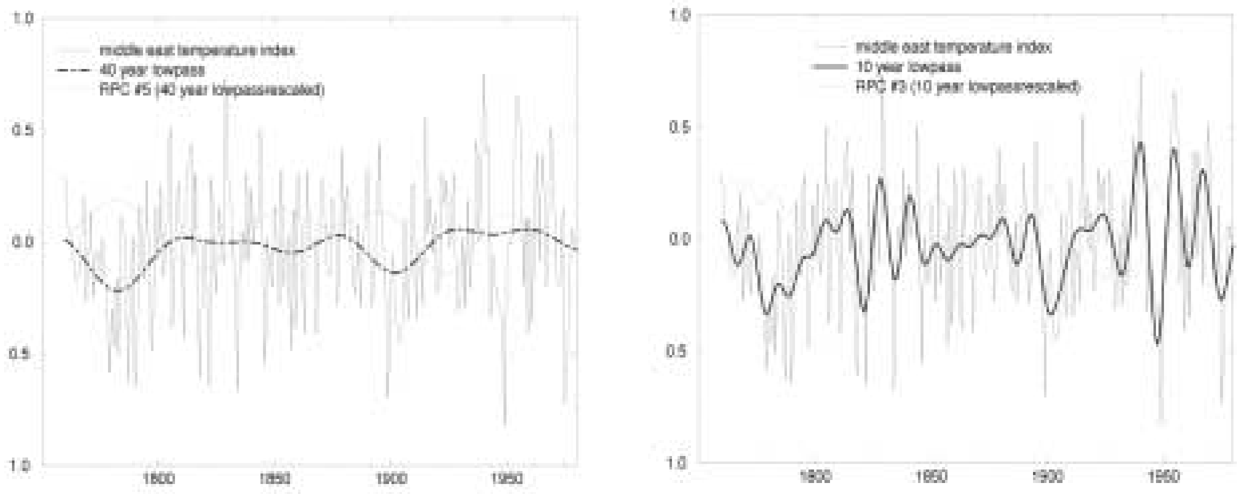

Figure 9 (left) RPC 5 along with MNET index, filtered on multi-decadal timescales (40 year lowpass) and (right) RPC 3 along with MNET index, filtered on interannual timescales (5 year lowpass).

Tambora eruption of April 1815 both in terms of the hemispheric coldness and the superimposed NAO-like pattern.

CONCLUSIONS

With the large-scale temperature reconstructions that we have available over the past couple of centuries, we are able to document the importance of at least two distinct patterns on the climate of the Middle East. One of these patterns is associated with the North Atlantic Oscillation (NAO) and dominated by inter-annual and decadal timescales. The other pattern is distinct from the NAO and more consistent with the atmospheric response to multi-decadal oceanic variations (Delworth *et al* 1993; Kushnir 1994; Mann and Park 1996). This suggests that patterns not easily resolvable in the short instrumental record (in particular, patterns *distinct from* the NAO) may be of increasing relative importance on progressively longer timescales, and are important to understanding climatic variations in the Middle East on multi-decadal and longer timescales. As increasingly larger numbers of high quality proxy reconstructions become available in diverse regions of the globe, it will be possible to assimilate a more globally representative multiproxy data network. Given the high level of skill possible in large-scale reconstruction back to 1450 with the somewhat sparse network of the present study, there is reason to believe that it may soon be possible to reconstruct much of the spatio-temporal variability of the global climate back over the last 500 to 1000 years. With such reconstructions in hand, we will be able to document more confidently the climatic variations in the Middle East during the past millennium. Such reconstructions should be useful for understanding changes in human land use and patterns of civilization in that region on longer timescales.

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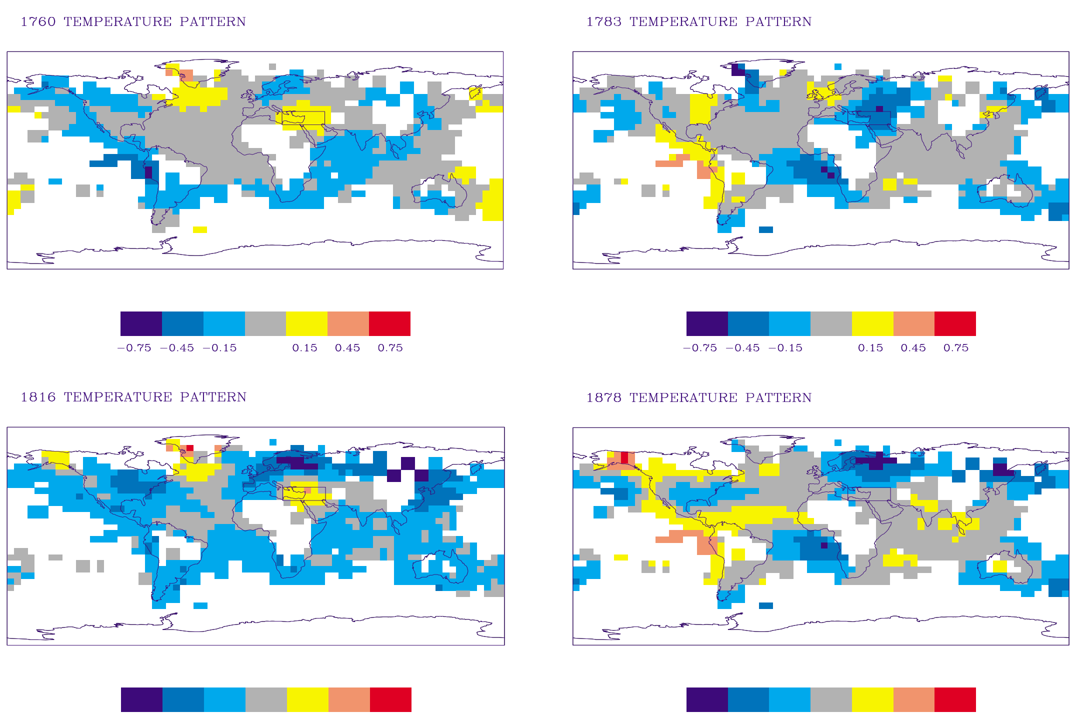

Figure 10 Reconstructed large-scale temperature patterns for (i) 1760, (ii) 1783, (iii) 1816, (iv) 1878. Middle Eastern box used to compute MNET index is shown. The color scale indicates regions which exceed (either positively or negatively) the threshold indicated. The zero baseline is defined by the 1902-1980 climatological mean for each gridpoint.

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Rapid Population Growth and the Fertility Policies of the Arab Countries of the Middle East and North Africa

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ABSTRACT
The population of the Middle East and North Africa (MENA) region has increased rapidly over the course of the 20th century. During the 70 years between 1914 and 1994, the region's total population has grown by nearly a factor of five, largely as a result of natural rates of increase in indigenous populations (with the notable exceptions of Israel and the Gulf states, whose population increases are generally attributable to migration). Population growth rates among many of the nations of the region are presently among the highest worldwide. Despite family planning measures undertaken in many MENA countries, continued population growth remains the most critical socioeconomic problem in the region as governments struggle to support their growing populations with inadequate resources. This paper argues that only the continued reduction of fertility levels, combined with massive shifts of financial resources away from the military toward socioeconomic development, will avert wide-scale human and environmental hardship in the region.

INTRODUCTION

During the last hundred years, the global population has more than tripled, growing from 1.7 billion at the turn of the 20th century to nearly 5.75 billion in 1995 (Durand 1977; United Nations Demographic Yearbook–1995). This rate of increase is far higher than has ever before been witnessed in human history.

Over time, the global population has undergone a "demographic transition" which can be generally divided into three stages. The first stage lasted from the beginnings of human civilization until the middle of the 19th century, a period characterized by high crude birth rates (over 40 per 1,000) and high total fertility rates (over six). Nevertheless, because mortality levels were also high during this period, natural increase rates of the world's population were generally quite low (and sometimes even negative during periods of starvation and epidemic disease).

In the developed West, the second stage of the demographic transition began in the middle of the 19th century (with the developing world following between 30-80 years later), as improved sanitation, preventive medicine, and nutrition resulted in vastly reduced mortality rates and significant increases in life expectancy. All of these developments were a result of the Industrial Revolution and thus occurred only in western countries. The decline in death rates was not followed immediately by a decrease in fertility levels, however, and the growing gap between high fertility rates and falling death rates led to a sharp increase in population growth as compared with past centuries.

In industrialized countries, a third stage of demographic transition began in the early 20th century, characterized by declining fertility rates caused by the forces of modernization. During the past two decades, falling birth rates have converged with low death rates to generate rates of natural increase approaching zero in many of the developed countries (Todaro 1990; Caldwell and Caldwell 1982; Lutz 1994). By 1995, in the United Kingdom, Denmark, and Germany, for example, the natural increase rates of the population were 0.2%, 0%, and -0.1%, respectively (UNICEF 1997).

Most of the world's countries, however, including those of the Middle East, have not yet reached the third stage of demographic transition. These developing countries have been the main contributors to rapid global population growth over the last two generations. By 1994, only a fifth of the world's population was living in regions classified as industrialized. However, during recent years, there have been strong indications of a worldwide fertility decline, even in sub-Saharan Africa, which appears to be the last region to begin the third stage of the demographic transition (Lutz 1994).

As in other developing areas, the Middle East has witnessed rapid population increases in the 20th century, especially from the late 1950s onward (see Figure 1). The total population of the Middle East and North Africa (including Iran and Turkey) increased from roughly 68 million in 1914 (Issawi 1982) to more than 340 million in 1994 (World Bank 1996; ESCWA 1995), a fourfold increase during a period of only 80 years. The reason for such a dramatic increase is not migration, as has been the case in North America, for example, but instead the growth of natural increase rates in the

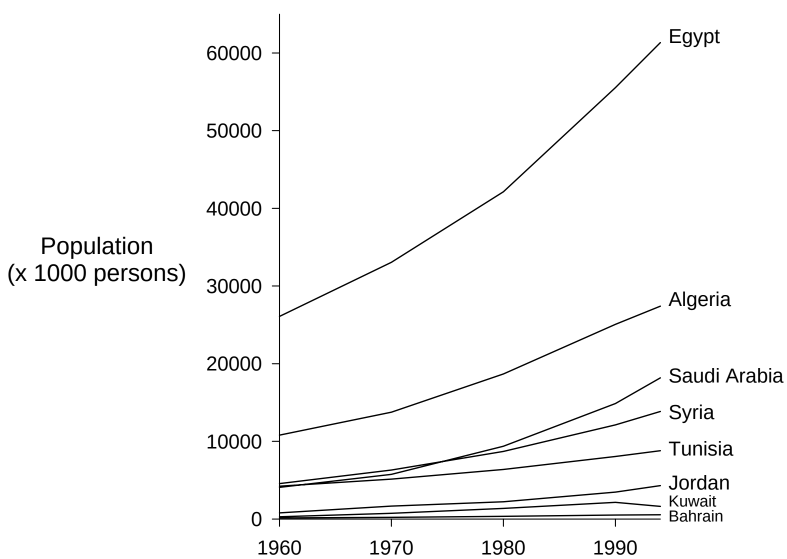

Figure 1 Population of select Arab countries as a function of time.

indigenous populations over the last two generations, which are considered to be among the highest worldwide.

The vast majority of the Middle East population is Muslim (primarily Sunni), but there are numerous other religious groups, including Christians, Alawis (concentrated in Turkey and Syria), Jews (almost all in Israel), and Druze (present in Syria, Lebanon, Israel, and Jordan). The most prominent ethnic group in the Middle East are the Arabs, representing about half of the total population of the region (including Iran and Turkey, but not including North Africa). Among the remainder, 25% are Turks, 12% Persians, 7% Kurds, 2% Jews, and 4% an amalgam of smaller ethnic groups, such as Armenians and Baluch (Omran and Roudi 1993; Weeks 1988).

This chapter is explicitly concerned with population growth in the Arab Middle East. Demographic trends and their socioeconomic implications among the Arab populations of Israel, the West Bank, and the Gaza Strip will not be taken up here. It is nonetheless important to note population growth patterns in Israel. According to official Israeli figures, by 1996 the total population of Israel (excluding the Palestinian population of the West Bank and Gaza Strip but including its Jewish Israeli residents) was 5.76 million, among which 4.64 million were Jews and 1.12 million were Arab and others, as compared with 3.9 million and 875,100, respectively, in 1990. The growth of the Jewish population in Israel during this period is centrally a result of large-scale migration from the former Soviet Union and Ethiopia, amounting to nearly 600,000 Jewish immigrants to Israel between 1990 and 1996, whereas the growth of the Arab and other populations is more attributable to natural growth (Israel, *Statistical Abstract–1997*).

The objectives of this paper are threefold: first, to examine the causes and effects of high natural increase rates in the Arab Middle East; second, to investigate government policy in reaction to the demographic changes in the region; and third, to analyze demographic projections for the future and their socioeconomic implications.

REGIONAL BACKGROUND AND THE NATURAL INCREASE OF THE MIDDLE EAST POPULATION

Crude birth rates, which were very high at the beginning of recorded history (about 45 per 1,000 inhabitants), remained so through the 1970s. In 1980, the crude birth rate was 38 in Egypt, 46 in Syria and Saudi Arabia, and 47 in Jordan. Only in the last decade has there been evidence of a reduction in crude birth rates. In 1994, the crude birth rate was estimated to be 29 in Egypt, 33 in Jordan, and 26 in Tunisia. However, in some countries in the region, even during the first half of the 1990s, fertility rates have continued to be very high, mainly in the oil-exporting countries of the Persian Gulf, as a result of the pro-natalist policies adopted by the regional regimes. However, even in these countries, there was some reduction in fertility levels during the past decade due to drastic improvement in the education of women as well as increases in their labor force participation (see Figure 2).

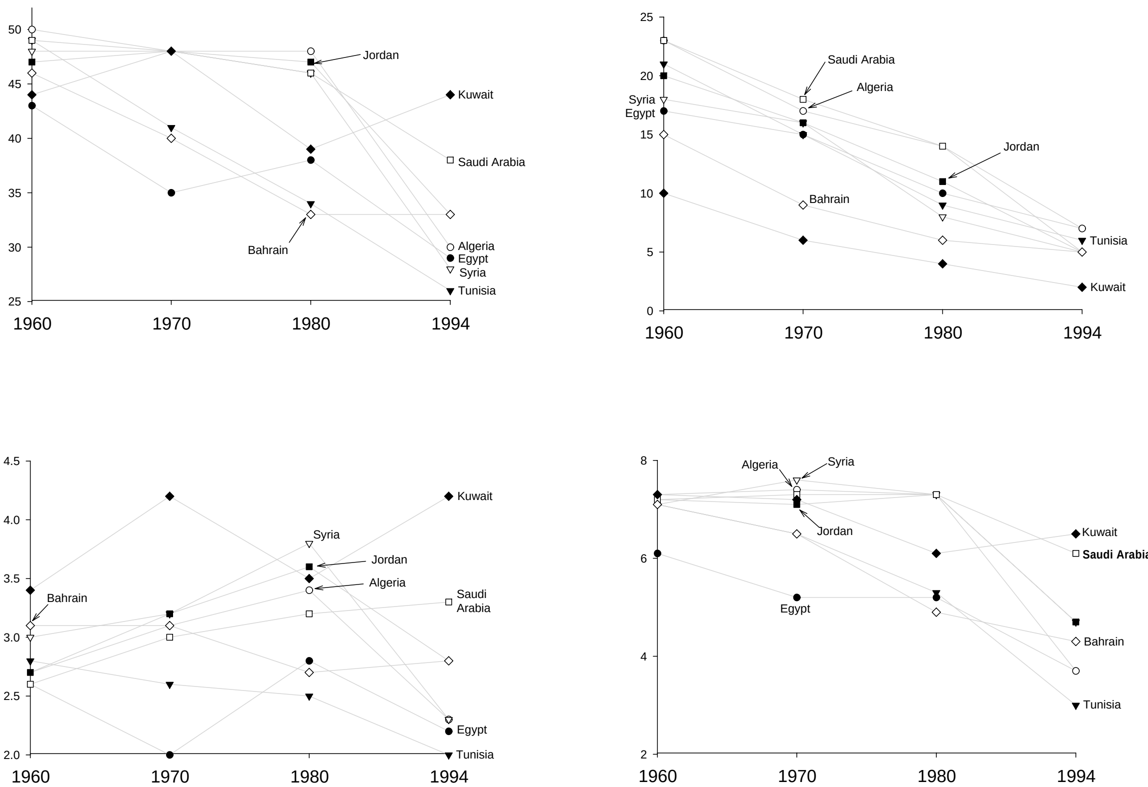

Figure 2 Crude birth rate, crude death rate, net population increase and total fertility rate for selected Arab countries as a function of time.

