Urban Coastal Area Management:

The Experience of Singapore

Edited by Chia Lin Sien and Chou Loke Ming

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Urban Coastal Area Management: The Experience of Singapore

Contents

List of Acronyms and Abbreviations

AOC	accidentally oil-contaminated
API	American Petroleum Institute
ASEAN	Association of Southeast Asian Nations
ASG	artificial seagrass
BOD	biological oxygen demand
Bt.	Bukit (in Malay, meaning "mountain" or "hill")
CAM	coastal area management
CFC	chlorofluorocarbon
CLRP	Coastal Living Resources Project
cm	centimeter
COC	continuously oil-contaminated
CPI	corrugated plate interceptor
CPOI	corrugated plate oil interceptor
CRM	coastal resources management
CRMP	Coastal Resources Management Project
DCE	Department of Civil Engineering
DOS	Department of Statistics
dwt	deadweight ton
ECP	East Coast Parkway
EEZ	Exclusive Economic Zone
ft	feet
FT	freight ton
g	gram
GDP	gross domestic product
GDS	geographically disadvantaged state
GNP	gross national product
GRT	gross registered ton
GT	gross ton
ha	hectare
HDB	Housing and Development Board
ICLARM	International Center for Living Aquatic Resources Management
IGCP	International Geological Correlation Programme
JICA	Japan International Cooperation Agency
JTC	Jurong Town Corporation

Kg.	Kampong (in Malay, meaning "village")
km	kilometer
LPG	liquefied petroleum gas
m	meter
MC	Marinescape Corporation
mg	milligram
mm	millimeter
MOCI	Ministry of Communications and Information
MOE	Ministry of the Environment
MOND	Ministry of National Development
MRT	mass rapid transit
MTI	Ministry of Trade and Industry
NA	not available
nm	nautical mile
NSTB	National Science and Technology Board
NUS	National University of Singapore
P.	Pulau (in Malay, meaning "island")
PATA	Pacific Area Travel Association
PCS	Petrochemical Corporation of Singapore Pte Ltd
PPD	Primary Production Department
ppm	parts per million
PRD	Parks and Recreation Department
PSA	Port of Singapore Authority
RSAF	Republic of Singapore Air Force
RSN	Republic of Singapore Navy
RSYC	Republic of Singapore Yacht Club
SAF	Singapore Armed Forces
SASAR	Singapore Association of Shipbuilders and Repairers
SBM	single buoy mooring
SDC	Sentosa Development Corporation
Sg.	Sungei (in Malay, meaning "river")
SHF	Sludge Handling Facilities
SL	standard length
SPBA	Singapore Power Boat Association
SS	suspendid solids
SSLC	Singapore Seasports Liaison Committee
SWF	Singapore Waterski Federation
t	ton
TAS	Telecommunications Authority of Singapore
Tg.	Tanjong (in Malay, meaning "cape")
TL	total length
tpa	tons per annum
UDMC	Urban Development & Management Company
UNEP	United Nations Environment Programme
URA	Urban Redevelopment Authority
USAID	United States Agency for International Development

UW	Underwater World
UWI	Underwater World International
UWS	Underwater World Singapore
VLCC	very large crude carrier
wt	weight

Preface

More than the coastal areas of the other countries in the Association of Southeast Asian Nations (ASEAN), those of Singapore have been intensively developed over the last three decades and have undergone a high degree of transformation. These massive changes have come about as a result of the need to achieve rapid economic and social advancements amid the severe constraints of limited land and seaspace. Unavoidably, development goals have for a long time taken precedence over environmental concerns which did not emerge as a major issue until the early 1970s. It was only in the 1980s when conservation for environmental as well as cultural and aesthetic reasons was given high priority as a matter of national policy. Thus, there is now a growing awareness among policymakers and the public to balance developmental goals with environmental imperativeness to achieve a high quality of life for Singapore and as befitting the status of an advanced society.

The ASEAN/US Coastal Resources Management Project (CRMP) is managed by the International Center for Living Aquatic Resources Management (ICLARM) in Manila, while its local component is administered by the Science Council of Singapore, now the National Science and Technology Board (NSTB). The project has involved the participation of the Marine Aquaculture Section of the Primary Production Department, Ministry of National Development and the National University of Singapore.

The Singapore component of the ASEAN-wide research project is divided into three subcomponents consisting of two field experimental studies: one on netcage culture and the enhancement of aquatic life in the Singapore and Kallang Rivers and the other on artificial reefs. The third subcomponent is aimed at putting together a database, mapping all elements found within the coastal zone of Singapore and developing a national management plan for it. The principle adopted for the plan is based on an integrated multisectoral long-term development strategy. An essential part of developing such a management plan is to understand the role, rationale and function of the various development agencies which are sectorally based and have been given the responsibility of managing the coastal resources, including seaspace, offshore islands and waterfront land on the main island of Singapore and of overseeing the proper development of the diverse activities and facilities found within the coastal area.

The Singapore National Workshop on Urban Coastal Area Management was a major step towards the completion of the CRMP which began in late 1986. The workshop brought together officials of government agencies, representatives of private organizations, researchers and academicians. They considered how the limited coastal resources can be better utilized and managed for the benefit of the nation. This volume comprises papers presented at the workshop. It is a prelude to the finalization of the management plan.

The achievements of the project thus far owe much to the strong support of the NSTB and, in particular, to the efforts of its two officers, Mrs. Rosa Tan and Ms. Koh Guat Wah. The help of Ms. Koh and her assistant, Ms. Betty Lim, was invaluable to the smooth organization of the workshop and contributed much to the enjoyment of all the participants. The organizing committee is indebted to Mr. Leslie John Cheong, the Project Leader, for providing assistance and facilities and to ICLARM, especially to Dr. Chua Thia-Eng, CRMP Coordinator, for giving personal encouragement, interest and enthusiastic support. Thanks also go to Dr. Alan T. White, CRMP Technical Advisor. I am grateful for the support of my colleagues, Associate Professors Chou Loke Ming, Wong Poh Poh and Dr. Habibullah Khan for their support and contribution to this workshop. These individuals have been sources of stimulation and encouragement to me. I appreciate the untiring assistance of Ms. Grace Lim, Ms. Maylene Loo, Mr. Christopher Chua and Ms. Beverly Goh during the workshop. Finally, thanks to Mrs. Irene Chee for her assistance and to Mrs. Tan Li Kheng, for her able cartographic work.

Chia Lin Sien
5 November 1990

Organizing Committee:

Dr. Chia Lin Sien	Chairman
Ms. Koh Guat Wah	Secretary
Ms. Grace Lim	Assistant Secretary
Mr. Leslie John Cheong	Member
Dr. Chou Loke Ming	Member
Dr. Habibullah Khan	Member

Foreword

The coastal waters of Southeast Asian countries have some of the world's richest ecosystems characterized by extensive coral reefs and dense mangrove forests. Blessed with warm tropical climate and high rainfall, these waters are further enriched with nutrients from the land which enable them to support a wide diversity of marine life. Because economic benefits could be derived from them, the coastal zones in these countries teem with human settlements. Over 70% of the population in the region lives in coastal areas where resources have been heavily exploited. This situation became apparent between the 1960s and 1970s when socioeconomic pressures increased. Large-scale destruction of the region's valuable resources has caused serious degradation of the environment, thus affecting the economic life of the coastal inhabitants. This lamentable situation is mainly the result of ineffective or poor management of the coastal resources.

Coastal resources are valuable assets that should be utilized on a sustainable basis. Unisectoral overuse of some resources has caused grave problems. Indiscriminate logging and mining in upland areas might have brought large economic benefits to companies undertaking these activities and, to a certain extent, increased government revenues, but could prove detrimental to lowland activities such as fisheries, aquaculture and coastal tourism-dependent industries. Similarly, unregulated fishing effort and the use of destructive fishing methods, such as mechanized push-nets and dynamiting, have seriously destroyed fish habitats and reduced fish stocks. Indiscriminate cutting of mangroves for aquaculture, fuel wood, timber and the like has brought temporary gains in fish production, fuel wood and timber supply but losses in nursery areas of commercially important fish and shrimp, coastal erosion and land accretion.

The coastal zones of most nations in the Association of Southeast Asian Nations (ASEAN) are subjected to increasing population and economic pressures manifested by a variety of coastal activities, notably, fishing, coastal aquaculture, waste disposal, salt-making, tin mining, oil drilling, tanker traffic, construction and industrialization. This situation is aggravated by the expanding economic activities attempting to uplift the standard of living of coastal people, the majority of whom live below the official poverty line.

Some ASEAN nations have formulated regulatory measures for their coastal resources management (CRM) such as the issuance of permits for fishing, logging, mangrove harvesting, etc. However, most of these measures have not proven effective due partly to enforcement failure and largely to lack of support for the communities concerned.

Experiences in CRM in developed nations suggest the need for an integrated, interdisciplinary and multisectoral approach in developing management plans that will provide a course of action usable for the daily management of the coastal areas.

The ASEAN/United States (US) Coastal Resources Management Project (CRMP) arose from the existing CRM problems. Its goal is to increase existing capabilities within ASEAN nations for developing and implementing CRM strategies. The project, which is funded by the US Agency for International Development (USAID) and executed by the International Center for Living Aquatic Resources Management (ICLARM) in cooperation with ASEAN institutions, attempts to attain its goals through these activities:

- analyzing, documenting and disseminating information on trends in coastal resources development;
- increasing awareness of the importance of CRM policies and identifying, and where possible, strengthening existing management capabilities;
- providing technical solutions to coastal resources use conflicts; and
- promoting institutional arrangements that bring multisectoral planning to coastal resources development.

In addition to implementing training and information dissemination programs, CRMP also attempts to develop site-specific CRM plans to formulate integrated strategies that could be implemented in the prevailing conditions in each nation. To date, these management plans have essentially reached the final phase of completion and require approval, endorsement and funding for implementation.

In holding the Second National Workshop on Urban Coastal Area Management on 9-10 November 1989, the island-state of Singapore reaffirmed its commitment to continue to address the issues and problems posed by the imbalance between developmental goals and environmental concerns. The country's firm resolve is outlined in the 18-point recommendation proposal made at the close of the workshop.

Urban coastal area management: the experience of Singapore bears testimony to the enormous commitment and hard work elicited from the workshop's speakers and participants. The efforts of the workshop's Organizing Committee are greatly appreciated.

At ICLARM, grateful acknowledgement is extended to the following for their invaluable assistance: Dr. Kenneth T. Mackay and Mr. Jay L. Maclean, for their technical reviews; Marie Sol M. Sadorra and Cecille Legazpi, for copyediting the papers; Rachel C. Josue, Ma. Teresa G. Cruz, Ma. Cherryl C. Roxas and Ariel Aquisap, for typing them; and Rachel Atanacio and Reynaldo Silvestre, for drawing some of the figures and preparing the layout.

Chua Thia-Eng
Project Coordinator
ASEAN/US Coastal Resources
Management Project

Opening Address

Singapore's Coastal Area Development: Promises for the 1990s

GOH CHEE WEE
Chairman, Government Parliamentary Committee on the Environment and Member of Parliament for Boon Lay

The coastal zone of Singapore, comprising the waterfront land, offshore islands and surrounding water, represents a very large part of the physical environment. Thus far, our nation's development has been confined primarily to its land area. Such a land-based mentality has tended to limit our horizon to the coastline. But increasing attention has been and continues to be drawn to the surrounding seaspace.

The major existing uses of the waterfront land have been port and industrial developments as well as for coastal parks to provide the much needed outlets for busy Singaporeans. To fully maximize the potentials of this waterfront land, we need to evaluate the special qualities presented by the interface between land and water.

The waterfront of the city center has undergone very great changes as a result of reclamation works which have added highly valuable land to the existing stock of commercial lands. A recent publication of the Urban Redevelopment Authority shows that the entire urban waterfront land will be developed and that we will see, over the next few decades, an entirely new skyline viewed landward from the sea. This development will be exciting and promises to support the physical development of our urban center. Moreover, the imaginative planning of waterfront development for a mixture of offices, services, tourist-recreational facilities, shopping and residential areas will add a new vitality and enhance the quality of life for Singaporeans. However, we must not forget that there are traditional uses of the coast for fishing, fishfarming, recreation, *kampong* settlement and a wide range of other miscellaneous uses. I have been informed that the workshop will consider at length how Singapore's limited coastal area and the resources found therein can be better and more fully utilized. Certainly, given the comparative advantage of each use, a way should be found to accommodate the rich and varied range of coastal uses to inject a greater interest in the seas around us.

An important part of the workshop's discussions will deal with environmental pollution and coastal resources degradation. Over the last two decades, we have come a long way to minimize the pollution in our environment with a series of environmental acts starting with the Environmental Public Health Act in 1970, the Clean Air Act and the Prevention of the Pollution of the Sea Act in 1971 and the Water Pollution Control and Drainage Act in 1975. The Antipollution Unit was likewise formed in 1971 followed by the establishment of the Ministry of the Environment in 1972. The Ministry, together with a number of agencies such as the Port of Singapore Authority and the Public Utilities Board, has been tasked to safeguard our environment. The evidence of their success is clear for all to see.

While much has been achieved on land, a great deal is left to be done for our coastal waters. Research has shown that the level of toxic materials in the sea is still acceptable by international standards, but that it should still be brought down to much lower levels to ensure the health of bathers. Moreover, as long as land reclamation continues, the silt content and the turbidity of the water will remain high. But have we done all we can to prevent silt from being dispersed widely? Are our standards for the discharge of industrial effluents and wastewater sufficiently stringent to ensure that our coastal waters remain clean and safe? Are there enough safeguards to ensure that the increasing number of ships found in and that pass through our port waters do not deliberately or accidentally discharge oily water and waste into our seas?

I understand that there is a suggestion to establish one or more marine conservation areas within the Southern Islands and elsewhere. This should be strongly supported because it will serve as an impetus for greater efforts to be made to prevent the deterioration of our marine environment and to make our seas lively again. It would be wonderful to have, within our territorial waters, sparkling clean waters teeming with plant and fish and our coral reefs preserved. Such a marine park will not only provide an additional recreational facility for all Singaporeans but also be a valuable tourist attraction.

Ladies and gentlemen, I wish you all the success in your deliberations. It gives me great pleasure to declare this workshop open.

Keynote Address

Coastal Area Management: New Possibilities for Singapore

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Abstract

The paper first discusses the nature of the coastal environment, the historical development of urban centers along the coast within the Southeast Asian region and the value of coastal resources for economic and social welfare before proceeding with the objectives of coastal area management (CAM). Among the management issues included are how best to satisfy developmental requirements while accommodating environmental needs to cater to the growing demand for the use of coastal resources for recreation and tourism. Highlighted are the new possibilities for utilizing coastal resources such as the creation of a marine park within the Southern Islands and the proposed residential developments on the coastal sites of Simpang, northeast of Singapore, and of Bugis in the Kallang Basin.

Introduction

In order to plan an island city-state for an eventual population size of around 3.5 to 4 million, it is essential for the nation to make possible all that it can use of its limited area and resources. Thus, the coastal area of Singapore, which is in many respects underutilized, deserves the greatest attention from those concerned with national development. Our island republic is already highly urbanized, having built up nearly half of its total land area. Its economy has been growing healthily and continues to expand. Its population with a per capita gross national product (GNP) of S$16,000[a] has become affluent. Moreover, the demand for more space for a variety of our needs and more amenities for our leisure activities has made it necessary that the frontier of the coast is not

[a]December 1988: S$1.00 = US$0.514.

simply extended but that the limited coastal area comprising the coastal land of the main island, the offshore islands and all of its territorial waters is also utilized in an optimal fashion for the greatest benefits now and in the future.

To do this, we need first to understand the physical and biological nature of the coastal area and second, to find out how this area and its resources can be utilized. Indeed, efforts have already gone into understanding the coastal environment and resources (Chou and Chia 1991) and the utilization of the offshore islands (Chia and Khan 1987). A profile of the coastal environment of Singapore based on available information has also been recently made (Chia et al. 1988). Still, there is more to be done.

This paper begins by exploring the nature of Singapore's coastal environment and then examines the use of coastal resources for urban, industrial and other developmental purposes within the context of the Southeast Asian region. The exercise is intended to gauge the development of the country's coastal area compared to others in the region; bring about a thorough understanding of the relationship between the natural coastal environment and the developments that have taken place on the island; and thus identify pressing issues that may also confront other coastal urban areas. The workshop's main concern, however, is directed at the national scene. The latter part of the paper examines the pattern of coastal resources use in Singapore and suggests some management possibilities in order to maximize the benefits these will give to the economy and the people.

The Nature of the Coastal Environment

The sea has always evoked feelings of mystery, romance, excitement and challenge. There is an indefinable quality about the atmosphere along the seafront and over the sea. The sea's intensity, tone of light and color change from day to day can elicit different moods from the beholder. Depending on the time of the day and the state of the weather, the sea can be brilliant, vibrant and angry on one occasion and, on another, brooding, morose and dark with a sense of foreboding. The seascape also changes according to its type of coast--flat or hilly, sandy or rocky, bare or vegetated, sand-duned or cliff-lined, open sea or island-strewn. The contrast in the texture, color, lineage and form between the land and the sea always lends interest to the coast. Over the centuries, artists, poets, writers and musicians have repeatedly drawn inspiration from the sea.

Man has regarded the sea both as a friend and an enemy, for in many coastal areas, natural disasters such as tsunamis and typhoons can wreak havoc and death. Thus, not surprisingly, the coastal waters are said to have become the dwelling places of spirits and dragons. There are many taboos and tales of the supernatural associated with the sea, signalling the fear and respect the power of the sea can evoke. There are also numerous legends associated with it, spawning the rise of many sacred and forbidden places in it and along the coast. As a result of these, many shrines and temples were built by coastal settlers to seek divine protection and succor from the sea. Some of these holy places later evolved into venues for religious festivals, social gatherings and centers for learning and medical practice.

In scientific terms, the coast represents the interface between the land and the sea. The interface is not a surface but a zone of some considerable width with a magnitude that may be determined by the mutual intrusion of many influences into each other's domain. The transfer of freshwater, nutrients, sediments and pollutants originating from the land can extend hundreds of kilometers seaward, while the intrusion of saltwater into the soil--helped by the agency of rivers--and airborne salt particles, moisture and heat can extend equally far inland. The intertidal zone is one of the most productive of all habitats. Many species of marine organisms depend on the supply of nutrients and materials from the land while plants (e.g., mangroves) respond and adjust to the influences originating from the sea and the land.

Biologically, there is an interdependence between life forms on land and in the sea across the coastline. Physically, the coastal seabed is continually modified by the supply of sediments from the land while the salinity of the coastal waters is changed by the influx of land-derived freshwater and materials. On some stretches of the tropical coast, storm-generated winds and the resulting high sea conditions can strongly modify sand dunes and erode or build beaches and other coastal features. Along low-energy coasts, the interaction between the land and the sea is far less dramatic but no less important and pervasive.

It is thus not possible to provide an unequivocal definition of the coastal zone in terms of its detailed characteristics and extent, for definitions tend to be modified depending on the way the coastal resources are used, as in the case of a biologist who would see the coastal area differently from, say, an engineer. Moreover, Singapore's territorial seas may be regarded as forming part of the coastal area, while the whole band of 200 nautical miles (nm) of the Exclusive Economic Zone (EEZ) may be considered, for management purposes, to be part of the coastal zone of countries with an open coast. On the other hand, the landward margin of a coastal area may be delimited by its distance from the coastline where marine influences are significant. Thus, in assessing the coastal zone of urban Singapore, it may be best to consider the landward boundaries of its waterfront properties although, for some purposes, the whole island may be regarded as coastal in nature.

Urban Development Along the Coast

Turning to coastal urban development, the coast has always been a favored site for population settlements in most parts of the globe. In tropical Southeast Asia, coastal settlements are common because of the readily available sources of food and other resources. Thus, some settlements became the premier urban centers for many ancient political entities. However, because some form of protection or defense was necessary for these settlements, many moved away from the open coast to more sheltered and strategic positions.

Both pre-European and Western colonial powers selected the coast, often at the estuaries of large rivers, to set up their centers of trade and administration. Since then, these centers have thrived and developed into "million cities" and great metropolises, of which Singapore is one among many.

However, cities such as Bangkok, Yangon (previously Rangoon) and Hanoi are estuarine rather than coastal urban centers. For some places, such as the littoral urban settlements along the east coast of Sumatra and parts of the Sarawak coast, extensive mangrove swamps have inhibited their development. On the other hand, cities like Medan can be broadly considered coastal in nature. In the case of Bandar Seri Begawan (capital of Brunei Darussalam), a part of its settlement in Kampong Ayer is actually built over the water of a river mouth. This practice has been rediscovered by modern cities, such as Hong Kong and those in Western-developed countries.

Strong historical, political and economic interests can be found in coastal cities and settlements. Many large coastal metropolises have also become centers of religious activities since statecraft and religion tended to reinforce each other in many of the countries within the region--the linkage being stronger for earlier nation-states and tending to be weak or deliberately separated for present nation-states. As a result, these cities emerged as the foci of education, culture and scientific innovations.

Valuable Coastal Resources

Those who live by the sea, such as *kampong* dwellers, benefit from the generous harvests of products of the sea. The coast is rich with a wide variety of biota, many of which are edible, useful and of commercial value. These have been exploited by coastal dwellers as materials for shelter, utensils and food as well as products for sale and exchange. Along much of the Southeast Asian coast, large numbers of the population are composed of poor fishermen and fish cultivators. For many of them, fish and shellfish are major sources of food and protein. Thus, there is a very high potential for coastal aquaculture which has been hailed as the answer to a large part of the problem of providing food for Third World countries. Apart from their living resources, coastal areas have also been exploited for their nonliving resources such as sand and mineral deposits.

The coast can also be considered an important resource in providing sites for seaports and terminals required for the transfer of cargoes and passengers from land to sea and vice versa. Indeed, the contribution from the operation of seaports for all of the major coastal cities is considerable in terms of the value of the services rendered. The spin-offs and direct and indirect linkages to the ports produce substantial financial benefits for the countries concerned and, generally, have been regarded as necessary prerequisites for the economic and social development of the hinterland.

Meanwhile, there is a wide range of marine industries, such as the building and repairing of ships, rigs and marine structures, and the supply of equipment and other materials for offshore oil drilling and exploitation as well as mining operations, to name a few, that require waterfront locations for the transfer of bulk products for trade or for use and consumption. Other industries include electric power generation; refining of oil and natural gas; petrochemical and chemical manufacturing; warehousing, storage and distribution of bulk, liquid and other products; processing of raw materials as in the making of cement, smelting of ore, and flour- and feed-milling; and many others. The combined services and outputs of these industries can be very large.

The development of coastal resources for recreation and tourism is becoming an increasingly important industry for many countries including those in the Association of Southeast Asian Nations (ASEAN) region. For some islands, tourism is the main source of revenue and employment for the entire community. Beaches, scenic sites, clean water, coral reefs and good recreational fishing grounds have indeed become valuable resources for tourism, education and scientific study. In recent years, the awareness of the need to preserve and conserve these resources has been heightened.

Purpose of the Workshop

The foregoing discussion on coastal resources brings us to a consideration of the purpose of this workshop. The workshop brings together researchers and practitioners concerned with the coastal zone and all its varied uses to an exchange of information and ideas. The tasks of the researchers are to: 1) gather information on the coastal area, its physical and biological characteristics, and its past and present patterns of utilization; 2) analyze the changes and factors that bring these about; and 3) raise issues concerning the uses and offer suggestions for the resolution of the issues.

Some of the workshop's participants include the policymakers, the users of coastal resources and practitioners involved in reshaping coastlines and seabeds. The participants are drawn from a wide range of disciplinary backgrounds--management, social sciences, law, engineering, science and planning.

The workshop then provides an opportunity for the users of resources to give other participants an account of their objectives, strategies, activities, needs, constraints and problems. An orientation on and appreciation of the resource uses will help identify the other uses of hitherto unused, misused or underused resources; improve coordination among the various users within the same locality; and find ways to avoid conflicts so that more benefits can be derived.

Recognizing that our coastal resources are valuable, limited and easily subjected to degradation through pollution and improper and unwise use, it is hoped that this meeting will help to develop a system of managing them with the view to increase, balance and optimize their use. It is also hoped that this meeting will help policymakers to formulate management strategies, identify instruments (legal, educational or otherwise) and establish appropriate administrative structures to help conserve, enhance and develop coastal resources.

The above broadly defines the objectives of CAM which can be summarized as follows:

- to promote the integrated multisectoral use of coastal resources to maximize their benefits;
- to identify and avoid conflicts on two or more resource uses;
- to minimize the damage to and the degradation of limited coastal resources;
- to promote the protection and conservation of coastal and marine ecosystems and the enhancement and revitalization of living coastal resources;
- to formulate policies to guide future resource management plans; and
- to identify and develop appropriate forms of management strategies and instruments.

Discussion of Issues

To stimulate discussion, this section highlights a number of issues within the Singapore context for consideration during this workshop. These include the following:

- Are the above objectives appropriate in the context of Singapore's local coastal environment and socioeconomic and political systems?
- How can we balance developmental against environmental needs, bearing in mind the present stage of development?
- Is there a need to restore the original state of the coastal environment?
- What form of management structure should be adopted to best meet the objectives?
- What role should government play and how may private initiatives be incorporated to help manage coastal resources?

There are many other questions that can be raised. The following sections seek to expand on these issues, while it is hoped that the workshop will identify and discuss them more fully.

Meeting developmental needs

There are many urgent developmental needs, especially for a fast-growing economy, that can be met with the use of coastal resources. The brief discussion above on the value of coastal resources has indicated their several uses, all of which generate substantial income, employment and other benefits. Indeed, there has already been a tremendous amount of investments in building and improving the infrastructure, plants, equipment, vessels, buildings and others within the coastal area. These investments in turn have produced a stream of goods and services which have contributed significantly to the national economy (see Khan, this vol.).

While meeting developmental goals has been and must remain the uppermost priority, they have been achieved not entirely without cost in terms of environmental and ecological damage, removal of pollutants and loss of benefits through the curtailment of previous forms of uses (Chia 1991). Some of these costs can take the form of less evident and often subtle changes as in the loss of scenic quality, clean water and marine life. Since some of these changes occur underwater, the losses may not even be readily perceived. Thus, while the benefits may be quite easily measured, the costs when accumulated over time from the present may be considerable and difficult to measure.

An example of this conflict between meeting developmental needs and experiencing the adverse consequences they generate can be seen in the industrialization of some of the Southern Islands. Before the islands underwent improvements and became sought after for sea bathing and several water sports and recreational activities, they had clean water and beaches, healthy coral reefs and abundant marine and bird life. The improvements were made despite the considerable losses sustained. No attempt had been made to put a value to the amenities, but if the numbers of fish and other marine products from the islands that will be used as food and as valuable commercial items and the thousands who will visit the islands and avail of its facilities were multiplied over time, these will prove to yield substantial benefits. Thus, the project was pursued because the benefits to be generated from the industrial use of the islands and its surrounding waters outweighed the retention of the islands' original natural form.

It is hoped that similar studies will be attempted in the future to provide a more accurate valuation of our coastal resources and, in the end, resolve the conflicts that modernization brings.

Meeting the environmental challenge

It is no accident that the recently concluded meeting of the Commonwealth Heads of Government in Kuala Lumpur has elected to focus on environmental issues (*Straits Times*, 17 October 1989), adopt the Langkawi Declaration on the Environment and set up a global fund to help save the world's environment (*Straits Times*, 21 October 1989). These programs of action can be attributed in part to the special attention to be given by the United Nations to environmental protection in the next decade. These concerns also rise from the real fear of the devastating consequences resulting from the increased output of carbon dioxide into the atmosphere that will lead to global warming, the rise of the sea's level and the depletion of the ozone layer in the stratosphere. Generated by man's activities in burning fossil fuels and destroying forests, on the one hand, and extensively and heavily using chlorofluorocarbons (CFCs), on the other, these environmental hazards pose considerable threats that will require the development of coastal area management plans, which must take these threats into account, to remain effective in the long run.

Our country's concern for the environment dates back to the early 1970s when the Ministry of the Environment (MOE) was established. It came at a time when the country had resolved some of its urgent problems of economic growth, unemployment and lack of housing through efforts in the 1960s. Since then, much has been achieved in creating a "garden city" and a "clean and green environment" for Singapore. While impressive progress has been achieved on land, it is safe to say that there remains much that can be done to protect, conserve and enhance our coastal and marine environments.

In the 1980s, there was a new phase of environmental consciousness which led to major efforts in environmental conservation. Two major efforts--one, the ten-year program of cleaning up the Singapore River and the Kallang River Basin and the other, the conservation of historic Singapore--illustrate this new direction. The cleaning up was coordinated by MOE and undertaken jointly by a number of ministries, including the Ministry of National Development and the Urban Redevelopment Authority (URA). But there remains the problem of maintaining and further improving the river and basin. On the other hand, the example of urban conservation under URA signifies that the country has begun to come of age and is anxious to strengthen its national identity.

Relating the new and ongoing conservation efforts to the topic of our discussion, we wish to point out that it remains for the Primary Production Department to undertake the stocking of the Singapore River with fish and prawns and to investigate the possibility of enhancing marine life through the use of artificial seagrass. We shall learn more about this in the workshop. On the efforts of our colleague, Dr. Chou, and his team of researchers in investigating the propagation of coral reefs and the creation of artificial reefs under the ASEAN/US Coastal Resources Management Project (CRMP), these are intended not only to conserve but also to regenerate and rehabilitate our marine ecosystem (Chia et al. 1990; Lim et al. 1990). It might be added that there can be substantial benefits from the better management of areas of our coastal environment geared towards recreation and tourism development as well as from the enhanced satisfaction of realizing the nation's goal of a heightened environmental quality.

Meeting new needs for recreation and tourism

As the population increases and the country becomes affluent, there will be a greater consciousness and eventually, a growing demand for good health, more recreational facilities and better living conditions, i.e., a higher quality of life. This demand can be met by providing for more and better nature reserves, bird sanctuaries, mangrove areas, parks, beaches and other facilities along the coast and on the islands, waterfront land for boaters, marinas and landing sites, and clean and safe water for seasports. Moreover, with the increasing number of both local and expatriate populations taking up some form of marine-related leisure activity, such as swimming, windsurfing, sailing, fishing, snorkeling and scuba diving, facilities should be made available to cater to these needs. Such efforts to provide and improve local amenities may even induce more Singaporeans to stay in the country rather than incur the expense of going on a tour outside the country, hence, saving Singapore's foreign exchange.

Considering that tourists are generally more demanding about the quality of the facilities and the scenic beauty of the holiday resorts they go to, it is necessary to offer them, apart from providing hotels and recreational facilities, high environmental quality to meet their requirements and lengthen their stay in the country. To achieve these, costly landscaping, creation of artificial beaches, erection of protective works on the shore and filtration of the seawater in lagoons and swimming pools are often necessary. Physically separating or visually shielding unsightly industrial facilities from sites given over to tourist development could be achieved through zoning regulations. Marine pollution must also necessarily be minimized and avoided.

New Possibilities for Utilizing Coastal Resources

The call for establishing a marine sanctuary or park within the Southern Islands area has been made by Chia (1991). The proposed scheme was to set aside the eastern portion of the Southern Islands--including the islands of Pawai, Senang and Sudong within the Live Firing Zone and those bounded by the Keppel Harbour area like Sentosa and Labrador Park--as a marine conservation area. The core of the area was to be designated as a marine park protected from all uses and open only to a limited number of visitors on a "see, no touch" basis. Such a scheme would make possible the vision of an area in Singapore where its clear waters teem with a rich and plentiful marine life and where the public and tourists alike can enjoy the experience of seeing and being surrounded by myriads of fish among our coral reefs.

The Minister of National Development, Mr. S. Dhanabalan, in a speech given at the Opening Ceremony of the Second International Convention on Urban Planning, Housing and Design on 27 July 1989, announced that two coastal sites--a 900-ha site in Simpang on the northeastern coast and an 80-ha site at Kampong Bugis along the Kallang River--would be set aside for those in the private sector so that they can participate in the planning process (Dhanabalan 1989). Two architectural and planning firms were selected to undertake development guide plans for the two sites, while URA planners were to develop independent guide plans for the same area. It is envisaged that the resulting plans would be highly innovative and imaginative and give much greater attention toward integrating the development of the waterfront and incorporating marine elements into the plans.

