Creating an Agenda for Research to Support Management of Fisheries for Highly Migratory Species

Mise en œuvre d'un agenda pour la gestion des pêcheries sur les espèces hautement migratrices

John Sibert

Introduction

The period from 1995 to 2000 should be remembered as pivotal in the history of the management of highly migratory species. The 1995 United Nations agreement concerning these species and endorsement of the precautionary principle have given a sense of urgency to the task of establishing effective management arrangements for these species. The Indian Ocean Tuna Commission has recently been established. The International Commission for the Conservation of Atlantic Tuna has renewed its mandate, and many observers are cautiously optimistic that ICCAT will at last become an effective conservation body. The nations of the Eastern Tropical Pacific appear to have reached agreements that will enable the Inter-American Tropical Tuna Commission to strengthen its role. Serious negotiations between the island states of the South Pacific and distant water fishing nations are progressing and will lead to a competent arrangement for management of highly migratory species in the western Pacific by the end of the century. Japan and the United States have formed an

"Interim Scientific Committee" that may also lead to a competent management body in the north Pacific. Domestic legislation in the United States has been changed to be consistent with the UN Agreement.

Rapid economic growth in Asia, increased demand for canned tuna in Europe, and expanding markets for new tuna products in the United States indicate that global demand for tuna products will likely increase. Fishing pressure will increase in the western Pacific and Indian Oceans on productive tropical species that have only been exposed to low or moderate levels of exploitation. Information from these fisheries will become more detailed, will be extensive in area, and will have unconsidered problems of accuracy. We must therefore begin to evaluate fisheries for highly migratory species on an ocean basin scale in near "real time". As demands for tuna products increases, we will no longer have the luxury of "managing" fisheries at low levels of exploitation. We must develop better ways to characterize fishing mortality that takes into account variability in the economic pressures on the fleets and on productivity of the population. These challenges require new approaches to understanding fisheries dynamics and new ways to organize research to ensure that fresh ideas are encouraged.

The rapid expansion of the Honolulu longline fleet in the late 1980s and changes to United States fishery management legislation created problems for the management of highly migratory species in the United States western Pacific EEZs. In this paper, I will describe some of these changes, emphasizing institutional responses that may lead to long-term improvements in research and management capability. I also will present the recent history of this fishery as an example of the management problems faced by the Western Pacific Regional Fishery Management Council (WPRFMC). This example illustrates problems faced by fishery managers in many jurisdictions and introduces a framework for guiding integrated multidisciplinary research on pelagic fisheries. Finally, I will attempt to apply this framework to identify some key areas of research.

Hawaiian Longline Fishery

The WPRFMC has the responsibility for fisheries management in the United States Exclusive Economic Zone in the western Pacific Ocean (Figure 1). In 1992, United States domestic legislation that mandates fisheries management, the Magnuson Fishery Conservation and Management Act, was extended to include highly migratory species. This change was a major increase in responsibility for the WPFRMC requiring more information than was available at the time. A multidisciplinary research program, the Pelagic Fisheries Research Program (PFRP), was created at the University of Hawaii Joint Institute for Marine and Atmospheric Research (JIMAR) to provide scientific information for development of pelagic fishery management policies by WPRFMC.