By 1995, according to UNICEF, the average crude birth rate in the Middle East and North Africa region was 33 per 1,000, as compared with 48 in 1960 (UNICEF *1997*). Crude death rates, which were very high in the 18th century (about 42-44 per 1,000 inhabitants), began to decrease during the 19th century, especially from the 1850s onward, dropping to approximately 33 by the end of the 19th century. During the 20th century, crude death rates declined even more rapidly, dropping by 1995 to 7 per 1,000, as compared with 21 in 1960 (UNICEF 1997).

There are several reasons for the marked reduction in crude death rates in the Middle East over the last two centuries. Initially,

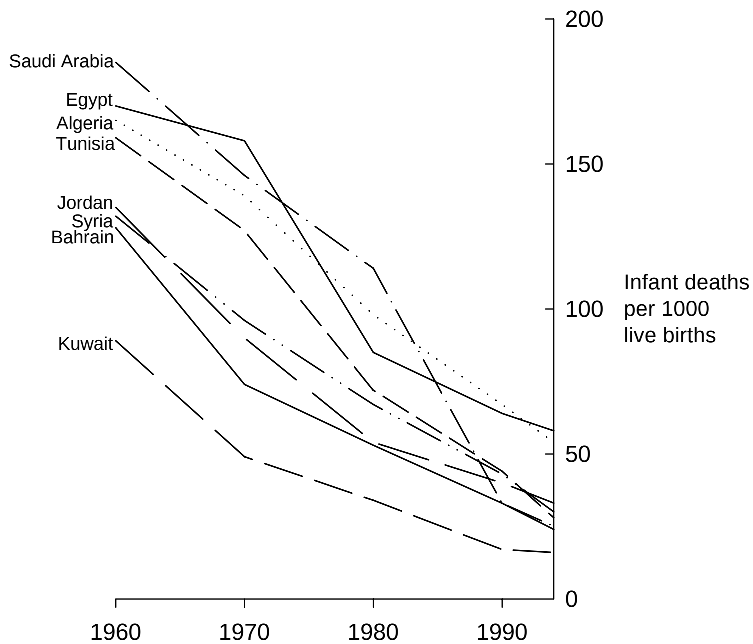

Figure 3 Infant mortality in select Arab countries as a function of time.

the decrease was a result of the elimination of starvation and epidemics. At the end of the 19th century and throughout the 20th century, the further reduction is attributed primarily to improvements in medical care, both in quantity and quality. During the second half of the 20th century, the rise in the standard of living has also been responsible (Gilbar 1990).

The result of this increasing gap between crude birth and death rates has been the growth in natural population increase throughout the Arab Middle East.The average natural increase rate in the region tripled from 1% to 3% in some countries over the course of the current century. By 1995, the natural increase rate in the Middle East and North Africa region generally was 2.6%, resulting in a net population increase of 9 million annually and a doubling of the population every 26.6 years (see Table 1).

This general trend has prevailed in most developing countries globally during the last two generations. However, while in most of the other developing areas the crude birth and fertility rates started to decrease during the late 1960s and early 1970s, in many Middle Eastern countries high crude birth and fertility rates have continued even into the 1990s. The "demographic revolution" of the Middle East was, more than anything else, a revolution in crude death rates.

The drop in crude death rates in the region has been in part a function of marked reductions in infant (0-1) and child (1-5)

Table 1 Relation between relative change per year and doubling time. Source: Joel E. Cohen, *How many people can the Earth support?*, Norton: New York, 1995. p.27.

Relative change per year (%)	Estimated doubling time (y)
0.1	693.0
0.5	138.6
1.0	69.3
1.5	46.2
2.0	34.7
2.5	27.7
3.0	23.1
4.0	17.3

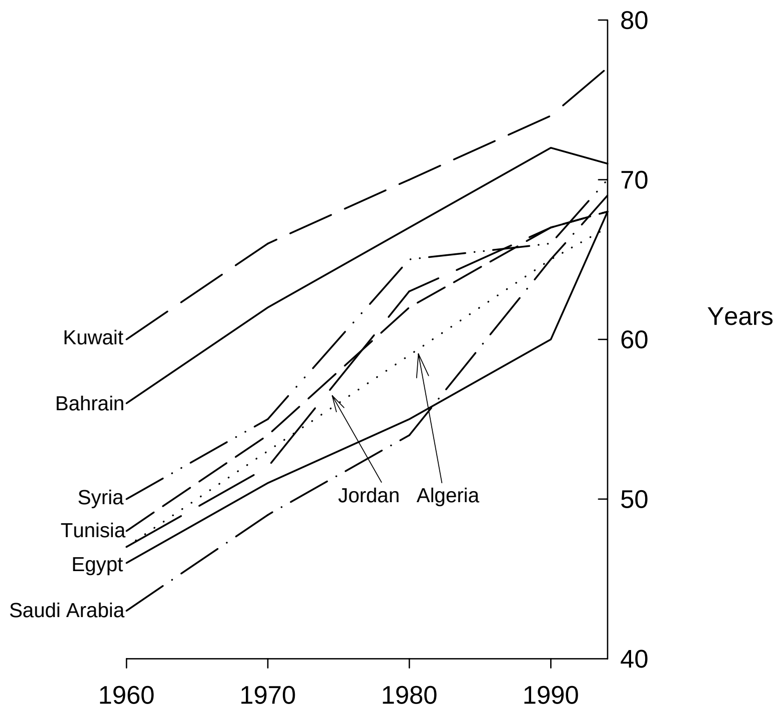

Figure 4 Life Expectancy in Selected Arab Countries in the Middle East, 1960-1994.

mortality rates. Average infant mortality rates in most of the Middle East dropped from 170-230 per 1,000 live births (U.N. ESCWA 1988), during the 1950s to 158 in Egypt, 96 in Syria, 90 in Jordan, 146 in Saudi Arabia, and only 49 in Kuwait in 1970. During the 1970s and the 1980s, this trend continued, particularly among the oil-exporting countries of the Persian/Arabian Gulf. By 1994, the infant mortality rate was estimated to be only 25 in Saudi Arabia,16 in Kuwait, and 24 in Bahrain. The other Arab countries of the Middle East also reached relatively low rates of infant mortality, including 30 in Syria and 33 in Jordan in 1994 (see Figure 3). Similarly, the under-five mortality rate also fell very sharply.The average under-five mortality rate in the Middle East and North Africa region dropped from 244 per 1,000 live births in 1960 to 64 per 1,000 live births in 1995 (UNICEF 1997). A second factor contributing to the crude death rate decline has been a dramatic increase in the life expectancy, also attributable to advances in medical care and general improvements in the standard of living. In Egypt, life expectancy increased from 46 years in 1960 to 68 years in 1994 and in Syria, from 50 in 1960 to 70 in 1994. In the Gulf, the increase in the average life expectancy was even more marked than in the other Middle Eastern countries (see Figure 4; see also Hill 1981).

ECONOMIC CONSEQUENCES OF HIGH RATES OF NATURAL INCREASE IN THE "OVERPOPULATED" COUNTRIES OF THE MIDDLE EAST

Many of the Middle Eastern countries are "overpopulated," which is to say that the ratio between the population and the available resources is so high as to limit economic development. For example: although the total population in Saudi Arabia is almost four times higher than Jordan's, Saudi Arabia is not deemed "overpopulated" because of its vast oil resources. Jordan, lacking substantial natural and economic resources, is considered overpopulated.

The most important consequence of the high natural increase rates among the Arab population of the Middle East during the last two generations has been the creation of a wide base of the age pyramid. In 1960, 51% of the total population was below the age of 15 in Egypt (Egypt, *Statistical Yearbook*, *1952-96*), and 46% in Syria (U.N., *Demographic Yearbook-1970*), 46% in Jordan (ESCWA 1992). A quarter century later, those percentages grew to 51% in Egypt in 1986 (Egypt, *Statistical Yearbook-1952-96*), and 49% in Syria in 1990 (Syria, *Statistical Abstract-1990*), 49% in Saudi Arabia in 1992 (ESCWA 1993), and 48% in Kuwait in 1988 (ESCWA 1992). In the developed West and Far East, such percentages are typically at least a factor of two lower, with only 20% of the population in France below the age of 15 in 1990, for example. (U.N. *Demographic Yearbook-1990*).

The high percentage of the young in the developing countries has led to very low crude economic activity rates, due to the relatively low percentages of the working age (15-64) population within the total population and the tendency of women not to work outside the home. The percentage was 28% in Egypt in 1986 (ILO, *Yearbook of Labour Statistics-1992*), 24% in Jordan in 1991 (ILO, *Yearbook of Labour Statistics-1994*:) and 18% in Kuwait in 1985 (Looney 1994). Again, in developed countries, such rates tend to be a factor of two higher, as the result of both larger percentages of the population in the working age group and high percentages of working women. In 1993, the economic activity rate was 53% in Japan, 50% in Hong Kong, and 49% in the United Kingdom (ILO, *Yearbook of Labour Statistics-1994*). Thus, the ratio between breadwinners and those being supported is 1:2 in the developed countries, as compared with 1: 4 or even 1: 4.5 in most countries of the Arab Middle East.

Children and teenagers are large consumers of public services, such as health care and education, while their productive contribution is marginal. In many countries of the Arab Middle East, where public services are largely free of charge, or are heavily subsidized, the high percentage of the young people has far-reaching consequences and a substantial negative impact on economic growth, particularly in the non-oil-exporting countries.

An additional problem of high population growth rates has been that growth in the labor force has outpaced economic growth and the creation of new work opportunities, causing an increase in unemployment and underemployment. In Egypt, for example, during the second half of the 1980s, approximately 400,000 people were entering the labor force every year (Egypt, *Statistical Yearbook-1952-92*), of whom 292,000 were graduates of universities and colleges (*al-Ahram*, April 12, 1990). Since it was beyond the capacity of the Egyptian economy to create hundreds of thousands of new work opportunities on an annual basis, unemployment rates increased very rapidly during the 1970s and 1980s, despite large scale migration of Egyptian workers to the oil-exporting countries of the Gulf and Libya after the "oil boom" of October 1973. The Egyptian unemployed numbered approximately 175,000 in 1960 but swelled to one million in 1982 and reached as high as two million in 1988 – an unemployment rate of some 15% in that particular year (*al-Musawwar*, June 30, 1989).

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In order to mitigate these high unemployment rates, Egyptian authorities increased available work opportunities by absorbing large numbers of employees into the governmental bureaucracy, service sectors, and other publicly-owned companies. Subsequent reductions in unemployment were not sustained over the long term and inefficiency within governmental services in the long run increased substantially.

Such unemployment and underemployment patterns are not unique to Egypt, but prevail in other Middle Eastern and North African countries as well. During the late 1980s, official figures placed the Tunisian unemployment rate at 14% in 1989, but unofficial estimates were substantially higher (25%), and higher still (40%) for the youngest working age population category (18-26) (EIU, *Country Profile-Tunisia, 1989/90*). In Algeria, unemployment grew from approximately 16% in 1984 to almost 23% in 1989 (EIU, *Country Profile-Algeria, 1991/92*).

In Jordan, during the 1970s and the early 1980s, the unemployment rates were among the lowest in the entire Arab Middle East. By the mid-1970s, Jordan had obtained almost full employment for its citizens, and in 1976 the unemployment rate in the Kingdom was less than 2% (Hammouda 1980) – an unusual statistic for a non-oil exporting country at the time. The central explanation for this phenomemon was the migration of hundreds of thousands of Jordanian workers to the Gulf, mainly to Kuwait and Saudi Arabia. This massive labor force export actually caused a manpower shortage in

Jordan, bringing about a counter-migration to Jordan primarily from Egypt and Syria (Winckler 1997).

However, as a result of King Hussein of Jordan's support of Iraq during the Gulf War of 1990-91, about 350,000 Jordanians and Palestinians returned to Jordan, mainly from Kuwait (*MEED,* August 14, 1992). The Jordanian labor market consequently changed dramatically, and by October 1991, the official unemployment rate rose to approximately 23%,with unofficial estimates placing the statistic closer to 35% (*Jordan Times,* October 14, 1991). This placed Jordan among the countries with the highest unemployment rates in the region.

An additional negative consequence of the rapid population growth patterns has been increasing pressure on natural resources, with the most obvious being a steady decline in the relationship between population, on the one hand, and water and cultivable lands, on the other hand. In Egypt, for example, cropped area per capita decreased by more than 40% during the years 1952-88 (Winckler 1992). A similar trend is also seen in Syria, where the cropped area per capita dropped during the years 1960-94, despite a nearly 40% increase in total cultivated area, as a result of a massive population growth over that period (Syria, S*tatistical Abstracts-1960, 1995*). Similar trends are also evident in Jordan and in most of the other countries in the region.

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Today, in Jordan (as in the West Bank, Gaza, and Israel), the demand for water already far exceeds the supply, and the gap is widening steadily. According to the Water Authority of Jordan, total annual water demand in the Kingdom was 900 MCM but total annual supply was roughly 550 MCM in 1990. By the year 2000, annual water demand in the Kingdom is projected to rise to 1,600 MCM, but supply is unlikely to surpass 700 MCM (*MEED,* May 28, 1993). In Egypt, the steep increase of water allocations for domestic use in parallel to the rapid population growth has caused a steady reduction in the water available for agriculture, while in other parts of the region, water continues to be devoted to irrigation with municipal consumers experiencing increasing shortages and higher prices. In general, however, water for municipal consumption has led to a growing food gap all over the Middle East, a region that was a net agricultural exporter until the beginning of the 1950s. (See Allan, Shamir, Elmusa, this volume).