Many projects are also being undertaken on Sentosa and other islands for tourist, recreational and residential developments. It is clear that more of these projects will be proposed and implemented. Based on the approach adopted by the ASEAN/US CRMP, these possibilities and potentials can best be realized with sound planning in an integrated, multisectoral manner.

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Management and Utilization of Singapore's Port Waters: New Directions

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Abstract

The sea is a national resource on which Singapore's well-being depends to a large extent. Because of the country's limited seaspace, it is important to manage it well. This paper presents a master plan of the sea being formulated by the Port of Singapore Authority (PSA) to maximize the use of the waters for port development and marine-related services. It discusses the distribution of the port waters for marine uses and some of the existing cables and flight path zones.

To fulfill the PSA's corporate mission of making Singapore a premier maritime center, it will adopt a more proactive strategy in managing the port waters. Pockets of people-oriented recreational facilities will also be allowed in areas where they do not significantly affect port operations and services. In other words, besides playing a regulatory role, PSA will fulfill a business development role in promoting and generating shipping activities for the port.

Finally, this paper highlights the main planning considerations to be adopted by PSA which includes the promotion of a strategy of coexistence, the differentiation of port waters by location and economic usage, the institution of efficient marine monitoring and control systems, and the undertaking of fairway engineering projects.

Introduction

The sea is a national resource and our nation's well-being depends to a large extent on how well we manage our limited seaspace. Hence, it is necessary to strike the right balance between land and water in our national development strategies by taking into account that our port is the busiest in the world and that the volume of shipping traffic will continue to grow as Singapore prospers and matures into a developed economy.

Our port is administered by PSA, a statutory board under the Ministry of Communications and Information. The PSA is responsible for the provision and maintenance of port facilities and services and the control of sea traffic and navigation within our port waters. These include a comprehensive range of marine services such as the provision of bunker fuel, pilotage and tug, freshwater services, gas-free inspection and fumigation, and slop reception for oil tankers. Environmental control services, such as cleaning oil and debris from the sea and firefighting, are also provided. The PSA operates five terminals with about 15 km of wharf front that can accommodate container ships, bulk carriers, freighters, coasters and passenger liners. The terminals are the Tanjong Pagar Container Terminal, Keppel Wharves, Pasir Panjang Wharves, Sembawang Wharves and Jurong Port (see Fig. 1). The last is owned by the Jurong Town Corporation, but managed by PSA on its behalf.

Apart from being responsible for providing port-related services, managing port waters and controlling navigation, PSA undertakes reclamation works for the expansion of wharf and berthing facilities; and dredging to deepen waters and thus, improve the conditions for navigation and port-side activities.

The PSA's mission is to be an excellent global hub and to make Singapore a premier maritime center. Its social responsibility to the nation consists of maintaining a clean and safe marine environment for the enjoyment of the public. Hence, strategic planning is of paramount importance to optimize the use of Singapore's scarce port waters.

Our port waters have a total area of 561 km^2. This is equivalent to 88.5% of our total land area of 634 km^2. Only 45% of this seaspace is available for the unrestricted use of ships that call at our port. Military live firing zones, airport height-restricted areas and submarine cables have placed constraints on our efforts to maximize the use of our port waters.

Port Waters

Port waters refer to water within our port limits that are under the management of PSA (see Fig. 1). Although port waters cater to the needs of a wide spectrum of users, the highest demand arises from the vessel population. In 1988, about 36,000 vessels passed through Singapore which means that a ship either left or entered the port every 7 to 8 minutes.

As shown in Fig. 1, about one-fifth or 18.8% of our port waters are demarcated as anchorages. Including fairways and vessel maneuvering areas, a total of about 45% of seaspace is used unrestrictedly by ships calling at our port. The section below discusses in detail the use of anchorages as well as the use of port waters for underwater cables and pipelines, jetties and military purposes.

Anchorages for Ships

The utilization of anchorages will increase with more vessels calling at our port. Vessel traffic arrival is estimated to increase by 3% annually. The trend and projection of ship arrivals from 1973 to 1993 are shown in Table 1. In view of the anticipated increase in future arrivals, proper management and administration of anchorages will be needed to meet the increasing number of shipping activities and to ensure that navigational safety will not be compromised.

Table 1. Ship arrivals in Singapore, 1973-1988 and projections to 1993.

Year	No. of arrivals	Percentage increase with 1973 as base
1973	18,916	0.0
1978	24,406	29.0
1983	30,287	60.1
1988	35,966	90.0
1993	43,445	129.6

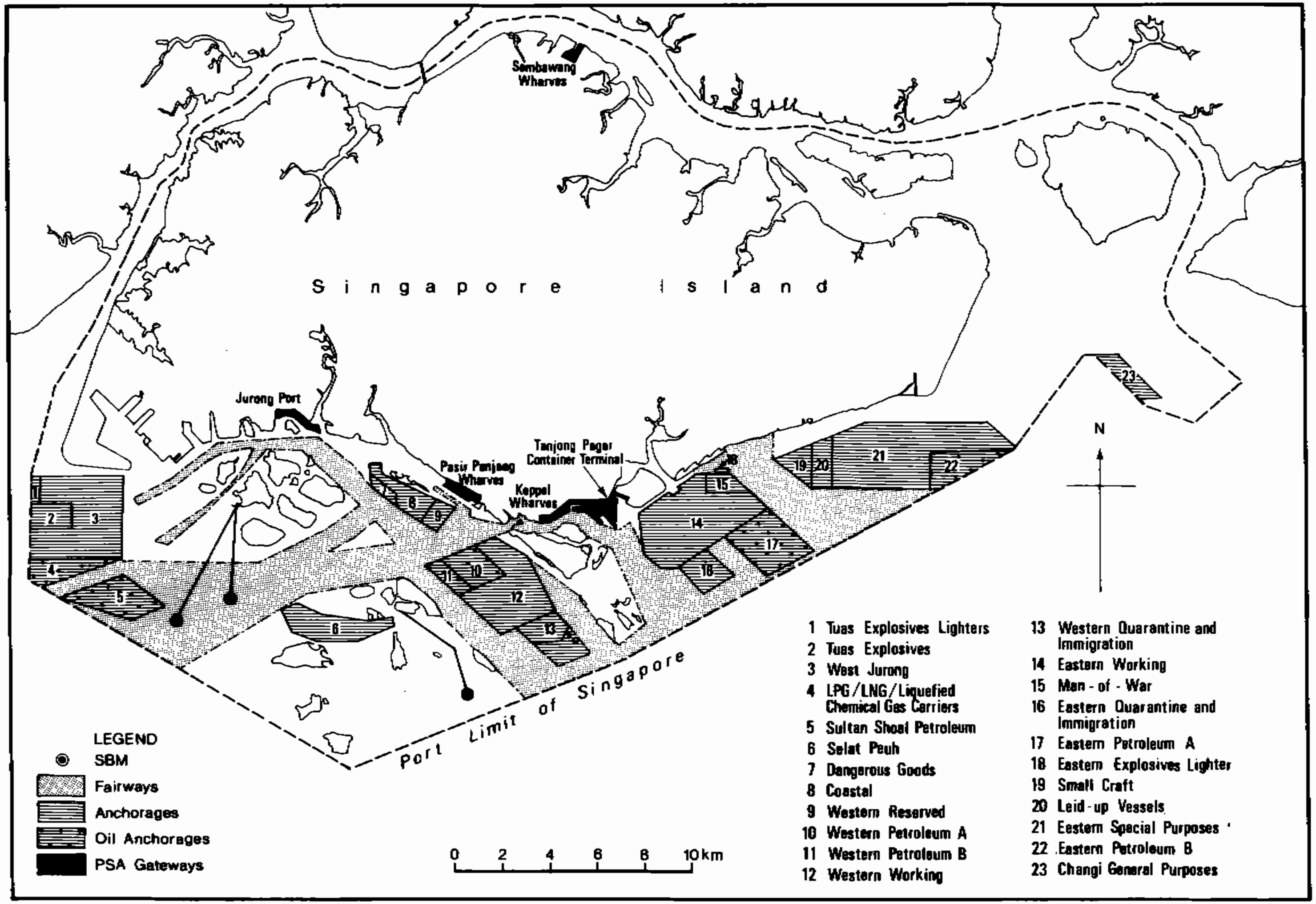

Fig. 1. Location of SBMs, fairways, anchorages, oil anchorages and PSA gateways in Singapore's port waters.

Table 2. SBMs, fairways, anchorages, oil anchorages and PSA gateways in Singapore's port waters.

Function	Western sector	Eastern sector
Dry cargo ships	West Jurong Western Working	Eastern Working
Tankers	Sultan Shoal Petroleum Western Petroleum "A" Western Petroleum "B"	Eastern Petroleum "A" Eastern Petroleum "B"
Liquefied gas carriers	Liquefied Gas Carrier	-
Small crafts	Pasir Panjang Lighter Mooring[a]	Small Craft Anchorage
Man-of-war	-	Man-of-war
Working dangerous goods	Dangerous Goods	-
Working explosives	Tuas Explosive Tuas Explosive Lighter	Eastern Explosive Lighter
Working dry cargoes	Pasir Panjang Coastal Anchorage	-
Obtaining health and immigration clearances	Western Quarantine and Immigration	Eastern Quarantine and Immigration
Laying-up	Selat Pauh	Eastern Laid-up
Reserved anchorage	Western Reserve	Eastern Special Purpose
General purpose	-	Changi General Purpose

[a]This is considered as a mooring area and not as an anchorage.

Distribution

Anchorages are located in the southern belt of our port waters. As shown in Fig. 1 and in Table 2, there are 10 anchorages in the eastern sector and 13 anchorages in the western sector. The anchorages employ a total of 5 basic vessel types and 7 activities as grouping parameters (Table 2 and Fig. 1). These are:

- By vessel type: petroleum tanker, liquefied gas carrier, dry cargo vessel, small craft and man-of-war.
- By activity type: working dry cargo, working explosive, working dangerous goods, obtaining health and/or immigration clearances, lay-up, special/reserved activities and general purpose.

Uses

Although 23 anchorages were created to provide the 12 recognized functions, their use by vessels could be grouped into three--as waiting areas, as alternatives to berths and as service bays.

As Waiting Area. Use of anchorages by vessels waiting for a berth will continue to be required by all categories of vessels. These include bunker barges which are required to share oil terminals with commercial tankers and to wait at anchorages for the arrival of their customers' vessels.

As Alternative to Berths. Anchorages used by dry cargo vessels increase their port cargo handling capacity without the need for additional berths. As supplements to berths and yard spaces, anchorages are most efficiently utilized by the ship repairing industry for such requirements as draft adjustments, gas-free inspections and afloat repairs.

As Service Bay. More than 30% of ship arrivals call at our port primarily for ship services such as bunkering, supplies and crew change. These are conducted purely at the anchorages without the need to berth. As these ship services require only a short stay, the anchorages provide a high turnover of port water utilization.

As mentioned earlier, the use of anchorages is primarily by vessel type segregation. However, as the pattern of vessel type arrival is largely dictated by market forces, the combination of these two factors have led to the congestion of use in four anchorages: Sultan Shoal Petroleum, Western Petroleum, Eastern Petroleum and Pasir Panjang Coastal Anchorages. The other 19 anchorages are relatively underutilized.

Management

The present system of managing anchorages will have to be changed to cater to the expected increase in vessel traffic in the port. There are three compelling reasons for this new strategy:

1. At present, anchorages are not evenly utilized, so their maximum use as a resource has not been exploited.
2. The present system is not geared towards facilitating higher economic benefits.
3. If we are to become a major one-stop maritime service hub, the use of anchorages must respond to the demand of all market segments, including the needs of vessels calling at Singapore purely for ship services.

Underwater Cables and Pipelines

Underwater cables and pipelines are used for the supply of utilities (water and electricity); the movement of oil from single buoy moorings (SBMs) to a refinery, the setup of a telecommunications link and the supply of natural petroleum gas from neighboring countries to Singapore. Presently, 28.8 km^2 or 5% of port waters have restricted use due to the presence of unburied cables or pipelines (Fig. 2).

To minimize the proliferation of cables and pipelines on the seabed which will restrict the use of our anchorages and affect the depths of our fairways, PSA is considering the establishment of a national integrated seabed tunnel pipeline and cable system. Under the system, cables and pipelines to and from the mainland may be laid from an optimal shore-based location to the nearest group of refinery islands. One island will then serve as a distribution center with branches to other islands. Individual ring tunnels could also be built to provide island-to-island cable/pipeline links. These concepts will be considered and studied so as to maximize the use of our port waters and make it more cost-effective for the oil industries concerned.

Jetties

In the past, approvals were granted for the building of jetties and berths from the shoreline out to the deeper waters without the need for dredging the surrounding waters. Examples of these jetties and berths are located in the following areas:

1. GATX terminal off Penjuru;
2. Caltex terminal off Penjuru;
3. Petrochemical Corporation of Singapore terminal at Pulau Merlimau and;
4. the Republic of Singapore Navy (RSN) jetty at Bedok.

The present configuration and layout of the jetties and berths prevent the widening of the fairways for the use of larger vessels. Moreover, they tend to sterilize the use of the seafront between the jetty end and the coastline. Thus, PSA will review the layout of these jetties so as to maximize the use of the waters in their vicinity.

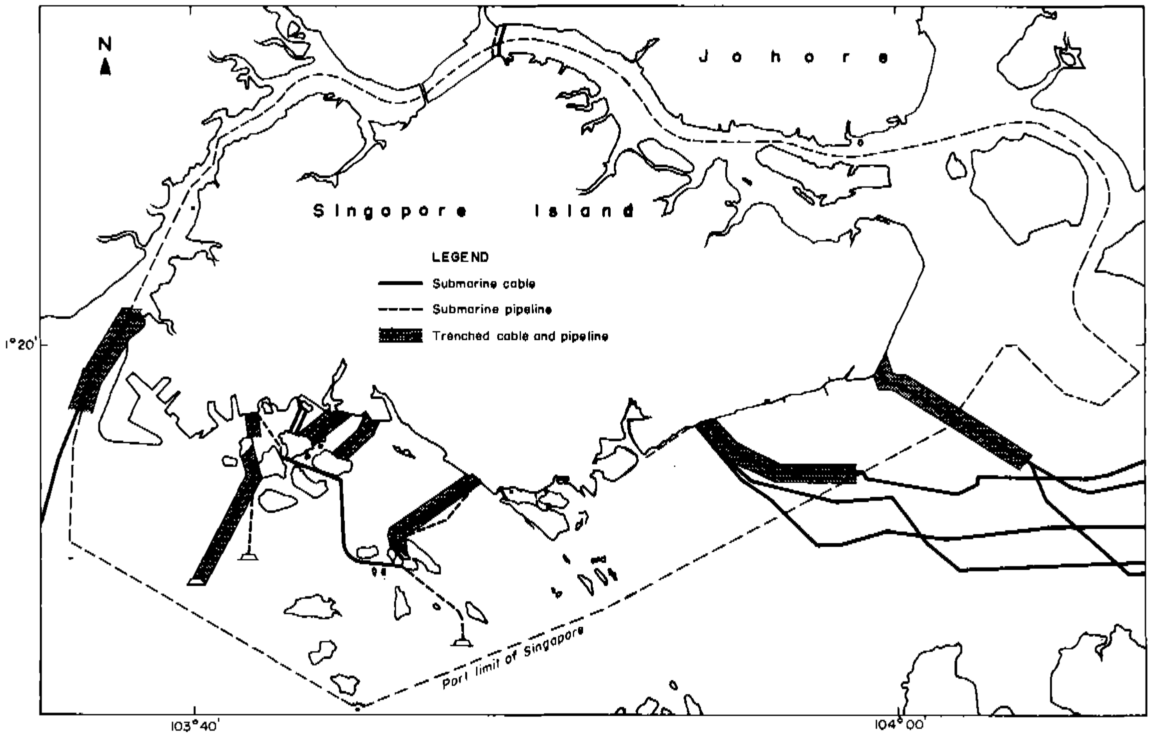

Fig. 2. PSA's submarine cables and pipelines.

Use of Port Waters by Military Forces

Training grounds

There are two training grounds which occupy about 5% of the port waters. The larger islands in the Live Firing Range on the extreme south are used by the Republic of Singapore Air Force (RSAF) for air-to-ground firing exercises. Additionally, RSN, the Singapore Armed Forces (SAF) and Marine Police also conduct small-arm firing practices in this area. The Lim Chu Kang training area, which extends over the West Johore Strait, is used by SAF to conduct military exercises. Both training grounds are gazetted by Parliament, thus, other uses are not allowed.

Buffer security zone for naval bases

The RSN maintains two bases at Pulau Brani and Tanjong Berlayer. The waters fronting these bases are gazetted areas strictly for use by RSN. This restriction has resulted in higher traffic density in adjacent waters; so has sharing the use of Keppel Fairway by small crafts with larger conventional container vessels.

Use by visiting foreign naval vessels

A 1.42 km^2 man-of-war anchorage located off the entrance to Marina Bay is used to accommodate visiting foreign naval vessels.

Dedicated offshore oil terminals

As dedicated offshore oil terminals, SBMs cater primarily to the operation of very large crude carriers (VLCCs). As shown in Fig. 3, the SBMs' floating mooring serves as a securing point for the VLCC and as a receptor for oil cargo. The oil is then transported through an underwater pipeline to the refinery. At present, all three SBMs are located in the western sector in waters of at least 22 m deep (Fig. 1).

Master Plan of the Sea

Planning the use of our port waters is influenced largely by the natural environment and by national development policies. The PSA is working out a master plan of the sea that will strive for the best use of each sector of the port, facilitate maritime economic growth, achieve PSA's corporate goals as well as provide a clean and safe marine environment for the enjoyment of the public.

Criteria

The principles governing the use of port waters are as follows:

The use of port waters should be maximized to commensurate with efficient marine traffic flow. Development proposals that do not impose unnecessary constraints on vessel movement such as height and anchoring restrictions should be ensured. Neither should these proposals hinder activities such as the construction of elongated jetties and berths which can effect sterility in the use of our port waters.

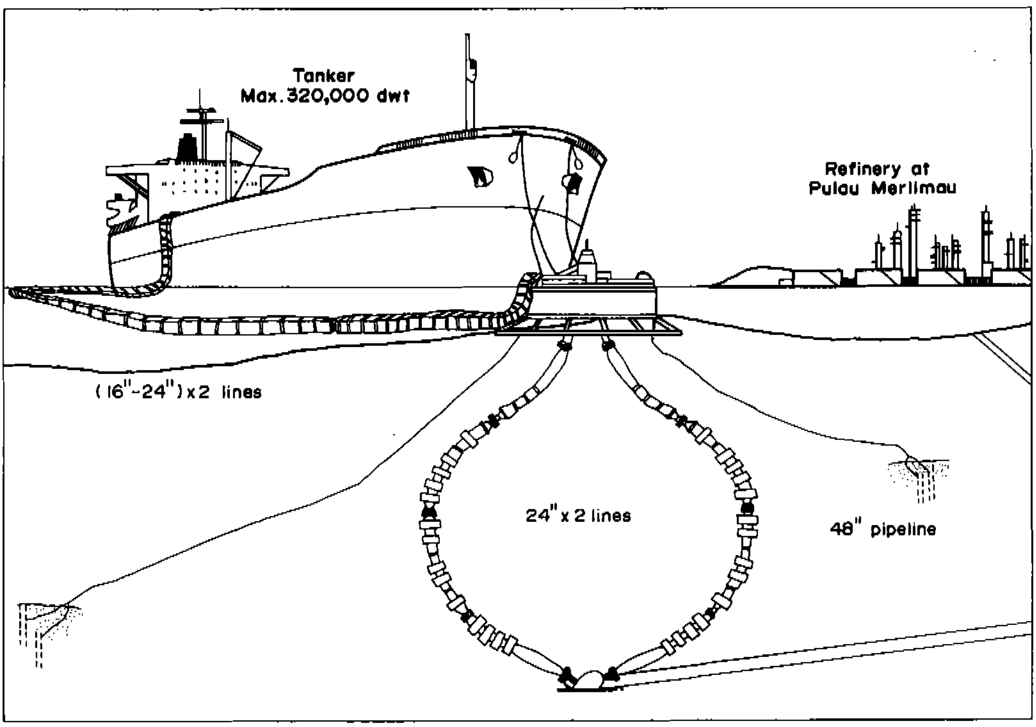

Fig. 3. PSA's SBM at Selat Sinki.

Since a port's water space has a "usage price" similar to a land's value to reflect its type of usage and locational advantage, then adequately deep waters essential for deep draft vessels should be provided. A slop barge anchorage should also be located adjacent to a slop reception center. A product tanker should be in the Western Petroleum Anchorage to be near the offshore oil terminals.

Strategies

The main planning considerations adopted by PSA are to promote the coexistence of two or more uses of port waters, differentiate use by location and economic factors, institute efficient monitoring and control systems, and undertake fairway engineering.

Coexistence Strategy. The PSA as the national authority on the use of port waters will maximize the use of available deep water seafrontage for port development. Therefore, PSA will adopt a policy of coexistence in which pockets of marine recreation will be permitted in areas where they do not significantly affect the operational efficiency of the port. This strategy takes into account the rising expectations and increasing demand of Singaporeans for access to the seafront. For example, the World Trade Center in Sentosa will be developed as a people-centered cruise terminal focal point. Proper routes linking this location to the Southern Islands will be demarcated to ensure the navigational safety of all concerned. In addition, the possibility of integrating port development projects with urban and other social amenities development will be looked into.

Differentiation by Location and Economic Usage. The use of anchorages will be seen from a multidimensional perspective, i.e., due regard will be given to the locational factor (whether it's a prime or fringe location), to the time factor (whether it's for a short, medium or long stay) and to the depth requirements (of shallow crafts and small or large vessels). Each anchorage space will be viewed as a valuable resource which must be optimally used in the national interest. In this way, apart from playing a regulatory role, PSA will also fulfill a business development role in promoting and generating shipping activities for the port. An example of this is the setting up in January 1988 of a special bunkering anchorage at the Eastern Petroleum "B" Anchorage which is at the fringe of the port limit.

Bunkering is important to PSA because vessels that take bunkers contribute 54% of the total shipping tonnage. As one of the goals of PSA's corporate plan is to develop Singapore into a total maritime services center, retaining our position as the top bunkering port in the world is thus essential. Records show that in 1988, a total of 10.08 million t of bunker was lifted. To encourage more vessels that pass by Singapore to come to the port to take bunkers, vessels of 50,000 GRT (gross registered tons) and above that do so at this bunkering anchorage (Fig. 4) are given a 50% concession on port dues. Moreover, for vessels going in and out of the anchorage, no pilotage is required from them. Because the response to this scheme has been very encouraging, PSA is now considering implementing it in the western sector of the port.

Marine Monitoring and Control Systems. The PSA has set up a Marine Traffic Control Section to ensure the orderly flow of ships in and out of the congested waters of the port. It is extremely important for ships to be guided in and out of the harbor in a systematic manner so that cargo operations can proceed efficiently and without any delay. The PSA has also committed to implement a Computer-Integrated Marine Operations System which is expected to be fully operational in 1992. When completed, it will enhance PSA's capability to maximize the use of our port waters. The system includes the active management of vessels, integrated graphic displays of all

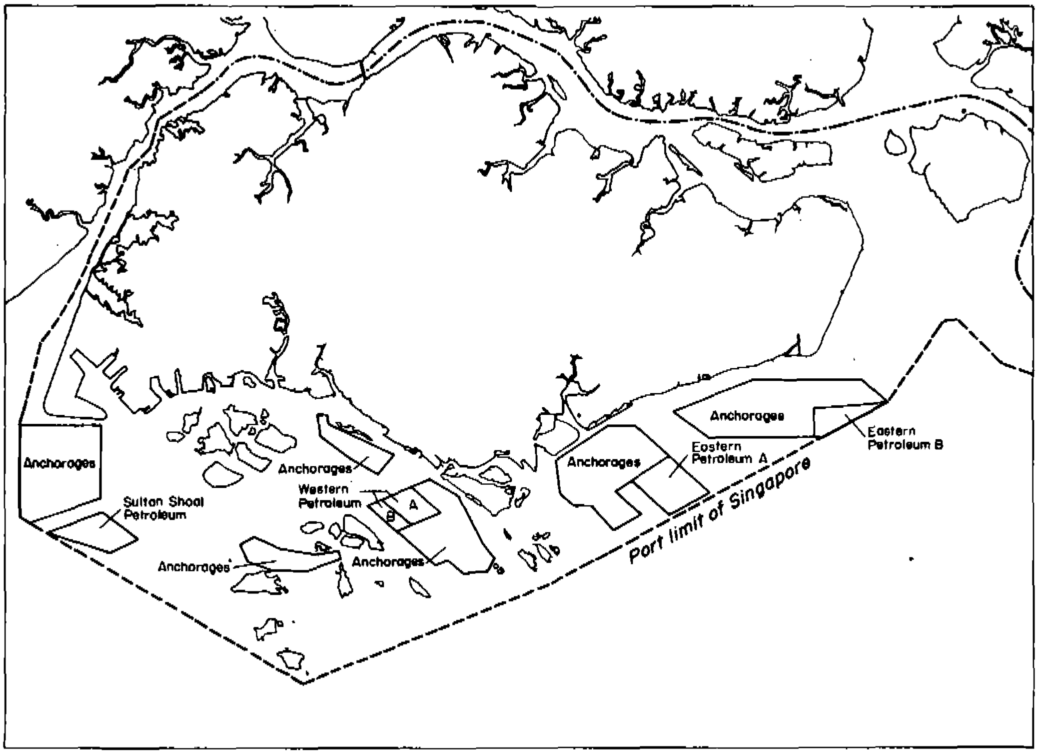

Fig. 4. A bunkering anchorage.

information for command and control, real-time tracking of vessels and resources, and expert systems for marine resource allocations and deployment.

Fairway Engineering. Fairways are essential to the smooth functioning of ports. Inefficient use of ports will lead to lower overall port productivity. Fairways consist of shipping channels and maneuverings which occupy 117.8 km² or 21% of our port waters. Unlike anchorages, fairways are used by all types of vessels. The present system used by fairways has evolved through usage and is therefore a proven pattern linking terminals with the approaches to the port.

Fairway engineering optimizes the use of port waters as this involves the anticipation of technological changes in ship designs and other shipping trends and developments in the maritime industry. A study of these factors will show whether or not our existing sealanes can cope with future shipping traffic flow and how we can redesign them to achieve maximum efficiency. The study will also establish the reserved depth and width of all existing and new fairways.

Conclusion

Over the past years, land reclamation has already reduced our port waters by about 10%. This has resulted in a significant loss in the number of shallow sheltered areas for launches and other harbor crafts. The size of seaspace is envisaged to further diminish with more reclamation works to be carried out in the future, particularly on offshore islands.

On the management of Singapore's scarce coastal areas, PSA will maximize the use of available deepwater seafrontage for port development while allowing people-oriented recreational facilities in areas where they do not significantly affect port operations. This is our coexistence strategy. It takes into account the rising expectations and increasing demand of Singaporeans for access to the seafront.

The PSA's corporate plan highlights its role as an exemplary public agency and its social responsibility for maintaining a clean and safe marine environment. Through the concept of coexisting with the environment and the wider community, we will fulfill that role and, at the same time, add economic value to our standing as the world's busiest port which carries with it the potential of being a major tourist attraction. Also, we will try to integrate our port development projects with urban and other social amenities development in a way that would enhance the overall value of the land in the vicinity of the port.

The Enhancement of Fish Community in the Singapore River through the Use of Artificial Seagrass

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Abstract

As an aid to the rehabilitation program of the Singapore River, artificial seagrass (ASG) was shown to effectively enhance fauna within three months of its implantation. Family numbers increased from 12 to 24 and the number of species from 16 to 30 during the study period. The ASG also made a good ecological niche for stocked seabass which were found to remain and grow at the habitat one to two months after the stocking. However, no stocked fish were recovered from the open areas. The younger stages of seabass fry (less than 0.1 g) may not have survived the river, while the larger ones (greater than 3 g) were more suitable for stocking. The predominance of indigenous sand shrimp (*Metapenaeus ensis*) in the ASG patches suggests that banana shrimp (*Penaeus merguiensis*), which did not survive well, may not be an effective species for stocking.

Introduction

Since the Singapore River served as a center for trading for decades, its water and surrounding environment became very polluted. In line with the "Clean and Green" image of Singapore, the government initiated a ten-year "Clean River" campaign in 1977 to transform the banks of the river and surrounding water bodies into beautiful parks and walkways, with clean water free of offensive smell. Marine life, previously almost nonexistent, is slowly returning, with such fish as groupers, snappers, gizzard shads, pony fish and silver bellies and crustaceans like flower and mud crabs and sand shrimps (Tan 1986; Yip et al. 1987; Khin and Chou 1991).

The Primary Production Department initiated a ten-year stocking program which began in 1986. It aimed to enhance the fish population, eventually establish the stocked fish as resident species, and promote game fishing in the Singapore River. So far, over 80,000 seabass *(Lates calcarifer)*, 8,500 cherry snappers *(Oreochromis niloticus)* and 630,000 banana shrimp *(Penaeus merguiensis)* have been stocked. Sampling results suggest that only the seabass have been able to establish a niche in the river (Khin and Chou 1991). The use of ASG was then unsuitable for natural seagrass growth (Fonseca 1988). This paper reports the findings of the ASG experiment in the Singapore River from March to July 1989.

Materials and Methods

The experimental site at Boat Quay in the Singapore River measured 22 m x 10 m and encompassed ten 2 m x 2 m experimental plots (Fig. 1). So as not to impede navigation, minimize disturbances to the site and make sampling easy, the area chosen was only 8 m away from the shore. The tidal levels varied from 0.4 to 2.0 m.

The species used for the stocking trials were seabass and banana shrimp. This was in line with the guidelines for species selection of the stocking program, i.e., they must be able to survive in seawater, be readily available from local hatcheries and be popular game and food fish. The shrimp were meant to be a food source for the stocked fish.

The ASG used was a grass mimic under the trade name FISH HAB*. Each stalk was nonpollutive and consisted of cylindrical strands fused at the base and designed to float upright, with a self-shedding mechanism. A 2 m x 2 m PVC frame was constructed using ten 2.5 cm (diameter) PVC pipes joined together by T- and L-joints. Holes were drilled at 10 cm intervals along the lengths for the insertion of the stalks (441 stalks per plot). The frame was held down by stainless steel rods of 1 to 1.5 m in length, depending on the substratum at the four corners (Fig. 2).

The design of the setup is shown in Fig. 3. Five 2 m x 2 m frames and five 2 m x 2 m control plots were laid out in two rows. The positioning of the plots was determined with the use of a random table. In addition, a 2 m buffer zone was demarcated around the site and between the rows. Separating the study plots were 2 m x 2 m buffer plots.

Three stocking operations were carried out. Initial stocking was with very young seabass fry (approximately 0.05 g in body weight) and shrimp (approximately 0.03 g in body weight). Subsequently, bigger fish and shrimp (greater than 3 g) were used in the stocking. Stocking density for the first stocking was 732 seabass and 10,000 shrimp per 4 m^2 plot (Table 1). The second stocking was at 16 seabass and shrimp each per plot. The third stocking involved only seabass which were floy tagged and stocked at 26 fish per plot.

Sampling operations were conducted before each stocking. A purse seine (dimensions: 12 m by 1.5 m depth, 0.5 cm mesh size) was used in the sampling for the stocked species. The purse seine required five men to operate (Fig. 4). A combination of two fishing methods was used for sampling other fish fauna, namely, fish trap (dimensions: 0.6 m x 0.4 m x 0.2 m) and purse seine. Six fish traps were used in each plot. These were held down by ropes and stainless steel rods (Fig. 5) and put in place two to three days before a sampling operation. The openings of the traps faced inwards, thus trapping fish only from within the plots. Before the fish traps were removed, the purse seine was used to enclose the plots. The fish caught in the seine were also collected. All specimens collected were identified, counted

*Mention of the above trade label does not mean endorsement of their use by the authors and the Department.