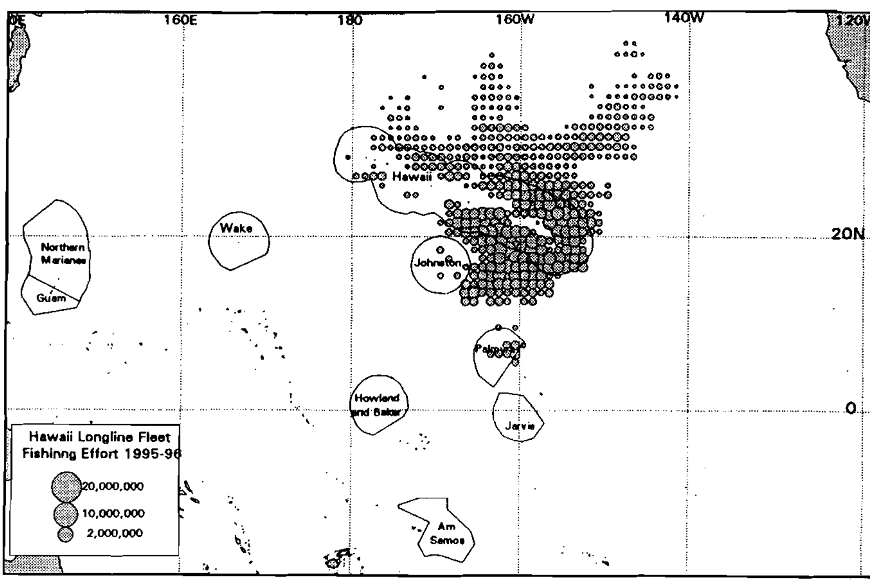

Figure 1
United States Exclusive Economic Zones in the western Pacific Ocean and the distribution of fishing effort by the Hawaii-based longline fleet in 1995 and 1996 at a resolution of 1º geographic square.

JIMAR is one of several "joint institutes" operated by the National Oceanic and Atmospheric Administration (NOAA) at universities around the United States. These institutes facilitate collaboration between government and academic researchers and promote multi-disciplinary collaboration among research workers from different institutions and from different nations. The joint institutes operate under special agreements between NOAA and the host universities. These agreements enable flexibility in implementing research projects and allow stable funding for multi-year projects. JIMAR was established at the University of Hawaii in 1977 and has a record of distinguished achievement. Over the last 10 years, fisheries has become an increasingly important research theme within JIMAR, involving extensive collaboration between the University of Hawaii and the NOAA National Marine Fisheries Service Honolulu Laboratory.

The NOAA joint institutes have been effective vehicles for conducting research and training young scientists. Academic scientists are able to understand the practical problems that challenge government scientists and often offer unique points of view. Conversely the intensely practical work of the government scientists ensures that the academics are well aware of the applications of their research. The arrangement ensures that university students are well trained and have employment opportunities after graduation.

The longline fishery in Hawaii dates back to the 1940's. In the 1970's, catches by the Honolulu-based longline fleet began to increase, and in 1983, longline landings exceeded the previous historical high set in 1948. Further increases occurred in the late 1980's when size of the longline fleet increased by a factor of three (Boggs and Ito, 1993; WPRFMC, 1996). Nearly 100 vessels and their crews migrated to Hawaii from other ports in the United States, mainly from the Atlantic Ocean and the Gulf of Mexico (Figure 2). Broadbill swordfish (*Xiphias gladius*) was the primary target of this fishery (Figure 3), and Honolulu quickly became the largest single domestic supplier of swordfish to United States markets.

This rapid influx of fishing power and fishing crews naturally caused problems for fishery managers. There were the usual resource questions: Is the swordfish resource capable of sustaining high levels of exploitation? (This question was particularly urgent in consideration of the perception by Hawaiian fishermen that swordfish catches in

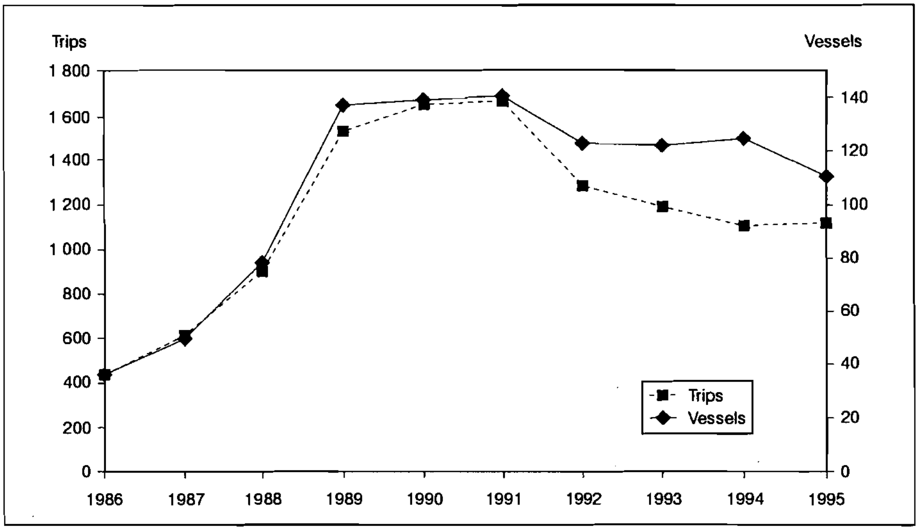

Figure 2
Growth of the Honolulu based longline fishery since 1986 (WPRFMC, 1996).