Egypt, which was a net agricultural exporter only two generations ago, has become one of the largest food importers worldwide. By the end of the 1980s, total food imports to Egypt amounted to $4 billion and constituted one of the major factors responsible for the large deficit in the Egyptian balance of trade, which was $7.5 billion

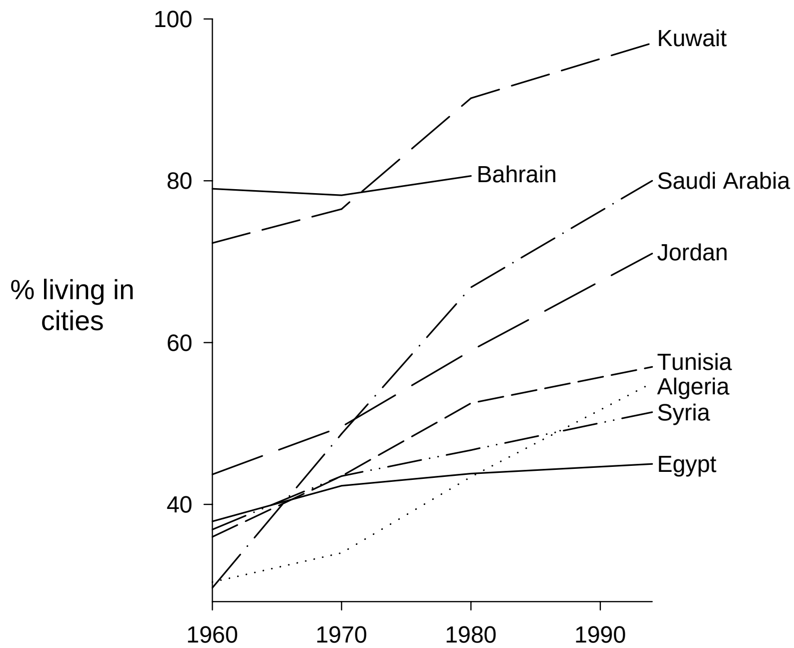

Figure 4

in the 1988/89 fiscal year (*MEED,* June 8, 1990). Jordan also became a net food importer as a result of rapid population growth and the increasing shortage of water for agricultural purposes. By 1987, net food imports to Jordan amounted to $359.5 million and increased to $487 million in 1991 (EIU, *Country Profile-Jordan, 1993/94*). Similar trends are apparent in Algeria, where the rate of cereal imports increased from 29% of total domestic cereal consumption during the years 1970-73 to 65% on average during the years 1979-82, staying at that level throughout the 1980s (EIU, *Country Profile-Algeria, 1991/92*; ESCWA and FAO 1993).

Urbanization in many developing countries began around the 1940s. While in the industrialized countries the "pull" factor (toward the cities and their economic opportunities) dominated, in developing countries the "push" factor (away from rural areas and their poverty) was responsible for the massive rural-to-urban shift.

Urbanization in many developing countries began around the 1940s. While in the industrialized countries the "pull" factor (toward the cities and their economic opportunities) dominated, in developing countries the "push" factor (away from rural areas and their poverty) was responsible for the massive rural-to-urban shift. In addition, while in the industrialized countries the urbanization process was gradual and continuous over more than a century and half, in developing countries (including those of the Middle East) it has been a very rapid process, occurring over less than two generations (Saad Eddin 1974, 1985; see Figure 4). The rate of urbanization in the Middle East has risen faster over recent decades than in any other region in the world, and is likely to continue in the coming decade as well. The Middle East's urban population rose from 28% in 1950 to 47% in 1980, and is likely to reach almost 60% by the year 2000 (Symarsky 1988).

As a result of this rapid urbanization, the larger cities in the region have been forced to absorb a large number of the rural migrants and have experienced a doubling of the urbanized area in a process of relatively uncontrolled sprawl. Urban expansion has far outpaced the capacity of governments to adequately integrate and service these new areas. Throughout the overpopulated Middle Eastern countries, there is a chronic shortage of housing, which has led to rising housing prices in the major Middle Eastern cities. This shortage has also brought about an increase in the construction of informal dwelling units, the most well-known of which is "the City of the Dead," the old cemeteries of Cairo.

Moreover, since the major cities in the Middle East are located near central water sources, their expansion has been at the expense of the cultivated lands. This phenomenon is particularly apparent in Cairo, where many villages have been swallowed by urban sprawl. Due to urban expansion, the total cultivated area of Egypt did not grow between 1952 and the mid-1980s, despite the construction of the High Dam in Aswan and massive projects to expand cultivated area (*The Egyptian Gazette,* May 10, 1985). Similar trends are apparent in Syria and Jordan.

FERTILITY POLICIES AMONG THE ARAB COUNTRIES OF THE MIDDLE EAST

Generally speaking, it can be said that all Middle Eastern countries are trying to influence the level of the crude birth and fertility rates of their citizens. However, the motivations for intervention differ. In general, the Arab countries of the Middle East can be divided into three main groups according to their reproductive policies during the second half of the 20th century.

The first group, comprised of Egypt, Tunisia, and Morocco, has put national family planning programs into effect as a result of the acute intensity of the resource pressures resulting from the overpopulation syndrome (Gilbar 1997).

The second group, consisting of Syria and Jordan, does not suffer from pressures as acute as those in the first group. While the Syrian and Jordanian governments do consider the high fertility rates an obstacle to socioeconomic development, neither has a declared family planning policy. The authorities of these countries are attempting to bring about reductions in population growth through indirect means, particularly via improvements in women's education and employment opportunities.

The third group includes countries whose governments are attempting to increase, or at least preserve, their current high fertility rates. This group is made up of the oil-exporting countries of the Gulf. The small national populations of these countries relative to their political aspirations and economic needs have led their governments to adopt pro-natalist policies following the "oil boom" of October 1973. Their purpose has been to rapidly increase the number of nationals so as to reduce the proportion of foreigners in the short run and to diminish labor scarcity and foreign worker demand in the long run.

DECLARED ANTI-NATALIST POLICIES: THE EXAMPLES OF EGYPT AND TUNISIA

In the late 1940s and early 1950s, many leaders in developing countries, including those in the Middle East, saw a blessing in rapid population growth and made no attempt to limit it. Instead, they adopted pro-natalist policies based on the idea that a large nation is a strong nation (Baer 1973).

However, during the late 1950s and into the 1960s, leaders in these same countries awakened to the link between rapid population growth and the socioeconomic problems which had begun to surface, and understood that their only solution was the reduction of the natural increase rates of their population (Symonds and Carder 1973).

The Free Officers in Egypt became aware of the population problem in their country shortly after the July 1952 revolution. They thought, however, that widespread socioeconomic development would gradually bring about a decline in fertility levels without direct intervention, particularly as a result of the education of women and improvements in living standards. The results of the 1960 census proved the approach to be a misguided one, indicating only that most of the economic development that had been achieved until that point was likely to be counterbalanced by the burden of supporting the exploding population. In any case, it was only in 1966 that the Egyptian government established the Higher Council for Family Planning, and in August of that year it was announced that 2,850 family planning clinics were operating throughout the country.

The Egyptian authorities adopted the "direct-supply" approach to family planning, which was the common approach among international organizations active in the field at the time. The theory was that the population was anxious to reduce its fertility rate but lacked the contraceptive methods needed to do so. By providing birth control along with instructions for its use, the aim of fertility reduction would be achieved. A similar approach was adopted by Tunisia, which was

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However, during the 1970s, and especially following the 1974 World Population Conference in Bucharest, this approach was changed to emphasize not only the availability of contraception but also the likelihood of its use. The governments of the participating nations decided that in order to increase the rate of contraceptive use, they would have to affect changes in traditional social norms, and that family planning objectives could only be achieved in the context of broader socioeconomic development plans.

In accordance with the new strategy, Egypt adopted a new family planning policy in 1973. Its aims were to bring about a substantial reduction in crude birth rates by (1) raising the educational level of the entire population, though particularly among women; (2) increasing employment opportunities for women so as to boost the rate of labor force participation; (3) enhancing agricultural mechanization in order to diminish the need for children as cheap labor; (4) increasing industrialization; (5) reducing infant mortality; (6) strengthening social security; and (7) improving family planning services (Gallagher 1981; Stycos *et al.* 1982).

The Tunisian government altered its reproductive policy in a similar fashion in the mid-1970s, folding family planning into the framework of comprehensive socioeconomic development initiatives aimed mainly at improving the status of women (Stubbs 1980; U.N., Department of International Economic and Social Affairs 1990; International Planned Parenthood Federation-Middle East and North Africa Region 1981; and Hill 1976). In 1987, the Tunisians added economic incentives, issuing allowances to employees supporting families with no more than four children and with amounts decreasing with the addition of each newborn. A year later, the allowances were limited to families with three children (Faour 1989; U.N., Department of International Economic and Social Affairs 1990).

Increasingly, the mass media have been utilized in Egypt to promote the lowering of fertility levels. During the past two decades, numerous articles by well-known journalists have highlighted the issue, and direct appeals by political leaders have appeared in the newspapers to increase public awareness. At the same time, the Egyptian government is actively expanding the network of family planning services, and making considerable effort to obtain the support of prominent religious leaders. Confirmation by the religious leaders that family planning does not contradict the tenets of Islam is considered by all an essential requirement for the success of national family planning programs (Gilbar 1997). Indeed, *fatwas* (religious decrees) and interviews with religious leaders have appeared in the Egyptian newspapers on a regular basis (see, for example, *al-Ahram,* February 7, October 22, 1989; April 20, 1990).

UNDECLARED ANTI-NATALIST POLICIES: THE EXAMPLES OF SYRIA AND JORDAN

While the countries included in the first group started to take anti-natalist steps from the mid-1960s onward, the countries in the second group initiated undeclared anti-natalist measures much later, in the mid-1970s in the case of Syria and only in the early 1980s in the case of Jordan.

Until the mid-1970s, the Syrian government did not advocate a family planning policy; instead, it strove to increase fertility rates by providing financial benefits to large families and forbidding the promotion, distribution, or use of birth control methods (Habbab 1974), largely out of the conviction that the Syrian population was small in comparison with the economic needs and political aspirations of the country.

However, at the beginning of the 1970s, especially after the results of the 1970 census became known, the attitude of the Syrian authorities toward family planning and the rate of population growth began to change. This was primarily due to the emergence of social and economic problems whose origin lay in the high birth and fertility rates, including a reduced rate of labor force participation, an increase in public spending on food subsidies and imports, and growth in costs for subsidized health care and education (Syria, CBS, 1973).

The change in the Syrian approach was gradual and did not lead initially to an overall national family planning policy. In 1974, the Family Branch of the Ministry of Health was established in order to coordinate activities in reproductive policy within the framework of the mother and child clinics that had been operating in Syria since the 1950s. In February of 1974, the Syrian Family Planning Association, headed by the Minister of Health, was established with the objectives of (1) improving health care for both mothers and children; (2) supplying contraceptives and providing training on their proper use; and (3) conducting research in the area of family planning and other demographic subfields (Habbab 1974; *al-Ba'th* April 28, 1974; ESCWA 1992; Population Division of the UN and UNFPA 1980).

During this period, the Syrian authorities consistently stressed the close connection between family planning activities and the health of mothers and children, as well as the socioeconomic condition of the family. The change in the authorities' attitude towards family planning was also reflected in the Syrian mass media, which is under strict governmental control. Since the late 1970s and the early 1980s, the Syrian press has published reports and articles about the rapid population growth and its socioeconomic consequences not only on the national level, but also on the individual family level, thus underlining the need to implement family planning measures (see, for example, *Tishrin,* August 23, September 6, and October 20-21, 1982; December 7, 1983; January 22, 1984; and October 30, 1985).

A turning point occured in 1987 in the natalist policy of the Syrian government. The subsidies given to large families were cancelled, and the Ministry of Health began to appeal directly through the mass media to young families to adopt family planning practices. At the same time, the range of activities of the Family Planning Association was expanded (ESCWA 1992) and conferences on demographic issues and family planning were convened with increasing frequency (Zisser 1994). As in Egypt, endorsements of official religious figures were sought (*Tishrin,* April 10, 1994).

Among the Arab countries of the Middle East, Jordan was one of the latest to take anti-natalist steps, beginning only in the early 1980s. This is surprising, since demographic pressures are considerably greater in Jordan than in Syria, for example, which began its anti-natalist agenda at least a decade earlier.

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The marked decline in oil prices in 1986-87 caused not only a massive reduction in workers' remittances (which until then had constituted the main source of foreign exchange in the Kingdom) but also a sharp decrease in foreign aid from the wealthy Arab oil-exporting countries. This caused experts in the areas of demography and economics to advocate a reduction in fertility rates by adopting open population policies in order to maintain the high rates of economic growth (*Jordan Times,* June 18, 1992; May 5, 1993).

The return of 350,000 Jordanians and Palestinians from the Gulf states at the end of 1990 and the first half of 1991, which created even greater pressures on employment, housing, and public services, sparked an acceleration of family planning measures instituted earlier. However, as in Syria, most of these steps were indirect and concentrated mainly in the improvement in women's educational and expansion of women's employment opportunities outside the home. In addition, the Jordanian government began subsidizing the Jordanian Family Planning Association and established family planning services in public clinics and hospitals (Warren *et al,* 1990; Badran 1992). However, in contrast to the clinics in Egypt, those in Jordan did not actively encourage the use of contraceptives, but rather provided information and guidance only to individuals requesting assistance with family planning.

Finally, the explicit statements of political leaders promoting family planning, such as those offered by President Mubarak in Egypt, are effectively absent in Syria and Jordan.

PRO-NATALIST POLICIES: THE EXAMPLE OF THE GULF STATES

Since the early 1970s, measures have been taken by the Gulf oil-exporting countries whose aim is to increase fertility rates among their national populations.

The strictest policy, adopted by the Saudi government partly as a result of the disappointingly small numbers of Saudi nationals reported in the 1974 population census, was that contraceptives were pronounced to be contrary to the teaching of Islam, and their import was banned in the spring of 1975 (Hill 1976; Allman 1978; ESCWA 1992).

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Another measure was government-initiated housing development. In all of the Gulf oil-exporting countries, albeit with some local differences, governments began to sell housing at-cost, provided plots of land for building, and offered long-term loans for housing at very low interest (Al-Najjar 1993). The Qatari government, for example, built housing projects whose buyers were required to pay back only 60% of the cost over a period of 20-25 years (Nafi 1983).

The encouragement of early marriage is a measure that has come to be accepted as the norm among the Gulf oil-exporting countries. Since the beginning of the 1980s, the Kuwaiti government has granted a marriage allowance of 2,000 Kuwaiti Dinar (KD) to nationals marrying for the first time, with an additional 1,000 KD offered as a soft loan. This allowance was designed to compensate men for the expenses incurred by the custom of *mahr* (bride's gift), which the groom is expected to offer to the bride's father (U.N. Department of International Economic and Social Affairs 1988a; ESCWA 1992).

Despite the severe damage to the Kuwaiti economy as a result of the Iraqi invasion, a substantial increase in the marriage grant to Kuwaiti nationals was approved by the Council of Ministers at the beginning of 1992. According to this decision, eligible Kuwaiti males were entitled to receive $14,000 (half as a grant and half as a loan) for their marriage to Kuwaiti women, amounting to twice the previous sum. The reason for the increase, according to the Kuwaiti Minister of Finance, was "to encourage Kuwaiti youths to marry"(*Gulf States Newsletter,* April 6, 1992). The Saudi authorities adopted a similar policy in 1982 (UN, Department of International Economic and Social Affairs 1990).

Although the full subsidies provided for education (including books, clothing, etc.) from the first grade through the university level, is generally considered to be admirable social policy, it nonetheless constitutes an implicit incentive to produce larger families.

EVALUATION OF THE FAMILY PLANNING PROGRAMS

The aforementioned pro-natalist measures were, without a doubt, effective in increasing or at least maintaining fertility rates in the Gulf oil-exporting countries. During the last 25 years, the national populations of these countries have risen at among the highest rates in the world. By 1994, the total national populations of the GCC (Gulf Cooperation Council) countries numbered 16.3 million (ESCWA 1995a), as compared with barely than 6 million in 1975 (Winckler 1997).

The aforementioned pro-natalist measures were, without a doubt, effective in increasing and at least maintaining fertility rates in the Gulf oil-exporting countries. During the last 25 years, the national populations of these countries have risen at among the highest rates in the world.

In all of the countries implementing declared anti-natalist policies, there has been an impressive decline in the fertility rates, especially over the last 15 years. In Egypt, the crude birth rate decreased from 43 per 1,000 in 1960 to 29 in 1994, and in Tunisia, from 49 to 26 during the same period. In the countries which operate undeclared anti-natalist policies, there has also been a substantial reduction in the fertility rates. In Jordan, for example, crude birth rates dropped from 47 in 1960 to 33 in 1994 (see Figure 2).