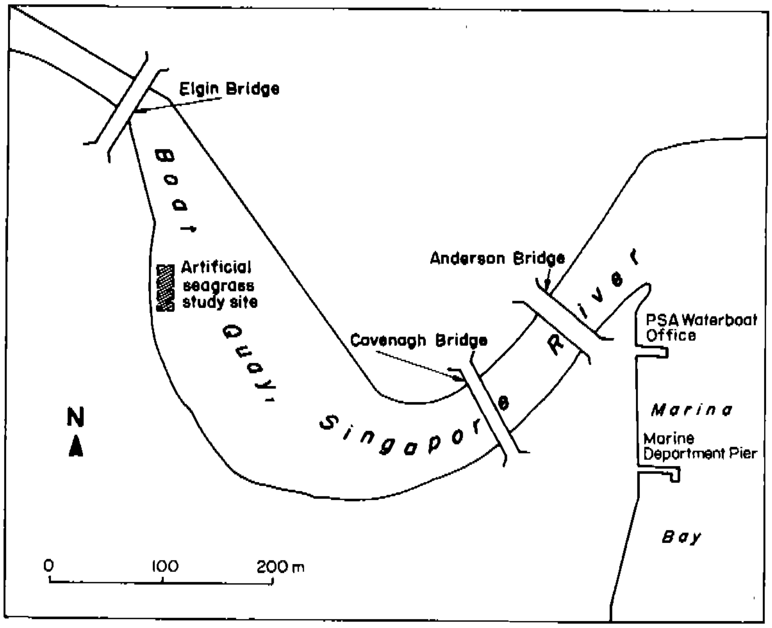

Fig. 1. Location of the study site at Boat Quay, Singapore River.

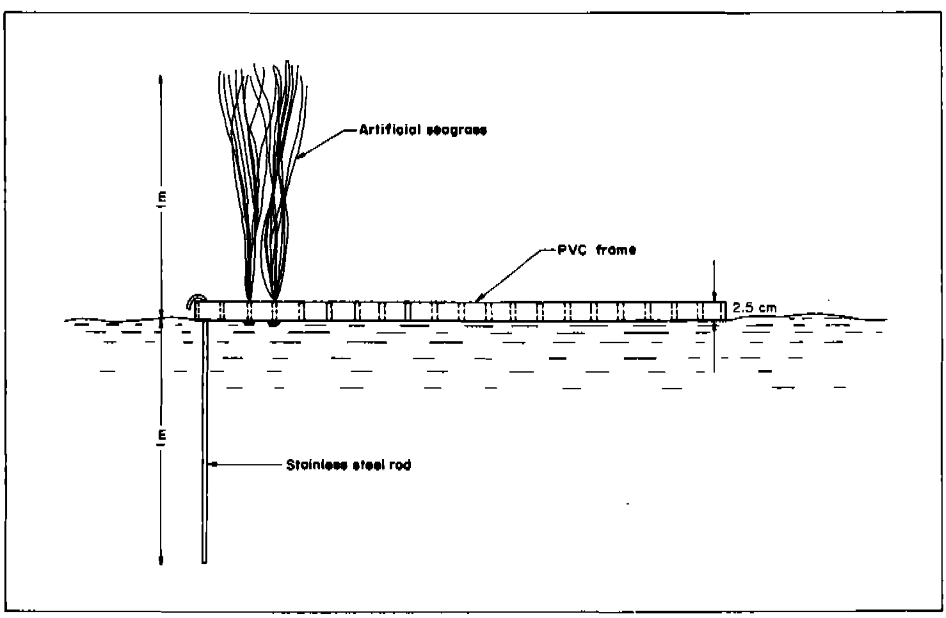

Fig. 2. Artificial seagrass unit in Singapore River.

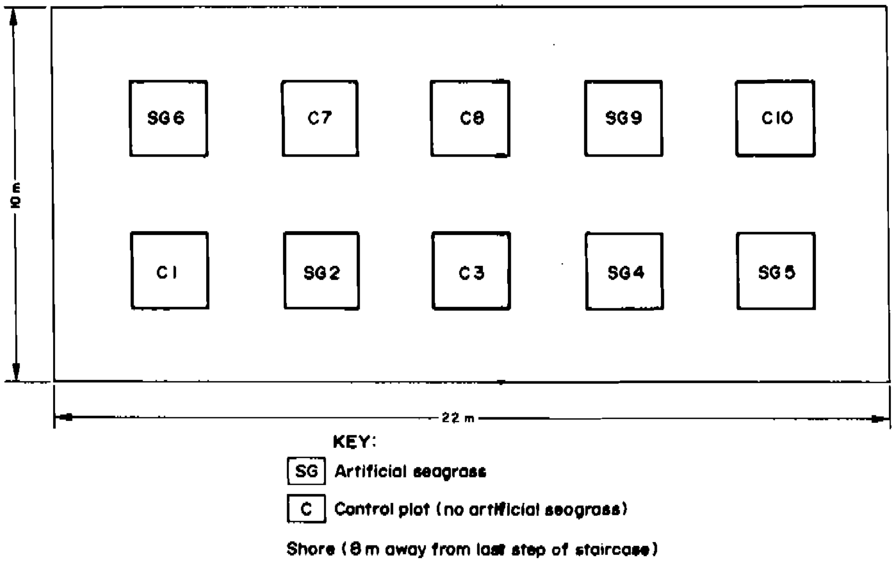

Fig. 3. Layout of the plots at the experimental site.

Fig. 4. Purse seining at a selected plot.

Table 1. Stocking and sampling trials at experimental site, May to July 1989.

		Control		Treatment	
		Fish	Shrimp	Fish	Shrimp
Observation 1					
Stocking:	04 May (seabass)				
	09 May (shrimp)				
	Number stocked*2	732	10,000	732	10,000
	Biodata	TL: 1.4 ± 0.1 cm	TL: 1.6 ± 0.3 cm	TL: 1.4 ± 0.1 cm	TL: 1.6 ± 0.3 cm
		SL: 1.2 ± 0.1 cm	SL: 1.2 ± 0.1 cm	SL: 1.2 ± 0.1 cm	SL: 1.2 ± 0.1 cm
		Wt: 0.05 g	Wt: 0.023 g	Wt: 0.05 g	Wt: 0.023 g
Sampling:	12 May				
	Number recaptured*2	0 (0%)	0 (0%)	0 (0%)	0 (0%)
	Biodata	-	-	-	-
Observation 2					
Stocking:	16 May				
	Number stocked	16	16	16	16
	Biodata	TL: 6.9 ± 1.1 cm	TL: 8.7 ± 0.9 cm	TL: 6.9 ± 1.1 cm	TL: 8.7 ± 0.9 cm
		SL: 5.7 ± 0.9 cm	SL: 6.9 ± 0.9 cm	SL: 5.7 ± 0.9 cm	SL: 6.9 ± 0.9 cm
		Wt: 5.08 ± 2.01 g	Wt: 5.38 ± 1.38 g	Wt: 5.08 ± 2.01 g	Wt: 5.38 ± 1.38 g
Sampling 1:	17 May				
	Number recaptured	0 (0%)	0.2 (1.3%)	8 (50%)	0 (0%)
	Biodata	-	TL: 3 cm	TL: 5 to 8 cm	-
Sampling 2:	13 June				
	Number recaptured	0 (0%)	0 (0%)	1 (6.3%)	0 (0%)
	Biodata	-	-	TL: 11.8 ± 2.1 cm	-
				SL: 9.8 ± 1.9 cm	
				Wt: 14.6 ± 6.2 g	
Observation 3					
Stocking:	13 June				
	Number stocked	26	0	26	0
	Biodata	TL: 8.9 ± 0.7 cm	-	TL: 8.9 ± 0.7 cm	-
		SL: 7.4 ± 0.6 cm		SL: 7.4 ± 0.6 cm	
		Wt: 8.92 ± 2.17 g		Wt: 8.92 ± 2.17 g	
Sampling:	26 July				
	Number recaptured	0.4 (1.5%)	0 (0%)	2 (7.7%)	0 (0%)
	Biodata	TL: 15.6 ± 3.6 cm	-	TL: 15.4 ± 4.3 cm	-
		SL: 12.4 ± 3.1 cm		SL: 12.6 ± 3.5 cm	
		Wt: 52.0 ± 22.6 g		Wt: 48.2 ± 44.2 g	

TL: Total length.
SL: Standard length.
Wt: Weight.

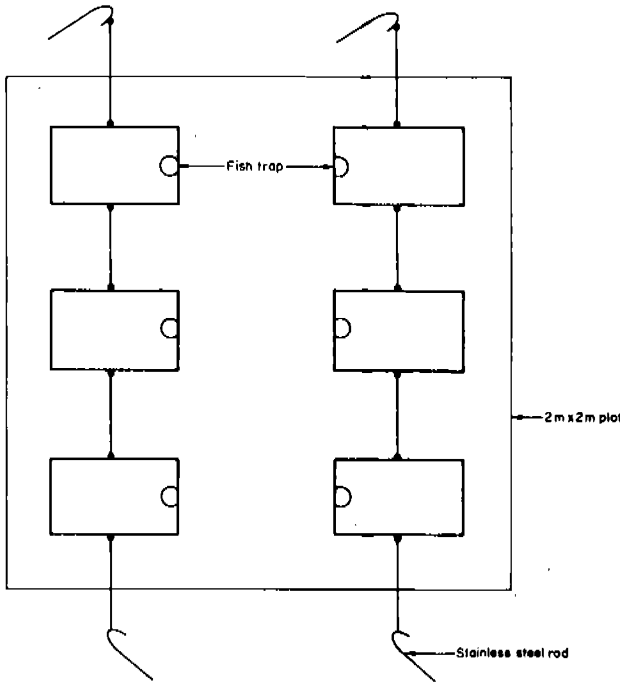

Fig. 5. Layout of the fish traps in a plot.

and weighed. Length measurements were also taken for the stocked species only. All seabass or banana shrimp captured were measured and weighed before being released to the plots they were caught from.

Results and Discussion

Habitat conduciveness of artificial seagrass for stocked fish and shrimp

The first sampling done one week after stocking yielded none of the younger seabass or shrimp (less than 0.1 g) from both control and treatment plots (Table 1). This may be because they were hatchery-bred, and, thus, may have easily been predated upon by the larger fish that were present (Table 2). This view was shared by a visiting sea-ranching consultant (Tashiro, pers. comm.). The results strongly suggest that, in their younger stages, seabass fry and shrimp cannot survive well in river conditions. Consideration for stocking older stages of seabass and shrimp was therefore warranted for the subsequent trials.

Subsequent stocking trials were done using larger seabass and shrimp (less than 3 g). An immediate sampling was conducted one day after stocking to ascertain the presence of stocked fish at the study site. An average of 50% or 8 pieces per plot of seabass were recaptured from the ASG plots and none from the control plots. The subsequent sampling was done one month after the stocking trial. A total of 5 seabass were caught from the ASG plots representing 6.25% or 1 seabass per plot, while none was recovered from the control plots. This indicates a strong preference by the seabass for the ASG. The final recapture operation (one-and-a-half months after the last stocking) yielded a total of 10

Table 2. List of fish species caught before and after stocking.

Family	Species	Control		Treatment	
		Before	After	Before	After
Finfish					
1. Apogonidae	*Apogon frenatus*			+	
	Apogon sp.	+	+	+	+
2. Batrachoididae	*Batrachomeous* sp.	+	+	+	+
3. Centropomidae	*Lates calcarifer*		+		+
4. Chaetodontidae	*Parachaetodon ocellatus*		+	+	
5. Clupeidae	*Sardinella fimbriata*				+
	Stolephorus indicus		+		
6. Gerreidae	*Gerres kapas*	+			
	G. oyena		+		+
7. Gobiidae		+	+	+	+
8. Haemulidae	*Therapon theraps*			+	+
	Pomadasys opercularis				+
9. Hemirhamphidae	*Hemirhamphus* sp.				+
10. Leiognathidae	*Leiognathus equulus*	+	+		+
11. Lutjanidae	*Lutjanus monostigma*	+		+	
12. Monacanthidae	*Monacanthus* sp.				+
13. Muraenidae	*Gymnothorax* sp.	+			
14. Platycephalidae	*Platycephalus indicus*	+	+		
	P. scaba	+			
15. Plotosidae	*Plotosus canius*			+	
16. Scatophagidae	*Scatophagus argus*		+		+
17. Serranidae	*Epinephelus malabaricus*	+			
	E. tauvina	+	+	+	+
18. Siganidae	*Siganus guttatus*			+	
	S. javus	+		+	+
19. Sphyraenidae	*Sphyraena jello*				+
20. Syngathidae	*Hippocampus kuda*				+
21. Tetradontidae	*Arothron reticulatus*	+			+
	A. immaculatus				+
Total no. of families		11	11	9	16
Total no. of species		13	11	11	18
Crustaceans					
1. Alpheidae	*Alpheus* sp.	+	+		+
2. Dorippidae	*Neodorippe* sp.		+		+
3. Menippidae	*Myomenippe hardwicki*				+
4. Palaemonidae	*Macrobrachium* sp.		+		+
5. Penaeidae	*Metapenaeus ensis*	+	+	+	+
	Penaeus merguiensis		+		+
	P. semisulcatus		+	+	+
	Peneaus sp.		+		
6. Portunidae	*Charybdis* sp.		+		
	Portunus pelagicus	+	+	+	+
	Scylla serrata	+	+		+
	Thalamita crenata	+	+	+	+
7. Sergestidae	*Acetes* sp.		+		+
8. Squillidae	*Harpiosquilla* sp.			+	
Total no. of families		3	6	3	7
Total no. of species		5	12	5	11
Grand total					
Families		14	17	12	23
Species		18	23	16	29

seabass (2 seabass or 7.7% per plot) from the treatment plots, of which one was tagged. A total of 2 seabass (0.4 individual or 1.5% per plot) were also caught from the control plots. These results further strengthen our view that the ASG provides a good habitat for the seabass and that only larger ones should be considered for future stockings. Moreover, a consultant is of the opinion that stocking 1,000 seabass is adequate for the river (Tashiro, pers. comm.).

Meanwhile, the results yielded from the recapture of shrimp were poor. No shrimp were recovered from the ASG plots during any of the samplings, while one shrimp (0.2 individual or 1.3% per plot) was caught from the control plots on the second sampling. No shrimp were used in the final stocking as the need for the stocking of shrimp as a food source was reviewed then (Tashiro, pers. comm.) because of the existence of a large number of other shrimp in the river, especially the sand shrimp *(Metapenaeus ensis)* (Khin and Chou 1991).

Effectiveness of artificial seagrass in enhancing the fish community

The seine catch data indicate that the ASG plots generally had a greater number of individuals compared to the control plots. This is probably due to the hiding places and micro-food source afforded to the smaller fish by the seagrass, which in turn attracted the larger fish.

Table 2 gives a list of fish species recorded at the study site from 31 March to 26 July 1989 (a period of four months). The results showed that fish fauna at the ASG after stocking increased by 100%--from 12 families (9 fish and 3 crustacean families) and 16 species (11 fish and 5 crustacean species) before stocking to 24 families (17 fish and 7 crustacean families) and 30 species (19 fish and 11 crustacean species) after stocking. The catch data at the control plots show a slight increase (less than 30%)--from 14 families (11 fish and 3 crustacean families) and 18 species (13 fish and 5 crustacean species) to 17 families (11 fish and 6 crustacean families) and 23 species (11 fish and 12 crustacean species). The sudden increase in the number of families and species at the ASG could be due to two factors, namely, the effect of stocking and the length of time the seagrass was put in place. Bell et al. (1985) also reported on the effect of ASG units in attracting marine life and concluded that such units would be comparable to natural seagrass sites if submerged for a long enough time. The increase in the control areas may be due to the indirect effect of ASG. We believe that this preliminary experiment has shown that the ASG units are indeed a useful tool in the creation of a habitat and in the enhancement of the fish community.

Problems and Constraints

It was unfortunate that due to multisectoral conflicts on the use of the site, the experiment was unable to continue to study the further growth and survival of the seabass and to confirm the usefulness of ASG as an ecological niche in the Singapore River. In addition, the ASG stalks were heavily fouled after three months by barnacles, bivalves, algae, tunicates and bryozoans. The weight of the fouling organisms caused the stalks to sag and lose their floating property, making sampling difficult. Further study needs to be done to overcome the sagging problem, although an immediate remedy to solve this present predicament is to reverse the setting of the ASG.

Conclusion

The results of this preliminary study show that ASG has a positive effect on both stocked seabass and resident fish community in the river. However, further experiments are needed to confirm these results and to assess the long-term impact of ASG on the environment of the Singapore River. Studies also need to be done on the use of ASG while plagued with the fouling problem, so that the artificial habitat can be maintained.

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Benthic Communities of the Rivers and the Coastal Waters of Singapore

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Abstract

This paper provides an overview of the research work conducted on benthic communities in Singapore's waters. The possibility of using the existing data for environmental monitoring is discussed.

Introduction

Studies on the benthic fauna and flora in the coastal rivers and waters of Singapore have been conducted since the establishment of the Department of Zoology at the National University of Singapore in 1950. Studies on mollusks and brachiopods by S.H. Chuang, crustaceans by D.S. Johnson and turtles by J.R. Hendrikson began in 1951; followed by that on corals by A.G. Searle in 1953; coral reefs, polychaetes and flying fish by R.E. Sharma in 1955; mangroves by A.J. Berry in 1956; coelenterates by S.S. Dhaliwal in 1959; and aquatic insects by C.H. Fernando and D.H. Murphy in 1961. Since then, many institutions have been involved in the study and investigation of the aquatic environment in and around Singapore (Lam and Khoo 1988). However, only a few studies have been published on the benthic communities of the coastal waters of Singapore. Some of the earlier studies include the zonation of the marine fauna and flora on a rocky shore near Singapore (Purchon 1954) and the faunal zonation of mangrove swamps (Berry 1963). Most of these studies are on the macrobenthos of the intertidal or littoral zone. Few studies have been conducted on the individual smaller organisms as well as on the faunal communities found in the subtidal zones. It is only until recently that more studies have been conducted on subtidal coral reefs (Chou 1987). Much less is known about other subtidal benthic communities such as the soft-bottom communities.

This paper describes studies which have been conducted on intertidal benthic communities as well as on subtidal bottom communities found in Singapore's waters since 1950.

Benthic Diatoms of Intertidal Habitats

A number of studies have been made on planktonic diatoms in Singapore's waters (Tham et al. 1970), but not much on benthic diatoms. Nah (1972) conducted a study on the benthic diatoms of the intertidal zone of Johore Strait in 1972. The study area was situated along the beach between Punggol point and Punggol's river mouth. The distribution of epipelic diatoms along a transverse transect was studied. The zonation distribution in the upper, middle and lower littoral is given in Table 1.

The density of the benthic diatoms generally increased from the upper to the lower littoral, but decreased from 0.2 m to 0.0 m of the tide's level. Only 7 of the 20 species occurred at the zero tide level. The highest density was found between 0.4 and 0.3 m tide levels (18,600 cm^2 and 21,400 cm^2, respectively).

Species of abundance are *Amphora bitumida, Bacillaria paradoxa, Navicula greville and N. cryptocephala.* Although *B. paradoxa* is considered a planktonic form, it is found in

Table 1. The occurrence, distribution and abundance (thousands/cm^2) of benthic diatoms in the sand.

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13		No. of sites a diatom occurs	Average no. of diatoms per site
	Site and tide levels															
	Upper		Middle		Lower littoral zone											
Species	2.5 m	2.1 m	1.7 m	1.2 m	1 m	0.1 m	0.6 m	0.5 m	0.4 m	0.3 m	0.2 m	0.1 m	0.0 m	Total		
1. *Amphora bitumida*	-	-	6	13	8	11	9	13	38	11	6	4	4	123	11	11.1
2. *A. limneolata*	-	-	8	4	6	8	9	9	5	12	4	4	1	70	11	6
3. *Navicula cryptocephala*	9	8	13	13	14	18	18	30	40	52	15	16	18	264	13	21
4. *N. greville*	3	4	6	8	10	13	12	31	40	56	14	18	9	224	13	17
5. *N. schroteri*	-	4	3	1	-	12	11	1	8	3	5	1	-	49	10	4.9
6. *N. halophila*	-	1	3	-	5	5	5	5	5	10	1	1	-	41	10	4.1
7. *N. cancellata*	1	1	5	3	5	5	5	5	5	6	1	1	-	43	12	3.4
8. *Diploneis oblongella*	1	1	1	1	10	8	15	9	9	10	4	2	-	71	12	6.8
9. *Nitzchia constricta*	-	1	1	1	3	-	3	3	-	3	-	1	-	16	8	2
10. *N. closterium*	-	-	-	-	1	3	1	-	3	3	1	-	-	12	6	2
11. *N. longissima var. strigosa*	-	-	-	-	-	-	-	-	9	4	5	3	-	21	4	5.2
12. *Bacillaria paradoxa*	-	-	-	-	-	-	3	23	10	40	25	19	3	123	6	20.5
13. *Pleurosigma scalproides*	-	-	-	-	3	-	1	-	-	-	-	-	1	5	3	1.7
14. *P. normanii*	-	-	-	-	-	-	-	1	1	1	1	1	-	5	5	1
15. *P. angulatum*	-	-	-	-	3	-	1	1	1	1	1	-	-	8	6	1.3
16. *P. angulatum var. strigosa*	-	-	-	-	-	-	-	-	1	1	1	-	-	3	3	1
17. *Pleurosigma* sp. 1	-	-	-	-	3	5	1	1	2	3	1	-	-	16	7	2.3
18. *Gryosigma* sp.	-	-	-	-	2	4	1	1	3	3	1	-	-	15	7	2.1
19. *Trachyneis* sp.	-	-	-	-	-	-	1	1	-	1	1	-	-	4	4	1
20. *Strauroneis* sp.	-	-	-	1	-	-	1	1	4	1	1	1	1	11	8	1.4
Total no. of diatoms	15	31	50	48	71	81	98	124	186	214	92	72	37			

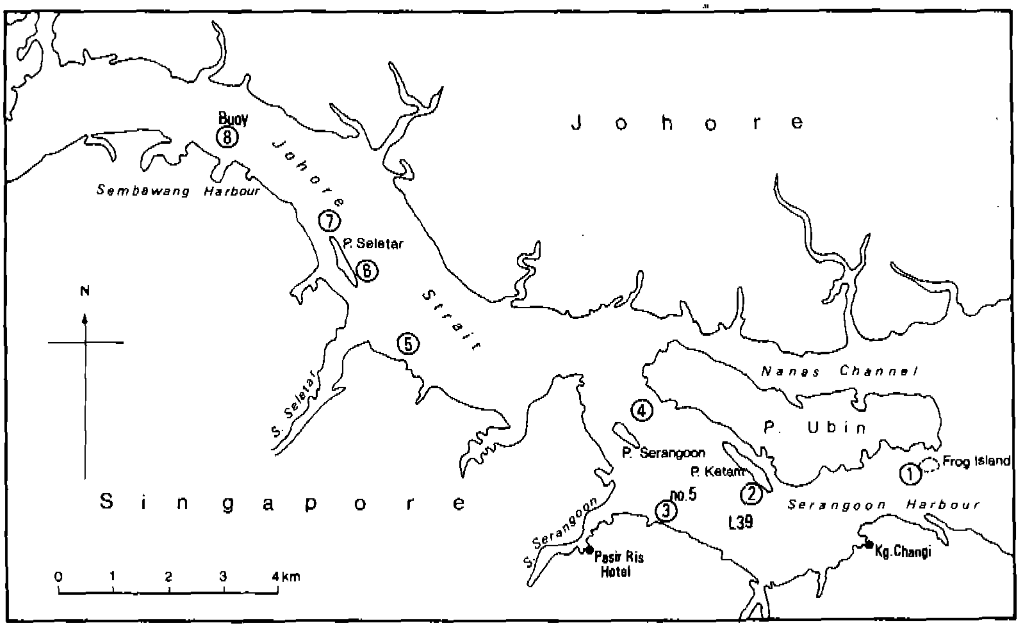

Fig. 1. Map of the Eastern Johore Strait showing the transects.

large numbers in the sediments (Lebour 1929). This baseline information on the distribution of benthic diatoms could form a basis for assessing changes in the coastal waters of Singapore. Because they are not mobile and have a fast reproductive cycle, benthic diatoms are useful indicators of the short-term changes in the overlying waters when the beaches are submerged during high tides.

Subtidal Macrobenthos of Eastern Johore Strait

The earliest study on the coastal subtidal benthic community was a dissertation by Lee (1973). The area of study was between the eastern entrance of Eastern Johore Strait at Pulau Ubin and Sembawang Harbour (Fig. 1). Eight transects were made and the organisms were distributed at the depths of 5-10 ft, 10-20 ft and 20-30 ft. Tanaka's simple bottom sampler and the naturalist's rectangular dredge were used. Monitored were the soil particle composition, phosphate, water and organic contents of the sediments and the presence of hydrogen sulfide at the sampling sites.

Phosphate values increased from the entrance of Johore Strait to Sembawang Harbour. Hydrogen sulfide was detected from bottom samples even at the entrance of the strait and the frequency increased as samples were taken farther inside the strait towards Sembawang Harbour. This indicates that an oxygen gradient was found at the bottom of the strait.

The occurrence and distribution of the benthic macrofauna were also investigated. A total number of 130 species was recorded. The distribution of the polychaetes, mollusks and echinoderms is given in Tables 2, 3 and 4, respectively.

As one moved from the entrance of the strait to Sembawang Harbour, the species

Table 2. The distribution of polychaetes.

Family/species	Transects	1				2				3				4			
		I	II	III	(T)	I	II	III	(T)	I	II	III	(T)	I	II	III	(T)
1. Serpulidae *(Hydroides)*			2		(2)	4	1		(5)			2	(2)		3	3	(6)
2. Eunicidae *(Diopatra)*				2	(2)			2	(2)	1	1	1	(3)		3		(3)
3. Neridae *(Nereis)*				1	(1)	1			(1)								
4. Capitellidae sp.		1			(1)												
5. Scalibragnidae sp.			1		(1)												
6. Eunicidae *(Eunice)*								3	(3)						1		(1)
7. Maldane *(Axiothella)*							1		(1)			1	(1)				
8. Cirratulidae *(Tharyx)*						1			(1)								
9. Cirratulidae *(Cirratulus)*							1		(1)	2			(2)				
10. Aphroditidae *(Lepidonotus)*						1			(1)								
11. Aphroditidae *(Panthalis)*												1	(1)				
12. Aphroditidae *(Sthenelais)*										1			(1)				
13. Aphroditidae sp.										1			(1)				
14. Glyceridae *(Glycera)*											1		(1)				
15. Sabellidae *(Dasychong)*										1			(1)				
16. Sabellidae *(Hypsicomus)*												1	(1)				
17. Terebellidae *(Polymnia)*										1			(1)				
18. Terebellidae *(Terebellides)*															1		(1)
19. Terebellidae *(Streblosoma)*															1		(1)
20. Syllidae sp.														1			(1)
21. Eunicidae *(Lumbriconerets)*																1	(1)
22. Typhloscolecidae sp. 1															1		(1)
23. Ampharetidae *(Amage)*															1		(1)
24. Aphroditidae *(Polyodontes)*														1			(1)
25. Maldanidae *(Maldane)*															1		(1)
26. Amphictenidae sp.																	
27. Sabellidae *(Potamilla)*																	
28. Paraonidae sp.																	
29. Amphictenidae *(Pectinoria)*																	
30. Typhloscolecidae sp. 2																	
31. Opelidae sp.																	
32. Maldanidae *(Euclymene)*																	
33. Eunicidae *(Marphysa)*																	
34. Ampharetidae *(Melinopsis)*																	
35. Unidentified species							2		(2)			1	(1)		1	1	(2)
Species diversity		1	2	2	(5)	4	5	2	(11)	7	2	5	(14)	2	8	3	(13)

Key: I = 5-10 ft, II = 10-20 ft, III = 20-30 ft.
T = Total no. of specimens.

Continued

Table 2. (continued)

Family/species	Transects	5 I	5 II	5 III	5 (T)	6 I	6 II	6 III	6 (T)	7 I	7 II	7 III	7 (T)	8 I	8 II	8 III	8 (T)
1. Serpulidae *(Hydroides)*				9	(9)		20		(20)		10	4	(14)			4	(4)
2. Eunicidae *(Diopatra)*		2	2	1	(5)	1			(1)	15	4		(19)				
3. Neridae *(Nereis)*		1			(1)						1		(1)		13		(13)
4. Capitellidae sp.						9			(9)								
5. Scalibragnidae sp.																	
6. Eunicidae *(Eunice)*																	
7. Maldane *(Axiothella)*			1		(1)												
8. Cirratulidae *(Tharyx)*																	
9. Cirratulidae *(Cirratulus)*																	
10. Aphroditidae *(Lepidonotus)*		1			(1)						5	1	(6)		3		(3)
11. Aphroditidae *(Panthalis)*																	
12. Aphroditidae *(Sthenelais)*																	
13. Aphroditidae sp.																	
14. Glyceridae *(Glycera)*		1			(1)												
15. Sabellidae *(Dasychong)*																	
16. Sabellidae *(Hypsicomus)*																	
17. Terebellidae *(Polymnia)*																	
18. Terebellidae *(Terebellides)*		1	1		(2)												
19. Terebellidae *(Streblosoma)*		1			(1)												
20. Syllidae sp.																	
21. Eunicidae *(Lumbriconerets)*											2		(2)		1		(1)
22. Typhloscolecidae sp. 1																	
23. Ampharetidae *(Amage)*																	
24. Aphroditidae *(Polyodontes)*																	
25. Maldanidae *(Maldane)*																	
26. Amphictenidae sp.		1			(1)	3			(3)								
27. Sabellidae *(Potamilla)*										1			(1)				
28. Paraonidae sp.										4			(4)				
29. Amphictenidae *(Pectinoria)*		2	1		(3)												
30. Typhloscolecidae sp. 2		1			(1)												
31. Opelidae sp.			2		(2)												
32. Maldanidae *(Euclymene)*																	
33. Eunicidae *(Marphysa)*																	
34. Ampharetidae *(Melinopsis)*												2	(2)				
35. Unidentified species															1		(1)
Species diversity		10	7	2	(19)	3	1		(4)	3	5	3	(11)		5		(5)

Key: I = 5-10 ft, II = 10-20 ft, III = 20-30 ft.
T = Total no. of specimens.

Continued

Table 2. (continued)

Family/species	Transects	I	II	III	(T)
		Total no. of species found			
1. Serpulidae *(Hydroides)*		4	36	22	(62)
2. Eunicidae *(Diopatra)*		10	10	6	(26)
3. Neridae *(Nereis)*		2	14	1	(17)
4. Capitellidae sp.		10			(10)
5. Scalibragnidae sp.			1		(1)
6. Eunicidae *(Eunice)*			4		(4)
7. Maldane *(Axiothella)*			2	1	(3)
8. Cirratulidae *(Tharyx)*		2			(2)
9. Cirratulidae *(Cirratulus)*		2	1	2	(5)
10. Aphroditidae *(Lepidonotus)*		2	8	1	(11)
11. Aphroditidae *(Panthalis)*				1	(1)
12. Aphroditidae *(Sthenelais)*		1			(1)
13. Aphroditidae sp.		1			(1)
14. Glyceridae *(Glycera)*		1	1		(2)
15. Sabellidae *(Dasychong)*		1			(1)
16. Sabellidae *(Hypsicomus)*				1	(1)
17. Terebellidae *(Polymnia)*		1			(1)
18. Terebellidae *(Terebellides)*		1	1		(2)
19. Terebellidae *(Streblosoma)*		1	1		(2)
20. Syllidae sp.		1			(1)
21. Eunicidae *(Lumbriconerets)*			3	1	(4)
22. Typhloscolecidae sp. 1			1		(1)
23. Ampharetidae *(Amage)*			1		(1)
24. Aphroditidae *(Polyodontes)*		1			(1)
25. Maldanidae *(Maldane)*		1	2		(3)
26. Amphictenidae sp.		4			(4)
27. Sabellidae *(Potamilla)*		1			(1)
28. Paraonidae sp.		4			(4)
29. Amphictenidae *(Pectinoria)*		2	1		(3)
30. Typhloscolecidae sp. 2		1			(1)
31. Opelidae sp.			2		(2)
32. Maldanidae *(Euclymene)*			1		(1)
33. Eunicidae *(Marphysa)*			1		(1)
34. Ampharetidae *(Melinopsis)*			3	3	(6)
35. Unidentified species			1		(1)
Species diversity		54	95	39	(188)

Key: I = 5-10 ft, II = 10-20 ft, III = 20-30 ft.
T = Total no. of specimens.

composition of the polychaetes changed. However, the change was not uniform within the 21,000-m stretch of the strait. Moreover, about 35 species of polychaetes were found with a serpulid from the genus *Hydroides* which seemed to be present in all the samples. A polychaete belonging to the eunicid genus *Diopatra* was also commonly found in all sites except in Sembawang Harbour. *Diopatra* is tubicolous with a membranous tube with adhering sand grains and detritus. It was quite numerous at transects 5 and 7 where the substratum was of medium coarse sand and clay. A large number of capitellidae polychaete species were found in transect 6. Some capitellids are reputed to be tolerant of extreme low oxygen conditions and are indicators of poor oxygenated environments (Day 1967).