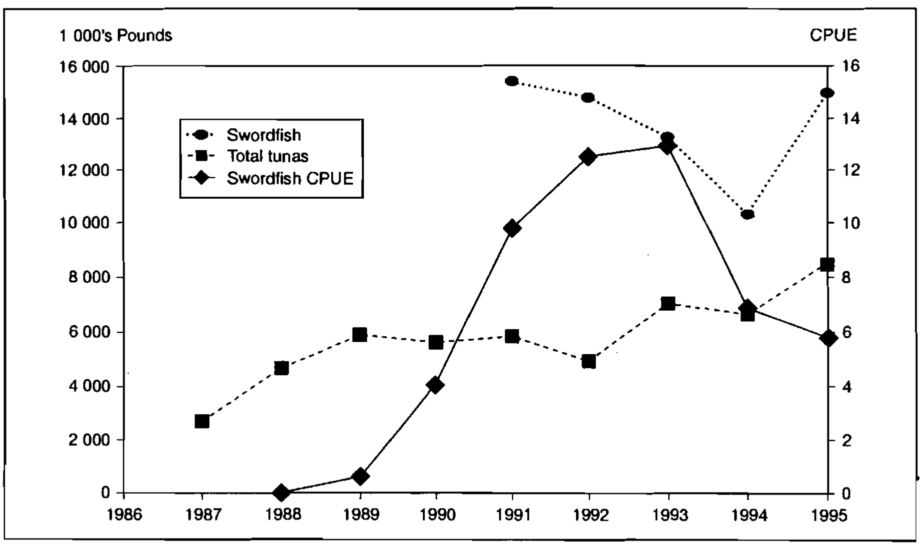

Figure 3
Tuna and swordfish landings and swordfish catch per unit of effort (CPUE) by the Honolulu based longline fishery. CPUE is given as swordfish per 1,000 hooks caught on swordfish directed trips determined from analysis of logbook reports (WPRFMC, 1996).

some parts of the Atlantic have declined drastically.) The longline fleet also catches significant amounts of yellowfin and bigeye tuna (Figure 3). Are the tuna resources capable of sustaining higher levels of exploitation? Will tuna harvesting by longliners impact the ability of the large numbers of small "commercial" trollers and handliners to catch tuna? If the swordfish stock declines, will the longliners begin to target tunas further increasing pressures on "local" tuna stocks? (This question concerns the users of the resource as well as the resource itself.) Is there a resident or "local" tuna stock in the vicinity of Hawaii?

There were also social problems: "Local" longliners had an established historical relationship with other components of the pelagic fishing fleet. There were informal divisions of fishing grounds and few conflicts. The "foreign" longliners did not share these common cultural values, and there were confrontations.

This situation developed very rapidly, and the Western Pacific Regional Fishery Management took precautionary action in 1991. A moratorium on new entries to the fishery was imposed, and some areas were closed to longlining to minimize interactions with protected species (Hawaiian monk seals). These actions calmed the social situation and allowed time for development of more thoughtful management strategies. Unfortunately, there were few data on the north Pacific swordfish population, data available on tuna populations were fragmented, and there were no data on longline economic performance. Several research programs, including the PFRP, were launched to generate technical information on which to develop future policies.

In 1993, the WPRFMC amended the pelagic fisheries management plan. Area closures are maintained, a limited entry plan is in place for the longline fleet, logbook reporting requirements have been established, and observers are required on longline vessels. While this plan is practical and effective in regulating the fishery and minimizing conflict among sectors, it is based on limited information. Knowledge of the swordfish population is still less complete than necessary. The historical data base pertinent to tuna population has only been compiled recently and preliminary analyses completed. Collection of economic information about the longline fleet has been very successful and has already been useful in modifying observer programs. Collection of information on other sectors of the fishery is only beginning. Fortunately, the management plan is strongly supported by an active interdisciplinary research effort and contains provisions for revision as more complete information accumulates or as conditions change.

The current geographic extent of the Hawaii-based longline fishery is summarized in Figure 1. The component of the fleet that targets swordfish generally fishes to the north, while the tuna-directed component fishes to the south. The approximate areas closed to longline fishing can also be seen in Figure 1.