Two main factors contributed to the reduction in the crude birth and fertility rates in the anti-natalist countries during recent years. The first and most important has been a massive increase in the rates of contraceptive use. In Egypt, the rate of contraceptive use among married women increased from 23.8% in 1980 to 47.6% in 1991 (Yehia 1994). In Jordan, the increase was from 22.8% in 1976 to 26.0% in 1983 (Jordan 1984), and 40.0% in 1990 (Jordan 1992; ESCWA 1994). The rate of contraceptive use in Syria also increased significantly, from 20% in 1978 (SAR 1982) to almost 40% in 1993 (Syria and PAPCD 1995).

The second factor was a significant rise in the mean age at first marriage among females, both in the countries operating anti-natalist policies, as well as in those advocating pro-natalist policies. This delay in the mean age at first marriage served to slow down reproduction and thus constituted a major factor in the reduction of fertility levels. In Jordan, for example, the mean age of first marriage for females increased from 20.1 years in 1961 to 24.5 years in 1992, and in Egypt from 20.2 years in 1960 to 22.6 years in 1991 (ESCWA 1994).

In the oil-exporting countries, the increase in the average age of first marriage was counteracted by the economic incentives of the pro-natalist policies in terms of the effect on reproduction within the marriage system. Thus, only relatively small reductions were made in the fertility rates, which remained very high as compared with those in the countries actively operating anti-natalist policies. By 1994, the crude birth rate among Saudi nationals was 38 per 1,000 inhabitants and 44 in Kuwait, while in Egypt and Tunisia, the rates were only 29 and 26 (see Figure 2).

SUMMARY, CONCLUSIONS, AND PROJECTIONS

Today, rapid population growth appears to constitute the most critical socioeconomic problem in the Arab Middle East. Nearly two generations of high natural increase rates have created a wide base of the age pyramid, and in most countries half of the national populations are under the age of 18, making them consumers but not producers. The wide base of the age pyramid, which also accounts for the low crude death rates, will be responsible for further high natural increase rates in the future, in spite of the decline in the fertility rates, at least in the next two decades.

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In spite of the relative success of the family planning programs in the Middle East during the last 15 years and the sharp reduction in the crude birth and fertility rates, the population growth rates in all of the countries in the region remain high. In Egypt, for example, despite the substantial decline in the natural increase rates, the net annual population growth at the mid-1990s was about 1.2-1.3 million. This increase is almost the same as it was a decade ago, in the mid-1980s, when the natural increase rate was 3%, simply because the total population has increased by 14 million during that period. The situation is common to the rest of the countries in the Middle East and North Africa region.

Rapid population growth is likely to continue throughout the region. According to World Bank projections, the Egyptian population will continue to increase rapidly, at least in the first half of the 21st century, and will reach 102.6 million by the year 2050. Likewise, the Algerian population at that time will be 58.6 million, and that of Syria almost 49 million (World Bank 1995).

The peculiar nature of the demographic problem, as compared with other socioeconomic problems, is that while it is possible to change economic policy within a period of only a few years, experience tells us that it generally takes at least two generations to alter reproductive behavior. Until changes take hold, governments of "overpopulated" countries must absorb and support their bulging populations with inadequate resources.

Since this process is irreversible, the governments of these countries have to plan the development of their economic infrastructure to support populations which will at least double in number. Is it possible for the Egyptian economy to support more than 100 million people, or for Jordan to support more than 10 million? The creation of a single job in Egypt costs about $5,000 (*al-Ahram al-Iqtisadi* March 12, 1990) and every year more than 400,000 additional people are joining the labor market.Therefore, Egypt needs to invest more than $2 billion annually just to create additional work opportunities without taking into consideration existing unemployment.

One of the major obstacles to reducing the fertility rates all over the Middle East has been a skewed set of economic incentives. Education at all levels, as well as health care and basic foodstuffs, are either provided entirely free of charge or are highly subsidized. These measures serve, in effect, as incentives for high fertility. Naturally, however, it is not advisable to terminate these social policies in these countries, thereby threatening the well-being of millions of citizens.

A key question is why the authorities of the overpopulated countries delayed the implementation of family planning programs for many years after they became aware of the population problem and its devastating consequences in their countries. Gamal Abd al-Nasser, for example, acknowledged the population problem in Egypt shortly after the July 1952 revolution. However, it took 13 years until the first Egyptian family planning program began operation. In addition, after the June 1967 war, the issue of the population problem was abandoned in favor of military buildup. President Mubarak began to devote greater resources and attention to the population issue only a decade ago. This means that during the better part of twenty years, the population problem in Egypt was almost totally neglected.

Egypt is only one example. Other governments in the region also delayed the implementation of family planning programs well after they became aware of the issue. In Syria, although overpopulation was recognized as problem in the mid-1970s, it took more than a decade until the financial benefits to large families were canceled.

It appears that the combination of two factors is to blame for the delay. The first was the sensitivity of family planning in traditional Islamic societies and the strong opposition of the Islamic fundamentalist movements to any anti-natalist measures. The movements claimed that the central reasons for economic hardship were not high natural increase rates but instead misguided leadership of the secular regimes. The Islamists argued that the establishment of religious regimes, in accordance with the Islamic *Shari'a*, would return the prosperity that they once enjoyed.

In an attempt to avoid direct confrontation with these movements, most of the regimes in the "overpopulated" countries delayed the implementation of family planning measures for as long as possible. However, the problem finally reached the point at which further denial of its consequences would constitute a greater threat to the continued stability of the current regimes, even in the short term, than a confrontation with the Islamic fundamentalist movements over the issue.

The second reason for the delay was the Arab-Israeli conflict, particularly in the cases of Egypt and Syria. The longstanding conflicts led the regimes of these countries to allocate scarce resources to military purposes, and away from socioeconomic problems (such as rapid population growth).

In the case of Syria, after the signing of the peace treaty between Egypt and Israel in 1979, and until the late 1980s, more than half of governmental expenditures went to the military, resulting in a reduction of more than 20% in the per capita GDP during the years 1981-89 (Kanovsky 1995).

Only the continued reduction of the fertility rates, combined with a shift in resources from military purposes to socioeconomic development, will bring about an easing of the population pressures in the Middle East. Indeed, this will prove to be one of the most critical variables in the prospects for Middle East peace.

SOURCES FOR FIGURES: World Bank, *World Tables*, 1984-93, various issues (Baltimore and London: The Johns Hopkins University Press); *World Development Report*, 1978-95, various issues (Oxford and New York: Oxford University Press); UN, *Demographic Yearbook*, 1970-95, various issues (New York: UN Publication); ECWA/ESCWA, *Demographic and Related Socio-Economic Data Sheets for Countries of the Economic and Social Commission for Western Asia*, 1978-93, various issues (Beirut, Baghdad, and Amman); *Statistical Abstract of the ECWA/ESCWA Region*, 1970-95, various issues (New York, Baghdad, and Amman); UNICEF, *The State of the World's Children*, 1984-97, various issues (Oxford and New York: Oxford University Press); UNDP, *Human Development Report* (Oxford and New York: Oxford University Press); Arab Republic of Egypt, CAPMAS, *Statistical Yearbook*, 1984-96, various issues (Cairo); The Hashemite Kingdom of Jordan, Department of Statistics, *Statistical Yearbook*, 1970-96, various issues (Amman); Syrian Arab Republic, Office of the Prime Minister, Central Bureau of Statistics, *Statistical Abstract*, 1960-95, various issues (Damascus); State of Bahrain, Central Statistical Organization, Directorate of Statistics, *Statistical Abstract*, 1967-92, various issues (Manama); State of Kuwait, Ministry of Planning, Central Statistical Office, *Annual Statistical Abstract*, 1966-94, various issues (Kuwait).

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Monitoring the Distribution, Use, and Regeneration of Natural Resources in Semi-arid Southwest Asia

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ABSTRACT
We describe a variety of satellite-derived datasets and their application to understanding changes in the landscape of southwest Asia, including regional climatology, natural vegetation, and the expansion and intensification of agricultural production. We demonstrate the effectiveness of several remote sensing tools in gauging environmental change in this semi-arid region as well as offering insights into the appropriate analysis of remotely sensed datasets.

INTRODUCTION

Agricultural and pastoral production in the semi-arid regions of southwest Asia has expanded rapidly over recent decades to meet the subsistence needs of one of the world's fastest growing populations and the demands of the international economy. This growth is constrained by great interannual variation in the amount and timing of rainfall, which restricts dependable farming to very limited areas. Development, nonetheless, has proceeded undeterred—defying climate through feats of hydrological engineering or betting against it by cultivating vast areas of agriculturally marginal land. These two processes, the intensification and extension of agricultural production, have been among the dominant forces shaping the modern environments of southwest Asia, but their spatial expression is complex. The many nations of this region differ widely in their climate and natural resources as well as in their development priorities, available capital, and access to technology. Everywhere, however, pressure on limited water, soil, and plant resources has increased, often nearing the point of exhaustion or international conflict. Growing concern about the natural resource base has led governments and independent groups across the region to initiate ambitious and costly conservation and management programs. Ultimately, the success of these efforts depends on the development of methods for efficient, quantitative measurement of the distribution, use, and regeneration of natural resources at a range of spatial scales.

Multispectral satellite data and techniques of image analysis offer a potentially powerful tool for understanding problems in the climatology, environmental history, and natural resource management of southwest Asia. Satellite data have been collected over southwest

Asia for the past twenty-five years and offer a virtually unexplored archive for analyzing regional environmental changes. During the next few years, a new generation of earth resource satellites will come on line, providing more frequent and more detailed measurements of the earth's surface than are yet possible. Southwest Asia is particularly well suited to satellite observation. There are few trees and, during much of the year, few clouds to obscure the land surface; the major vegetation cycles of the region (winter cereal farming, summer cash cropping, deciduous forest growth) occur out of phase, allowing them to be studied easily and independently of one another. On the other hand, the bright reflectance of the land surface and the high dust content of the atmosphere can often cause difficult technical problems in the detection of change over time and in the estimation of surface biophysical parameters.

Satellite sensors are best described as imaging spectrometers that measure the earth's reflectance or emission of electromagnetic radiation over small areas, or pixels, ranging in size from several meters to several kilometers. Most satellite sensors measure pixel reflectance or emission in multiple bands of the electromagnetic spectrum, so that each pixel is characterized by several different values. These values can be treated in one of two ways. First, pixel values or ratios among them can be assigned to the three primary colors and used to modulate their intensity so that they combine to produce for each pixel one color from a palette of millions. The result is a richly detailed, false color representation of the land surface that can reveal features, contrasts, and textures not apparent on aerial photographs. A second approach treats pixel values as discrete physical quantities that can be compared mathematically to each other and to known spectral characteristics of plants, soils, rocks, and other surface materials (Figure 1). In this way it is possible to produce rapid land-use and land-cover classifications and to estimate land surface properties such as vegetation density, temperature, and evapotranspiration, among others.

The most commonly used satellite-derived estimate of vegetation density is the normalized difference vegetation index (NDVI), which takes advantage of the strong reflectance of green vegetation in the near-infrared wavelengths and its relatively strong absorption of visible wavelengths (Tucker 1979). This index, calculated as the difference between infrared and visible reflectance divided by their sum, is a dimensionless quantity ranging in value from –1 to 1.

$$NDVI = (REF_{VIS} - REF_{NIR}) / (REF_{NIR} + REF_{VIS})$$

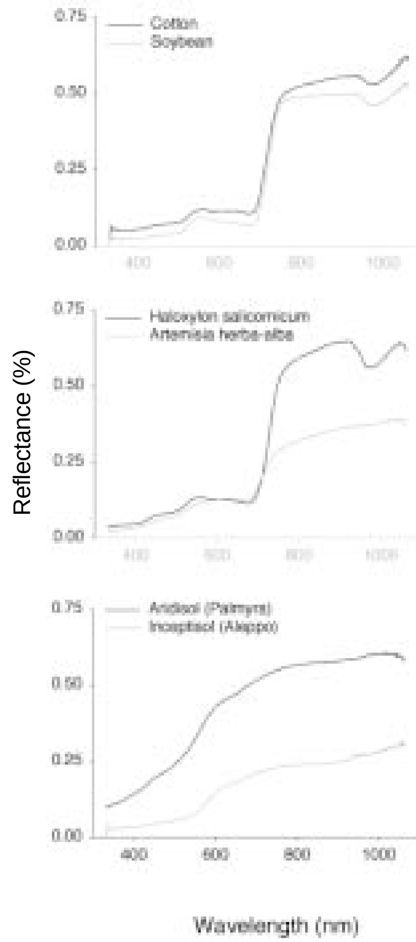

Figure 1 Reflectance spectra for common crop, shrub, and soil types in semi-arid southwest Asia.

Numerous studies have demonstrated strong positive correlation between NDVI and widely used surface measures of vegetation density such as biomass and leaf area index, though the precise nature of this relationship for a particular crop and region must be determined experimentally. Because it is a ratio of two reflectances, NDVI is particularly resistant to varying scene illumination and thus provides fairly consistent measurement fields across broken terrain. On the other hand, in very dense or multi-layered vegetation canopies, some vegetation may be obscured from direct view and hence not measured by the NDVI. In sparsely vegetated areas, bright soils tend to dominate the measured pixel reflectances, resulting in low signal-to-noise ratios. A number of alternative vegetation indices have been developed to minimize these problems, but their judicious use typically requires additional information about soil properties and other surface characteristics, complicating their application over large areas (Huete 1988; Qi *et al.* 1994). In general, NDVI is well suited for exploratory analysis of changing vegetation patterns in southwest Asia and is used extensively in the analyses that follow.

At present, multispectral data collected by existing satellite sensors are of two general types (Table 1). The first is coarse to moderate spatial resolution, high temporal frequency reflectance data collected within a limited number of spectral bands. The most common sensor of this type is the Advanced Very High Resolution Radiometer (AVHRR) carried on NOAA's meteorological satellites, which provides daily measurements of global reflectance and thermal emission in five spectral channels with a pixel size of 1 km. Another general type of satellite sensor provides high spatial resolution data in as many as seven spectral channels every 14–16 days. Sensors of this type include the widely used Landsat, SPOT, and IRS systems, which produce images with pixel sizes as small as 5-10 meters. New satellite systems are breaking down this dichotomy of data types, but successful application of satellite data to ecological problems has depended and will continue for some time to depend on the integration of different spatial and temporal scales of analysis as well as ground-level and satellite data. This paper presents ongoing research by the Southwest Asia Project at the Yale Center for Earth Observation on the application of satellite data to mesoscale climatology, environmental history, and resource management in southwest Asia.