As for the mollusks, 29 species of the commonly found bivalve juveniles and egg cases of *Thais* sp. and *Melongena pugilina* were recorded. However, as one moved from the entrance of the strait inwards, there was a change in species composition, indicating that there was a gradient in the habitat conditions. Abundant species were *Dentalium* sp., *Modiolus penelegans* and *Placuna sella*. *Nassarius jacksonianus* was common in the sandy habitats of transects 6 and 8.

Table 3. The distribution of mollusks.

Family/species	Transects	1				2				3				4			
		I	II	III	(T)	I	II	III	(T)	I	II	III	(T)	I	II	III	(T)
1. *Cerithium patulum*		1			(1)												
2. Buccinidae sp.		1			(1)												
3. *Dentalium* sp.				7	(7)					1	4		(5)	1			(1)
4. *Ostrea*				2	(2)	1			(1)			3	(3)				
5. *Circe tumefacta*				1	(1)												
6. *Arca rufescens*						1			(1)								
7. *Modiolus penelegans*						11	40	1	(52)						4	7	(11)
8. *Malleus albus*						1			(1)							1	(1)
9. *Thais tissoti*						1			(1)								
10. *Striarca sculptilis*						1			(1)								
11. *Anadara auriculata*								1	(1)							2	(2)
12. *Cerithidea cingulata*										1			(1)				
13. *Nitra incarnata*											1		(1)				
14. *Placuna sella*											5	6	(11)			2	(2)
15. *Murex martineanus*												1	(1)				
16. Nuculanidae																1	(1)
17. *Strombus isabella*															3	4	(7)
18. *Modiolus nitidus*															3		(3)
19. *Mytilus viridis*															1	3	(4)
20. Spondylidae															1	1	(2)
21. *Melongena pugilina*																1	(1)
22. *Nassarius jacksonianus*																	
23. *Anomalocarida squamosa*																	
24. Chitonidae sp.																	
25. *Vermetus*																	
26. *Thais echinulata*																	
27. *Dosinia exasperata*																	
28. *Glauconome* sp.																	
29. *Ostrea* sp.																	
Species diversity		2		3	(5)	6	1	2	(9)	2	3	3	(8)	1	5	9	(15)

Key: I = 5-10 ft, II = 10-20 ft, III = 20-30 ft.
T = Total no. of specimens.

Continued

Table 3. (continued)

Family/species	Transects	5				6				7				8			
		I	II	III	(T)	I	II	III	(T)	I	II	III	(T)	I	II	III	(T)
1. *Cerithium patulum*																	
2. Buccinidae sp.																	
3. *Dentalium* sp.		3			(3)			4	(4)								
4. *Ostrea*																	
5. *Circe tumefacta*				1	(1)	1			(1)								
6. *Arca rufescens*																	
7. *Modiolus penelegans*			12		(12)												
8. *Malleus albus*																	
9. *Thais tissoti*																	
10. *Striarca sculptilis*																	
11. *Anadara auriculata*			1		(1)					2			(2)				
12. *Cerithidea cingulata*																	
13. *Nitra incarnata*																	
14. *Placuna sella*										1			(1)				
15. *Murex martineanus*																	
16. Nuculanidae		1			(1)												
17. *Strombus isabella*				2	(2)					2			(2)				
18. *Modiolus nitidus*																	
19. *Mytilus viridis*																	
20. Spondylidae																	
21. *Melongena pugilina*										2			(2)				
22. *Nassarius jacksonianus*							1		(1)							1	(1)
23. *Anomalocarida squamosa*										1			(1)				
24. Chitonidae sp.											1		(1)				
25. *Vermetus*													(1)				
26. *Thais echinulata*													(1)				
27. *Dosinia exasperata*		2	1		(3)												
28. *Glauconome* sp.			2		(2)												
29. *Ostrea* sp.				1	(1)												
Species diversity		4	3	4	(11)	1	1	1	(3)	5	3		(8)			1	(1)

Key: I = 5-10 ft, II = 10-20 ft, III = 20-30 ft.
T = Total no. of specimens.

Continued

Table 3. (continued)

Family/species	Transects	Total no. of specimens found I	II	III	(T)
1. *Cerithium patulum*		1			(1)
2. Buccinidae sp.		1			(1)
3. *Dentalium* sp.		4	4	11	(19)
4. *Ostrea*		1		5	(6)
5. *Circe tumefacta*		1			(1)
6. *Arca rufescens*		1			(1)
7. *Modiolus penelegans*		11	66	8	(85)
8. *Malleus albus*		1		1	(2)
9. *Thais tissoti*		1			(1)
10. *Striarca sculptilis*		1			(1)
11. *Anadara auriculata*		2	1	4	(7)
12. *Cerithidea cingulata*		1			(1)
13. *Nitra incarnata*			1		(1)
14. *Placuna sella*		1	5	8	(14)
15. *Murex martineanus*				1	(1)
16. Nuculanidae		1		1	(2)
17. *Strombus isabella*		2	3	6	(11)
18. *Modiolus nitidus*			3		(3)
19. *Mytilus viridis*			1	3	(4)
20. Spondylidae			1	1	(2)
21. *Melongena pugilina*		2		1	(3)
22. *Nassarius jacksonianus*			1	1	(1)
23. *Anomalocarida squamosa*		1			(1)
24. Chitonidae sp.				1	(1)
25. *Vermetus*				1	(1)
26. *Thais echinulata*				1	(1)
27. *Dosinia exasperata*		2	1		(3)
28. *Glauconome* sp.		2			(2)
29. *Ostrea* sp.				1	(1)
Species diversity		37	90	52	(179)

Key: I = 5-10 ft, II = 10-20 ft, III = 20-30 ft.
T = Total no. of specimens.

As for the echinoderms, 16 species were recorded. The abundant ones included *Astropecten vappa*, *Ophiocnemis marmorata* and *Salmacis dussumieri*. A few of these species were found at the two extreme sites of the study area.

In general, the entrance of the strait seemed to have a stringent environment in which a few species were found in low abundance. This could be due to its exposure to the open seas. Similarly, the site at Sembawang Harbour showed fewer species and numbers probably because of the organically polluted bottom, resulting low oxygen content and high hydrogen sulfide environment.

The detritus production, utilization and decomposition of bottom sediments in the Eastern Johore Strait were studied by Khoo (1980). The detritus deposition on the benthic environment was correlated with the monsoons. The results show that an estimated 6.8 kg C/m^2 of detritus was deposited annually in the Johore Strait to support about 130 species of mostly filter-feeding detrital benthic organisms.

Soft-bottom Benthic Communities in Rivers and Coastal Waters

In conjunction with the ASEAN/Australia Coastal Living Resources Project (CLRP), the soft-bottom benthic communities of the Singapore River and other rivers such as Kallang Basin, Punggol, Buloh and Serangoon (Lim et al., in press) were studied from 1986 to 1988. Forty families of mollusks, 31 of annelids, 23 of arthropods, 22 of chordates and 2 of echinoderms were collected.

Table 4. The distribution of echinoderms.

Species	Transects	1				2				3				4			
		I	II	III	(T)	I	II	III	(T)	I	II	III	(T)	I	II	III	(T)
Ophiuroids																	
Ophiarachna incrassata		1		2	(3)						2		(2)			4	(4)
Ophiochemis marmorata							6	19	(25)						2	3	(5)
Ophiotrichoides nereidina								8	(8)					2			(2)
Ophiuroid sp. 1				1	(1)												
Ophiuroid sp. 2						4			(4)					4			(4)
Ophiuroid sp. 3												5	(5)			4	(4)
Ophiuroid sp. 4																	
Holothurians																	
Holothuria scabra																1	(1)
Holothurian sp. A				1	(1)		2		(2)								
Holothurian sp. B																	
Echinoids																	
Salmacis dussumieri						9	2		(11)						1		(1)
Asteroids																	
Anthenea chinensis												1	(1)				
Archaster typicus												1	(1)			1	(1)
Astropecten vappa																	
Species diversity		1		3	(4)	42	3	2	(47)		1	3	(4)	2	2	5	(9)

Key: I = 5-10 ft, II = 10-20 ft, III = 20-30 ft.
T = Total no. of specimens.

Continued

Table 4. (continued)

Species / Transects	5 I	5 II	5 III	5 (T)	6 I	6 II	6 III	6 (T)	7 I	7 II	7 III	7 (T)	8 I	8 II	8 III	8 (T)
Ophiuroids																
Ophiarachna incrassata											1	(1)				
Ophiochemis marmorata	2		2	(4)												
Ophiotrichoides nereidina																
Ophiuroid sp. 1																
Ophiuroid sp. 2									2	9		(11)	1			(1)
Ophiuroid sp. 3																
Ophiuroid sp. 4	2			(2)												
Holothurians																
Holothuria scabra																
Holothurian sp. A																
Holothurian sp. B									3			(3)				
Echinoids																
Salmacis dussumieri		21	1	(22)						8	12	(20)				
Asteroids																
Anthenea chinensis																
Archaster typicus									10			(10)				
Astropecten vappa										1		(1)	39	50	4	(93)
Species diversity	2	1	3	(6)					3	3	2	(8)	2	1	1	(4)

Key: I = 5-10 ft, II = 10-20 ft, III = 20-30 ft.
T = Total no. of specimens.

Continued

Table 4. (continued)

Species	Transects	Total no. of specimens found I	II	III	(T)
Ophiuroids					
Ophiarachna incrassata		1	2	7	(10)
Ophiochemis marmorata		2	8	24	(34)
Ophiotrichoides nereidina		2		8	(10)
Ophiuroid sp. 1				1	(1)
Ophiuroid sp. 2		11	9	1	(21)
Ophiuroid sp. 3				9	(9)
Ophiuroid sp. 4		2			(2)
Holothurians					
Holothuria scabra			1	1	(2)
Holothurian sp. A			2	1	(3)
Holothurian sp. B		3			(3)
Echinoids					
Salmacis dussumieri		9	32	13	(54)
Asteroids					
Anthenea chinensis				1	(1)
Archaster typicus		10		2	(12)
Astropecten vappa		39	51	4	(94)
Species diversity		79	195	72	(256)

Key: I = 5-10 ft, II = 10-20 ft, III = 20-30 ft.
T = Total no. of specimens.

The coastal soft-bottom habitats were also surveyed during the same period under CLRP (Koh et al., in press). Offshore subtidal areas near Pulau Tekong, Western Johore Strait and Pulau Ayer Chawan were monitored. Collected were 126 families composed mainly of annelids, crustaceans, coelenterates, echinoderms, mollusks and sipunculids. Attempts were made to characterize and classify the benthic communities and their environments using the family composition collected during the CLRP survey (Khoo and Loo, in press; Khoo 1990).

Using the clustering program, PATN (Belbin 1987), the grouping of sites was made. One of the resulting dendrograms is shown in Fig. 2. It was shown that the coastal sites (Western Johore Strait, Pulau Tekong and Pulau Ayer Chawan) could be grouped together and differentiated from riverine sites (Kallang Basin, Singapore River, Sungei Buloh, Sungei Serangoon and Sungei Punggol) which were grouped in a separate cluster. This indicates that despite the use of higher taxonomic levels of identification, such as families, it is possible to objectively classify the study areas with similar benthic communities that would correspond to meaningful physical and environmental conditions.

Another objective attempt (Khoo 1990) to derive a meaningful pattern using the same benthic composition data was the use of the program, TWINSPAN (Hill 1979). This study showed that it is possible to objectively classify the samples with the same geographic locations and environments together, as hypothesized, using the data on the benthic species composition and to help identify benthic families that characterize these groupings. A typical outcome is shown in Fig. 3.

Offshore coastal sites can be characterized and differentiated from riverine sites by benthic organisms belonging to the families Syllidae, Nereidae, Polynoidae, Ceinidae, Porcellanidae, Xanthidae, Eunicidae, Alpheidae, Ophiactidae and Terebellidae.

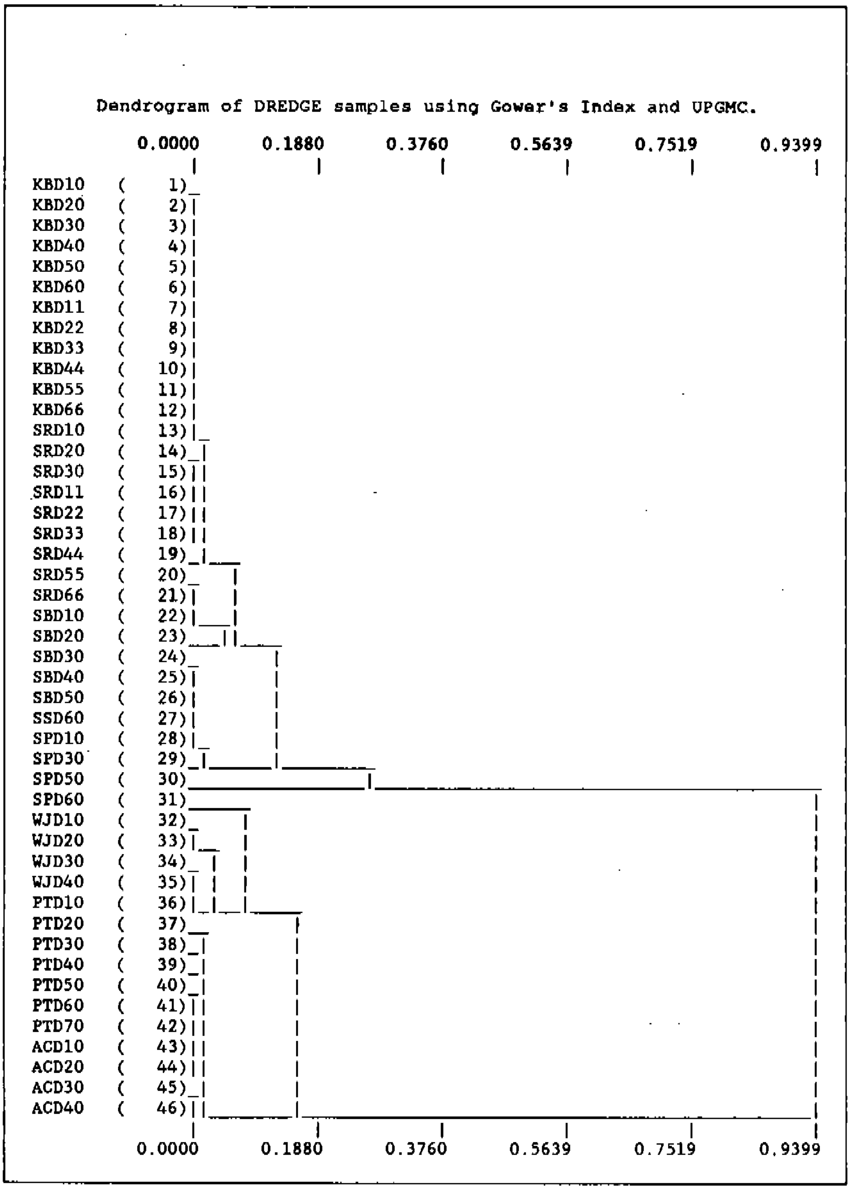

Fig. 2. Results of the PATN classification on dredge samples taken from the rivers and offshore coastal areas of Singapore.

Site ID consists of 5 characters.

Character 1, 2 = site acronym (KB=Kallang Basin; SR=Singapore River; SS=Sungei Seranggon; SP=Sungei Punggol; WJ=West Johore Strait; PT=Pulau Tekong; AC=Ayer Chawan).

Character 3 = Sampling method (D=dredge)

Character 4 = Site number.

Character 5 = Duplicate number.

Discussion and Conclusion

Applications of benthic studies on the monitoring of marine pollution in Singapore have not been as much as expected. The above studies' practical significance, for one, is that of providing some form of baseline information on the existing benthic commu-

```
                          III -       II          III +                    I
                          111111222223334444333333 22      111113444222
                          24453890823410234563467893561567801267501217 99

 11 Ciro lani   -----532----1--4-2----------------------------------  0000
 24 Bala nida   --552555555442--1-----------------------------------  0000
 34 Myti lida   --3--3-2-1121----1--1--3------------1--------------  0000
 41 Ophe liid   -5----------1---------------------------------------  0000
110 Onup hida   ------------14-------------3------------------------  0000
111 Drei ssen   --455----11-----------------------------------------  0000
113 Fami ly 1   -----------1--5-------------------------------------  0000
 74 Troc hida   ------14-------------11-1---------------------4-----  0000
 76 Dona cida   ----------1----------1------------------------------  0000
 83 Fami ly 3   ----------1----------1------------------------------  0000
101 Ostr eida   -------1----------------1-------------------1-------  0000
 29 Pena eida   5554-3---11--------2--1-------5534-3-431-22--------  0001
 37 Arci dae    5-----------1------------3---5-------------2-------  0001
 62 Crep idul   ----2--------1-----------------------3--------------  0001
125 Asel lida   --532-----------------------------------------------  0001
  2 Nere idae   ---------42111--52-21---1---------------------------  0010
 86 Isog nomo   -------1----------------2---------------------------  0010
126 Loli gini   ----1----------------2------------------------------  0010
  9 Euni cida   -----11--1115-4-455-21-----2-----4---3-24-----------  0011
 68 Aphr odit   -----------1------------21-1-----------------1------  0011
 79 Muri cida   -------------2----------11-1-----------------2-2----  0011
 40 Tell inid   ----------114----------1----1555----4--35--424-----  0100
 49 Spio nida   -----------1-21-------------2-----4-5---------------  0100
 52 Sole nida   ----3-----15-----------------33---5454325--2--------  0100
 54 Lacy doni   ------------1-----------------------4---------------  0100
 23 Cirr atul   -------------1---1-------------------5-----2--------  0100
 26 Luci nida   ---------1-------1-----------43---------------------  0100
 38 Vene rida   ---------43---5----2411-2--35-3---43-14554----------  0100
 44 Port unid   -----------1-1---------1--1----4---24-----12--1-----  0100
 42 Dori ppid   ----2---------------------------4--53-----2---------  0100
 43 Nass arii   ---------12-1-----------1-11----44---434-532-45-----  0100
 45 Grap sida   -------1------------------------3--4---2------------  0100
117 Mact rida   ------------1-----------------45--------------------  0100
 19 Tere bell   -----------------1-11------------4-----1------------  0100
 32 Pinn othe   -------------------1---------------4----------------  0100
 35 Nucu lida   -------------------1----------------------3-2-------  0100
 39 Gobi idae   ----------------------------5-----------------------  0100
 46 Fami ly 2   --------------------------------5-------------------  0100
 47 Plat ycep   --------------------------------3-------------------  0100
 48 Syna ncei   --------------------------------3-------------------  0100
 53 Leuc osid   -----------------------1-1--------4--4----32--------  0100
 55 Squi llid   ------------------------------------43------1-------  0100
 58 Ceri thii   -------------------------------------5--------------  0100
 59 Gone plac   -------------------------------------4--------------  0100
 60 Neph tyid   --------------------1------------------5------------  0100
 61 Maji dae    ----------------------11-1-------------321-2-2------  0100
 63 Bucc inid   ----------------------1------------------2----3-4---  0100
 64 Oliv idae   ---------------------------------------------2------  0100
 66 Capi tell   -----------------------------2----------------------  0100
 90 Penn atul   -----------------------1---------------------2------  0100
104 Nati cida   ---------------------------------------------2--4---  0100
105 Nucu lani   ---------------------------------------------21-----  0100
```

Fig. 3. Results of the TWINSPAN classification on dredge samples taken from the rivers and coastal waters of Singapore. Sampling site acronyms are the same as in Fig. 1.

1=KBD1, 2=KBD2, 3=KBD3, 4=KBD4, 5=KBD5, 6=KBD6, 7=KBD7, 8=KBD22, 9=KBD33, 10=KBD44, 11=KBD55, 12=KBD66, 13=SRD10, 14=SRD20, 15=SRD30, 16=SRD11, 17=SRD22, 18=SRD33, 19=SRD44, 20=SRD55, 21=SRD66, 22=SBD10, 23=SBD20, nities in Singapore's waters. Certain species and families that have been identified may also be used as indicators for monitoring.

These studies alone are obviously insufficient for practical usage for environmental impact assessment and pollution monitoring. Nevertheless, some indications on the distribution and occurrence of benthic species are provided so that future investigations and more precise and specific identifications of indicator species for monitoring particular environments could be made. However, to

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108 Psam obii  ----|-----------|-----------|-----------------4---|-  0100
109 Sicy onid  ----|-----------|-----------|-----------------2---|-  0100
122 Pare rgod  ----|-----------|-----------|--------------------5|-  0100
127 Sepi idae  ----|-----------|-----------|------------2-------|-  0100
131 Neri tida  ----|-----------|-----------|------------------4--|-  0100
132 Nati dida  ----|-----------|-----------|-------------------5-|-  0100
140 Cras sate  ----|-----------|-----------|-------------5------|-  0100
------------------------------------------------------------------------
  6 Porc ella  ----|-----------|3--1--345--|----55---------51----|-  0101
 70 Amph iuri  ----|-----------|-------1222|---------------52----|-  0101
 75 Pagu rida  ----|----------1|-------12-2|---------------32----|-  0101
 84 Turb inid  ----|-----------|-----1-1---|------------------5--|-  0101
 14 Ophi acti  ----|-----------|--3-31354-1|--------------------|-  0101
 51 Cras sate  ----|-----------|---------25|---------------22---|-  0101
 69 Cucu mari  ----|-----------|-------3---|--------------------|-  0101
 71 Ophi otri  ----|-----------|------51523|-----------------5--|-  0101
 72 Orbi niid  ----|-----------|-------1-2-|--------------------|-  0101
 73 Cham idae  ----|-----------|-------1--1|--------------------|-  0101
 78 Cyma tiid  ----|-----------|-------1312|--------------------|-  0101
 80 Pala emon  ----|-----------|-------1-1-|--------------------|-  0101
 85 Fami ly 1  ----|-----------|-------1-1-|--------------------|-  0101
 87 Virg ular  ----|-----------|--------2--|--------------------|-  0101
 88 Goni aste  ----|-----------|-----2--1--|--------------------|-  0101
 92 Astr opec  ----|-----------|-----53-1--|13------------------|-  0101
 93 Pate llid  ----|-----------|---------2-|--------------------|-  0101
 95 Ophi urid  ----|-----------|------2--1-|--------------------|-  0101
 97 Pect inid  ----|-----------|----------2|--------------------|-  0101
 98 Chth amal  ----|-----------|----------2|--------------------|-  0101
138 Dent alid  ----|-----------|------4----|--------------------|-  0101
139 Colu mbel  ----|-----------|------2----|--------------------|-  0101
  1 Syll idae  ----|-----------|52-41-1-2--|2---------3---------|-  0101
  3 Poly noid  ----|-----------|5252-2-----|--------------------|-  0101
  4 Cein idae  ----|-----------|31-1-------|--------------------|-  0101
  5 Mall eida  ----|-----------|33---------|--------------------|-  0101
  7 Sabe llid  ----|-----------|31-3---1---|--------------------|-  0101
  8 Xant hida  ----|-----------|31-1--1-21-|--------------------|-  0101
 10 Flab elli  ----|-----------|-4-1-------|--------------------|-  0101
 12 Golf ingi  ----|-----------|-3---------|--------------------|-  0101
 13 Alph eida  ----|-----------|-3-4--2143-|-----------32-------|-  0101
 15 Serp ulid  ----|-----------|-3---------|--------------------|-  0101
 16 Psam mobi  ----|-----------|-2---------|--------------------|-  0101
 18 Palm yrid  ----|-----------|-1-1-------|--------------------|-  0101
 20 Gamm arid  ----|-----------|-1---------|--------------------|-  0101
 28 Ampl eisi  ----|-----------|---2-------|--------------------|-  0101
134 Pter oedi  ----|-----------|5----1-----|--------------------|-  0101
135 Koph obel  ----|-----------|4----------|--------------------|-  0101
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24=SBD30, 25=SBD40, 26=SBD50, 27=SSD60, 28=SPD10, 29=SPD30, 30=SPD50, 31=SPD60, 32=WJD10, 33=WJD20, 34=WJD30, 35=WJD40, 36=PTD10, 37=PTD20, 38=PTD30, 39=PTD40, 40=PTD50, 41=PTD60, 42=PTD70, 43=ACD10, 44=ACD20, 45=ACD30, 46=ACD40.

enhance the usefulness of such information on a community's composition, other biological data such as the environmental tolerances of the composite species, particularly the indicators, are needed.

With the present limitation in identifying most of the benthic organisms to family or genus levels only, it may not be possible to make a precise assessment of any subtle changes in the coastal environment. Thus, it is necessary for further taxonomic studies to identify benthic organisms to species level in Singapore's rivers and coastal waters.

There is much to be done in benthic ecological studies. Because they are not mobile, benthic organisms are advantageous as environmental indicators since their presence or absence and abundance will provide a good measure of the changes taking place in the environment. Therefore, more studies in this field should be encouraged.

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Artificial Reefs in Singapore: Development Potential and Constraints

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Abstract

The first artificial reef in Singapore, consisting of tire-pyramid modules and hollow concrete cubes, was established within the vicinity of the Southern Islands in mid-1989. Early observations indicate their positive role in attracting fish like snappers and batfish. Juvenile stages of fish preferred the tire reefs, while the larger-sized ones stayed with the concrete modules. Since the potential for fish population enhancement appears good, many seafloor areas of Singapore can benefit from artificial reefs. However, the present approval mechanism for the use of such sites represents a strong constraint.

Introduction

Artificial reefs have been in use in various parts of the world. Japan and the USA have the longest histories in the establishment and development of artificial reefs. The success of this concept of enhancing marine life, especially fish, encouraged many other countries worldwide, particularly in Southeast Asia, to establish artificial reef programs for their seas. The purposes of these programs vary from country to country. In Japan, it is meant to enhance commercial fisheries while in the USA, it is intended to improve recreational fisheries. However, in spite of the varying intentions, these man-made reefs have clearly demonstrated their capability to increase biomass production in the aquatic environment, with the success rate higher in the more properly managed programs (Chou 1989).

In reality, artificial reefs also serve as additional habitats offering a new substratum for the settlement of an entire range of encrusting organisms which contribute to the establishment and development of natural communities. These organisms play a major role in food chains capable of sustaining animals of higher trophic levels such as fish. When newly established, artificial reefs attract fish from the vicinity because of the shelter that they offer. As encrusting communities develop, some of the organisms serve as the diet of certain fish species. When food and shelter become available, these fish species will remain almost permanently within the vicinity of the artificial reefs as the requirements of the different stages of their life cycles can be satisfied.

Marine Life

Almost all the natural coral reefs are located south of the mainland (Fig. 1). High sedimentation rates over the last 20 years have reduced the zones suitable for growth. Personal observations showed coral growth extending down to 8 m along the reef slope prior to the early 1970s. Now, coral growth is poor--below the 5 m depth of the reef slope. However, within the upper zone of the reef slope, coral diversity and abundance remain high (Chou 1988), indicating that sedimentation has reduced the zone suitable for growth but has not affected biodiversity and abundance in the zones still suitable for growth.

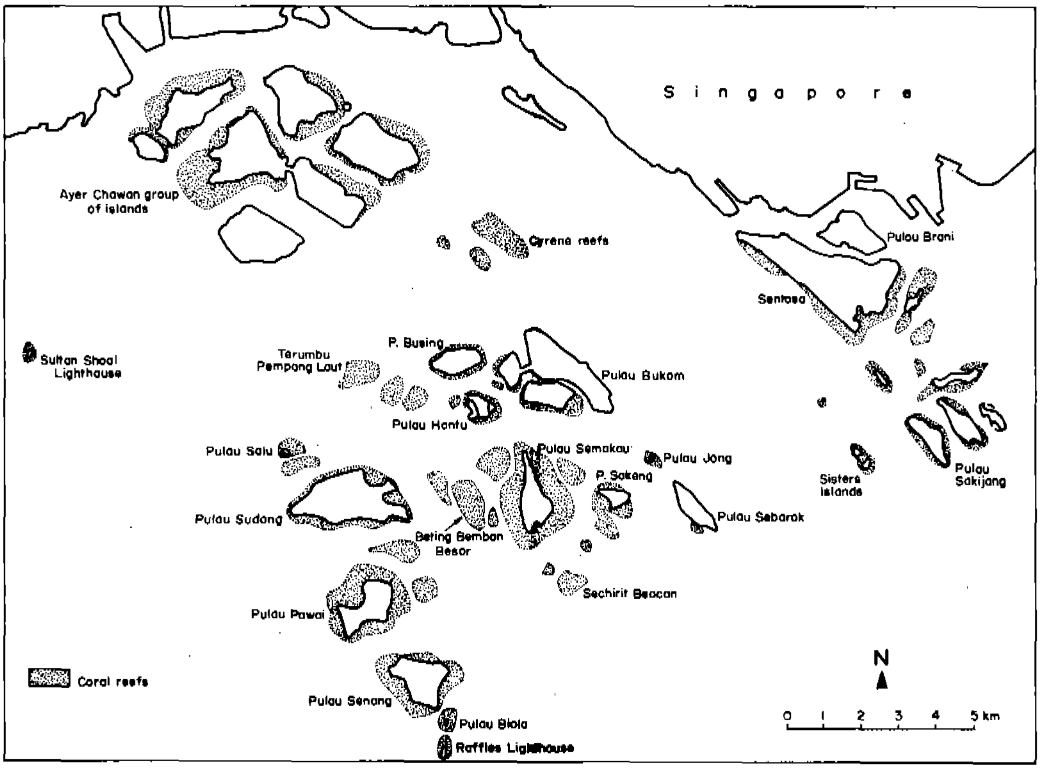

Fig. 1. Map of Singapore and the Southern Islands showing the coral reefs.

The upper zone of reef slopes supports up to 66% of live coral cover at the 3 m depth while the lower zone has less than 14% at the 10 m depth (Lim et al. 1990). The maximum generic diversity of hard corals at the 3 m depth zone was 0.29/m while at the 10 m depth zone, it was 0.11/m. A total of 51 genera of hard corals from our reefs has been recorded, representing a comparatively good diversity when considering the limited extent of these reefs.

The seafloor supports a scattering of various life forms which differ according to the physical characteristics of the substratum. Although the abundance of the benthic communities is low, the diversity of some groups remains high.

Fish life associated with reefs is also poor. Only four indicator species (Chaetodontids) are present. Food fishes are also low in diversity and abundance. Lim et al. (1990) suggest two possible reasons for the low overall biomass, namely the reduced coral growth zone and fishing pressure.