Swordfish catches declined severely in 1994 (Figure 3). This development reinforced the worst fears of many people associated with the fishery. The causes of the decline were not clear, however. Several scientists associated with the Management Council felt that the situation should be examined more closely before jumping to the conclusion that the swordfish population was on the verge of collapse. An *ad hoc* interdisciplinary group of researchers –biologists, economists, oceanographers– from the PFRP and the National Marine Fisheries Service (NMFS) Honolulu Laboratory assembled to examine the problem in more detail. The group posed three hypotheses to explain the decline in swordfish catch and then tested each of these hypotheses against the data that had accumulated since 1991.

Possible Causes of Swordfish Catch Decline
Decline in Absolute Abundance
Fishing pressure
Environmental (recruitment & mortality)
Decline in Availability
Large-scale distribution (migration)
Local distribution (depth)
Decline in Fishing Power
Change in participation
Change in targeting

The Honolulu-based longline fleet is not homogeneous. Economic data as well as analysis of catch composition reveal three relatively distinct modes of operation depending on targeted species: (1) swordfish-directed, (2) tuna-directed, and (3) mixed. The catch-per-unit-effort (CPUE) of the swordfish directed segment of the longline fleet declined between 1992 and 1994, but then recovered sharply in 1995 (Figure 3); preliminary statistics indicate that the recovery continued in 1996. The size distribution of the fish did not change in any way that was suggestive of high levels of exploitation. The group concluded that there may have been a reduction in overall swordfish abundance, but if so, the rapid recovery in 1995 is difficult to understand. Participation in the fishery has also changed significantly and partially accounts for the sustained decline in total catch and effort, but cannot account for the change in CPUE. The spatial distribution of the catch was also different in each year further increasing the difficulty of reaching general conclusions about the fishery. The most important factor in mediating the observed changes in CPUE during this period may have been the variability in the volume of the southward flow of water associated with the convergent Subtropical Front at 30 °N in the middle of the primary fishing ground. The *ad hoc* group concluded "the most likely explanation for the CPUE decline in 1994 appears to be a change in the environment which affected the availability and/or the catchability of swordfish" (WPRFMC, 1996). While this conclusion is offered with great caution, we now have on hand a multidisciplinary team capable of quickly applying biological, economic and oceanographic analyses to fishery management problems.

Fisheries as Globally Coupled Systems

The swordfish example shows how rapidly distant events may impact local conditions. In this case, longline vessels moved from one ocean to another. The move was not predicted and happened so rapidly that it was essentially complete before fishery managers could react. Migration of pelagic fishing fleets is common. In the early 1980's, large purse seiners moved from the eastern Pacific to the western Pacific and from the Atlantic to the Indian Ocean. In each case, these large scale fleet movements challenged local fishery managers with both social and resource problems, and the challenges arrived as suddenly as the vessels. Fishery management, at least with respect to pelagic fisheries, has acquired global dimensions.

The swordfish example also illustrates that analysis of fishery management problems is a multidisciplinary enterprise, a conclusion that should not surprise late twentieth century observers. Social and economic changes in the fleet interact with environmental changes to cause changes in catches and catch rates that are difficult to understand. Fisheries inextricably couple human and natural systems. The *production* of fisheries resources depends on the dynamics of the species and the constraints imposed on natural production systems by the environment. The *exploitation* of fisheries resources depends on economic and cultural forces. The *act of exploitation* couples natural production systems to human social systems and induces additional layers of research problems. The task of fishery management is made more difficult by the fact that these systems *and the nature of the coupling* are incompletely understood. Further complications arise as the scope of these systems expand from local to global. Research programs to support development of fishery management policies for the next century must acknowledge the globally coupled aspects of fishery systems. They must not only be multidisciplinary ; they must explicitly include emergent complexities arising from the coupling of large-scale systems.

Policy development requires a means of discriminating among alternative policies in the context of management goals. Decisions will be made that some management scenarios are "better" or "worse" than others. The United States Fishery Conservation and Management Act includes the notion of *optimal use* as a goal of fishery management. Optimality is an inherently quantitative notion. A minimum requirement for the development of optimal policy is a consistent metric, or yardstick, that can be used to objectively compare policies. Although the goal of basing policy on an objectively determined optimum may be a naive hope and an impossible goal, the information required to make the attempt is essential. Science, after all, progresses most rapidly through the conflict between prediction and observation.