Platform / Sensor	Spatial Resolution	Temporal Frequency	Period of Record	Spectral Channels	Spectral Range	Remarks / Sponsoring Agency
Earth Observing Satellites						
Landsat MSS	79 m	16-18 d	1972-1992	4	vis, n-IR	NASA/US Dept. of the Interior
Landsat TM	30 m	18 d	1984-present	7	vis, n-IR, m-IR, thermal-IR	NASA/US Dept. of the Interior
SPOT	10-20 m	3-26 d	1986-present	3	vis, n-IR, pan	France (CNES), Belgium, Sweden
IRS	6-70 m	22-24 d	1988-present	4	vis, n-IR	Republic of India/EOSAT
RESURS	160-600 m	4-21 d	1994-present	5	vis, n-IR, thermal-IR	Swedish Space Corporation
Imaging Radar Systems						
ERS-1/2	30 m	16-18 d	1991-present	2	C-band SAR, IR	European Space Agency
JERS-1	18 m	44 d	1992-present	8	L-band SAR, vis, n-IR, m-IR	Japanese Space Agency
RADARSAT	10-100 m	3-24 d	1996-present	1	C-band SAR	Canadian Space Agency
ALMAZ-1	10-30 m	5-11 d	1991-1992	1	S-band SAR	Russian Space Agency
SIR-A,B,C	12.5-25 m	variable	1981, 1984, 1994	3	C-, L-, X-band SAR	NASA/Jet Propulsion Laboratory
Pathfinder Satellites						
GOES	8 km	0.5 hr	1978-present	3+	vis, thermal IR, +	NASA/NOAA Pathfinder Project
AVHRR	1.1-8 km	daily	1981-present	5	vis, n-IR, thermal IR	NASA/NOAA Pathfinder Project
SSM/I	12.5-25.5 km	daily/nightly	1987-present	7	passive microwave	NASA/NOAA Pathfinder Project
EOS Era Satellites						
ETM+	30 m	16 d	1998-	8	vis, n-IR, m-IR, thermal IR, pan	NASA/Goddard Space Flight Center
MODIS	250 m-1 km	1-2 d	1998-	36	vis, n-IR, m-IR, thermal IR	NASA/Goddard Space Flight Center
ASTER	15- 90 m	5-16 d	1998-	14	vis, n-IR, m-IR, thermal IR	Japan, Ministry of International Trade
MISR	275 m-1.1 km	9 d	1998-	4	vis, n-IR@9 viewing angles	NASA/Jet Propulsion Laboratory
MIMR	6-70 m	daily	2000-	20	passive microwave	European Space Agency
Photographic Images						
CORONA	variable	variable	1957-1972	1	panchromatic	US Dept of the Interior
SSEOP	variable	variable	1981-present	2	pan, n-IR	NASA Space Shuttle Program

MESOSCALE CLIMATE, HYDROLOGY, AND VEGETATION OF SOUTHWEST ASIA

One objective of the Southwest Asia Project is to understand the relationships among climate, water resources, and the distribution of vegetation across southwest Asia. There are two unique aspects of our work in this area. First, we carry out geographical analysis on a rather small spatial scale (i.e. the mesoscale) using a grid spacing of five kilometers. The advantage of mesoscale analysis is that it captures many of the significant natural patterns and human induced features of the landscape, including meteorological phenomena and terrain variations. Examples of mesoscale landscape features are mountains, coastlines, rivers, cities, and rangeland and agricultural patterns. Second, we make use of satellite-derived data extensively to complement conventional climate station data. Satellite sensors, even in their current early state of technical development, can describe fine scale spatial patterns of standing water, snow, and vegetation at reasonably frequent intervals.

A classic problem in climate and vegetation description is the combined spatial and temporal variation of the relevant field quantities: temperature, precipitation, snow cover, soil moisture and runoff. Putting aside long-term trends and interannual variation, one must still capture the seasonal cycles of these quantities. We approach the problem of graphical presentation using the technique of cluster analysis, known also in the remote sensing field as unsupervised classification. This approach groups into a particular class all pixels in the image having similar seasonal cycles, independent of where they occur geographically. The complete spatial and temporal description of a particular field quantity (e.g. precipitation) can then be concisely presented in two diagrams: a class map showing the geographical distribution of each class and signature plots showing the seasonal cycle of the quantity. There is of course some lost information and some arbitrariness in such a descriptive method. First, one must choose how many different classes are to be defined. The more classes one defines, the more information is retained, but the more complex the result. Second, a quantitative measure of pixel difference must be defined. It is this difference that will be minimized among pixels assigned to the same class.

The objective of the Southwest Asia Project is to analyze most of the relevant climatological, hydrological, and vegetation fields and to examine the relationships among them using simple models. In this short paper, however, we can only give the briefest description of two important fields: precipitation and vegetation cover.

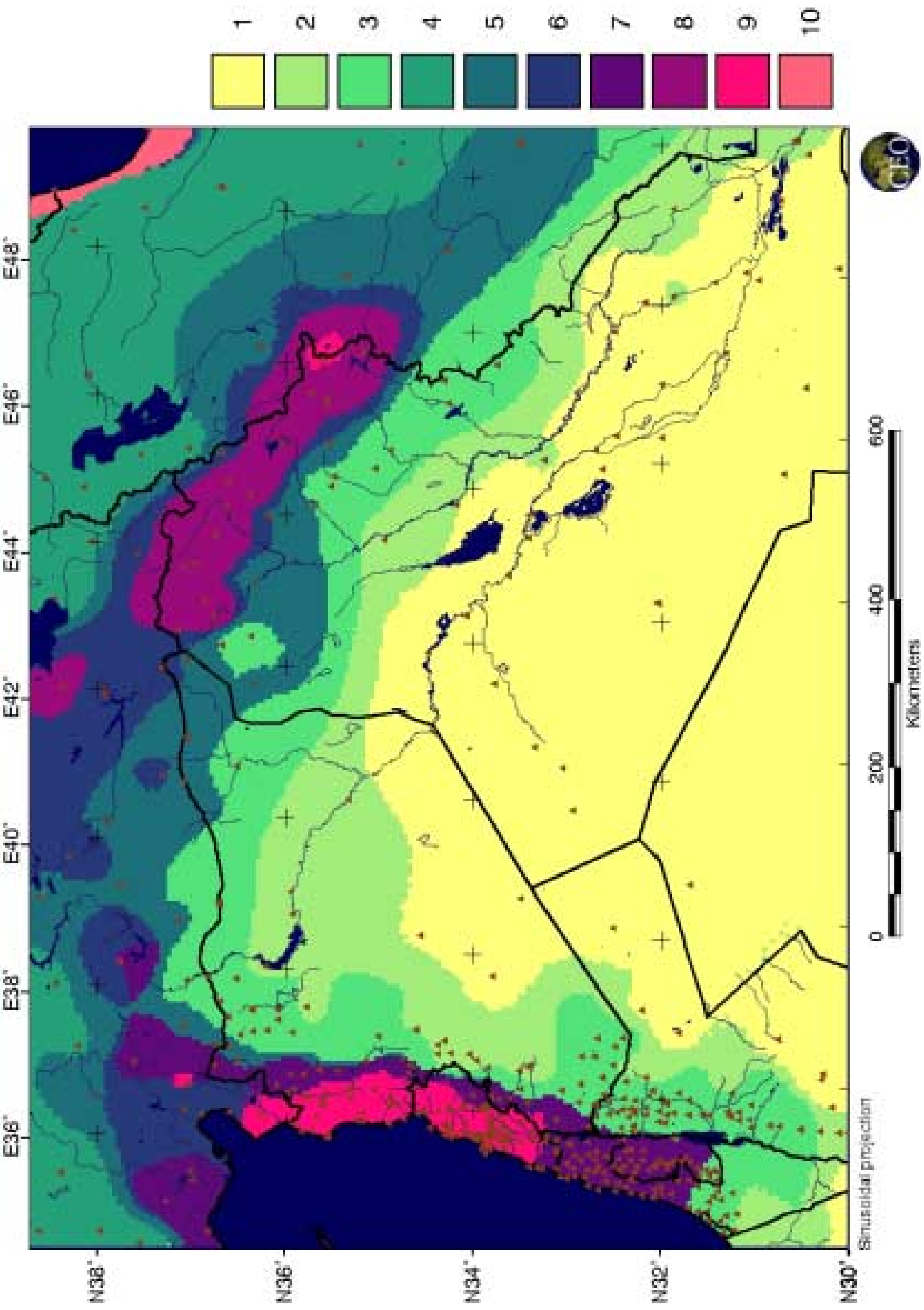

Figure 2 K-means classification of average monthly precipitation in semi-arid southwest Asia.

PRECIPITATION

The starting point for our analysis of climatological precipitation is a collection of station data available from FAO (FAOCLIM version 1.2). This dataset includes monthly values for standard climate quantities, averaged over a period from 1940 to 1970, for about 1500 stations in southwest Asia. The station density is quite variable. It is particularly high along the Mediterranean coast but very low in the desert and mountainous interior regions. The typical distance between stations varies from about 10 to 200 km, depending on the region. A critical step in our analysis is the interpolation of station data to a regular array of grid points with 5 km spacing. This interpolation is done using a Gaussian weighting function:

$$W = e^{-r^2/R^2}$$

where *r* is the distance between station and grid point and *R* is the radius of influence. To account for the variable station density, the value of R is adjusted at each grid point so that the sum of the station weights remains constant. During the interpolation procedure, the temperature values are corrected for altitude using an assumed lapse rate of –5ºC/km. The resulting monthly gridded fields are then subjected to a k-means clustering algorithm to assign each grid point to one of ten classes. The members of each class have similar seasonal cycles of precipitation. The geographical distribution of the precipitation classes is illustrated in Figure 2. The seasonal cycle of precipitation for each class is shown in Figure 3.

Several important aspects of Middle East precipitation are clear in this analysis. Throughout the region, precipitation is low or absent in summer, reaching a maximum in mid-winter, excepting only the coastal regions of the Caspian Sea (class #10), where a striking autumn rainfall maximum is evident. Several strong spatial gradients are also clear. The plentiful winter rains along the Mediterranean Coast decline rapidly inland due to orographic lifting and descent as well as decreasing water source proximity. From south and southwest to north and northeast in the interior, precipitation increases due to the decreasing influence of the subtropical high and the increasing effect of mid-latitude frontal storms and orographic lifting.

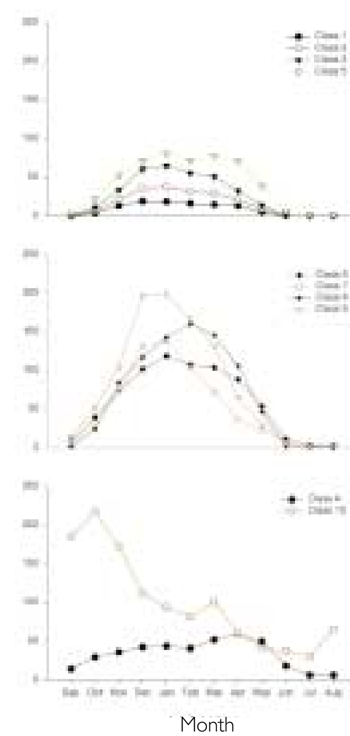

Figure 3 Class signatures from k-means classification of monthly precipitation

VEGETATION COVER

The most appropriate satellite sensor for studying vegetation cover and dynamics over large areas is the AVHRR. This instrument has been in continuous operation since 1979, and there are several ongoing projects to produce consistently processed global images at a high temporal frequency (James and Kaluri 1994; Eidenshink

1994). Because on a given day a significant part of the land surface is obscured from view by clouds, daily AVHRR images are routinely lumped into 10-day groups, and a single image is derived for the period by choosing the pixel with the highest NDVI. The result is an image that is largely (though not completely) cloud-free and is suitable for many types of multi-temporal analysis (Holben 1989, Myeni *et al.* 1997).

To produce a preliminary analysis of vegetation cover in southwest Asia, we acquired one year (October 1992 – September 1993) of 1-1 km resolution AVHRR data, geometrically registered, radiometrically calibrated, and composited into 10-day periods by the USGS EROS data center (Eidenshank and Faundeen 1994). After computing NDVI for all pixels in each image, we stacked the images so that each pixel is characterized not by one but 36 NDVI values. As in the preceding analysis, we then used a k-means clustering algorithm to assign each pixel to one of thirteen classes having similar seasonal cycles of vegetation cover. The geographical distribution of each class is shown in Figure 4 and the characteristic seasonal NDVI cycle for each class in Figure 5.

Table 2 Description and provisional interpretation of classes from k-means cluster analysis of NDVI from 10 day composite 1 km AVHRR data, Figure 4). Interpretations must be verified by fieldwork.

Class #	Area (10^2 $km^{2)}$	Mean NDVI	Class Description
1	242	0.14	Extreme desert, sand dunes, no vegetation
2	353	0.17	Desert with sparse seasonal grasses or shrubs
3	99.5	0.21	Semi-arid steppe with spring grasses or winter barley
4	59.3	0.20	High-altitude forest and/or grasslands; snow cover in winter from Dec-Apr; leafout of deciduous trees or annual grasses in June; slow decline in vegetation cover during summer; first snowfalls in Dec.
5	81.8	0.20	Elevated interior steppe; brief snow cover during Jan/Feb; modest grass or other vegetative cover in June; declining greeness through summer and fall
6	48.6	0.24	Moderate and high-altitude forest; snow cover from Dec-Apr; leafing out of dense deciduous forests in June; declining greeness throughsummer and fall.
7	19.5	0.35	Summer cropland; possibly with supplemental irrigation; bare soil in winter from Dec-March; increasing vegetation during spring, reaching a maximum in June; constant high vegetation cover through the summer until October
8	80.6	0.24	Moderate altitude interior grassland or rainfed farming; brief snow cover in Feb; increasing vegetation during the spring peaking in June; rapid decline in greeness in July and Aug
9	36.4	0.29	Possible mixed class including moderate altitude forests and coastal farming; strong rise in vegetation cover from March to June; decline in moderate cover duringthe summer; barren ground or brief snow cover during the winter; also includes irrigated areas in lower Mesopotamia
10	44.7	0.27	Irrigated farming; nearly barren ground in Dec; slow rise of vegetation cover during the late winter and spring; partial harvest in May; moderate vegetation cover during summer; second harvest during Oct; may also include moderate altitude orchards and other forms of agriculture
11	51.6	0.28	Intense grain farming; rapid rise in vegetation cover in April peaking in late May; harvesting in June; low vegetation cover in late summer
12	49.9	0.27	Intense grain farming; similar to Class 11 but earlier cycle due to dryer climate; rapid rise in vegetation cover in March, peaking in late April; harvesting in May
13	28.4	0.37	Intense irrigated farming; similar to class 10 but denser vegetation cover; high vegetation cover from Apr until Oct

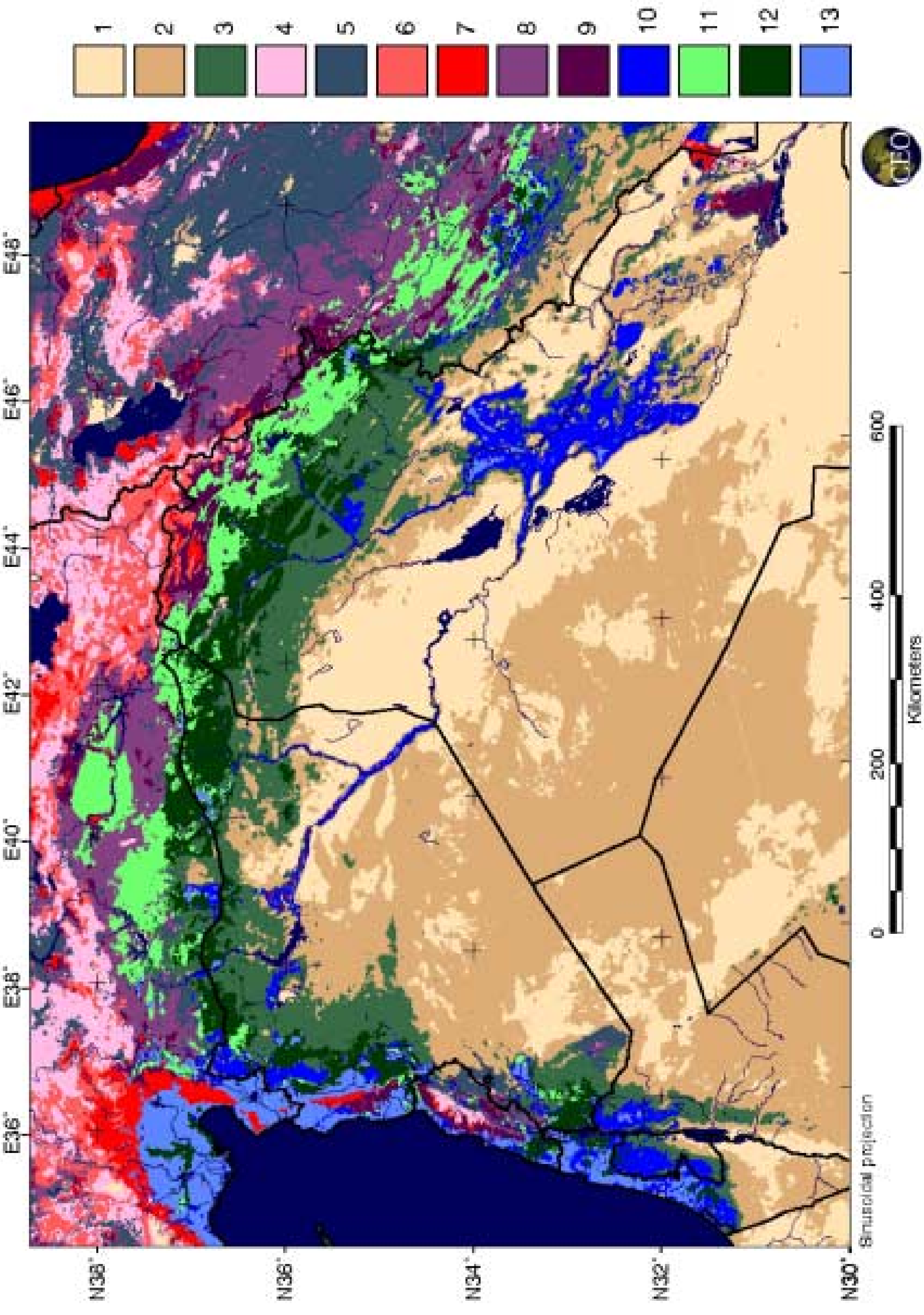

Figure 4 K-means classification of 10-day composite 1 km AVHRR NDVI data for southwest Asia., October 1992-September 1993.