The First Artificial Reef

Under the current ASEAN/US Coastal Resources Management Project, experimental artificial reefs in Singapore are to be established at 2 sites. Each artificial reef consists of 2 sections, one of 50 precast hollow concrete cubes (1 m^3) and the other of used tires tied into pyramidal modules (Fig. 2). Twenty tire modules were deployed, each containing 42 tires. The first reef was established north of Terumbu Pempang Tengah, between mid-August and the end of September 1989. It is a patch reef (Fig. 3) with a depth of 10 to 15 m. The cost of the construction, transportation and deployment of the artificial reef amounted to S$30,000.00. Fig. 4 shows the arrangement and position of the reef modules. The tire modules were placed side by side on the seafloor. Of the concrete modules, 40 were placed next to each other on the seafloor while 10 were double-stacked above them. The second artificial reef is intended to be established in an area west of Pulau Semakau.

Observations of the first artificial reef, since its establishment, showed that within the first few weeks, filamentous algae formed a layer over the surfaces of the materials. This was followed by the settlement and growth of encrusting organisms such as tunicates, hydroids and barnacles, particularly on the concrete modules. The rubber tires did not appear to encourage the growth of these encrusting organisms. Sea cucumbers and mollusks were also observed among the modules. The concrete modules attracted adult batfish *(Platax)* and snappers which appeared to have taken up residence. Subsequent dives revealed their continued presence. The batfish were seen feeding on the encrusting organisms such as the barnacles attached to the concrete modules. Coral reef fishes were observed sheltering among the concrete as well as the tire modules, while various stages of juvenile fishes seem to favor the tire modules.

The results obtained during this initial stage are mostly descriptive. Quantitative data that can calculate the cost effectiveness while paying close attention to the role of these structures in supporting marine life will be obtained with further monitoring in the next few years.

Potential Areas for Development

The two sites selected for the pilot study on artificial reefs have firm sandy substrata. There are many areas with similar seafloor characteristics and suitable depths that can be utilized for artificial reef development. Shallower areas can also be used but these may interfere with the movement of small crafts. Artificial reefs established in shallow areas have the greater potential for the colonization of hermatypic corals since the sedimented

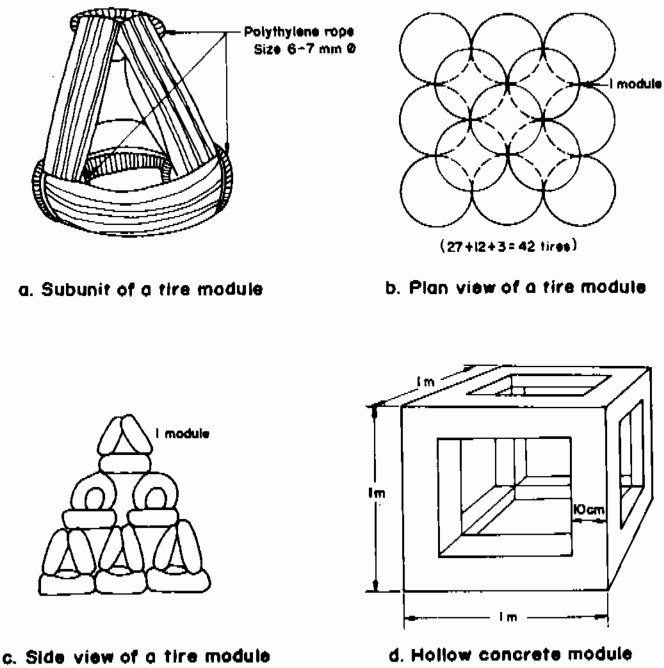

Fig. 2. Artificial reef modules used in the experiment.

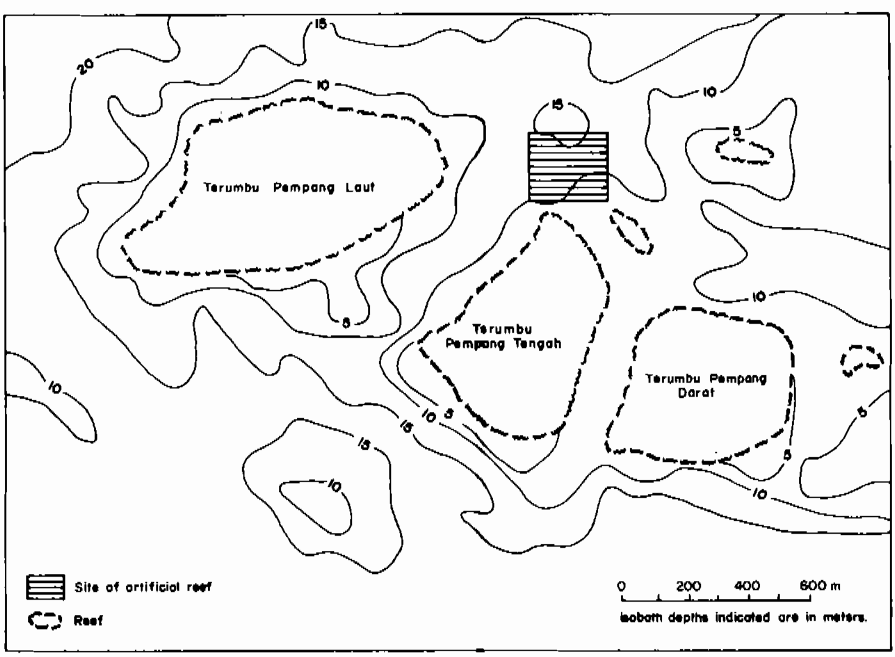

Fig. 3. Site location of the first artificial reef.

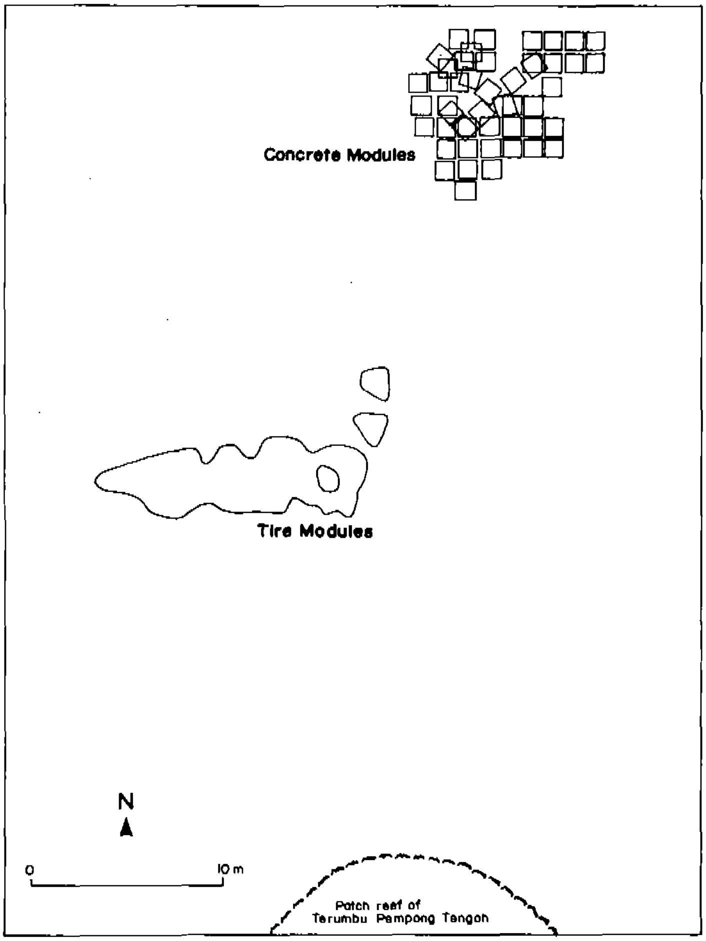

Fig. 4. Plan view of the artificial reef modules.

conditions have limited their growth to the shallower depths. The biota of the fringing reefs of the Southern Islands which are designated for tourism can be enhanced by the placement of suitably designed artificial reef structures in strategic locations where the movement of small crafts is prohibited. They can also serve as mooring buoys to minimize damage to the reefs by anchors. The enhancement of such reefs will make scuba diving more interesting, apart from increasing biodiversity and abundance.

Deeper areas with soft muddy bottoms can also be developed and transformed into suitable habitats for fish and other marine life. The muddy bottom of these areas does not support much marine life because of their anoxic condition. Artificial reef modules can be designed so that while the base remains buried in the mud, the upper part projects well above the substratum which immediately serves to provide shelter as well as space for marine organisms. This will also encourage the growth of encrusting organisms which the muddy seafloor itself could not. The soft muddy seafloor along the East Coast, for example, can be enhanced and made more productive with the use of artificial reefs. The placement of such structures can also increase the recreational fishing potential there.

Constraints

The intense use of the limited seaspace by various sectors makes it difficult to obtain early approval for the use of even this first experimental site. The relevant government agencies to which the plans and details were submitted each took time to evaluate the request for the use of the site. This resulted in as long a period as 19 months before the approval for the use of the first site was given. Requests for the use of other sites which were surveyed and found to be suitable (Chou and Hsu 1987) prior to this first site were turned down after a lengthy process of evaluation by the agencies concerned. This points to the lack of coordination among the agencies as well as the uncertainty on the use of many areas as far as the marine environment is concerned since decisions could not be made before the agencies had consulted one another. A comprehensive management plan for the marine environment is therefore desirable.

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Planning for the Development of Singapore's Urban Waterfront

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Abstract

The history and nature of maritime cities are reflected by the image and character of their urban waterfronts. In Singapore, the cleanup of urban waterways has unlocked the potential for waterfront developments centered around the Singapore River, Marina Bay and Kallang River Basin. The ongoing process of making improvements while conserving traditional buildings and promoting watersports and recreational activities at urban waterfronts is encompassed within the broader framework of realizing long-term plans for them. But for urban waterfronts to become total environments where work and leisure can take place in the heart of the city requires coordinated efforts of government planners, private developers, architects and indeed, the general public. This paper focuses on these plans and outlines the vision for the country's urban waterfronts.

Introduction

Many cities have been built along riverbanks and seacoasts since water provides an easy means of transportation and communication for trade to take place. It also provides food from its depths and enables agricultural activities to take place on the surrounding land.

In these maritime cities rose factories, warehouses, railroads and docks which were brought along by the industrial revolution in Europe that began in the nineteenth century. Many of these cities' waterfronts became an impassable maze of factories and railroads. Bodies of water were not only a convenient means of transportation, but also constituted the cheapest and most convenient dumps for human and industrial wastes, poisoning aquatic life and breeding a number of diseases. As a result, the urban charms of many great cities were marred.

Moreover, the modernization of industrial activities and the subsequent improvements in marine and other modes of transportation had a great impact on the early industrial complexes along the waterfronts. No longer able to cope with the problems of increased volume and speed of production and transportation, the exodus of many of these industries to specially designated industrial areas outside city centers became widespread. With the urban waterfronts abandoned, many of them decayed and became slum areas where crime and pollution held sway.

However, in Singapore, the ill effects of industrialization impinging on the environment of our urban waterfronts had not been as drastic as in Europe and elsewhere. As a young nation, we were spared the earlier century's industrial revolution that swept through many other established maritime cities of the world. The planning and development strategy adopted by the nation for our economy has also been crucial to the well-being of our urban waterfronts.

Nevertheless, our waterways were not spared the pollution caused by human settlements and cargo-carrying boats that plied our rivers. Thus, some of the rivers that flow into our urban waterfronts were found to be grossly polluted with little or no marine life just a little more than a decade ago. Today, organic and inorganic wastes from farms, squatters, street hawkers, and unsewered industrial premises and boatyards continue to be discharged into these waterways.

In response to this situation, the government set up a plan to permanently remove the stench, flotsam and debris that characterize these rivers. Coordinated by the Ministry of the Environment, a ten-year project to clean up the Singapore River and the Kallang River Basin was initiated in 1977. It involved four phases: (1) the waterways were physically cleaned and dredged; (2) pollutive activities were phased out; (3) farms, squatters, hawkers and improper workshops were resettled; and (4) suitable infrastructure, factories, housing and food centers were developed for those affected by the relocation.

Planning

Today, these waterways are clean and free from stench. Aquatic life has returned and will be further enhanced by the fish stocking program currently undertaken by the Fisheries Department. With some new park developments along the waterfronts, the potential for outdoor activities and waterfront developments also becomes evident.

In 1988, the draft master plan for the urban waterfronts at Marina Bay and Kallang River Basin, which was prepared by the Urban Redevelopment Authority (URA) and other relevant government departments and agencies, was made known to the public through a two-week exhibition and several press releases. This master plan, together with that for the Singapore River which was earlier drawn up by URA in 1985, is aimed at formulating a clear development strategy for our urban waterfronts. Specifically, the objectives of the plan are to:

1. optimize the assets of the different waterfront locations;
2. guide and integrate water-based and waterfront developments;
3. establish a comprehensive implementation program; and
4. create a distinctive image and character for our urban waterfronts as future international landmarks.

In drawing up the master plan, the strengths and weaknesses of our urban waterfronts were analyzed and studies of successful waterfronts, such as the Baltimore Inner Harbor and Darling Harbour, were made. An overall conceptual framework was then formulated for our waterfronts along the Singapore River, Marina Bay and Kallang River

Basin. The idea was to develop each of these waterfronts with a distinctive theme and character in relation to their existing strengths and potentials for the various forms of developments. Based on this overall concept, detailed plans were drawn up.

Overall Concept

Singapore River, a legacy of a rich cultural mix of traditional shophouses, godowns, civic monuments, modern skyscrapers and meandering river malls, will be developed following conservative and modern building schemes along with the addition of new shopping and food establishments and recreational facilities. It will be designed as a river for history and entertainment.

Marina Bay, with its panoramic view and expanse of land and water, will be the future core of downtown Singapore since the bay provides an excellent setting for the staging of national events and celebrations. With quality buildings to frame its waterfront promenades, it will become a bay for events and celebrations.

The Kallang River Basin has its sandy beaches and informal shoreline profile, parks, and recreational and sports facilities in close proximity to residential areas. It will be turned into a basin for fun and recreation.

Singapore River

The Singapore River meanders through the traditional center of Singapore. With different bridges linking both banks of the river along its length, it can be characterized by its division into three areas, namely the Boat Quay area, the Clarke Quay area and the Robertson Quay area.

Over the years, the customary activities of bumboats, *tongkang* and *sampan* plying the river and loading and unloading sacks of rice, spices and rubber have been replaced with the contemporary hustle of modern banking and office blocks, hotels and some old remaining shophouses and warehouses which will be restored as part of our traditional building conservation effort to save our cultural heritage. However, in keeping with the times, these will be used as food, shopping and recreational facilities.

Along the Boat Quay, plans for the restoration of the shophouses have been submitted by their private owners. Scheduled for completion by mid-1991, the restored shophouses, together with the colonial Civic Hall, the Parliament House and the modern skyscrapers already there, could then lend their charm to this crescent-shaped section of the river. Plans are also being drawn up to improve the existing promenades fronting the shophouses to complement the many structures that have been built. When these riverside promenades are properly landscaped, ample shade would be provided by the trees to be planted along the length of the promenades for outdoor pedestrian activities. The restored shophouses operating as food establishments could also use these promenades to put their tables and chairs in case of a spillover of customers. By the end of 1991, it is expected that we would all be able to enjoy the pleasure of eating under the canopy of trees along the riverside.

The Clarke Quay area consists of predominantly low-rise traditional warehouses on its north bank next to Liang Court Hotel and the shops undergoing improvements. These large warehouses, which can be restored for a wide variety of new uses, have been tendered out to the private sector. Within the next few years, we would be able to eat, shop and relax amid these rows of restored warehouses with their village kind of atmosphere on this portion of the Singapore River next to Fort Canning Park. The Reed and Ord Bridges will provide important pedestrian links to the opposite bank near the Havelock area where there are still a number of existing shophouses. These could also be conserved to add to the traditional charm of the Clarke Quay area.

The Robertson Quay area is characterized by its large solidly built warehouses and new hotel developments. Many of these warehouses could be refurbished for adaptive reuse and integrated with the new infill commercial developments that will soon rise from the vacant land available there.

The three areas that characterize the Singapore River will be linked by landscaped promenades along both of its riverbanks. Additional landing points could be provided to allow for more boats for the river cruise which is already in operation. Apart from providing a novel way for people to discover the charm of the river, the riverboats could also be an interesting means to travel from one point to another. There are also plans to have *tongkang* moored on the river to serve as floating restaurants. These permanent activities would complement the existing annual and other organized activities such as the New Year *hong bao* show, the river regatta, and the boat and raft races, so that the Singapore River would be rendered exciting not only along the banks but also in the river itself.

Marina Bay

Marina Bay was formed from the additional reclaimed land taken from Marina Center, Marina South and the natural shoreline along Collyer Quay. Its strategic location in the heart of the city, together with the existing financial and business centers at Shenton Way and the modern hotels and shopping complex at Marina Square, provides the bay with a dramatic view of the city's skyline. On the other hand, its calm waters and extensive water frontage of about 4.5 km of shoreline around the bay can accommodate large crowds of people. This makes the bay an ideal venue for staging international water-based events and celebrations. Currently, the powerboat races, dragon-boat races and national events, such as the National Day Celebration and the Cultural Festival, are being held at the bay.

However, the development potential and character of Marina Bay should be further improved because, compared to other successful urban waterfronts, such as the Baltimore Inner Harbor and the Sydney Cove, the present size of the bay is too large. Thus, the bay lacks urban scale and focus. But if the bay is farther reclaimed along the Telok Ayer Basin and on the East Coast Parkway (ECP) side, this would allow for the improvement of road access to the waterfront along the bay at Marina South, increase the width of the existing narrow strip of land next to ECP and, at the same time, fully realize its development potential.

In the long term, Marina Bay could become the focal point in downtown Singapore. The urban scale and formal profile of the bay, when framed by a strongly defined edge of developments along the waterfront with well-designed promenades, will reflect the grandeur and dignity of our city. Also, good quality residential developments in the area and the enhancement of public access by the mass rapid transit (MRT) will extend the life of the city beyond regular working days into long nights and weekends. Possible developments for pleasure boating and international boating events and celebrations will further enhance the character of the bay.

In the interim, Marina South has been put to good recreational use with the completion of bowling alleys, billiard saloons, golf-driving ranges, fastfood outlets, restaurants and the Marina South City Park. These establishments will provide the public with opportunities for fun and leisure right in the heart of the city.

Kallang River Basin

Linked to Marina Bay via the Marina Channel is the Kallang River Basin. The basin is surrounded by Kampong Bugis to the north, Tanjong Rhu to the south, the Kallang Stadium area to the east and the Beach Road area to the west. The Rochor, Kallang and Geylang Rivers drain here. Moreover, the Kallang River Basin area is located close to the residential districts on Crawford/Beach Road and in Kallang/Geylang, and is increasingly accessible through the Lavender and Geylang MRT stations.

Thus, there are plans to develop this urban waterfront into three main areas, namely, the Kampong Bugis area, the Tanjong Rhu area and the Kallang Stadium area, each with its distinct character and identity. However, the development potential of the large tracts of available land for recreational and residential uses would mean that the remaining shipyards, engineering workshops, warehouses and the Kallang Gasworks will have to be phased out to avoid conflicts.

In the case of the Kampong Bugis area, residential and commercial places will be built to maximize the potential of the nearby Lavender and Geylang MRT stations. The development of a waterfront park with carparks and recreational facilities will likewise enhance and complement the use of the area for fun and leisure. At present, the existing sandy beaches and waters along the Rochor and Kallang Rivers on each side of Kampong Bugis have made it a favorite location for canoeing, rowing, dragonboating and waterskiing.

At the Tanjong Rhu area, the existing irregular and untidy profile of its shoreline will be evened out through reclamation to give way to more waterfront developments and allow for the creation of a continuous waterfront promenade fully accessible to the public. However, the main intention is to develop Tanjong Rhu into a good-class residential area with a carefully controlled design. With key focal developments along the waterfront for leisure, such as marinas and water-related activities, Tanjong Rhu will become an exciting and unique waterfront area for its residents and the public.

The Kallang Stadium area is Singapore's established national sports center where the National Stadium, Tennis and Squash Center and the People's Association grounds are located. With proper landscaping and the addition of other amenities, the area can be developed as an ideal urban recreational sanctuary.

Implementation

The implementation of the various development plans for our urban waterfronts on Singapore River, Marina Bay and Kallang River Basin will be carried out in several stages. However, plans that could be immediately implemented will be carried out to provide the impetus for future developments.

For the Singapore River, the emphasis will be on the conservation of the traditional shophouses and warehouses and the promotion of recreational and boating activities along the river. Restoration work for the shophouses at Boat Quay will commence very soon and improvements on the river promenade fronting these shophouses will be carried out. On the other hand, the major Clarke Quay conservation project has been tendered out and will also be ready within the next few years. Boating activities along the river are now being promoted and organized by the Singapore Tourist Promotion Board, the Singapore Sports Council and various watersports organizations. Riverboat cruises will be intensified with the construction of additional landing points at the Boat Quay and Robertson Quay areas. Eating on board *tongkang* moored in the Singapore River could soon be possible, too.

In the Kallang River Basin, the shipyards and engineering workshops on Tanjong Rhu will be phased out to immediately enhance and encourage developments for residential, hotel and other ancillary commercial uses. This will be supported by proposed reclamation plans to improve road accessibility, infrastructural services and the waterfront environment as a whole. Thus, Tanjong Rhu would become a choice location for urban living along the waterfront. Park developments with recreational facilities along the National Stadium and the Kampong Bugis waterfronts will further encourage the use of the area for leisure and water-based activities.

While the development of Marina Bay as the future downtown core of Singapore is a long-term process, plans for additional reclamations in Marina South and the setup of a road network have been made to provide the necessary infrastructure for its development.

In planning for our urban waterfronts, the participation of the general public, related professional bodies and institutions has been actively encouraged. Since the objective is to create a better waterfront environment to serve the public's needs and aspirations, their feedback and suggestions on the proposed master plan will be solicited through public exhibitions, dialogue sessions and press releases. It is only through the coordinated efforts of public developers, planners and architects that we can ensure the success of our urban waterfront development projects.

Coastal Reclamation in Singapore: A Review

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Abstract

Land reclamation has been part and parcel of Singapore's economic growth in the past two decades. By 1992, after the completion of the North Eastern Coastal Reclamation Project, nearly 6,000 ha of land or about 10% of Singapore's original size of 581 km^2 in 1966 would have been reclaimed to meet housing, commercial, industrial, infrastructure and recreational developments. This paper presents a brief review of the coastal reclamations in the country. Major reclamation projects in the East Coast, Changi and Tuas are described, highlighting the methods of reclamation and their impact on the country's development. Landfill used in these projects came from hills which were levelled off, sand dredged from the seabed and, more recently, sand imported from neighboring countries. Future reclamations will be in deeper waters of up to 15 m and will require a considerable amount of fill materials and a higher level of engineering capability. As an alternative source for these reclamations, a cheaper layered clay-sand scheme has been proposed.

Introduction

Early land reclamations in Singapore date back to the 19th century when historical records tell of Sir Stamford Raffles supervising the filling of a swampy land off the main harbor in 1891, using earth cut from the nearby hills. Between 1879 and 1887, reclamations created land in Telok Ayer and Tanjong Pagar in 1884. In the 1930s, the estuaries of Kallang and Geylang Rivers were reclaimed for the construction of a civil aerodrome (Wei 1983; MOCI 1986).

Land reclamation, as we know it today, began in 1964 with the Kallang River Basin Reclamation Project. Since then, land has been reclaimed from the foreshores in the East Coast, Changi and Tuas while offshore islands have been merged or increased in size. So far, over 5,000 ha of land have already been reclaimed. By 1992, after the completion of the North Eastern Coastal Reclamation Project, nearly 6,000 ha of land (equivalent to about nine times the size of the Ang Mo Kio housing estate) will have been added to the original land area of 581 km^2 in the 1960s to meet housing, commercial, industrial, infrastructure and recreational developments.

In the past, fill materials for reclamations comprised hillcut soil from the Siglap plains, Bedok and Tampines and dredged seabed sand from the shoals around the coastal waters of Singapore. However, due to the depletion of materials from these local sources, fill materials for recent reclamations, such as those in Tuas and the North East Coast, were imported from neighboring countries. In these reclamations, water was generally from 5 m to 10 m deep, but in future undertakings when water depths will reach 15 m, reclamation will not only be difficult but also expensive. Also, imported sand is not only likely to be costlier, but supplies for large reclamation schemes face the possibility of being inadequate. Thus, because the need for alternative fill materials has become increasingly evident, a layered clay-sand scheme for land reclamation, which uses marine clay and sand as fill materials, has been proposed in future projects.

Recent Foreshore Reclamation

Foreshore reclamation is carried out by three statutory boards as agents for the government, namely, the Housing and Development Board (HDB), Jurong Town Corporation (JTC) and Port of Singapore Authority (PSA) (Fig. 1 and Table 1). Perceptible

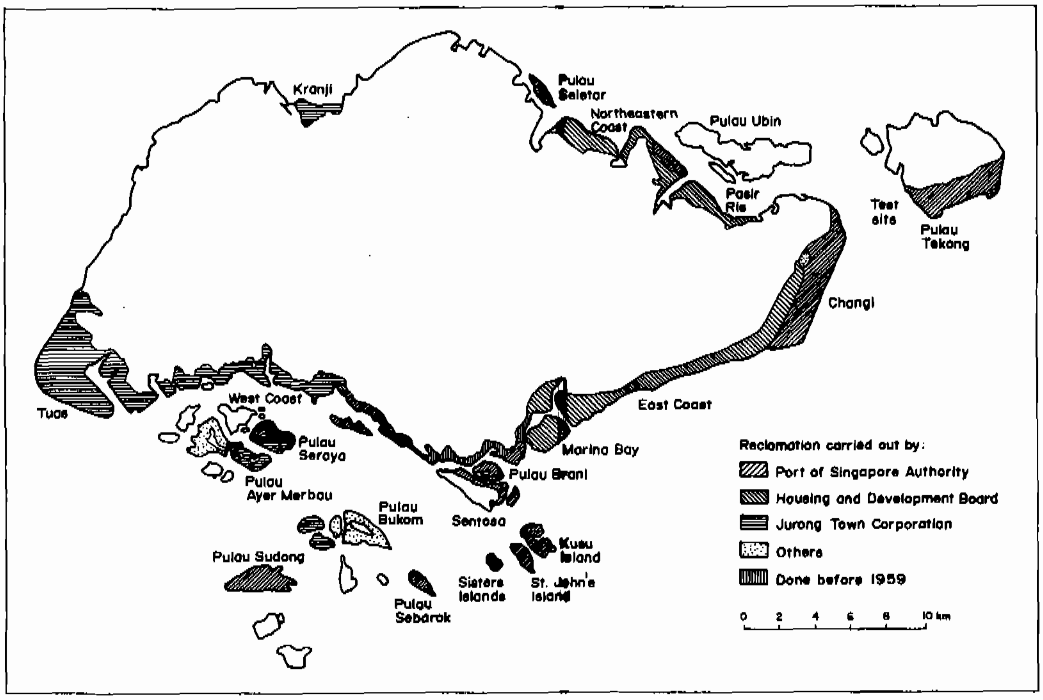

Fig. 1. Foreshore reclamation in Singapore.

Table 1. Major reclamation projects in Singapore.

Project	Period	Area (ha)	Statutory board	Purpose
East Coast (Seven phases)	1966-1985	1,525	HDB	Housing, parks, expressway
Changi	1976-1978	663	PSA	Airport
Tekong	1981-1986	400	PSA	Land bank
Punggol	1983-1987	276	HDB	Housing, parks
Tuas	1984-1988	613	JTC	Industrial
Northeast Coast (Four phases)	1985-1992	685	HDB	Housing, parks
Southern Islands	Future	800	JTC PSA	Industrial

changes in the coastline from Tuas in the west to Changi in the east can also be seen.

Reclamations in Singapore are covered under the Foreshore Act which facilitates leases or grants of offshore and submerged lands. Reclamations up to 4 ha within port limits or 8 ha outside port limits can be authorized by the Ministry of Law; otherwise, approval from the Parliament is necessary. Reclaimed land is then gazetted as state land and then sold to the respective statutory board for further development. The HDB has been reclaiming land solely for meeting housing and recreational needs, with the exception of Marina City which will be developed into a commercial center. The JTC reclaims land onshore and offshore for industrial development, while PSA does so for the development of port, airport and recreational facilities.

Reclamation Methods

The coastal area of Singapore is in a low-energy environment; that is, there are no high waves. The average wave height from crest to trough is between 0.6 m to 0.7 m. This is a significant advantage when land is being reclaimed from the sea because it means that the fill material placed into the sea will not easily be scoured away by wave action.

In the East Coast Reclamation Project, fill material was obtained by cutting hills from Siglap and Tampines which were subsequently excavated to construct the Bedok Reservoir (Wei 1983). Fig. 2 shows the reclamation procedure employed for the later phases of the project. Briefly, hillcut soil was excavated from Tampines Hill by way of bucket wheel excavators and transported by belt conveyors to a loading jetty off Bedok. The fill was then loaded on and transported by barges and dumped directly into the reclaimed area. When the draught limited the movement of the barge, the fill material was unloaded by a reclaimer and conveyor system onto the newly reclaimed land. Bulldozers and dump trucks were employed to spread, grade and compact the reclaimed land to its final levels.

In the Tuas Reclamation Project, the average depth of fill was about 10 m, with 70 million m^3 of sand imported from neighboring countries. The sequence of this reclamation work is shown in Fig. 3 where construction involved (stages 1 and 2) dredging the soft seabed clay and replacing the excavated trench with sand by means of hopper barges to ensure the stability of the bund wall or containment dike. A disadvantage of this method of forming a sand key was that the

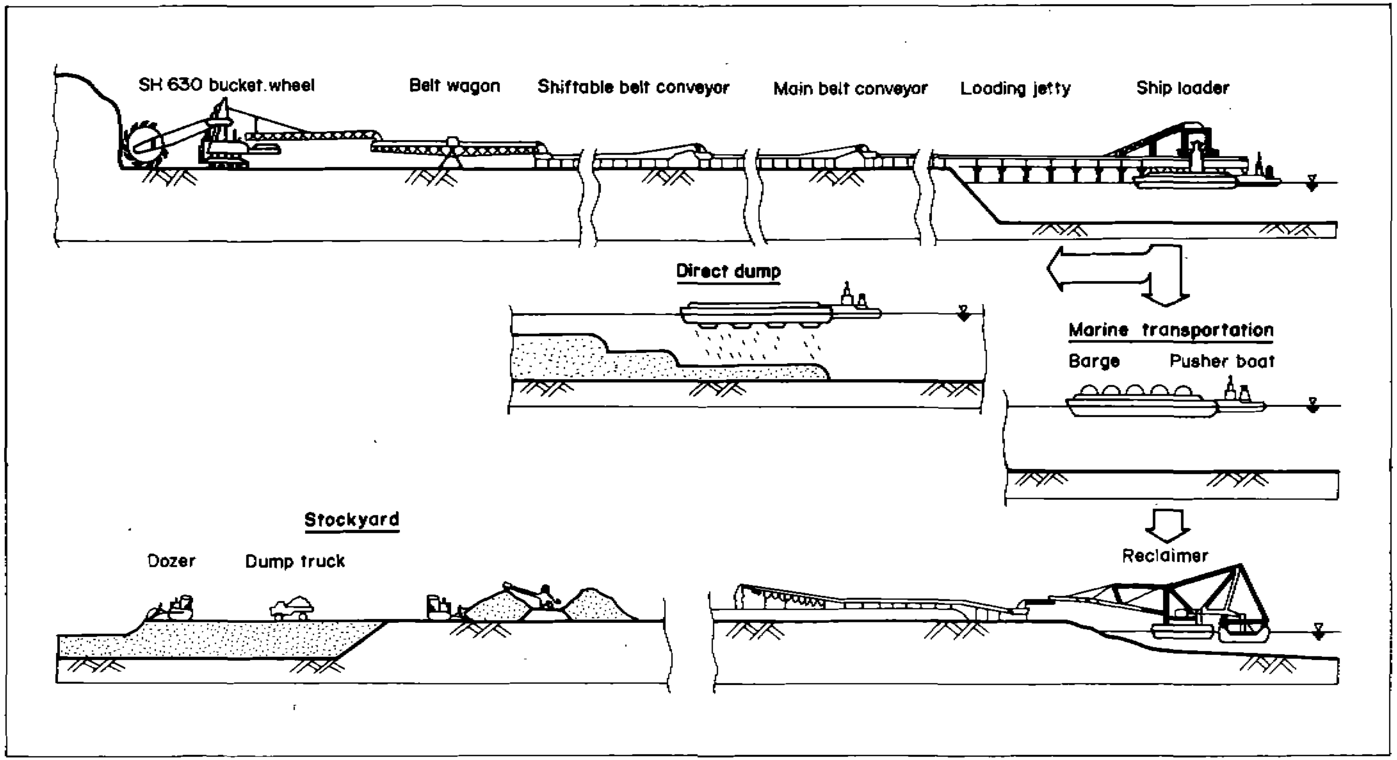

Fig. 2. Reclamation method for the East Coast Reclamation Project (Phases VI and VII).