The information required to develop optimal policies is essentially the same as the information required to predict catch. Prediction of catch obviously requires the ability to make predictions about the resource, but catch ultimately depends on the users of the resource. Therefore, the prediction of catch also requires the ability to make predictions about the resource users. The information needed to make these two types of predictions should guide research for fishery management. Predicting effects of management actions on the resource and its users are essential components of any feasible policy evaluation metric. These predictions are achievable goals and could form the basis of research program. ***The ability to predict catch is a prerequisite to the development of optimal policy*** is therefore a potentially useful premise on which to construct an integrated research agenda. A unifying premise is the distinction between a research program that is merely multidisciplinary and a truly integrated approach. The need to make predictions about the resource leads to much of the research usually conducted under the rubric of "fisheries research". The need to make predictions about resource users leads to an agenda of social, cultural and economic studies that are *not* usually conducted under the rubric of "fisheries research".

Resource	Users
Forecast Population	Forecast Effort
Identify and Characterize	Identify and Characterize
Movement Between Fishing Grounds	Movement Between Fishing Grounds
Response to Exploitation	Response to Change in Resource
Response to Environment	Response to Economic Conditions
	Response to Changes in Policy

These two branches of inquiry concern the resource on one side and the users of the resource on the other. Viewed in this way, fisheries research is a set of parallel inquiries directed at the resource and its users. Making quantitative forecasts about resources is part of the normal fisheries research agenda. Making quantitative forecasts about resource users is apparently a novel and challenging goal for the social science community.

The usefulness of the "catch prediction" premise for policy development is becoming established. In Hawaii, one of the tools used by the WPRFMC to evaluate the current pelagic fishery management plan was a simple catch prediction algorithm or model that computed hypothetical catch levels under different management policies. Although this model lacked population dynamics and used simplified fleet dynamics, it was a useful attempt to understand implications of allowing varying numbers and types of fishing vessels to participate in the longline fishery.

A Catch Prediction Model

Models are useful, some would say essential, components of scientific research. In the most general sense, models outline the conceptual understanding of the phenomenon under study. The use of a model to shape a research agenda for resource management focuses attention on processes rather than problems. Understanding of processes enables researchers and managers to anticipate problems before they occur instead of reacting to problems in an *ad hoc* way.

Figure 4 outlines a conceptual model for policy optimization and catch prediction. This model explicitly includes the idea that exploitation couples two rather complex and disparate systems and attempts to decompose the problem of catch prediction into component problems. Research activities begin to suggest themselves as decomposition proceeds and information requirements become more specific. This model illustrates how analysis of a general model leads to specific information requirements and ultimately suggests research topics to appropriate specialists. If the model were complete, research activities would simply consist of projects to estimate quantitative relationships between model components.

Each of the boxes and arrows in Figure 4 can be further decomposed to yield specific research problems. Between 1993 and 1996 the University of Hawaii Pelagic Fisheries Research Program has implemented thirty-five different research projects addressing topics in most of the boxes in Figure 4.

Inspection of Figure 4 reveals two essential pieces of information required to predict catch: *population density* and *fishing effort*. In the past 10 years, considerable research effort has been directed to the creation of fish population dynamics models that explicitly include spatial structure and movement, for example Sibert (1984), Hillborn (1990), Kleiber and Hampton (1994), Sibert *et al.* (1996). These models appear to be successful in accurately predicting time and place of tag recapture. Further work, i.e. Mullen (1996) and Bertignac (in prep.), has extended this approach to modeling the age-structured population density on various spatial scales up to the scale of the Pacific ocean basin. Population dynamics models that explicitly