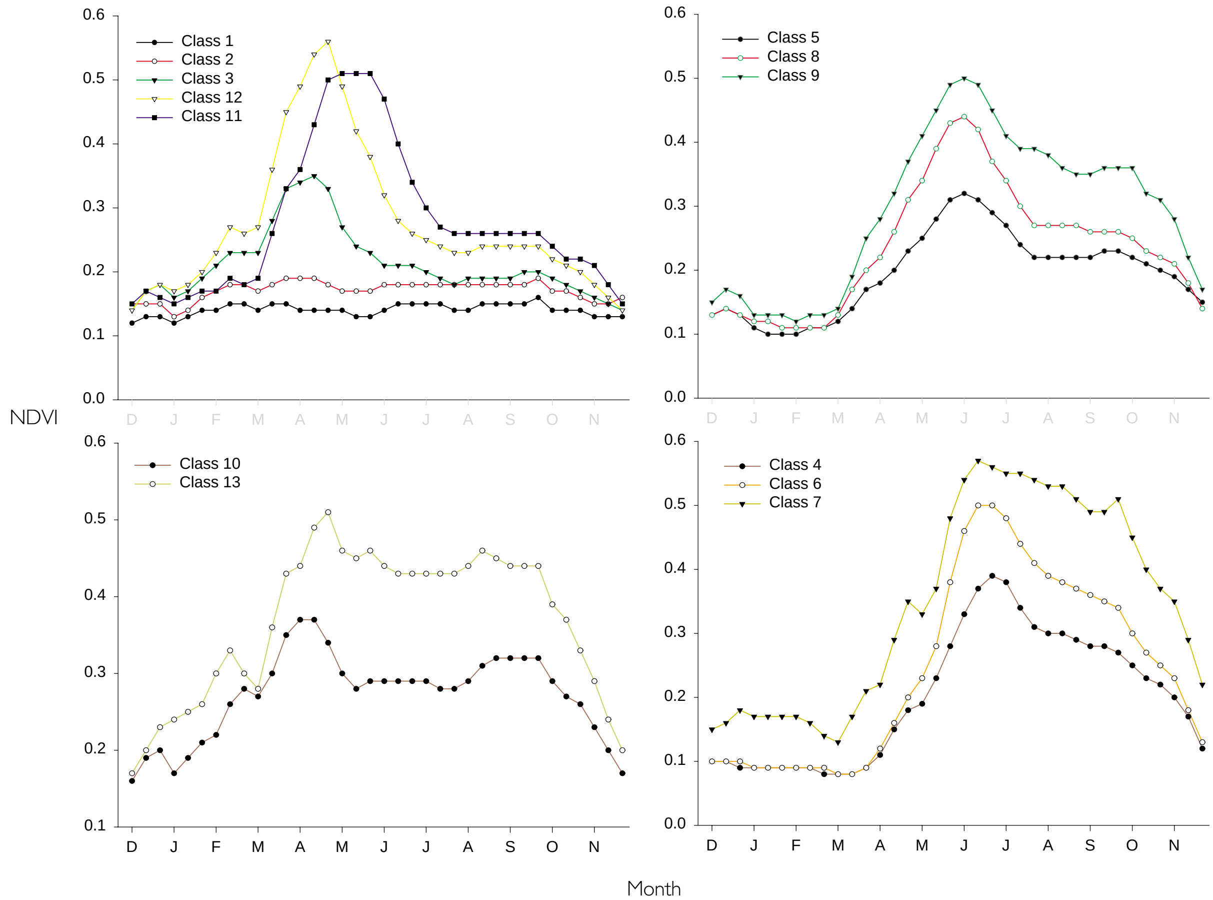

Figure 5 Class signatures from k-means classification of NDVI from 10 day composite 1 km AVHRR data.

The resulting distribution of vegetation classes is complex. On broad scales, it reflects the natural influence of rain and winter snowfall. On finer scales, however, it shows the effects of city building, deforestation, grazing, and rainfed and irrigated agriculture. Using characteristic NDVI curves for each class and partial analysis of corresponding climatological fields, tentative interpretations of each class are presented in Table 2.

ALTERNATIVE APPROACHES TO CLASSIFICATION

The k-means algorithm employed above uses Euclidean distance to describe similarity among pixels characterized by measurements of a single variable at multiple time points. This approach emphasizes the mean of the time series for each pixel and, to a lesser extent, each pixel's value at a given time point but ignores the sequence in which these values occur. In other words, the k-means algorithm assigns greater significance to the amplitude of the seasonal curve than to its shape. This is clear from the plot of class means from the vegetation classification (Figure 5), where several classes having the same general shape differ only in their amplitude.

For some applications, however, it is useful to emphasize the shape of the seasonal curve when classifying multitemporal datasets. For example, in Mediterranean-type ecosystems there is considerable regional and interannual variability in both the timing and the length of the growing season, and hence subtle changes in the timing of seasonal maxima and minima may be of considerable interest to agroclimatologists (Benedetti *et al.* 1992). Patterns of land use and land cover may also be better differentiated by the shape of the annual cycle, especially in areas where there are multiple cropping cycles.

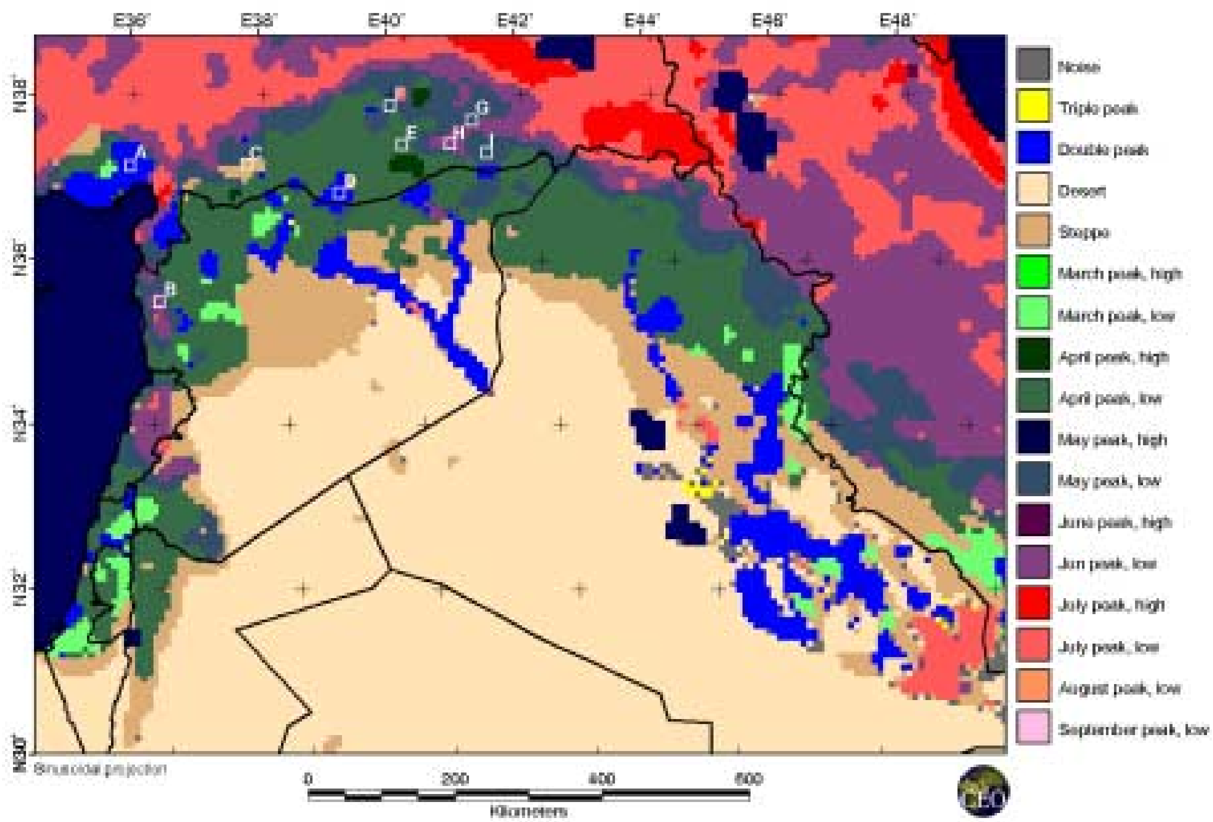

Figure 6 Rules-based classification of Fourier coefficients 1-6 computed for average monthly NDVI from 10-day composite 8 km AVHRR data, 1982-1993.

Finally, it is important to consider that in moderate to coarse resolution satellite data vegetation signals are often diluted by mixture with seasonally invariant terrain, such as barren or urban land. Thus in the case of pixels having the same general type of vegetation but at different densities, a k-means classification would separate them by density, while a classification based on the shape of the curve would correctly recognize the basic ecological similarity among them.

One common method for describing the shape of time series data is Fourier analysis, a technique that represents complex waveforms as the sum of simpler components, usually sine waves. To assess the utility of Fourier methods for analysis of vegetation patterns in southwest Asia, we computed mean monthly NDVI values over the period 1982-1993 using the 8 km resolution Pathfinder AVHRR dataset (James and Kaluri 1994). As in the precipitation analysis presented earlier, averaging helps reduce inherent noise and the effects of interannual variability on the analysis of seasonal cycles. Following a method described by Olsson and Eklundh (1994), we computed the first six Fourier coefficients for the 12-month time series for each pixel and the proportion of the series variance explained by each component and by the sum of all components up to and including the one in question. These components provide information about the general shape of the curve (number of NDVI peaks), its phase (timing of peaks), and amplitude (height of peaks). Using a series of rules and threshold values, we then divided pixels into distinct classes based on the number, timing, and magnitude of NDVI peaks. The results of this classification are presented in Figure 6.

Like the k-means method, the Fourier approach distinguishes well among the major ecological regions of semi-arid southwest Asia: 1) the desert and steppe (no peaks), 2) the dry-farmed areas (March-May peaks), 3) the irrigated areas (double and triple peaks), and 4) the deciduous forests (June-July peaks). To examine the differences between the two classification techniques more closely, we used the k-means algorithm to assign the image pixels in the 12-year average dataset to 16 classes, the same number recognized in the Fourier approach. We then chose a representative sample of individual pixels and compared their seasonal NDVI cycles to those of the classes to which they were assigned by each method. Figure 7 (left) shows two pixels, a and d, which have very similar double-peaked seasonal cycles but differ in amplitude. In the Fourier classification, both of these are assigned to class 3, while the k-means classification divides them between two classes (15 and 10) based on their different annual means. Significantly, the Fourier technique recognizes neither pixel b nor c as double peaked, though the k-means technique lumps them with Classes 15 and 10, respectively, because of general similarity of overall mean. The difference between the two techniques in the case of single-peaked pixels is more subtle but still significant. Figure 7 (right) plots the seasonal cycle of five pixels (e-i) that the k-means algorithm divides into two classes (e-f and g-i) based on differences in their annual means. The Fourier approach, which is more sensitive to the timing of the maximum, groups pixels f, g, and i together on the basis of their sharp May peak (Class 13) but classifies pixels e and h separately.

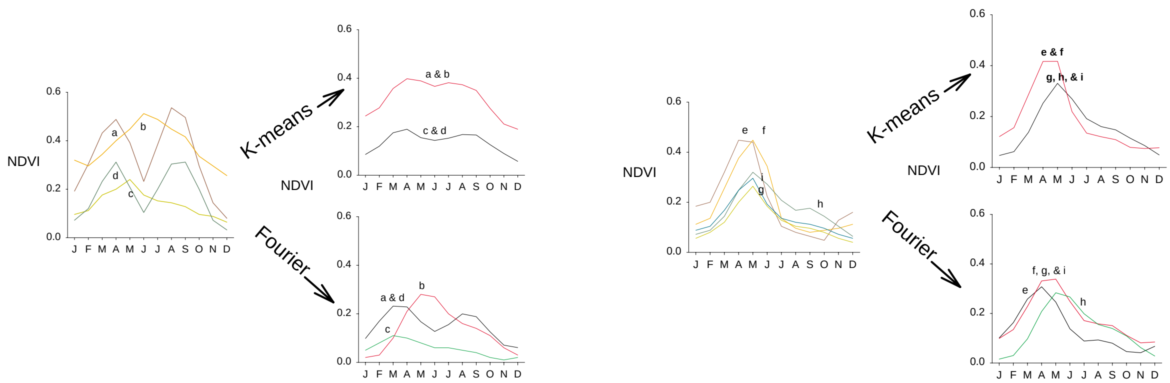

Figure 7 Comparison of k-means and Fourier classifications

In general, we found that the Fourier technique is a useful method for classifying pixels according to the shape of their seasonal cycle and is therefore an invaluable complement to the more widely used k-means method. Unlike the k-means algorithm, however, the rules-based approach to classification contains an element of subjectivity, as the analyst must decide *a priori* what classes are to be distinguished and what the threshold values should be. While this limits the usefulness of the technique for exploratory data analysis, it provides a powerful tool for isolating and extracting specific classes of interest.

CHARACTERIZING INTERANNUAL VARIABILITY

All of the analyses presented so far have used either a single year of data or multiple-year averages to represent climate or vegetation patterns generally or during a particular period of time. With their fast and efficient repeat coverage, satellite sensors also provide important data for the analysis of land surface change over time. While these changes are easy to detect, they often have multiple causes that are difficult to infer from satellite data alone. In the analysis of vegetation dynamics, climate variation is clearly an important driving force, but not all types of vegetation respond uniformly to climate change. Some cropping systems in southwest Asia are heavily buffered against climate variation either by irrigation or by careful assessment of risk. In other systems, enforced schedules of crop rotation or speculative cultivation in marginal areas can amplify minor climate fluctuations considerably (Nguyen 1989).