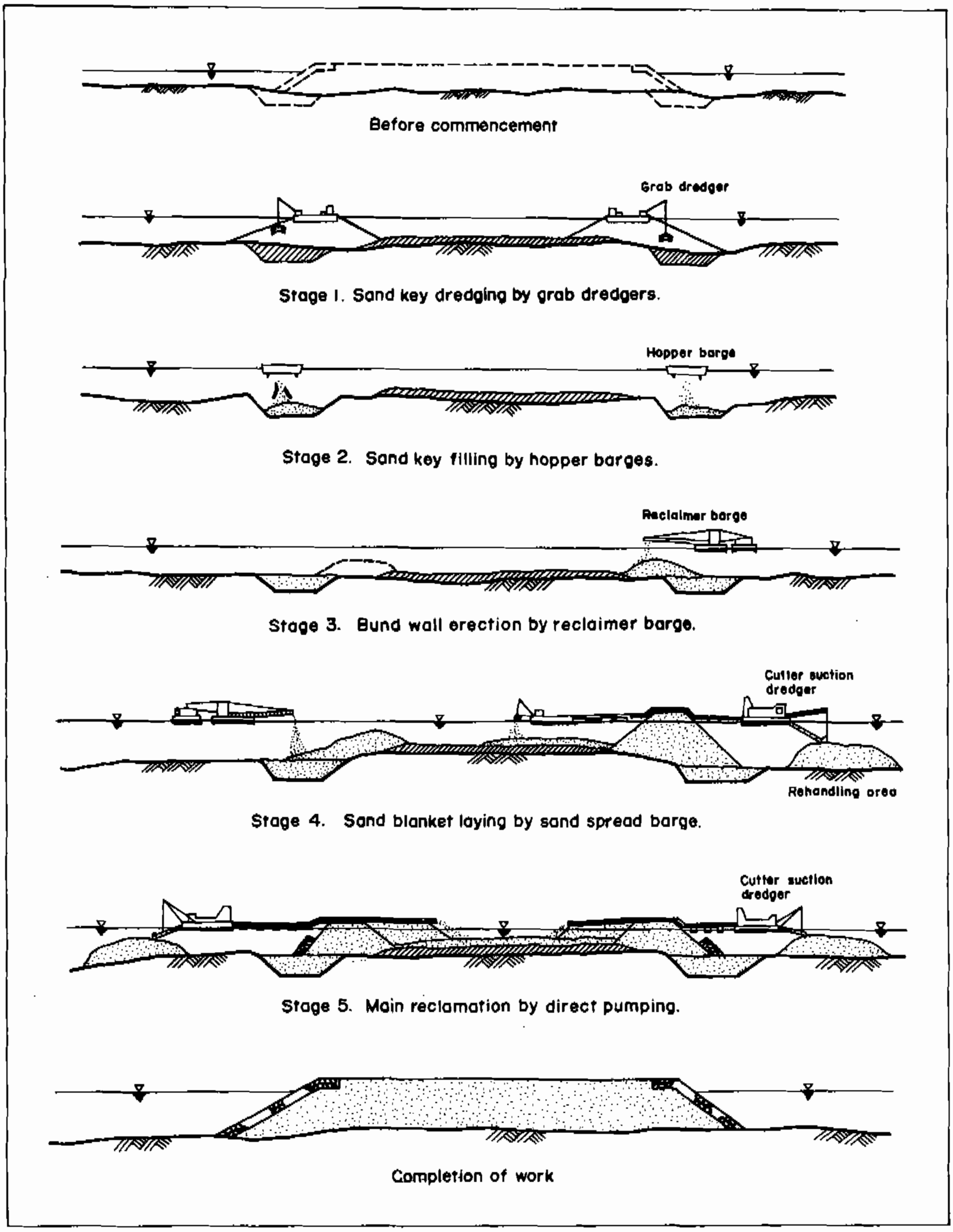

Fig. 3. Sequence of the reclamation work for the Tuas Reclamation Project.

dredged soft clay had to be disposed in "international waters." A better method would have been by controlled failure or replacement with sand without any dredging. The bund wall was then constructed by a reclaimer barge with sand transported from distant sources (stage 3). Sand was also deposited in an interim rehandling area near the reclamation site and pumped hydraulically into the fill area through pipelines with the aid of a cutter suction dredger after the placement of a sand blanket (stages 4 and 5). This sand blanket was put in place by a sand spread barge prior to direct pumping to minimize disturbance to the soft seabed sediments during hydraulic filling. Because the Tuas area is less protected and the waves are slightly higher, some 0.75 million m^3 of stones were used to protect its 13 km bund wall which formed the new shoreline. A layer of filter cloth between the well-graded stones and the sandfill was also applied to prevent the finer materials from being lost to the sea.

A similar sequence of reclamation was adopted in the North East Coastal Reclamation Project where the sandfill was imported from neighboring countries.

Cost of Reclamation

When current reclamation works are completed by 1992, the reclamation bill would be over S$3.15 billion. Computation generally depends on the:

- depth of water which determines the quantity of fill material required;
- quality of seabed which determines whether seabed soil stabilization is required;
- shore protection requirements; and
- cost escalation of materials, equipment and labor.

The costs of reclamations since 1964 are shown in Fig. 4. Although the depth of the water and hence the quantity of fill used per square meter varies with different projects, it is obvious that the cost increases every year. Moreover, the actual construction cost shown in Fig. 4 is only part of the total cost per project and therefore does not include the costs of the feasibility studies; collection of data on seabed levels and soil characteristics; hydraulic model studies made to determine the optimal shape of the reclamation; and other detailed technical and economic studies.

Impact of Reclamation

For Singaporeans, the impact of reclamation is felt in many ways. The East Coast Reclamation Project has created a modern suburb of private and public estates and a major park with a host of recreational facilities that includes a 9-km stretch of stable sandy beaches. The East Coast Parkway, on reclaimed land, has helped to facilitate transportation on the island. Changi Airport, which is built partially on reclaimed land, has taken heavy commercial air traffic away from Paya Lebar Airport which is located in a densely populated area. Even birds stand to benefit from a sanctuary to be created in a landscaped habitat along the East Coast and in the North East Coast.

However, all these gains on land came with their share of controversy. Private land had to be acquired to provide for excavation areas or for developments associated with the reclamation projects. In the sea, where reclamation works were to be carried out, submarine cables were diverted, anchorages relocated and palisade traps *(kelong)* removed.

Conservationists lament the loss of natural coastlines, the threat to marine life and the burial of coral reefs. Others are saddened by the disappearance from the map of Coney Island, a favorite haunt of watersports enthusiasts, with the reclamation of the Punggol foreshore for public housing. So as to compensate, if not in sentiment, at least in area, for the loss of parts of beaches and picnic

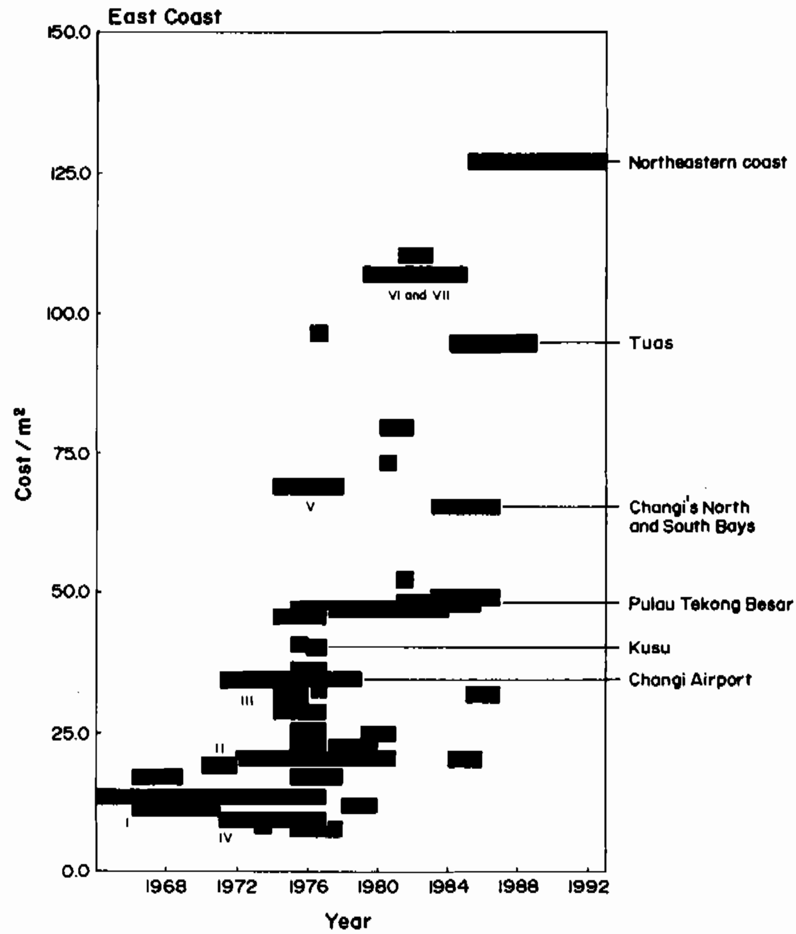

Fig. 4. Project time and cost of reclamation (after MOCI 1986).

areas on the mainland, the Southern Islands and the barren reefs were reclaimed to form holiday islands with sandy beaches.

But these nearshore land reclamations may alter the flow regime in the coastal environment and cause higher levels of turbidity and the reduction in light penetration which is likely to significantly affect the natural ecosystem. Thus, with the pressing need to develop the capability to make changes in flow patterns and attendant transport-dispersion processes involving fine sediments and water quality, the Department of Civil Engineering (DCE) at the National University of Singapore (NUS), in collaboration with the PSA, developed a mathematical model of the coastal region of Singapore that studies the effects of reclamations on the hydraulic regime. Moreover, a clause in all the contracts for land reclamations specifically states that there shall be no siltation/pollution of surrounding sea/seabed areas. The contractor is further required to submit with his tenders full details of measures he will pursue to thoroughly comply with the above requirements.

Future Reclamations

Recently, the government announced plans to reclaim about 9,100 ha of additional land to house an envisaged population of 4 million by the year 2000. The reclaimed land will help provide better quality housing and recreational facilities and possibly relocate some industries there, thus making the Republic the first developed city on the equator. Together with the 6,000 ha of land which have been and are being reclaimed, this future reclamation will make Singapore bigger by 25% than its original size in 1967.

On the other hand, the reclamation of 38 ha of land at Marina Bay will begin sometime next year and is expected to be completed in three years. With the additional space it will provide, the commercial activities at Raffles Place and Shenton Way can then be extended to Marina South. The reclamation will also allow for the development of a waterfront promenade running all the way from Tanjong Rhu to Marina South.

Other areas targeted for new reclamation works include Changi, Tuas, Pasir Panjang and some offshore islands.

A major limitation to future reclamations, though, is the availability of suitable fill materials since some of the proposed reclamations involve water depths of up to 15 m. At these depths, the estimated fill volume required could easily exceed 1,000 million m^3, which makes shore protection quite costly. Imported sand is also not only likely to be costlier but possibly inadequate for large reclamations. The early solution to these problems came when the sonic prospecting of seabed materials showed extensive deposits of soft marine clay in the territorial waters of Singapore (JICA 1979). This prompted DCE at NUS to carry out research on the use of this marine clay over the last seven years, leading to the development of a layered clay-sand scheme for reclamation.

In this scheme, soft clay is dredged and pumped using hydraulic cutter suction dredgers and reaches a slurry consistency when discharged. The slurry is then contained in a pond enclosed with sand dikes where the sedimentation of the clay takes place. When the clay slurry acquires sufficient strength, a thin layer of sand is spread on its surface before it is drained. The process of alternating the placement of clay with sand can be repeated until the desired land elevation is achieved. Details of this scheme have been reported by Lee et al. (1987a; 1987b; 1987d).

The layered clay-sand scheme has been successfully implemented in the 40-ha reclamation of the land in Changi South Bay (Fig. 5) (Lee et al. 1987c; 1989).

Conclusion

With the limited land area, it is essential to promote the development of ocean space around Singapore. Even Malaysia and Indonesia have separately announced plans for extensive reclamations around their coastal waters. In Japan, new industries, ports and airports are being built on man-made islands. It is ready to spend almost US$500 billion on reclamation projects over the next ten years.

The high premium on land and the shortage of space in Singapore, though not conspicuous now, will be increasingly felt in the future. However, reclamations cannot go on indefinitely. We must protect our anchorage areas and the navigational channels to our port from obstructions if we are to remain one of the world's busiest ports. A practical solution to land shortage is therefore the effective and efficient management of our available lands without relying too much on reclamations from the sea which will become very expensive ventures in the future.

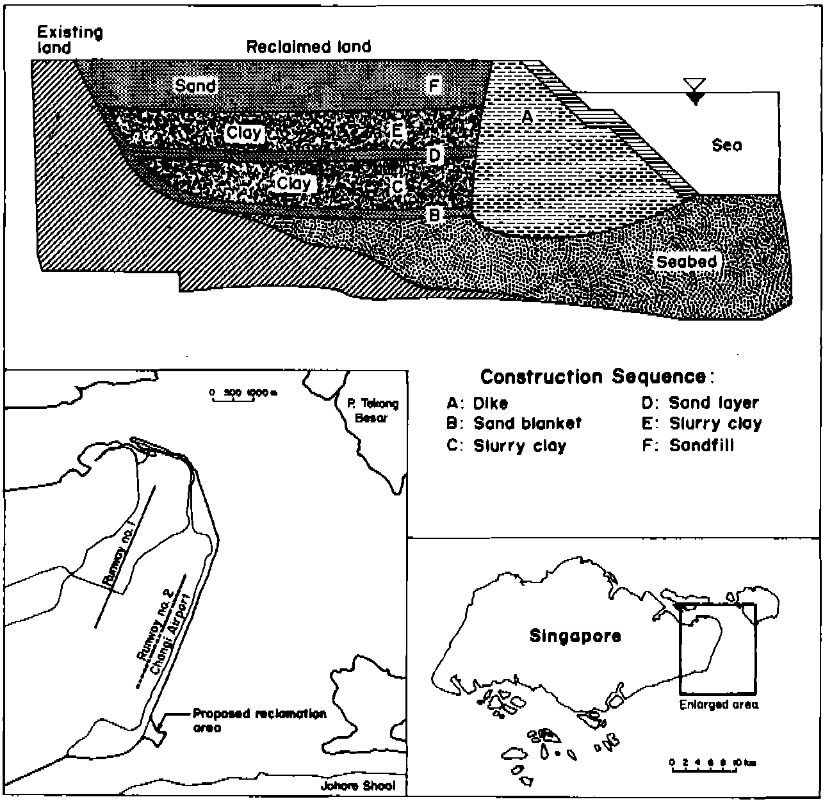

Fig. 5. Cross-section (northwest to southeast) of the layered clay-sand reclamation scheme off Changi South Bay. Inset shows location plan of the reclamation scheme.

Acknowledgement

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Treatment of Sludge and Wastewater in Pulau Bukom

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Abstract

This paper describes the procedure adopted by the Shell Refinery Complex in Pulau Bukom to control the pollution created by its wastewater and sludge. For better control, it segregates wastewater into various streams. Sour water streams are stripped to remove hydrogen sulfide (H_2S), ammonia (NH_3) and hydrocarbon gas. Acidic/caustic streams are neutralized. Dry oil streams are sent to dry slops tanks. Continuously oil-contaminated (COC) streams are sent to oil interceptors. Accidentally oil-contaminated (AOC) streams are sent to oil traps or holding basins. The oily ballast water from oil tankers and the wet slops skimmed from oil interceptors and oil traps are de-watered by slops tanks. Shell's Sludge Handling Facilities (SHF) oversees the treatment of the oil/water/sludge mixture from drainage cleaning and storage tank cleaning. It uses an American Petroleum Instiute (API) oil separator, grit classifier, sludge thickener, corrugated plate oil interceptor and oil trap to remove oil and grit/sludge. The removed sludge is then sent to a sludge farm for biodegradation. An underground drainage and its layer of polyethylene sheet prevent the migration of leachate water. To further enhance the treatment of wastewater at Pulau Bukom, a dissolved air flocculation-flotation unit is being developed.

Introduction

The Shell Refinery Complex at Pulau Bukom consists of crude distillation, lubrication oil, bitumen and solvent plants and conversion units like platinum reformers, catalysts, hydrogen desulfurizers, thermal and hydrogen crackers and sulfur recovery plants. Environmental protection measures have been incorporated into the design of each of these plants. In these plants, some 29,000 m^3 of process cooling water, 120 m^3 of process water and 80 m^3 of tank draining and ballast water are discharged in an hour. In addition, 6,500 m[3] of oily sludge (50% of which is water) is disposed of every year. Following the implementation of the Marpol Convention, more oily water is expected to be unloaded. Stringent environmental control procedures have also been applied throughout the process of treating sludge and wastewater, even at the waste disposal stage.

Management

The Health, Safety and Environmental Steering Committee, led by the Chairman of the Shell companies in Singapore, lays down the general direction of the companies' environmental policy. With the assistance of the Environmental Services Section, each department is responsible for the abatement of pollution within its area. The Environment Adviser gives his recommendations to the Operations and the Environmental Services Sections, while the technologists develop environmental projects and ensure the optimum operation of environmental facilities.

Wastewater Treatment

The schematic flow of wastewater and sludge is shown in Fig. 1.

Segregation

Wastewater streams are segregated into various streams for easy treatment:

- sour water streams to strippers;
- acidic/caustic streams to neutralization pond;
- dry oil streams to dry slops tanks;
- COC streams to oil interceptors; and
- AOC streams to oil traps or holding basins.

Stripping

Most of the process water is used for crude washing in the desalters, where most of the phenols and sulfur compounds are removed. The desalter effluent is then sent to strippers for the removal of H_2S, NH_3 and hydrocarbon gas.

Neutralization

Process water streams which are acidic or caustic are sent to the neutralization pond to correct their pH to 6.6-8.0 before discharging them into oil traps. The majority of the caustic streams, however, are used for crude neutralization.

Oil removal

Since COC streams contain much oil, the Pulau Bukom refinery has incorporated three oil skimming steps before considering the water acceptable for discharge into the sea:

1. preskimming before entering the oil interceptor;
2. oil/water separation and skimming in the corrugated plate oil interceptor (CPOI); and
3. oil/water separation and skimming in oil traps or holding basins.

Since AOC streams contain only small amounts of accidentally contaminated oil, these are sent directly to oil traps or holding basins for oil removal before discharge into the sea. On the other hand, the oily water from ships and the wet slops from CPOIs and oil traps or holding basins are sent to wet slops tanks for oil/water separation. After the oil is skimmed off, the water goes to SHF, where the slops/sludge from tank and drainage cleaning and water from the sludge farm are treated.

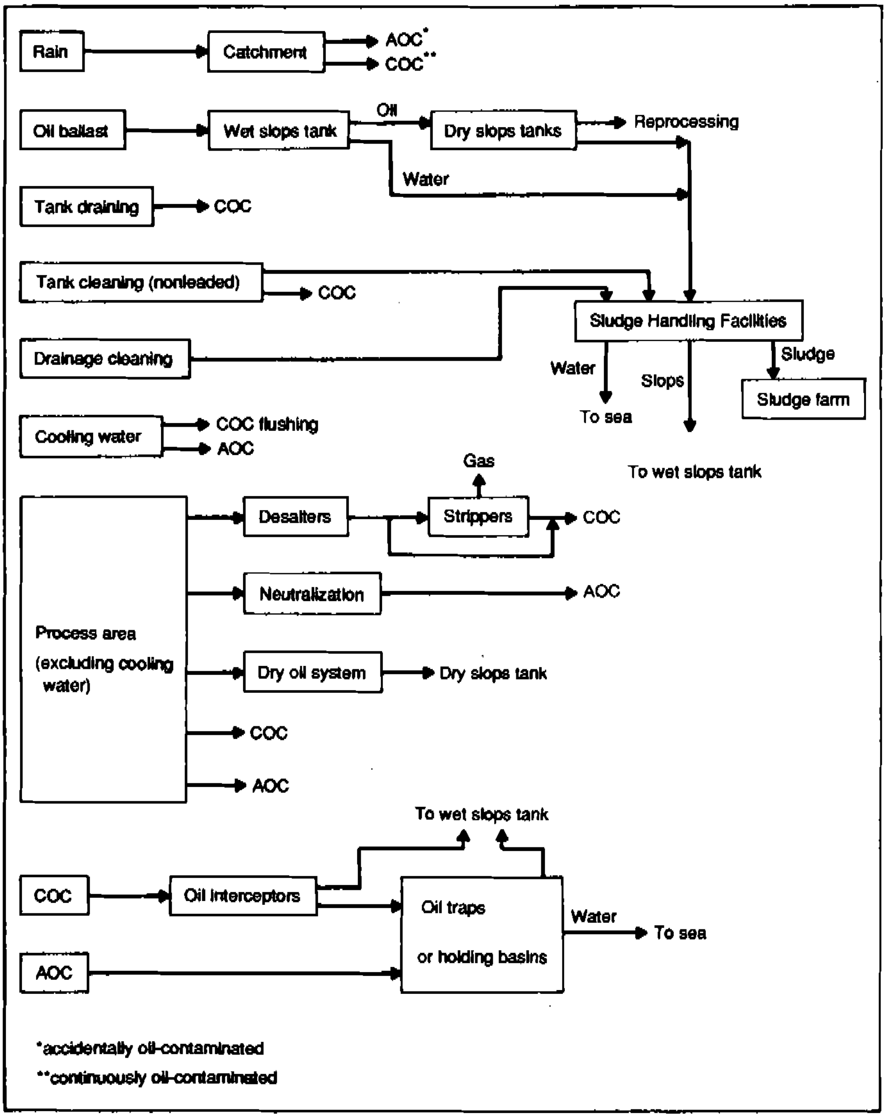
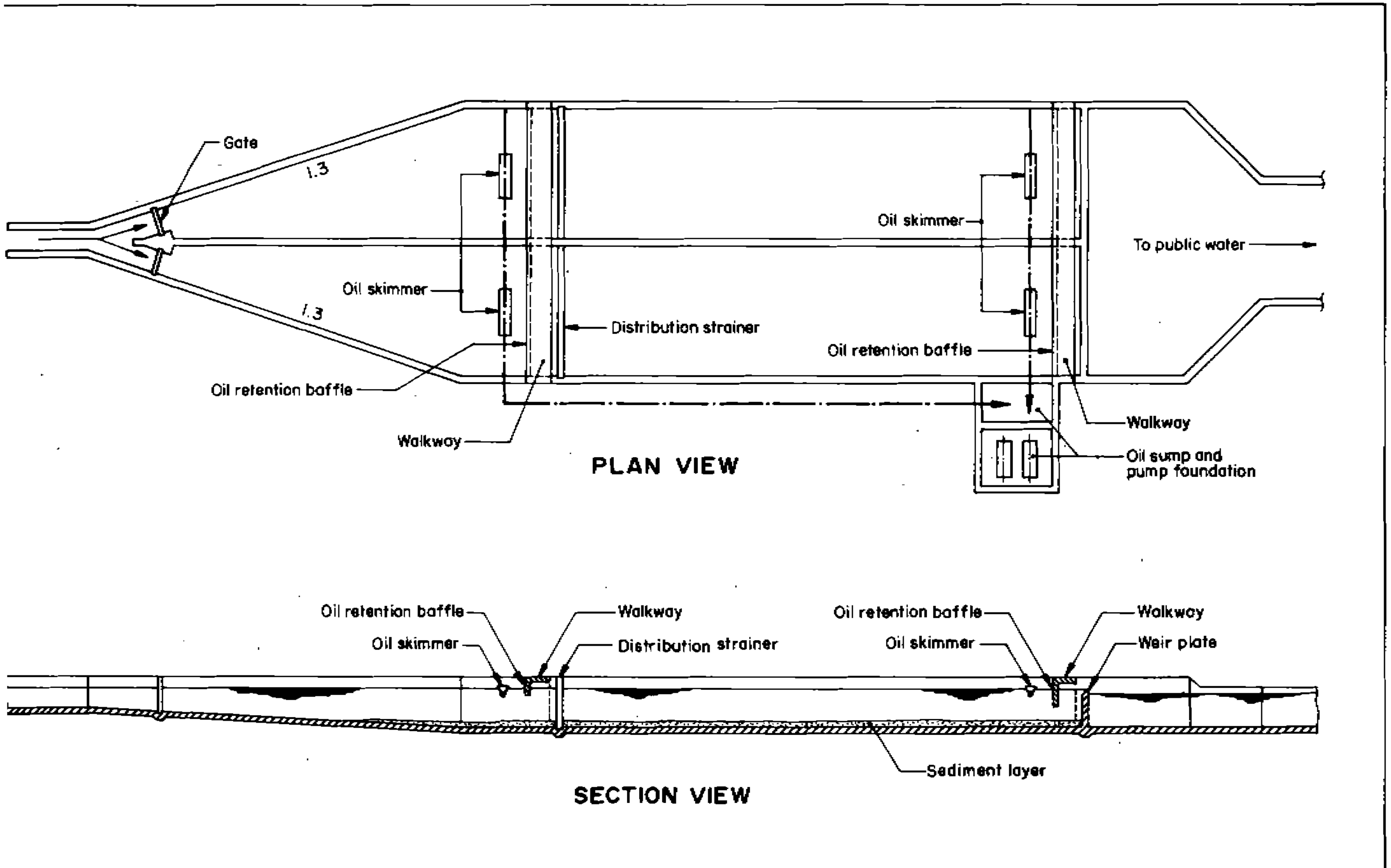


Fig. 1. Schematic flow of wastewater and sludge.

Oil traps and interceptors

An oil trap or a holding basin consists of a long channel which slows down the flow of water to provide laminar flow and sufficient residence time for oil globules to float to the surface and be skimmed off (Fig. 2). An oil interceptor like the CPOI contains corrugated plate packs tilted at an angle of 45° to reduce the distance required for oil globules to rise before these separate from the flow of water. The oil globules are guided by the plate packs to the surface where these are skimmed off (Fig. 3).



[ypical oil-holding basin.

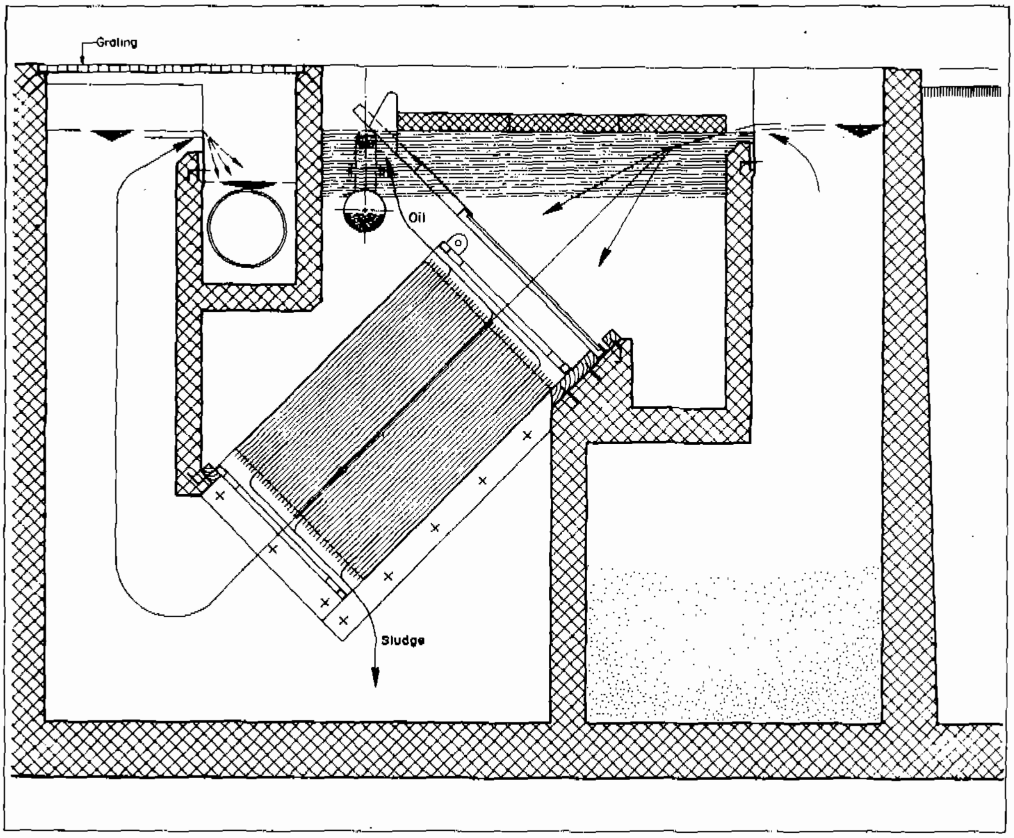


Fig. 3. Corrugated plate oil interceptor (CPOI).

Slops and sludge handling facilities

The wet slops tanks receive oily water skimmed from the oil interceptors and oil traps of ships and wet slops. After settling, oil is skimmed off in the dry slops tanks and the water is drained in an oil interceptor like the CPOI and subsequently, in an oil trap for further oil removal.

Slops and sludge from nonleaded tanks and drainage cleaning are sent to SHF, where these are discharged into a huge basket (sieve) which filters off larger pieces of rubbish. The oil, water and sludge mixture is then sent through an API oil separator, grit classifier and sludge thickener to separate the oil and sludge. Flappers in the API oil separator push the oil into the skimmers and the sludge into the classifier. The grit that settles at the bottom of the classifier is combed off and sent to the sludge farm. The fine particles that are left over are concentrated by the thickener. The thickened sludge is then pumped into the nearby sludge farm for further treatment.

Water from the thickener is recycled in the API oil separator, while the excess water is sent to the CPOI and subsequently to the oil trap to further remove the oil (Fig. 4).

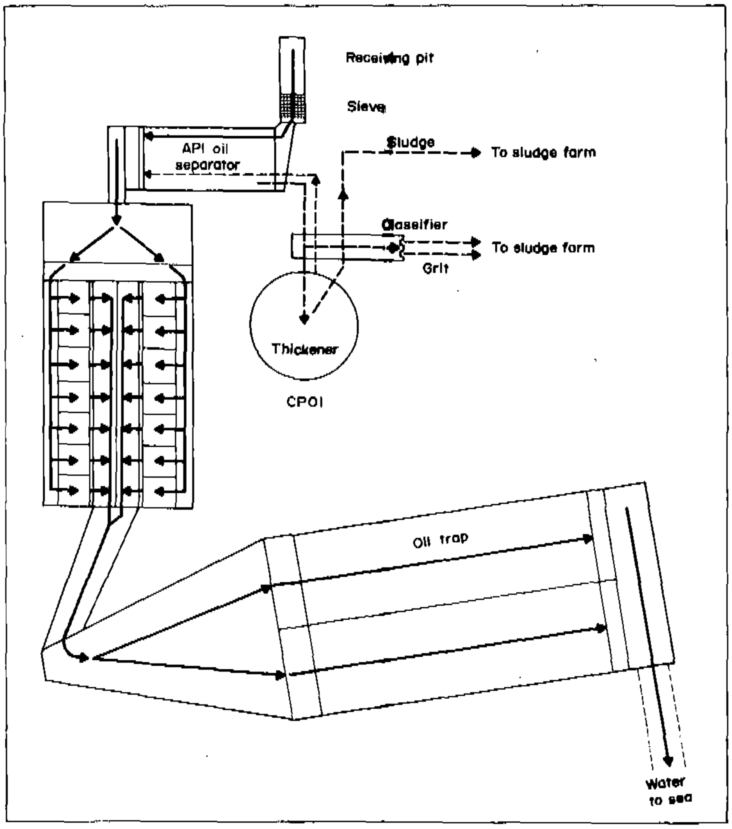


Fig. 4. Sludge Handling Facilities (SHF).