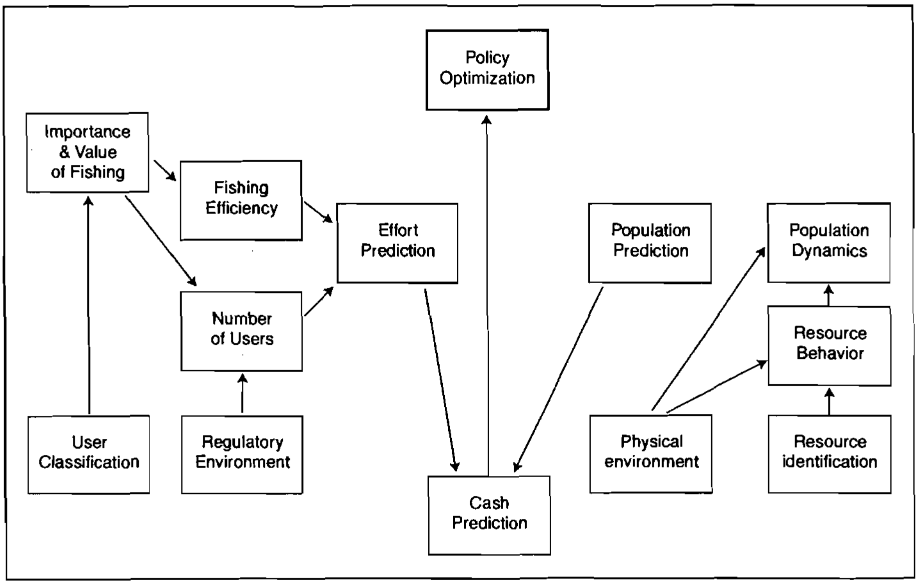

Figure 4
Information flow in a catch prediction and policy optimization model.

include movement, spatial structure of the habitat, and spatial variability in fishing are starting points for the development of complete catch prediction models. However, some substantial difficulties remain to be solved. It is at this point that models are of great value in shaping research priorities.

Measuring the amount of fishing. The ability of the populations movement models currently in use to predict catches depends on knowing the distribution and intensity of fishing. The population dynamics components of the models predict the general distribution of the population, but specific catch predictions depend on the amount of fishing at a particular time and place. These models "hindcast" catches provided adequate fishing effort data are available. The ability to "forecast" catches will depend on the ability to "forecast" fishing effort. This conclusion emphasizes the critical importance not only of *collecting detailed information from the fishery* on the time and place of fishing, but also of *research into fishing practices.* Understanding the complex interaction between fisheries policy, economic factors, social factors, and resource abundance in determining the time and place of fishing is a critical but sadly neglected research topic. Further, the relationship between catch and effort used in the computation of fishing mortality, sometimes known as "catchability", is known to vary in ways that are not well understood. Accurate forecasts of catch will require a more thorough understanding of the social, economic and ecological determinants of catchability.

Ecology and habitat. Population movement models currently describe large scale movements of fish in two fundamentally distinct modes. One movement description is most suited to the notion that fish have consistent, fixed migratory pathways. The tempo and direction of movement are strictly functions of season and locality. This model has proved useful in the analysis of skipjack and yellowfin tag recapture data. Alternatively, movement can be considered to be a function of habitat quality in the sense of MacCall (1990). Preliminary attempts to model large scale movement of tunas as a function of the thermal properties of the ocean show that some of the features of large scale movement and distribution can be attributed to sea surface temperature, thermocline depth and the gradients of these two variables (Sibert, unpublished). Tunas are also sensitive to other features of their environment such as forage abundance and oxygen. Incorporation of these variables has produced realistic models of skipjack distribution in the Pacific (Bertignac, in prep. and Lehodey, in prep.).

Conclusion

Beverton and Holt published their seminal book on the dynamics of exploited populations in the mid 1950's. Nearly every "new" idea in the analysis of fisheries to appear in the last 40 years data has its roots in this book. Of necessity, Beverton and Holt devoted a considerable amount of space in their book to the estimation of individual population dynamics parameters such as growth rate, mortality, and catchability. The parameters were then inserted into various models to attempt to describe responses of a population to exploitation. Furthermore, Beverton and Holt developed their models to analyze fisheries operating in relatively small areas in which omission of spatial structure caused few problems (perhaps). Their models also omitted the dynamics of the fishing process.

We now have computational and mathematical tools that were almost unimaginable 40 years ago. The simplifying that were necessary for Beverton and Holt are no longer supportable. Critical issues, such as spatial heterogeneity, age dependent mortality, and variable catchability, can now be treated in an integrated fashion. It is possible to conceive of population models that integrate all important features of population dynamics with the realistic expectation of simultaneously to estimating model parameters directly from fisheries data (e. g. Fournier and Hampton, 1996). Some fisheries scientists hold the view that stock assessment is a routine matter and that complex models are counter-productive luxuries. On the contrary, such models are essential if we are ever to test how our concepts of growth, mortality, movement and exploitation interact with one another and with the often meager information content of fisheries data. The results from such analyses will assist in determining pragmatically where to invest research dollars. We can extend ideas about the *dynamics of exploited fish populations* to embrace the dynamics of whole fishery systems. In short, we can begin to build a comprehensive theory of the *dynamics of fisheries systems*. The challenge of the twenty-first century will be to manage the world's fisheries at full exploitation. To meet this challenge we need tools that explicitly include the large scale complexities inherent in coupling of global systems.

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