One very useful approach to isolating climate effects on vegetation is the vegetation condition index (VCI), proposed by Kogan (1993) for use in drought monitoring. This index is computed for a particular time point in a long, cyclical time series by comparing the

NDVI value of each image pixel to that pixel's maximum and minimum value at the same time point in all years spanned by the series. The result, typically scaled between 0 and 100%, provides a relative measure of vegetation cover within the ecological parameters of each vegetation type. In other words, the VCI attempts to normalize ecological variability across the image and to emphasize changes due to relatively high frequency meteorological fluctuations.

In Figure 8, we use the 8-km pathfinder AVHRR dataset to compute the VCI across southwest Asia in April for four years characterized by markedly different precipitation patterns. In each image, the approximate distribution of rainfall during the preceding six months

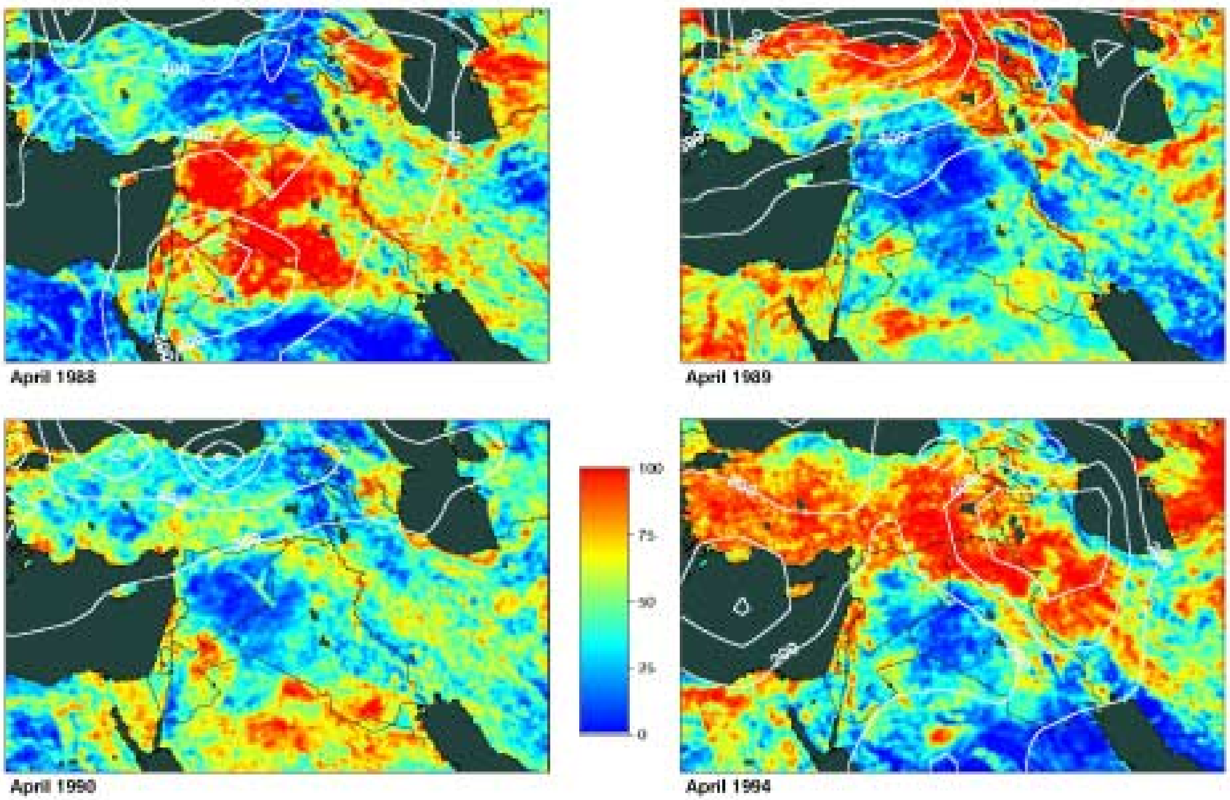

Figure 8 Vegetation condition indices (VCIs) for April of four successive years. Contours show the approximate distribution of total November-April precipitation for each year.

(November-April) is represented by 200mm contours derived from the Global Precipitation Climatology Project's Combined Precipitation dataset (Huffman *et al.* 1997). This analysis highlights both the high interannual variability of rainfall and vegetation state across southwest Asia and the strong correlation between these two variables.

MONITORING THE INTENSIFICATION AND EXPANSION OF PRODUCTION

A steady expansion of cereal cultivation into regions used traditionally as rangeland has been underway for decades in southwest Asia. The principal crop sown in these marginal areas is barley, and a graph of annual changes in its harvested area in Iraq and Syria shows rapid increase throughout the 1980s and early 1990s (Figure 9). This increase is due in large part to the growing economic importance of barley and barley straw for livestock feed as sheep and goat numbers far exceed the carrying capacity of available rangeland. Much of this cultivation has been carried out on very large scales, and tractors are often used to plow and sow fields several kilometers in extent. If adequate rain falls, crop production can be very high, but crop failure is very common during normal or dry

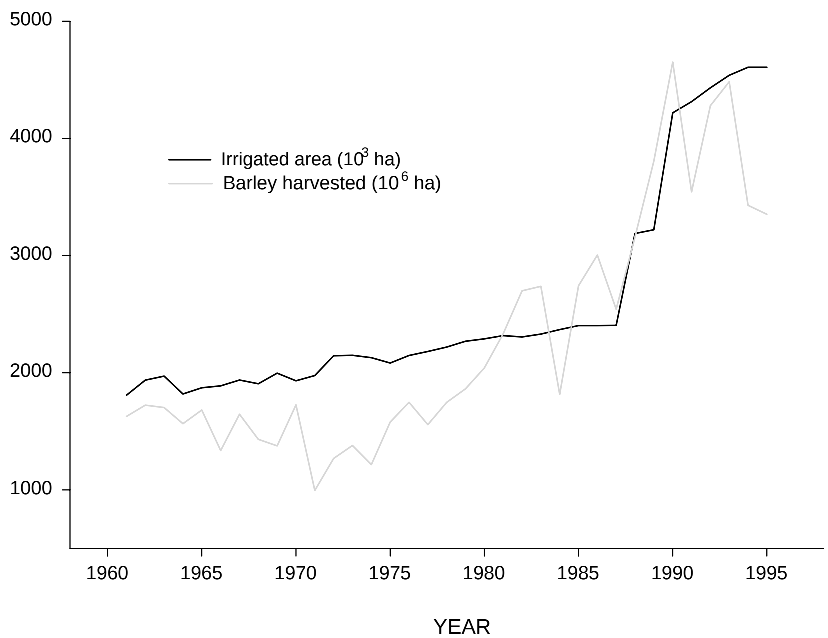

Figure 9 Trends in irrigation and barley cultivation in Syria and Iraq, 1960-1995 (from FAO/FAOstat).

years. Because deep plowing destroys the natural vegetation communities adapted to local climatic conditions, cultivation in the steppe can result in serious erosion hazards and rapid deterioration of forage production. Although cultivation of marginal zones is now outlawed in many countries, identifying areas where high-risk cultivation has occurred and continues to occur can aid in formulating conservation strategies and revising policy.

To identify areas where high risk agriculture was practiced during the 1980s and early 1990s, we have summed March and April NDVI maxima computed from the 8-km Pathfinder AVHRR dataset for each year between 1982 and 1994. The resulting series of 13 images shows the approximate density and distribution of green vegetation across the study area just before the maturation and harvest of winter crops. We then calculated the standard deviation of this series for each image pixel and divided the result by the series

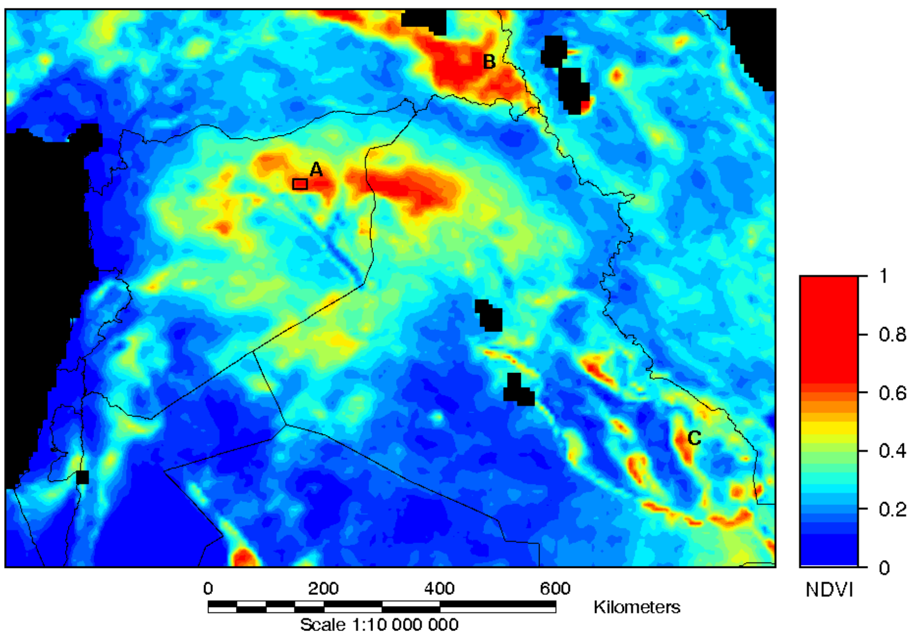

Figure 10 Marginal agriculture in semi-arid southwest Asia. Standard deviation of March-April NDVI divided by mean of March-April NDVI.

mean (Figure 10). Low values of this ratio indicate stable spring NDVI values as expected in core agricultural areas, healthy rangeland, and barren desert. High values, on the other hand, indicate areas where spring NDVI fluctuates strongly about a lowered mean or where agriculture has been introduced or abandoned during the period of observation. The distribution of high values therefore provides a useful tool for recognizing areas where vegetation cover has changed significantly during the period of observation.

The three regions highlighted in this analysis are A) the lower Jazirah in eastern Syria and Northern Iraq, B) the Hakkari and Van provinces of southeastern Turkey, and C) small areas along the branches of the Euphrates and Tigris Rivers in southern Iraq. Of these regions, only the first corresponds to regions where extensive dry farming of cereals is practiced. A plot of the full NDVI time

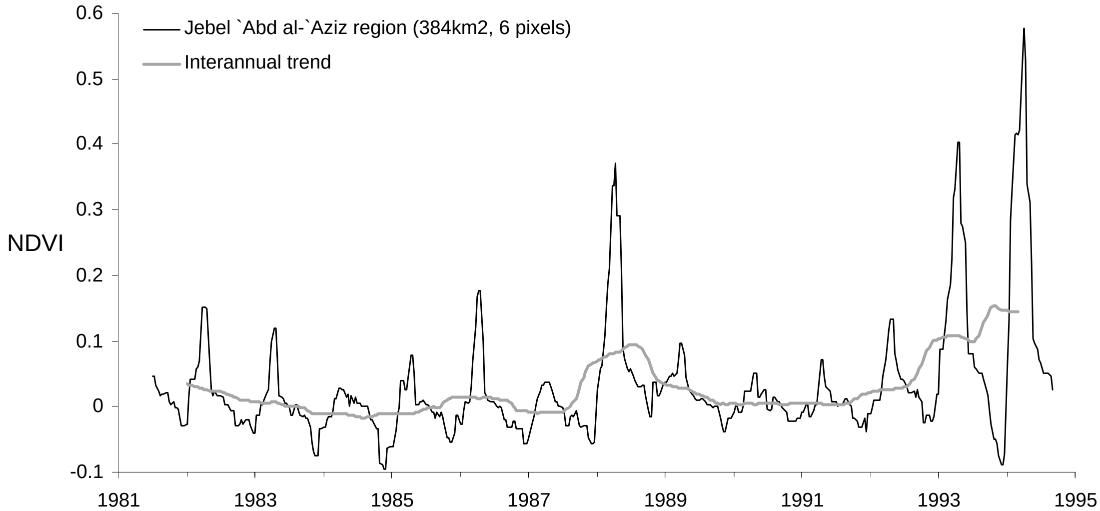

Figure 11 Mean NDVI values as a function of time, northeastern Syria test area.

series from a roughly 400 km[2] area within this zone confirms high interannual variation of vegetation cover about a low mean (Figure 11). In the last two years of the time series, NDVI values rise sharply, signaling either unusually high rainfall (which did not occur) or a qualitative change in land-use practices.

Higher resolution satellite data (Figure 12) allow further analysis of land use change in this area. A Landsat MSS image acquired June 1975 (top) shows barley cultivation on an extremely large scale. Fallow and plowed fields, which appear pink and green respectively, are often several kilometers in length and are arranged haphazardly across a broad basin where deep calcic soils have developed in a region with otherwise very limited agricultural potential. This pattern is a clear result of the use of mechanized plows to till large areas in hopes of abundant winter and spring rains. A second image acquired nearly twenty years later by an imaging radar system on board the Space Shuttle (bottom), shows that these broad fields have been subdivided into hundreds of smaller parcels. This change, which began in 1993, resulted from the discovery and exploitation of ground water reserves and represents a transition from extensive dry farming to intensive irrigation.

The rapid growth of irrigation elsewhere in southwest Asia over the past two decades (cf Figure 9) can also be investigated through a combination of moderate and high resolution satellite data. Because much of the irrigation agriculture in the region is practiced in the summertime, when dry farming is impossible, it is easy to recognize irrigated areas by elevated August-September NDVI. In addition, because of higher ground surface temperatures and increased evapo-

Figure 12 Landsat MSS (top) and SIR-C (bottom) imagery depicting the expansion of irrigated farming in the Jebel 'Abd-al 'Aziz region, eastern Syria.

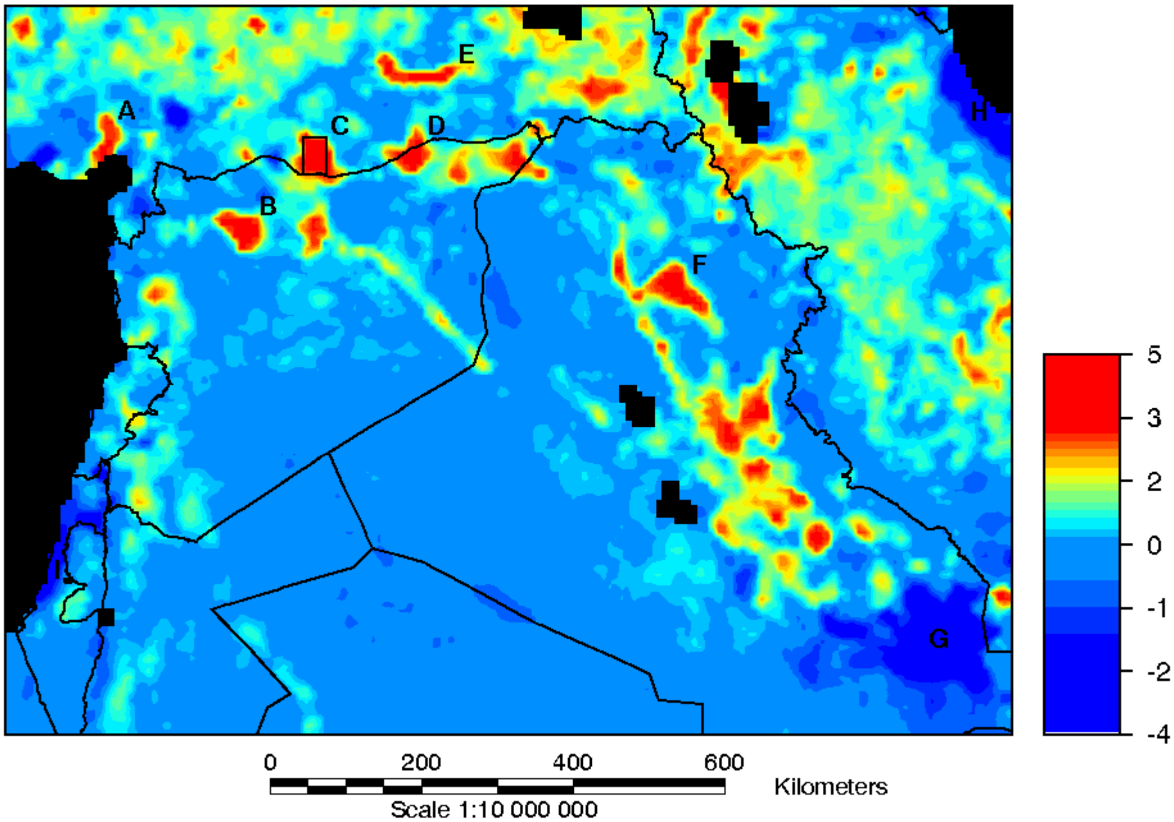

Figure 13 Intensification of irrigated agriculture in semi-arid southwest Asia. Standardized difference between mean August-September AVHRR Channel 5 brightness temperature in 1993-4 and 1981-2 subtracted from standardized difference between August-September NDVI in 1993-4 and 1981-2.

transpiration during the summer, irrigated fields may also be recognized by their comparatively low emission in the thermal infrared wavelengths. To map areas where irrigation increased or decreased between 1981 and 1994, we computed and standardized the difference between mean August-September NDVI in 1993-94 and 1981-82 and between mean brightness temperatures at the two time points. A simple difference of these values (NDVI-Temperature) assigns high values to pixels where NDVI has increased and temperatures have decreased and low values to areas where NDVI has decreased and temperatures increased.