Dissolved air flocculation-flotation unit

A dissolved air flocculation-flotation unit for SHF is being developed to further enhance the treatment of wastewater at Pulau Bukom. Dissolved air and iron sulfate when injected into the first basin oxidizes hydrogen sulfide into harmless (thio) sulfate and elemental sulfur. The addition of a polyelectrolyte coagulates the suspended particles which float to the surface as minute air bubbles (from the action of the dissolved air) to form the floc. The floc is then skimmed off and sent to the sludge farm.

Sludge Treatment

Sediment and sludge from the above-mentioned facilities are sent to the sludge farm for biodegradation. Soil is added to improve porosity. The mixture is aerated by tilling to encourage the growth of aerobic microbes which biodegrade the sludge faster than anaerobic microbes. Lime is then added to counter the acidity produced by biodegradation. Fertilizer is also added to provide the needed nutrients for the microbes to speed up biodegradation. To keep the mixture moist, water is sprayed on it. Runoffs from the sludge farm are sent to SHF for treatment. After about four months, the biodegraded sludge and soil mixture undergoes a leachate test to check its oil, lead, nickel and copper content. When the leachate passes the limits set by the Trade Effluent Regulations, the residue from the biodegraded sludge is used for landfill.

The sludge farm is provided with an underground drainage and a 2 mm layer of high-density polyethylene sheet which prevents the migration of oily water. Observation wells set up at the periphery of the farm monitor the quality of the underground water outside the sludge farm.

Conclusion

As described in the foregoing, the Shell Refinery Complex at Pulau Bukom has a comprehensive system for the treatment of its wastewater and sludge. For this, millions of dollars have already been spent and more are going to be spent to maintain and improve the facilities.

Land-based Sources of Pollution in the Coastal Waters of Singapore

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Abstract

In Singapore, domestic and industrial wastewaters are two of the main sources of water pollution from land. These are treated by a comprehensive sewerage system before their final discharge into the sea. The third main source of pollution is farmwastes which primarily come from pig farming. By the end of 1990, this kind of farming will be phased out completely in the country.

The Ministry of the Environment (MOE) has kept a tight control on other sources of land-based pollutants such as riverine activities and runoffs. Proper solid waste management practices and other engineering procedures are employed to prevent these pollutants from entering the coastal waters and eventually, the urban areas.

Introduction

Singapore is highly urbanized and industrialized. This is reflected in its land use distribution where 48.7% has been set aside for residential, commercial and industrial purposes. A summary of the land uses in Singapore in 1987 is given in Table 1.

Domestic wastewater

Domestic wastewater is generated from human activities such as cooking and washing. It consists mainly of organic matter in solution or suspension and other substances including silt and grit, salts and microorganisms. As these are biodegradable, they can be

Table 1. Land uses in Singapore in 1987.

Land use	Area (km^2)	%
Built-up areas (residential and industrial)	302.9	48.7
Farmholding areas	32.6	5.2
Forests	28.6	4.6
Marsh and tidal wastelands	15.7	2.5
Others (inland waters, open spaces, public gardens, quarries, cemeteries, rubber and coconut plantations and unused land)	242.8	39.0
Total land area (main island and offshore islets)	622.6	100.0

assimilated by a receiving body of water up to a certain extent. However, very often the volume of wastewater generated by large conurbations exceeds the assimilative capacity of the receiving water. Thus, some treatment is necessary.

This is indeed the case with Singapore where the government has invested hundreds of millions of dollars to build and maintain a comprehensive sewerage system. The system comprises a network of underground sewers, pumping stations and sewage treatment so designed to ensure that the wastewater is conveyed to the sewage treatment works before its final discharge into the sea.

Today, about 96% of the population in Singapore is provided with modern sanitation facilities compared with only 57% in 1971. The remaining 4% who lives in the outlying rural parts of Singapore uses low-cost on-site sanitary systems such as the pit latrine, the water-sealed latrine and the R-2 system. The latter is a locally designed improved version of a double-vaulted latrine with a soak-away system.

Apart from domestic wastewater, sewers in Singapore also receive industrial effluents. But these have to meet the stipulated discharge limits before consent is given for their discharge into the sewers. The discharge limits are necessary to prevent overloading the sewerage system and to protect the sewers from damage by corrosive and other types of discharges that may in turn endanger sewer workers. Thus, industries that fail to meet discharge limits are required to do so by treating their effluents properly.

Singapore is well-served by six major sewage treatment works with a total capacity of about 917,000 m^3/day. All these treatment works are highly mechanized and use the activated sludge treatment process to purify the wastewater before discharging it into the sea. Some treated wastewater is reused for nonpotable purposes such as cooling equipment and watering golf courses.

Industrial wastewater

Industrial wastewater varies with the type of activities it is used for. It may contain organic matter, nonbiodegradable or hazardous materials such as heavy metals and synthetic organic compounds.

Except for a few industries in outlying areas, all industries in Singapore are required to comply with the limits to discharge their effluents into public sewers. Those industries not served by the sewerage system are allowed to discharge directly into drains and rivers. They are, however, still subjected to stringent discharge limits.

Oil refineries are allowed to discharge their effluents into the sea after appropriate treatment. The treatment process is principally aimed at the removal of oil and grease and consists typically of American Petroleum Institute (API) separators, dissolved air flotation units and oxidation ponds.

The sewage treatment works in Singapore are capable of treating both domestic and industrial wastewaters to produce an effluent with a biological oxygen demand (BOD) of less than 20 mg/l and suspended solids (SS) of less than 30 mg/l. The treated effluent represents a 90-95% reduction of the original BOD and SS in the wastewater. About 2.3% of the treated effluent undergoes advanced treatment to produce nonpotable industrial water for factories and for toilet flushing in three housing estates. Some treated effluents are used for golf course watering and at the sewage treatment works themselves for engine cooling, chemical mixing and washing.

Agricultural wastewater

The main source of water pollution from agriculture in Singapore is found in pig farming. Thus, the farms are required to provide a primary treatment system consisting of a cesspit capable of a hydraulic retention time of seven days. The solids settle and accumulate in the cesspits, then undergo anaerobic decomposition. However, only the resulting liquid is discharged. Some farms have additional ponds to improve their effluents' quality. Here solids are accumulated and brought by road tankers to sewage treatment works. About a 60% removal of BOD and SS can be attained with this primary treatment.

In December 1987, there were about 459,000 pigs in 195 farms in Singapore. The number has decreased significantly with pig farming scheduled to be phased out completely by the end of 1990. To compensate, poultry rearing is carried out undercover, usually in batteries. The dung of these domestic fowls is removed and disposed of as a solid waste.

There is a small-scale horticultural industry in Singapore, farming mainly vegetables, orchids and ornamental plants. Since the main pollutants from these farms are the pesticides and nutrients from fertilizers, the farmers are not permitted to use highly toxic and persistent pesticides. They are encouraged to use correct methods of pesticide and fertilizer applications to minimize excessive washouts. Many of them provide a drainage system to collect surface runoffs and use these for watering.

Solid wastes

Singapore generates about 5,000 t of solid wastes per day. Much of these are incinerated. Those that are not, including incineration residues, are disposed of at sanitary landfills which are built on impervious clay to minimize leachate infiltration. However, surface runoffs and seepage from landfills do occur. While they contribute to only a small amount of pollutants entering our coastal waters, the improper disposal of solid wates on the whole would still result in the release of putrescibles and chemicals which would later find their way into the sea.

To prevent litter from entering our coastal waters, engineering measures have been implemented in conjunction with public education programs. Some of the measures being used to trap and remove litter are the slabbing of drains, the mechanical screening of canals and the deployment of float booms. Cleaning river mouths is also practised, using work boats known as "water witches".

Table 2. Potential pollutants from land-based sources which enter the coastal waters of Singapore.

Mass to source/sea (t/yr)	BOD	SS	Total N	Total PO_4	Detergent	Oil and grease
Treated effluent discharged directly into the sea	12,031.1	25,795.3	8,219.0	566.8	130.4	1,107.7
Wastewater discharged through rivers	Nil	Nil	Nil	Nil	Nil	Nil
Total load from discharge	12,031.1	25,795.3	8,219.0	566.8	130.4	1,107.7
Total waste thrown directly into the sea	Nil	Nil	Nil	Nil	Nil	Nil
Solid waste washout into rivers	Nil	Nil	Nil	Nil	Nil	Nil
Total load into the sea	12,031.1	25,795.3	8,219.0	566.8	130.4	1,107.7

Quantifying Wasteloads

Not all the wastes discharged into the coastal waters of Singapore can be classified as pollutants. To be precise, the waste discharged can be a pollutant if it destroys living and nonliving constituents in the environment. Since there are no precise techniques of differentiating between wastes and pollutants, it is a general practice to treat all wastes as potential pollutants. Table 2 shows the potential pollutants from land-based sources which enter the coastal waters of Singapore.

Control and Legislation

The MOE is responsible for pollution control of all land-based activities. As a result of our continued efforts to remove and control these sources of pollutants, the water quality in our coastal waters has improved.

The Singapore River and the Kallang River Basin which used to be heavily polluted by wastes from land-based and riverine activities are now visibly cleaner. Aquatic life is making a comeback. However, there are still inputs of pollutants from diffused sources. The ministry is currently exploring engineering means to minimize these sources.

The Punggol River receives effluents from the cesspits of pig farms. When pig farms are phased out, the coastal water quality there is expected to improve.

The current legislation to control water pollution in Singapore is the Water Pollution Control and Drainage Act and its subsidiary regulations. This legislation is regularly being reviewed to maintain or upgrade its effectiveness. Under the act, the government is seen as one that takes a stern view towards offenders. To demonstrate this, 121 cases were prosecuted for causing pollution or for failure to comply with the act.

Conclusion

In Singapore, the method of controlling the pollution of our coastal waters has been to build sewers, pumping stations and sewage treatment works and to require all wastewater to be channelled into the sewers. This approach has been found to be the most effective for land-based sources and thus, will continue to be adopted.

Economic Valuation of Singapore's Coastal Resources

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Abstract

This paper attempts to determine the economic significance of Singapore's coastal resources in terms of their contribution to the gross domestic product (GDP), value added and employment. These three factors are seen as important parameters to enable policymakers to decide on the allocation of these resources for the development of projects such as those being undertaken for the marine sector. Comprising this sector are the marine industry's shipbuilding, repairing and rig construction, port and shipping services, and the marine-related operations of the petroleum, tourism and fishing industries. All of these industries are estimated to have contributed the overall amounts of 9.6% and 5.7% to the GDP and total employment, respectively. The future prospects of these activities are also discussed.

Introduction

As land-based resources have become increasingly scarce from increased economic activities, policymakers have begun to emphasize the need for developing sea-based resources.for quite some time now. The realization of such a need worldwide has led to the recent extension by the United Nations of the maritime jurisdiction to 200 nautical miles (nm), a move which has brought most known ocean resources and the activities related to them under the control of individual states. As a result, developing countries pay closer attention to the effective utilization of these resources, if available, since they realize their future progress depends on them. The Association of Southeast Asian Nations (ASEAN) member-countries, in particular, are interested to develop their coastal resources on a sustainable basis in order to meet their long-term development needs.

Their active participation in the ASEAN/US Coastal Resources Management Project (CRMP) is a manifestation of this interest.

Although Singapore has been called a "geographically disadvantaged state" (GDS) because of its limited coastal area, this same "disadvantage" played an important role to promote the country's economic growth and prosperity. One of the properties of its surrounding waters, high depth, led to the natural development of Singapore's port. Then, as a strategically located harbor between the oil sources in the Arabian Gulf and the expanding market for oil products in East Asia, the country was encouraged to maximize the use of such a convenient route to become the third largest oil refining center in the world. Moreover, the frequent movement of oil tankers along with other specialized bulk carriers further accentuated the growth of its port facilities and prompted the emergence of various support industries such as shipbuilding, shiprepairing and oil rig construction.

Given the above data, this paper seeks to determine the economic significance of Singapore's coastal or marine resources. Such resources usually refer to all the natural resources found within the "coastal zone" of a country including the coastal space (i.e., sea and coastal land) itself. In Singapore, there is presently no waterfront zoning, special districting or any other official demarcation of coastal areas. Thus, Krausse (1983) in his study of Singapore considered all the reclaimed areas as well as locations within three miles (4.8 km) of the shore as "coastal". In fact, no part of Singapore is more than 15 km from the sea and, therefore, the entire country may be regarded as coastal in nature.

Due to the absence of an official definition of a coastal zone, it is difficult to specify what constitutes coastal or marine activities for valuation purposes. Also, the marine sector tends to be related to a number of other sectors directly or indirectly which makes the task of specification even harder. Moreover, once a certain set of activities is identified as coastal, a valuation technique has to be chosen to quantify the economic contributions of these activities. The wide variety of valuation techniques again poses a serious problem to the investigator who has to make careful comparisons among these highly complex procedures before choosing a particular method. The choice of a technique, however, is often constrained by the availability of data.

In this paper, the conventional national income approach is adopted for the purpose of valuation. Thus, the economic potential of a marine-related industry is measured by its contribution to the country's GDP or some other macroeconomic indicators. Data for different time periods are obtained from various published sources and are presented in such a way that changes over time can be easily observed. Important trends are likewise highlighted and conclusions drawn from them.

Identifying the Coastal Resources

For Singapore, it is difficult to identify the coastal or marine resources because the sea is virtually related to everything directly or indirectly through backward and forward linkages. "Backward linkages" refer to those establishments that supply the ocean sector with goods and services that are used as inputs in its production process, while "forward linkages" refer to those establishments that utilize ocean sector outputs as inputs for their activities. There are other establishments which are not related to ocean resources directly but nevertheless benefit from their existence with the development of activities associated to them. Included under this category are the tourism industry and those establishments that manufacture sporting and recreational goods.

Using the suggestions of Pontecorvo (1980) and Cortez (1986), the marine sector should include the following:

1. establishments with activities that exploit the oceans as a source of natural resources; by "natural resources" is understood the living and nonliving, including the energy and resources of the oceans; and
2. establishments that utilize seaspace in their productive processes and for which the very use of this space is a *sine qua non* condition for the development of their activities.

The economic activities in the first group include offshore fishing; aquaculture; mariculture; mining, oil and gas exploration; sand, clay and gravel extraction; power generation; and the desalination of seawater. The classification of industries in the second group is somewhat subjective due to its *sine qua non* condition but may include shipping and port activities, cable communication services, refuse and sewage disposal services, marine-related tourism, navy- and ocean-based security systems and some other secondary marine services.

Considering the above criteria and the popular perceptions towards coastal or marine resources, Singapore's marine sector should include the following: rivers and water catchment areas, reclaimed lands, mangroves, aquaculture, marine fisheries, beaches, coral reefs, offshore islets, oil and petrochemical plants, shipping, shipbuilding and shiprepairing, oil rig construction, and marine-based tourism and recreational activities. Although it is now possible to assign a value to virtually any kind of resource-based activity by using various cost-benefit and survey techniques (Dixon and Hufschmidt 1986), such a valuation is beyond the scope of this paper for its main focus will be on the economic contributions of the most commonly recognized marine resource uses. These uses include fisheries, oil refining, petrochemicals, shipping services, shipbuilding, shiprepairing and oil rig construction.

Economic Significance of the Marine Sector

The contributions of the marine sector to the economy can be studied in several ways. One can disaggregate the components of the national income or output. Although more sophisticated techniques can be applied, the results of such an analysis are often difficult to interpret. Policymakers, who have to make decisions on resource allocation, usually consider the relative share of the various sectors, including the marine sector, to the country's GDP, value added and total employment. The present study used these same factors to determine the percentage distribution of the industries comprising the marine sector.

Singapore virtually possesses no commonly recognized marine resources such as offshore petroleum, natural gas and minerals, while its mariculture remains a relatively minor activity. Its limited coastal zone, however, has been extensively developed for port and shipping activities as well as for marine-related industrial uses such as shipbuilding, shiprepairing, oil refining and oil rig construction. Some coastal resources have also been utilized to develop water-based recreational facilities in order to cater to the needs of an expanding tourist industry. The fishing industry, though gradually declining, is still in existence. A brief account of Singapore's marine sector and its importance to the economy is given below (Chia et al. 1988).

Petroleum industry

There are five major oil refineries located in the coastal area of Singapore. Their total refining capacity is more than one million barrels per day, which makes Singapore the third largest refinery in the world, after Houston and Rotterdam. These five refineries had been processing crude oil into various

Table 1. Percentage distribution of GDP by industry, Singapore, 1960-1988.

Industry	1960	1970	1980	1988
Agriculture and fishing	3.8	2.3	1.1	0.4
Manufacturing	12.8	21.6	29.5	28.8
Trade	31.3	27.4	18.9	17.9
Financial and business services	11.7	14.3	20.3	27.5
Transport and communications	13.3	11.5	12.0	14.2
Others	27.1	22.9	18.2	11.2

Source: DOS 1960-1988.

types of products until the demand changed and called for more emphasis on the production of lighter products through secondary processing. Thus, they had to make gradual adjustments in the composition of their output.

One of Singapore's oil refineries is found on Pulau Ayer Merbau. It is a S$2 billion joint venture project between the government-owned Petrochemical Corporation of Singapore (PCS) Pte. Limited and a consortium of Japanese firms. The complex was launched in 1977, although construction began only in mid-1980.

PCS started its operations in 1984 with the first naphtha/liquefied petroleum gas (LPG) cracker in Southeast Asia which has a production capacity of 300,000 tons per annum (tpa) of ethylene and 160,000 tpa of propylene. PCS also produces other petrochemicals like acethylene, benzene, toluene and xylene which it has successfully marketed overseas. Because of the reasonable amount of profits it has earned in recent years, the company has been able to make direct positive contributions to our economy. Besides the petroleum industry, PCS supports other industries such as the plastic industry through the supply of necessary inputs, e.g., plastics and resins. PCS also helps promote the transfer of technology and skills by collaborating with many local enterprises.

Table 1 shows the percentage distribution of GDP by industry for the years 1960, 1970, 1980 and 1988. Manufacturing's contribution to the economy increased substantially in the past decades, accounting for nearly 29% of the GDP in 1988. International trade also contributed heavily to the economy, although its share of GDP gradually diminished over the years.

While the petroleum industry contributed quite substantially to both the manufacturing and trade sectors in the past decade, its contribution to the country's manufacturing output fell rather sharply after 1985. In 1988, the industry accounted for only 14% of the total manufacturing output compared to a high of 37% in 1978 (Table 2).

On the average, the value added by the petroleum industry, which is the gross income generated by the industry, was about 15% of the total manufacturing output during 1978-1988 (Table 3). Although it was the second largest contributor to the industrial sector, after the electronic products and components industry, the oil industry's contribution dropped sharply in the later part of the 1980s. At present, it accounts for merely 4% of manufacturing's value added.

The petroleum industry is highly capital-intensive in nature and therefore, not a major employer of labor. The industry's very low ratio of workmen to total employment can be seen in the statistics of 1988 when a total of 3,103 workers were engaged by the industry, which is only 1% of total employment in the manufacturing sector. This reflects the high degree of automation and mechanization in the industry.

Table 2. Contribution (S$ million) of the petroleum industry to Singapore's manufacturing output, 1978-1988.

Year	Petroleum and petroleum products	Total manufacturing output	% of total output
1978	7,498.3	20,492.3	36.6
1979	9,308.1	26,331.0	35.3
1980	11,520.5	32,805.8	35.1
1981	14,453.8	37,694.0	38.3
1982	14,641.2	37,141.1	39.4
1983	13,163.6	37,888.3	34.7
1984	12,448.8	41,704.1	29.9
1985	11,031.3	38,817.8	28.4
1986	6,990.3	37,502.9	18.6
1987	7,491.1	46,196.2	16.2
1988	7,765.3	55,524.1	14.0

Source: DOS 1988.

Over the years, capital investment in the petroleum industry has been rising, although the rate at which this investment grew was quite uneven. Table 4 shows this and that in 1978 in particular, nearly 41% of total manufacturing investment was committed to petroleum. After 1985, the investment declined quite noticeably. In 1987, only 7% of manufacturing investments went to the industry.

The industry's important role in Singapore's foreign trade was seen during 1978-1986 when petroleum and petroleum products accounted for an average of about 27% of total exports, while the average share of the commodity in total imports reached 28% for the same period (Table 5). In recent years, however, the share of the industry in total trade diminished to 13% of total exports and 14% of total imports in 1988.

Table 3. Value added (S$ million) by the petroleum industry as compared to that of the manufacturing sector, 1978-1988.

Year	Petroleum and petroleum products	Total manufacturing output	% of total output
1978	787.0	5,220.0	15.1
1979	916.0	6,523.9	14.0
1980	1,470.4	8,652.8	16.9
1981	1,707.2	9,866.9	17.3
1982	1,617.7	9,505.8	17.0
1983	1,382.6	10,012.4	13.8
1984	955.6	11,268.9	8.5
1985	873.7	10,812.8	8.1
1986	779.9	11,978.3	6.5
1987	728.2	14,501.8	5.0
1988	743.5	17,568.1	4.2

Source: DOS 1988.

Table 4. Net investment commitments (S$ million) in the petroleum industry, excluding petrochemicals, 1977-1987.

Year	Petroleum	% of total manufacturing investment
1977	66.2	16.7
1978	330.0	40.6
1979	224.5	23.8
1980	200.0	14.0
1981	162.0	8.6
1982	337.7	20.5
1983	367.1	20.5
1984	358.8	19.8
1985	190.0	17.0
1986	116.0	8.0
1987	122.4	7.0

Source: DOS 1988.

Marine industry

The industry has its roots in mid-19th century when the first commercial dry dock was built in 1859, fifty years after Stamford Raffles founded Singapore. In the early years after World War II, the industry grew from one to six dry docks. Later, more shipyards were built, the by-products of Singapore's trade and entrepôt services. During this period, the shipyards were used to service the merchant ships which called at the port and the naval ships which protected British interests in the region.

In the late 1960s, after Singapore's attainment of self-rule in 1959, the next phase of the industry's growth saw the birth of the Jurong, Sembawang and Keppel shipyards. With these large shipyards in place, the marine industry began to play its role as a contributor to the country's economic development.

During the 1970s and early 1980s, the industry continued to show impressive growth. Its total revenue nearly doubled between 1977 and 1982 (Table 6). However, after 1982, the turnover of the industry declined sharply, earning a meager S$724 million in 1986, which is about half of its earnings in 1977. In 1987, the industry rebounded when the turnover again exceeded the billion dollar mark with its three sectors showing marked improvements over the 1986 figures. Shiprepair revenue, for example, increased by 16% to reach $688 million, its highest record in five years. Shipbuilding and oil rig construction reversed their downward slide to expand three times to $337 million and four times to $84 million, respectively. The upturn of the industry was largely aided by the appreciation of the Japanese yen, the increase in shipping movement and the rising number of aging ships in operation.

Table 5. Trade statistics (S$ million) for petroleum and petroleum products, 1978-1988.

Year	Export of petroleum and petroleum products	% of total exports	Import of petroleum and petroleum products	% of total imports
1978	5,279.1	23	7,074.5	24
1979	7,337.2	24	9,668.0	25
1980	11,828.0	29	14,879.5	29
1981	13,980.6	32	19,819.2	34
1982	14,437.3	33	20,471.4	34
1983	12,761.9	28	18,601.4	31
1984	12,992.3	25	16,949.4	28
1985	13,456.1	27	17,019.9	29
1986	10,038.9	20	10,986.1	20
1987	9,649.9	16	12,515.6	18
1988	10,008.5	13	12,412.8	14

Source: DOS 1988.

Table 6. Revenue breakdown (S$ million) of the marine industry, 1977-1987.

Year	Shipbuilding	Shiprepairing	Rigbuilding	Total
1977	530	537	156	1,223
1978	374	541	130	1,045
1979	387	725	281	1,393
1980	537	865	499	1,901
1981	540	1,088	790	2,418
1982	643	860	781	2,284
1983	430	673	392	1,495
1984	277	668	183	1,128
1985	142	457	52	651
1986	113	591	20	724
1987	337	688	84	1,109

Source: SASAR 1987.

Today, Singapore has some 70 shipyards located in its southern and western parts, offering a wide range of sophisticated marine services including shipbuilding, shiprepairing and rigbuilding.

Shipbuilding facilities in the Republic include a 10,000 deadweight ton (dwt) syncrolift dock, various slipways and some 50 building berths capable of taking vessels of up to 8,999 dwt. Local shipbuilders are also now capable of constructing high value-added supply vessels, specialized patrol crafts, LPG carriers, cellular container ships, fast missile naval crafts, seismic vessels, pipe-laying barges, fire-fighting boats and other utility crafts.

Singapore's shiprepairers, on the other hand, presently operate 21 dry docks with an aggregate tonnage of 2.4 million dwt, which represents the heaviest concentration of repair facilities in any major port today. The well-equipped shipyards offer various types of specialized services such as underwater cleaning and maintenance, marine electronics, communication, inspection and certification. In terms of investment and revenue, shiprepairing is the largest among the three sectors of the marine industry.

Meanwhile, in terms of production and design, Singapore's rigbuilders are among the world's best. Since the first rig was built in 1970, the Republic has exported a total of 127 rigs to other countries. The local rig yards are capable of building jack-up drillships, drill barges, crane barges, submersibles and semisubmersibles. The rigbuilding sector is, however, experiencing serious underutilization of capacity as seen by the fall of the rig utilization rate from a high of 99% in 1980-1981 to an average of below 50% in 1987. At present, the rigbuilders are trying to diversify their business and to integrate their existing capabilities with newly acquired technological know-how in design, engineering and production.

Based on the above, it would still be difficult to determine the contribution of the marine industry to the country's output or employment precisely because of the lack of disaggregation of the national income and manufacturing statistics. The available evidence, however, suggests that the three sectors of the marine industry altogether employed a total of 14,138 workers in 1986, which accounted for 5.7% of the total number of workers in manufacturing that year. The industry's share of the total manufacturing output and value added in the same year were estimated to be about 4.0% and 5.6%, respectively (DOS 1986a).

Port and shipping services

Strategically located at the crossroads of the trade routes between the East and the West is the port of Singapore. Ships of more than 500 shipping lines flying the flags of almost all the maritime nations of the world converge at this port. At any one time, a ship arrives or leaves every eight minutes. Thus, it has been rated as the busiest port in the world in terms of shipping tonnage.

The Port of Singapore Authority (PSA) is responsible for administering the port and managing an area covering 583 km^2 of a major portion of Singapore's territorial waters. PSA at present operates five main gateways which have a total wharf length of 14 km. These gateways can provide berthing facilities to accommodate container ships, bulk carriers, cargo freighters, coasters, lighters and passenger liners. These also have the capacity to handle over 80 million freight tons (FT) a year.

PSA's total staff strength stood at 7, 694 in 1987, a decline of about 4% over 1986's figures. However, productivity continued to improve because of the computerization of its services. Thus, value added per employee grew at more than 10% on the average during the past decade. In fact, PSA's financial position has been quite sound over the years, even showing a net surplus of $266.7 million in 1987.

Meanwhile, port activities gradually improved during the past decade (Table 7). This performance was due to an increase in the number of containerized cargoes handled at four of PSA's gateways. The combined seaborne cargo, for example, in 1987 amounted to 129.5 million FT. This includes 73.6 million FT of mineral oil-in-bulk. There was, however, a marked decline in cargo handling during 1984-1985 when Singapore experienced the worst ever recession in its history of economic development.

In line with the growth of cargo volume, the number of ships which entered and left Singapore's port also increased during 1977-1987 (Table 8). The period from 1983 to 1984 was the only exception, for it saw a decrease of about 5% in the total number of ship arrivals and departures and a nearly 6% drop in shipping tonnage.

Besides cargo handling, the port offers a comprehensive range of marine services such as bunker fuel and ship supplies, pilotage and tug, gas-free inspection and fumigation, and slop reception for oil tankers. It also provides environmental control services such as cleaning oil and debris from the sea and fire-

Table 7. Cargo (in FT) handled by PSA, 1977-1987.

Year	General and bulk cargo	Mineral oil-in-bulk	Total
1977	20.5	45.3	65.8
1978	25.1	51.0	76.1
1979	29.8	53.3	83.1
1980	33.8	52.5	86.3
1981	35.8	56.8	92.6
1982	39.5	62.0	101.5
1983	42.8	63.6	106.4
1984	48.7	63.2	111.9
1985	42.2	63.6	105.8
1986	48.0	72.7	120.7
1987	55.9	73.6	129.5

Source: PSA 1987.

Table 8. Arrivals and departures of vessels (over 75 GT), 1977-1987.

Year	Number	GT (million)
1977	44,018	393.9
1978	44,403	386.0
1979	51,163	456.5
1980	54,061	474.1
1981	56,634	521.0
1982	60,973	554.1
1983	60,515	562.3
1984	57,442	527.5
1985	60,512	528.8
1986	66,650	647.9
1987	67,686	686.3

Source: PSA 1987.

fighting. Moreover, the port has the best facility in the region for the reception and treatment of slop, sludge, dirty ballast and tank washings on the island of Pulau Sebarok. Facilities at the center include four piers which can accommodate vessels of up to 264 m long with a 45,000 t displacement. Six deslopping barges with capacities ranging from 1,200 m^3 to 2,000 m^3 are also available.

Singapore is also the most well-known salvage and towage center in the region due to its location astride the Europe-Asia shipping lane. The largest of the salvage companies operating out of Singapore are Selco Singapore, Smit International, Fukada Salvage and Singapore Salvage Engineers. The companies all keep tugs equipped with the latest in surveillance equipment. Thus, while these tugs are permanently at sea in the region's crowded waterways, they are able to be in constant radio contact with their home bases.

Table 9. Ships registered in Singapore and their aggregate tonnage, 1978-1988.

Year	Number of vessels	Tonnage (thousand GT)
1978	1,742	7,959
1979	1,583	7,690
1980	1,552	7,420
1981	1,682	7,776
1982	1,780	7,731
1983	1,743	7,140
1984	1,555	6,864
1985	1,406	6,622
1986	1,265	7,262
1987	1,229	7,247
1988	1,243	7,328

Source: DOS 1988.

Singapore's merchant fleet now ranks 16th in the world. General cargo ships constitute the largest percentage by number while oil tankers provide the largest percentage by tonnage. As of 31 December 1988, 1,243 ships totalled 7,328 thousand gross tons (GT) on the Singapore register. However, compared with 1978, the number of ships decreased by 29% and the tonnage, by 8% (Table 9).

Although the Republic has a large fleet, locally owned tonnage already accounts for about a third of this total. This composition is a direct result of an open registry from 1969 to 1982. However, the indigenous component of the fleet tends to be old with about half beyond 15 years and with most vessels below 6,000 dwt. Thus, in recent years, a large number of shipowners registered a drop in their profits and had been writing down the book values of their ships in line with the depressed shipping market. The number of seamen employed at sea also dropped continually in recent years until there were only 1,799 seamen working at sea in 1986. This can be attributed to the fewer number of ships on the register, the depressed shipping market and the lower manpower requirement of modern ships.

Meanwhile, port, shipping and other marine engineering services are included in the transport and communications industry under the GDP industrial classification scheme. The sector is a major contributor to the GDP, accounting for more than 14% of Singapore's GDP in 1988 (Table 1). It is, however, difficult to determine how much port and shipping services contributed to this sector due to the lack of disaggregated industrial statistics. Still, some useful information in this regard can be obtained from the results of the survey on services conducted yearly by the Department of Statistics (DOS 1986b). For example, the transport, storage and communication services were found to compose the largest industry in the services sector in 1986 in terms of employment and value added, for it engaged a total of 87,000 workers and generated a value added of $4,779 million. The other services offered by this sector, like financial and business services, accounted for nearly 54% of the total GDP in 1986. The relative shares in employment and value added of the sector were 34% and 41%, respectively. Of the total value added of the transport, storage and communication services in 1986, water transport services contributed about 30% or $1,441 million, of which one-third came from port services. It engaged 22,382 workers in the same year or about 9% of total employment in the services sector, which is about 2% of total employment in Singapore.