The spatial distribution of this index is shown in Figure 13. High values correspond well to known locations of major irrigation projects: A) the Ceyhan valley in southern Turkey, B) the Maskanah region of central Syria, C) the Harran plain (GAP project area) of south central Turkey, D) the Ceylanpinar-Ras al-ʻAin region on the Turkish-Syrian border, E) the upper Tigris valley, and F) the Hamrin region of northern Iraq. The analysis also highlights areas

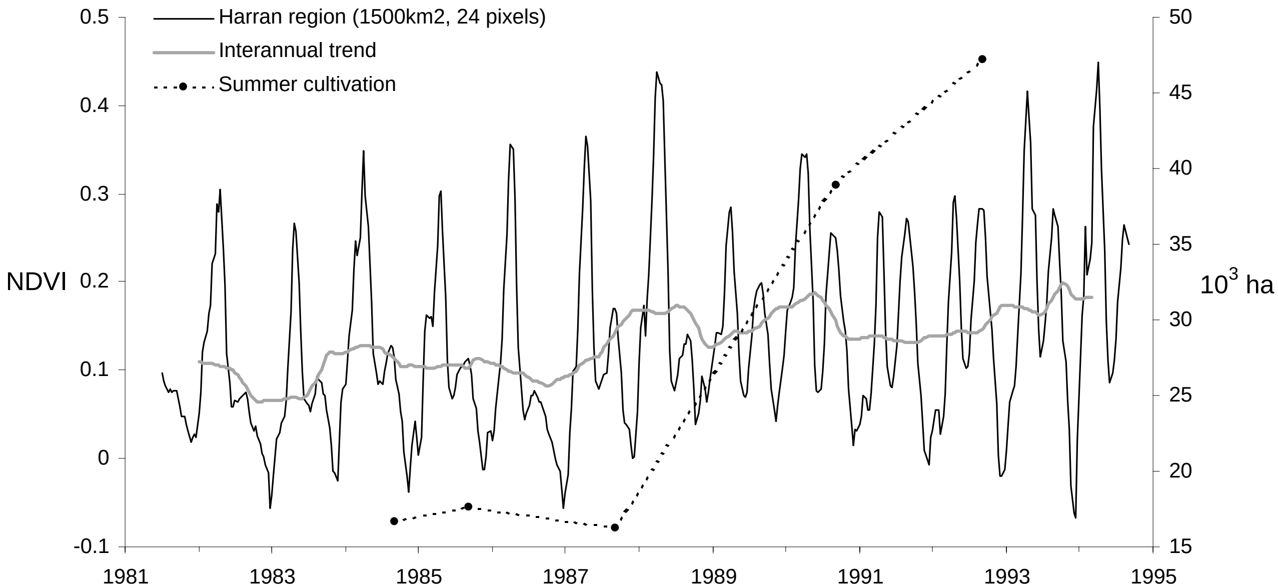

Figure 14 NDVI and summer cultivation profiles of the Harran Plain, Southeastern Turkey.

where summer vegetation has declined significantly such as the marshes of southern Iraq (G) and the shores of the Caspian Sea (H). As in the preceding analysis, much more can be learned about the nature of vegetation changes in specific areas by examining the full time series of NDVI values. Figure 14 shows the NDVI profile of a 1500 km^2 region of the Harran plain in southern Turkey (area C, Figure 13). Between 1981 and 1987, the characteristic seasonal NDVI cycle of the region was characterized by a large late winter-early spring peak representing dry-farming in the region and by a second, considerably smaller peak in July-August indicating limited summer cultivation. After 1987, however, the size of the late summer peak grew rapidly as water from deep wells and later from the Attaturk dam was used to irrigate larger areas each year.

The magnitude and spatial distribution of these changes can be seen clearly in a pair of late summer Landsat images of the Harran plain in 1984 and 1992 (Figure 15). In this color combination, which approximates that of an infrared aerial photograph, vegetation (mostly cotton) appears bright red due to its strong reflectance in the infrared wavelengths. Using unsupervised classification techniques to distinguish cultivated from fallow land, we estimate that between these two time points, the extent of summer irrigation on the Harran plain increased from 15,000 ha to more than 45,000. Similar estimates from images from 1985, 1987, and 1990 provide further information about the timing of this growth and generally confirm trends apparent in the AVHRR data (Figure 14).

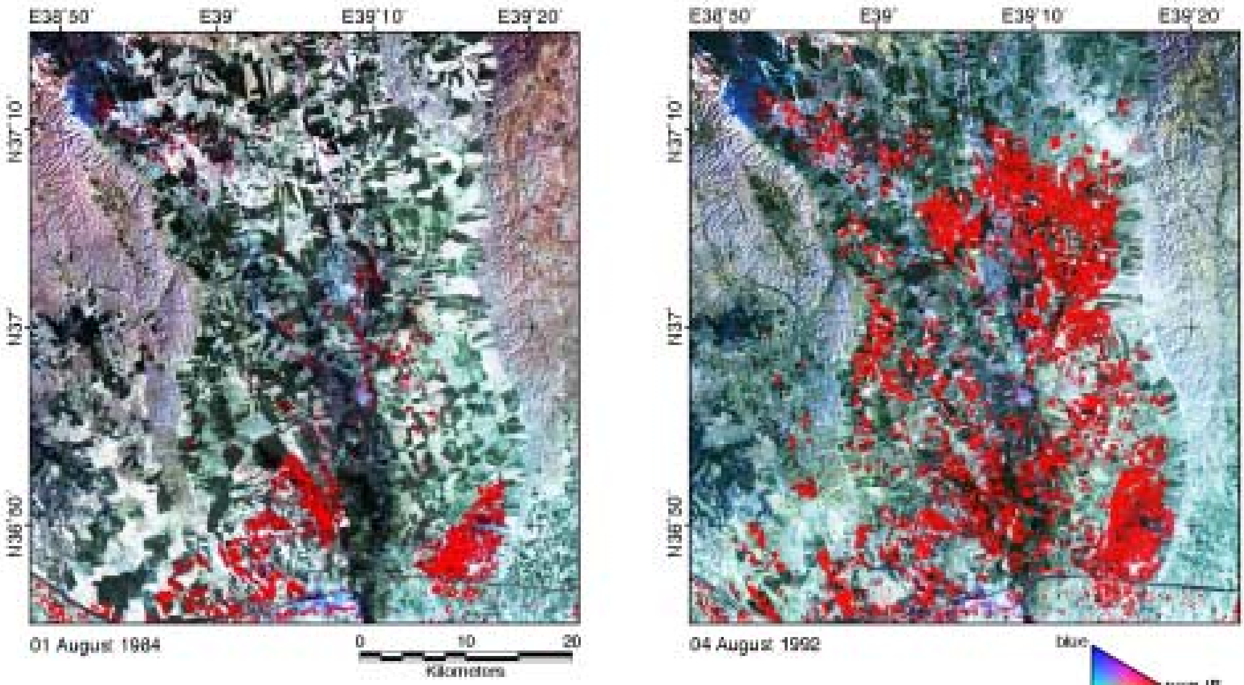

Figure 15 Expansion of summer irrigation in the Harran Plain (GAP project area), southeastern Turkey.

ESTIMATING BIOPHYSICAL PARAMETERS

As demonstrated in the preceding examples, two key aspects of the SWAP methodology are a multi-sensor approach and the use of satellite data from archives maintained over the past 20-30 years by the National Aeronautic and Space Administration (NASA), the U.S. Geological Survey (USGS), and other national and international agencies. Successful integration of data acquired by different instruments at different times and under different conditions requires careful attention to the different sensitivities and calibration of satellite sensors as well as to the effects of atmospheric aerosols and gases on the transmission of electromagnetic radiation.

To illustrate the importance of these considerations, we have selected two Landsat TM images of the Palmyra region in Syria, taken one month apart (August 31 and October 10, 1984). Because vegetation and land-use changes are minimal in the region during this time of year, the spectral signatures of corresponding areas on the two images should be nearly identical. A plot of the average pixel values of four different 20 ha test areas present in both images, however, shows no clear similarity between the spectra of each test area on the two different dates and no systematic difference among the spectra of the different test areas (Figure 16, top). These results, which bode poorly for the use of satellite images to analyze land surface changes over time, have two main causes. First, differences

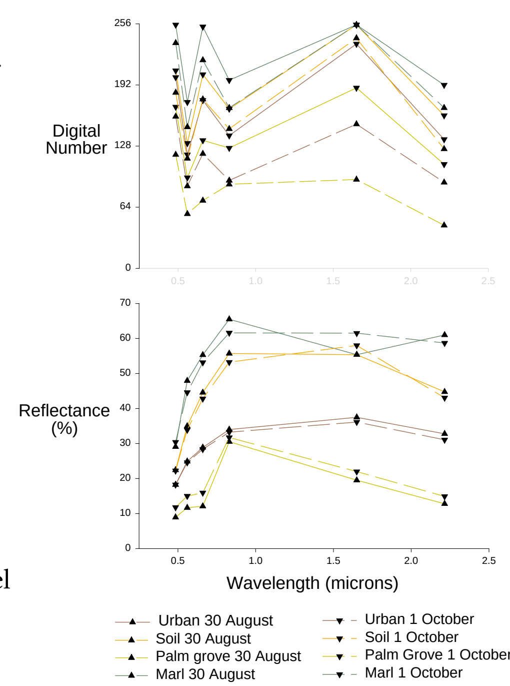

Figure 16 Comparison of raw (DN) and reflectance spectra for test areas in the Palmyra Basin, central Syria.

in the relative positions of the satellite, the sun, and the earth's surface at each time point can result in significant differences in the amount of sunlight illuminating the earth's surface and the amount that is reflected toward the satellite sensor. Second, the intensity of solar radiation varies significantly across the visible and near-infrared wavelengths and different scaling factors are used to convert satellite-measured radiances within each wave band into digital numbers for computer image analysis. By applying known calibration equations for each wave band to recover pixel radiances measured at the satellite and normalizing these for the viewing angle of the sensor, digital numbers can be converted into estimates of surface radiance that are comparable across space and time. By further dividing this result by the total amount of incident solar radiation in each waveband, radiance spectra can be converted to reflectance, a dimensionless quantity that allows the integration and comparison of spectra obtained by many different kinds of sensors in orbit, in the field, or in the laboratory. Although these operations neatly recover coherent and reproducible reflectance spectra from satellite data (Figure 16, bottom), full integration of multitemporal and multisource spectral data must consider also the more subtle (but cumulatively significant) effects of changing atmospheric conditions, degradation of satellite sensors over time, and complex changes in the reflectance of different materials under varying illumination and viewing conditions.

Once reproducible and physically meaningful spectral measurements are obtained from satellites, they can be combined with the results of field investigation to develop techniques for estimating ground surface properties. The use of multispectral reflectance data to estimate physical parameters such as leaf area index, as well as related climate and soil conditions is well-established (Wiegand *et al.* 1992; Penuelas *et al.* 1992; Moran *et al.* 1996). Considerable improvement in the accuracy and spatial scale of these estimates is expected with the development and launch of new sensor systems that better describe surface reflectance characteristics. These advances along with improved temporal coverage, will enable the routine use of satellite data for agro-ecological characterization, precision farming, and agricultural decision support systems.

Taking full advantage of improvements in satellite sensor design depends on accurate characterization of the reflectance properties of major crops at different stages of their growth cycles and in different soil conditions. Very few studies of these relationships have been carried out in southwest Asia, and considerable research remains to be done before satellite-derived data can be fully integrated into agricultural research and development in the region. For this reason, we have begun a program of field research that uses portable spectrometers to acquire high-resolution spectra from crops in different settings and stages of growth. Much of this fieldwork is scheduled during times of satellite overpass to insure the comparability of *in situ* and satellite data.

This research, carried out in collaboration with scientists from the International Center for Agricultural Research in Dry Areas (ICARDA), has focused primarily on the region around Aleppo, Syria, where rainfall varies between 300 and 350 mm/year. The first season of field research in this region during the late summer and early autumn of 1997 focused on major irrigated crops such as cotton (*Gossypium*), potato (*Solanum erianthum*), soybeans (*Glycine max)*, corn (*Zea mays*), sunflower (*Helianthus*), and various vegetables. At each of 231 different locations, we measured the spectral characteristics of crop and soil, and took samples for laboratory measurement of wet biomass and leaf areas index. In the analysis of these data we have focused on characterizing the relationship between conventional spectral indices such as NDVI and developing new indices which are more closely related the physical characteristics of different crops. In general, we found that NDVI explained between 50 and 80% of the observed variability in wet biomass and leaf area index for the five crops intensively studied. The closest relationship between spectral and biophysical variables was observed for cotton and soybean (Figure 17). In most cases, the relationships between the variables were non-linear, as other researchers have found (e.g. Wiegand *et al.* 1992).

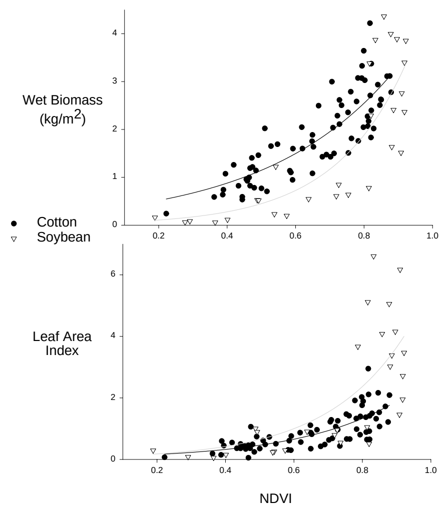

Figure 17 Relationships between physical and spectral parameters for cotton and soybean.

CONCLUSIONS

In this paper, we have illustrated some modern methods for analyzing spatial and temporal patterns of climate and vegetation in southwest Asia. These methods combine conventional climate observations, multispectral satellite data, and computer-intensive interpolation and clustering algorithms. When combined with more systematic fieldwork, these approaches may ultimately provide the level of completeness and accuracy needed for modeling, monitoring and managing the rapidly changing environment of the region. As the quality and accessibility of satellite data improve, we should expect wider application and rapid improvement of the methods.

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Transformations of Middle Eastern Natural Environments: Legacies and Lessons

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