Fishing industry

The importance of fisheries in Singapore has declined considerably due to a rapid industrialization program. Moreover, as a shelf-locked city-state, it has little potential for offshore fishing. With local production meeting only about 25% of the country's fish requirement and the remaining demand borne by imports, the contribution of fisheries to the country's GDP is thus understandably negligible. In 1988, for example, the entire agriculture and fishing sectors accounted for only about 0.4% of Singapore's GDP (Table 1). Also affected were the employment opportunities and prospects that the fishing industry was able to provide. Table 10 shows the number of licensed fishermen and fishing vessels engaged in the industry from 1978 to 1988. Both columns exhibit a clearly downward trend.

Meanwhile, fishing around Singapore waters that normally use nonpowered boats is classified as "inshore fishing". The bulk of these catches is from palisade traps *(kelong)* and drift nets. "Offshore fishing" is carried out mainly in the South China Sea and the Indian Ocean. The most commonly used offshore fishing gear are otter trawls and bottom long lines for demersal fish and troll lines for pelagic fish. Fish is auctioned primarily at the Jurong fishing port, with the bulk coming from overseas imports. However, a relatively small quantity of local landings are auctioned at the Kangkar fish market.

Singapore is currently concentrating on fish processing and trading rather than on increasing its fish catch, although the government is encouraging the adoption of modern technology in order to increase the productivity of existing farms (Khan 1988a). Today, the country is quite well-known for the production of aquarium fish. Its export value amounted to $59.7 million in 1988.

Table 10. Fishing vessels and fishermen, Singapore, 1978-1988.

Year	Fishing vessels		Total	Licensed fishermen
	Powered	Nonpowered		
1978	546	173	719	2,084
1979	546	139	685	1,959
1980	511	130	641	2,025
1981	526	129	655	2,047
1982	514	108	622	1,848
1983	460	56	516	1,641
1984	443	40	483	1,321
1985	415	31	446	1,321
1986	401	22	423	1,250
1987	380	17	397	NA
1988	367	17	384	NA

Note: NA - not available.
Sources: DOS 1988; MOND 1978-1988.

Marine-intensive tourism

The development of a country's tourist industry depends largely on the effective utilization of its marine and coastal resources. Beaches, coral reefs, sport fishing, surfing, waterskiing, seafood restaurants, seaside accommodations and others help significantly to promote tourism. However, due to the high demand for limited coastal resources from various competing users, only a small part of the coastal zone could be devoted to the development of recreational facilities in Singapore. Today, the most important marine attraction is the country's only island resort, Sentosa, which lies just half a kilometer to the south of the mainland and covers 335 ha of green tropical flora. The Sentosa Development Corporation (SDC) which was set up in 1972 has been relegated the task of developing tourism on the island. Apart from Sentosa, it also manages 12 other offshore islets earmarked for recreational activities (Chia and Khan 1987).

Although several studies have been undertaken to estimate the demand function for tourism, very few attempts have been made to study the impact of marine factors on the tourists' preference function. Chou (1986) attempted to estimate the marine intensity of tourism in Singapore by using a relative weighting procedure (Khan 1988b). Based on the opinion of a small group of tourists, the study determined the relative weights (Table 11) for the six criteria of site selection as these applied to Singapore.

Although the estimate of marine intensity (i.e., 14% of tourism demand) was quite tentative in nature, it enables one to make a rough estimation of the contribution of coastal resources to tourism earnings. For example, if Singapore receives about $4 billion through tourist expenditure in a year (the actual receipts in 1988 were close to that figure), at least 14% of these earnings (i.e., $560 million) is due to its coastal and marine attractions. Since tourism at present accounts for 12% of the GDP, then coastal and marine factors made a contribution of about 1.7% to the economy through their impact on tourist preferences.

Table 11. Relative weights for tourist site selection criteria.

Criteria	Weights
Cultural attractions	0.209
Historical sites	0.168
Flora and fauna	0.153
Science and man-made views	0.142
Marine attractions	0.139
Shopping and entertainment	0.189

Source: Chou 1986.

Summary and Conclusion

Singapore's limited coastal resources have been effectively utilized to bring substantial economic benefits. Since it embarked on a large-scale industrialization program during the 1970s, with a view to achieve the twin development objectives of high economic growth and full employment, the bulk of marine and coastal resources was diverted towards various industrial uses. Although it is difficult to separate the marine sector from various other sectors, a few industries are identified in this paper as marine for the purpose of economic valuation. The contributions of these industries to the country's GDP (at 1985 market prices) and employment (in 1986) are shown in Table 12.

It is clear from the above figures that port and shipping services contributed the most to the country's economy. It is often said that "The port is Singapore and Singapore is the port." Thus, port authorities are continually upgrading the facilities and standard of their services, so that the outlook continues to be optimistic.

Table 12. Contribution of the marine sector to the economy and employment in Singapore.

Industry	% of GDP	% of total employment
Petroleum industry	2.0	0.3
Marine industry	1.7	2.4
Water transport (mainly port and shipping services)	3.7	2.0
Fisheries (including agriculture)	0.5	0.9
Marine tourism	1.7	0.9
Total	9.6	6.5

Meanwhile, the contribution of the petroleum industry has declined drastically in recent years. The value added of the industry currently accounts for only 2% of the GDP and, since it is a highly capital-intensive industry, its contribution to total employment is as low as 0.3%. In the face of the declining global demand for oil products and the stiff competition from neighboring countries, the outlook for Singapore's oil refineries does not seem to be bright. The long-term future of the industry calls for more product diversification and increased industry participation in trading activities.

The importance of the marine industry has also diminished over the years. The three components of the industry altogether contributed only 1.7% to the GDP and 2.4% to total employment. Although the industry's revenue earnings increased relatively in 1987 and 1988 over the preceding years, it is highly unlikely that the business turnover would reach the high levels of the early 1980s. Moreover, the short-term positive effects of the high Japanese yen should not be taken for granted. Rather, attempts should be made to diversify the industry's products as well as its export markets.

As for the fishing industry, it will continue to play a minor role in the national economy because of the lack of fishing grounds. However, the demand for freshwater fish in Singapore is presently very high and will continue to rise with the increased standard of living. The country, therefore, will have to depend even more heavily on imported fish. High-tech fishfarming, which was introduced recently, can help only marginally to meet the rising demand. Singapore can, however, be developed as a distribution center for fish in the region because of its excellent infrastructure and communication network.

As the bulk of the coastal resources has been utilized for various industrial purposes, very little is left for the development of tourist and recreational facilities. The country's only known tourist resort is Sentosa, which has reached more or less its optimum capacity in terms of the number of visitors and scope for further expansion. The development of other offshore islands, such as St. John's, Kusu, Sisters and Lazarus, is, therefore, urgently called for. Since these islands are very small in size, the recreational activities designed for them should be carefully planned to make them cost-effective. Perhaps, it will be more worthwhile to use them for expanding the network of seasports and interisland cruising rather than developing them into separate beach resorts. This will also help make Singapore an international seasports center and thus bring additional economic benefits through increased tourism earnings.

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Developing Legal Instruments for Coastal Area Management

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Abstract

Managing the coastal area of Singapore can be an awesome task since the entire country can be regarded as coastal in nature. Thus, this paper identifies the boundaries of Singapore's coastal area. It defines the composition of the coastal resources and their uses. There is also a brief description of the nine environmental acts which have been legislated to ensure the well-being of the coastal area and its resources.

Introduction

The Republic of Singapore consists of the main island of Singapore (hereinafter referred to as "Singapore Island") and about 60 small offshore islands with a total aggregate area of about 621 km^2. The 60 offshore islands account for 46 km^2.

The Republic has a short coastline--131.5 km for Singapore Island and about 150 km for the offshore islands. The main island is 41.8 km long and 22.5 km wide. No broad expanse of ocean lies between Singapore and its neighbors. However, it is separated in the north from the Malaysian state of Johore by the Johore Strait, while the Strait of Singapore separates the Republic from the Indonesian Riau (or Rhio) Archipelago.

Importance of Coastal Area Management

The extent of the country's coastal area is not easy to decide since no part of Singapore Island is more than 15 km from the sea. Hence, one could even regard the entire country as coastal in nature and broadly refer to its coastal area as the area on either side of its coast. However, for practical purposes, this paper includes all of Singapore's territorial waters (on the seaward side) and a narrow strip of land along the coast (on the landward side) when referring to its coastal area.

Coastal resources will refer to all the natural resources within the coastal area, while coastal resource utilization will include the many economic activities carried out within the coastal area, namely, oil refining and production of petrochemicals, shipbuilding and repairing, oil rig construction, sawmilling, woodworking, flour- and feed-milling, cement making, iron and steel manufacturing, tourism and recreation operations, etc.

Management By Legislation

This section will briefly discuss the management of the coastal area through legislation which falls within what is known as "environmental law".

Since this management requires a multidisciplinary approach, legislation will therefore have for its broad objective the maintenance of the well-being of the coastal area both on land and in water by controlling and regulating the activities which may adversely affect the quality and use of resources. One of the most significant of these activities is the pollution of canals, rivers, beaches and the sea through the discharge of industrial wastes, trade effluents, refuse and oil from vessels.

A number of laws that deal with activities which may affect the coastal area have been enacted. One of ther laws provides for the protection, inter alia, of trees and plants from diseases and pests. To achieve this objective, various powers have been granted, e.g., in the entry and inspection of property containing affected trees and plants, in placing this property under quarantine, etc.

Animals and Birds Act (Cap 7). Bird life is found among the less developed coasts and in bird sanctuaries in the coastal parks. This legislation is intended, inter alia, to prevent the introduction and spread of bird diseases. Thus, the authorities may prohibit the import of birds from specific countries, examine birds which have been imported and order the destruction of imported birds found to be infected.

Environmental Public Health Act (Cap 95). The act deals, inter alia, with the disposal and treatment of industrial wastes, especially from industries sited in the coastal areas. A person is said to dispose of industrial wastes if he burns, sells, gives away, discards, dumps, incinerates, deposits, processes, recycles, throws or treats such wastes. Under this act, the occupier of any place where industrial wastes are produced has to keep or properly dispose of these so as not to create a nuisance, cause harm to persons or animals or pollute the environment. The occupier is also allowed to dispose of the refuse or industrial waste only at a public disposal facility. There are also provisions that deal with toxic industrial wastes and require the furnishing of information on industrial wastes.

Parks and Trees Act (Cap 216). Under this legislation, the power to make rules for the management and control of public parks (including coastal parks) and the protection of flora and fauna, is provided.

Water Pollution Control and Drainage Act (Cap 348). The act enables the minister to make regulations with respect to the quality, use and conservation of inland water. The term "inland water" includes rivers, streams, reservoirs, lakes or ponds, whether natural or artificial. Here, the discharge of any toxic substance into any inland water which can give rise to any environmental hazard is made an offense. Thus, owners of premises are required to treat their trade effluents before discharging them into sewers or drains.

Fisheries Act (Cap 111). This act provides for the protection and conservation of fisheries and the control of fishing. Here, fishing using a trawl net or any poisonous or explosive substance to stupefy, poison or kill fish is made an offense.

Petroleum Act (Cap 229). This legislation prescribes various measures to ensure the safe handling of petroleum as it is a dangerous material. One of these requires petroleum-carrying vessels to obtain permission from the port master before entering port limits. In giving such a permission, he may impose the following conditions: (1) petroleum is not to be landed before 7 a.m. and after 7 p.m.; (2) a vessel may be required to anchor at a special anchorage; (3) a vessel may not be kept at the quay for a longer period than is necessary to load and unload; and (4) petroleum must be stored in accordance with prescribed rules.

Merchant Ship (Oil Pollution) Act (Cap 180). The act provides for the civil liability of merchant ships for oil pollution. Thus, if any oil is discharged or escapes from a ship carrying a cargo of oil in bulk, its owner is liable for any damage caused by the oil, the cost of measures that will be reasonably taken to prevent or reduce the damage and any other damage caused by the measures so taken.

Prevention of Pollution of the Sea Act (Cap 243). The act makes it a criminal offense for a vessel to discharge oil or a mixture containing oil into Singapore's waters. A fine of up to S$500,000 or imprisonment not exceeding two years or both can be imposed for its contravention. Similarly, the act also punishes any vessel for the discharge of refuse, garbage, waste matter, substance of a dangerous or obnoxious nature, or trade effluents into Singapore's waters. In the same manner, any person who throws any oil or oil mixture, refuse, garbage, waste matter, etc. into Singapore's waters may be charged with a criminal offense.

Port of Singapore Authority Act (Cap 236). The act provides, inter alia, for the management of the port waters by the Port of Singapore Authority.

Conclusion

To tackle problems in the coastal area, a range of legislation is required. Used effectively, the acts could certainly go a long way to ensure that the adverse effects to coastal resources are minimized.

Cinderella-in-waiting: The Problems and Prospects of Seasports Development in Singapore

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Abstract

This paper describes Singapore's coastline and the traditional and existing locations of its seasports activities and facilities. It discusses the reports of the Tourism Task Force (1984) and the Economic Committee (1986), the study commissioned by the Singapore Seasports Liaison Committee (SSLC) and the representations made to the government. The decision of the government to allocate two sites for yacht clubs/associations and the identification of two other sites for the development of commercial marinas in 1986 are also presented.

Introduction

The great sage of English literature, Shakespeare, could have been accurately describing the sentiments of many Singaporeans in the continuing plight of their seasports community when he made this observation: "Sweet recreation barr'd, what doth ensue but moody and dull melancholy?" (Comedy of Errors, V. I. 78). Based on available statistics, almost 2% of Singapore's land area is taken up by golf courses--the highest in the world! This compares with only about 6% of the land area actually occupied by all public housing on which over 80% of the population lives. This further compares with the negligible, mostly ragtag sites, occupied by seasports facilities in Singapore.

Notwithstanding these circumstances, it is the author's wish that he will be able to leave the reader with the faint hope of a visitation from that long-awaited fairy godmother, Cinderella (of the sporting world), who might transform the "pumpkin" which represents the present-day primitive facilities of our seasports, into a grand carriage of world-class facilities fit even for royal personages as the lovely princess in the fairy tale.

Fig. 1 shows the location of existing facilities, promised new sites and proposed megamarinas. Of the main island's total coastline area of approximately 130 km, Keppel Harbour, Jurong Port and Sembawang Wharves take up approximately 31 km or 24% of the said area. The balance of some 99 km is taken up for other uses or remains unutilized. It is estimated that if only 1% of the coastline was to be allocated for seasports, it would yield about 1.3 km of water frontage which would be sufficient for about ten sizeable yacht clubs, marinas or seasports centers. This does not take into account potential locations on offshore islands, like Sentosa and Lazarus Island for which projects have already been planned, and many other islands which could be added to existing locations.

Traditional and Existing Locations of Seasports

Wind-powered seasports

These include sailing and windsurfing which require windy locations. Best suited for these activities are southeast and southwest of Singapore where the seas offshore are

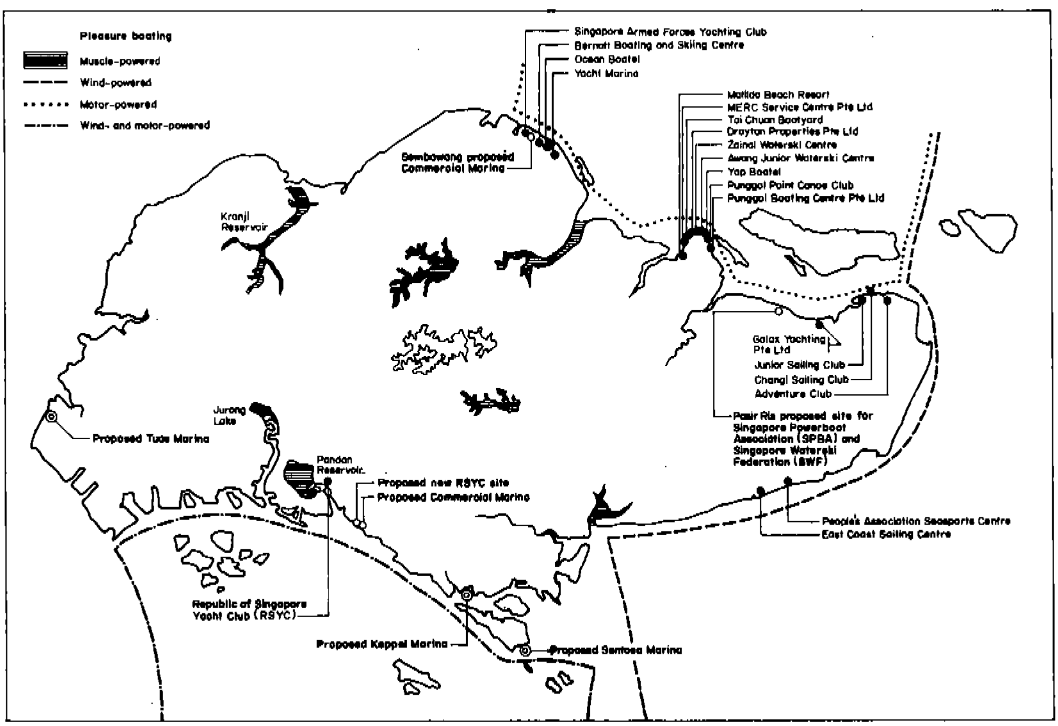

Fig. 1. Existing and proposed seasports facilities in Singapore.

fanned by the northeast and southwest monsoons. For the remaining part of the year, the land and sea breezes there are usually adequate for sailing.

Muscle-powered seasports

For these types of activities--canoeing, rowing and dragonboating, inland waters which are reasonably sheltered or calm waters are required. The northeastern, southeastern, southern and southwestern areas are suitable, with the rivers and reservoirs lending additional locations to those near the coastal and sea areas.

Motorized seasports

These include waterskiing, powerboating and bluewater cruising. While calm waters are needed for waterskiing, convenient access to the offshore islands and the blue yonder is all that powerboating and cruising require. Suitable locations are found in the east and southwest, with Punggol and Westpoint as the focal points.

Reports and Representations

Tourism Task Force and the Economic Committee

In 1984, SSLC was invited to submit its recommendations to the government's Tourism Task Force. The committee recommended the recognition of Singapore's distinctive tropical island character and the development of more beach and island resorts so that the country can be promoted as an international seasports center. These proposals were adopted by the Task Force, incorporated in its report and endorsed by the Cabinet. In 1986, the Economic Committee was formed to pull Singapore out of the recession and to chart a long-term strategy for its economic growth. Based on the committee's report, it recognized, among other things, that seasports and marinas can enhance the country's attractiveness as a tourist destination and thus contribute significantly to its economic development.

From these two committees' reports, it appeared that dawn was beginning to break on the prospects of Singapore becoming an international seasports center. But, alas, the sun seems to have been held back by the chains of bureaucracy for after the lapse of three years, the seasporting community is still waiting for daybreak!

Commissioned reports and representations to the government

As early as 1983, SSLC commissioned a study to be undertaken by the Applied Research Corporation and Akitek Tenggara, a planning firm. Their task was to provide the committee with background information on the condition of seasports in Singapore prior to its planned representation to the government the following year.

Based on the two groups' findings, the committee sought an enlightened national policy or long-term guideline on the allocation and use of coastal sites in particular and the development and promotion of seasports and other waterfront-associated activities in general.

Provision of Sites for Seasports and Marinas. Following the representation by SSLC in 1984, the government took the first concrete step in 1986 to meet the needs of the seasports community. Through the Singapore Sports Council, the government allocated a site in the West Coast Park for the Republic of Singapore Yacht Club (RSYC) and another site in the Pasir Ris area jointly for the Singapore Power Boat Association (SPBA) and the

Singapore Waterski Federation (SWF). Because these two sites were intended for the development of nonprofit yacht clubs and seasports organizations, the proposed cost was made nominal for the 29-year lease of the land. Moreover, the choice of these locations was not accidental but matched the plans and needs of RSYC, SPBA and SWF to relocate their activities/facilities to the West Coast and Punggol areas.

At about the same time, the government also identified two sites for commercially operated marinas: one in Sembawang Park and the other in the West Coast to cater to the "bread-and-butter" needs of the commercial boatels which had been displaced by land acquisition and coastal reclamations. As these sites were meant for commercial use, they were to be tendered out.

The year 1986 must, therefore, be regarded as the high point of government action in recognizing and providing the much needed waterfront sites. But, alas, after more than three years, the Liaison Committee is still waiting for these sites' development! With all due respect, it would seem that even decisions that emanated from such high places suffer from bureaucratic wrangling and ineptness. This paper not only decries the gross mishandling of the issues at hand and makes known the plight of Cinderella, but also wishes to alert the workshop participants of the need to unclog and streamline government bureaucracy if anything good is to come out of any coastal area management plan or other such proposals however enlightened they may be! Otherwise, these plans or proposals will be destined only for the archives of academic libraries or the dusty shelves of some government office.

Representations to the Advisory Council on Sports and Recreation

In June 1988, SSLC further prepared and submitted lengthy representations to the Advisory Council on Sports and Recreation. These were submitted on behalf of the eight national seasports associations and clubs which together represent the entire seasports community. The committee is glad that some of its submissions have been adopted, particularly those relating to sailing and scuba diving. But it laments the fact that there has been insufficient action taken to meet other needs, particularly, on the release of the two sites promised for seasports.

Megamarinas and Their Implications for Seasports

For the total development of seasports in Singapore, a whole spectrum of facilities and establishments is desirable. This can range from the humble nonprofit yacht clubs and seasports centers catering to the needs of the average Singaporean and tourist to the ultra-luxurious private marinas which are for profit and thus cater only to the well-heeled. So far, several large marinas have been proposed. While this is a welcome development, they are certain to become the exclusive retreats of the rich. The Tuas Marina, Keppel Marina Condominium and Sentosa Marina Condominium are cases in point.

In the meantime, the two sites identified for seasports remain stuck, inactive, underdeveloped. Since the single site in Tuas was released for tender recently, a very high benchmark market price has been placed for marina sites. Thus, the perception is that you have to be a business conglomerate or a statutory board before you can influence the bureaucracy to approve marina-related developments.

Cinderella-in-waiting: the Condominium Saga

In conclusion, daunting as the problems of seasports development are in Singapore, the prospects are more than promising. The plight of the seasports community is not the result of some Shakespearean *Comedy of Errors*. The root cause is the understandable preoccupation with things economic and the absence of a well-coordinated and truly enlightened national policy for seasports. This, despite the repeated official recognition given to the actual and potential contributions that seasports make and can make to the nation.

Meanwhile, Cinderella is waiting to be rescued from her distressful situation.

Development of Coastal Parks in Singapore

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Abstract

With over 80% of the population living in high-rise buildings with its enclosed environment, parks and open spaces offer relief. Towards this end, the Parks and Recreation Department (PRD) has targetted the provision of 0.8 ha of open space per 1,000 persons. Moreover, since Singapore is an island, most of its coastal areas have been developed into large regional parks from reclaimed land. These are grouped into recreational parks, esplanades, nature reserves and scenic parks. Each of these types is described in this paper. The problems of poor soils, drainage and coastal erosion confronting these parks are also discussed.

Introduction

Since Singapore launched its Garden City campaign in the late 1960s, it has gone through several stages of development, from greenery and shade along our roads and highways to quality parks and open spaces. Thus, as soon as a visitor steps out of the terminal building at Changi Airport, he is greeted by a pleasant green and lively environment which leads him all the way to the city center.

So far, the total area of existing public parks and open spaces which have been developed amounts to more than 1,800 ha. This includes all public parks and open spaces in Singapore irrespective of whether they were developed by PRD, Housing and Development Board, Jurong Town Corporation, Public Utilities Board, Sentosa

Development Corporation or the Singapore Zoological Gardens.

In Singapore, the open space is not for a single homogeneous land use but for a rather broad sector land use. It is meant not only to meet the recreational needs of people of various age groups, but also to enhance the environment, especially in the urban area. It must also be able to provide the kind of facilities that, in some respects, tourists look for. Public parks and open spaces should then provide environments suitable for both active and passive recreation.

The above objectives are specially important in the context of Singapore because more than 80% of our population lives in high-rise buildings and needs the relief that these parks and open spaces can offer from its enclosed environment. Thus, to provide the public with a quality environment, the government is working towards the target of providing 0.8 ha of open space per 1,000 persons.

Development of Coastal Parks

Singapore is an island where water is abundant as a landscape element. This has enabled PRD to develop 12 coastal parks over the years (Fig. 1). At present, these parks (excluding those on offshore islands) occupy some 428 ha of land and constitute about 22% of all the public parks in Singapore. Newer ones have been developed from reclaimed land.

Thus, compared with those situated inland (where space is limited), most of these coastal parks are large in size. As regional parks, these are meant to serve not only the immediate neighborhood but also a large sector of the population. The East Coast Park is an example.

Moreover, due to their configuration, these coastal parks share one common characteristic. They are developed in a linear manner.

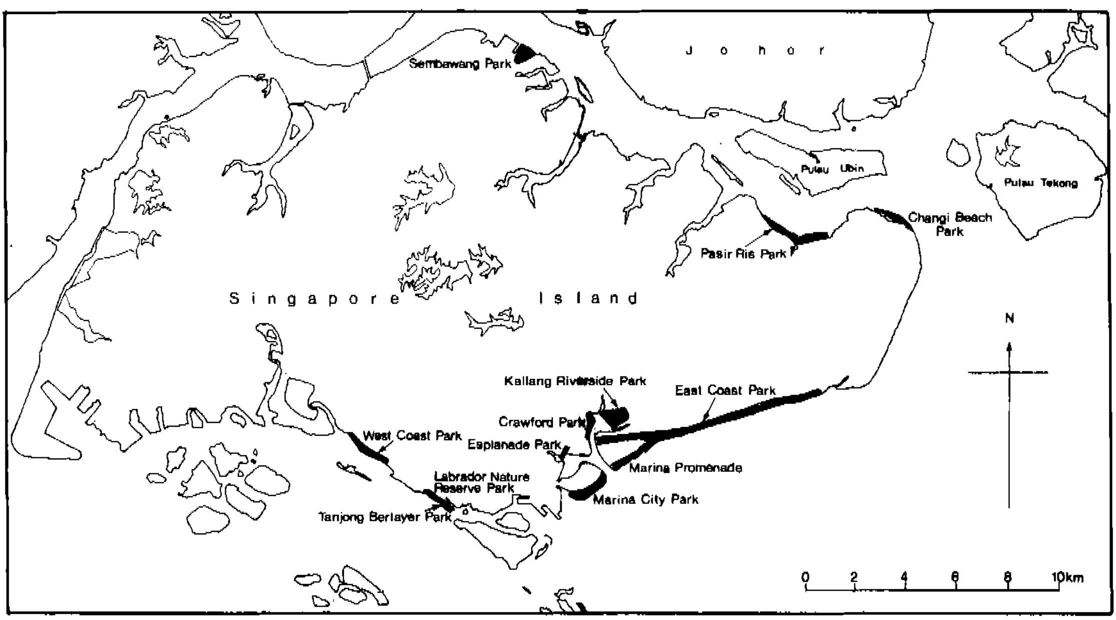

Fig. 1. Location of the existing coastal parks.

Types of Coastal Parks

Recreational parks

Three major coastal parks belong to this category: the East Coast Park, West Coast Park and Pasir Ris Park.

The East Coast Park enjoys the widest popularity, being the oldest and the largest. Built in 1972, it took about 14 years to complete it at the cost of S$21 million. The park occupies 206 ha and is about 12 km long with its broadest part measuring about 300 m.

The whole park is divided into areas A to H. The nine sections are separated by drainage canals. Development began with area C which is directly opposite the Marine Parade Housing Estate, a government-built, low-cost housing project development. It was completed with area H in 1986.

The park boasts of many recreational facilities which cater to both the young and the old and people with diverse interests. The fishing enthusiast will find the Bedok Jetty a favorable spot; the fitness conscious can make use of the 12.5 km-long jogging track and cycling paths and find the fitness course a welcome feature; while the outgoing will enjoy the barbecue and picnic facilities provided. For the more adventurous, there is the People's Association campsite to meet their demand.

Meanwhile, in order to provide a wider variety of recreational facilities and to take advantage of the participation of private developers, parcels of land have been leased to them. Based on the facilities they have developed, their response has been enthusiastic. These include the East Coast Recreation Centre, Big Splash Swimming Complex, Parkland Golf Driving Range, East Coast Sailing Club and the Seafood Centre.

Pasir Ris Park is the second largest of all the coastal parks. It occupies an area of 77 ha and commands a panoramic view of the Johore Strait and the land beyond. The park has completed three phases of development. The fourth phase will commence very soon. The main feature of this park is its S$1 million children's playground, which is the largest of its kind in Singapore.

The Marina City Park, situated in Marina South (a reclaimed land), is the latest recreational park and one of the premier ones to be developed by PRD.

Esplanades

The Elizabeth Walk which is part of the Esplanade Park used to be a very popular place with the local population. An evening walk in the breeze, ending with a snack at the Satay Club, was once a favorite pastime. However, since the reclamation of the Marina Centre, the Esplanade Park has lost some of its appeal to the newer and more modern Marina Promenade. The latter's wide and colorful walkways are beautifully landscaped with sculptures, trees and flowering shrubs, thus attracting many visitors. It is also favored as the venue for the annual Dragon Boat Race, Power Boat Grand Prix, walkathons and many other community activities. However, the Esplanade Park will not allow the Marina Promenade to steal the limelight from it and be left to deteriorate. So, work has already begun to upgrade it as part of the Civic District's master plan.

The Labrador Nature Reserves Park hugs the southern coast of Singapore Island and rises 40 m above sea level. It commands a fantastic view of the open sea and some of the offshore islands. Moreover, the entire park is covered with a secondary forest where it is claimed that the fern, *Dipteris conjugata*, can be found exclusively and nowhere else in Singapore. Prior to its development as a park, the site was used as a defense post against enemy invasion from a seaward approach during the Second World War. Relics of old bunkers, gun batteries and tunnels can still be seen there.

Another park in this group is the Sungei Buloh Bird Sanctuary. It is scheduled to be developed in 1990. The entire 85 ha of the site is covered with mangrove swamp and prawn ponds. The former will serve as a good natural habitat and the latter, good feeding grounds for numerous species of birds, including migratory ones. To preserve its natural character, the park will require only limited development. For example, tracks and some basic park infrastructure, a bird-watching tower and hideouts, a visitors' center with carparks and toilets will be built. Information about the park will be displayed to orient the visitors. When completed, the park will provide a different kind of outlet to satisfy the recreational needs of those who prefer environments with natural habitats.

Scenic parks

Because of their peaceful and scenic quality, parks in this category are mainly for passive use. They are best appreciated as perfect retreats on quiet weekends. The Sembawang Park is an example.

Problems

The development of coastal parks is not without its set of problems and constraints. A reclaimed land handed over from the engineer is a flat, featureless and uninteresting piece of land. To create a more interesting and undulating landform out of it, extensive earthworks have to be made. Not only must large amounts of earth be moved and piled to produce artificial hillocks but every time land has to be reclaimed from the sea. In so doing, coastal erosion takes place. This has happened especially along the East Coast Park.

Moreover, reclamation projects usually use poor fill materials with little nutrients, resulting in poor soil. Soil that is mostly clayey inhibits good drainage as there is little vertical percolation and lateral seepage that can take place. In such a water-logged condition, many plant species will fail to establish themselves.

Conclusion

Due to the diminishing size of its open space, the demand for reclaimed land in Singapore will certainly continue to increase in the foreseeable future. However, advances in technology will answer this need by bringing about new ways of reclaiming land. Already, the new technique in reclamation called "the sandwich method" is seen as a big help in the development of our coastal parks. Providing water-related activities such as marinas and fishing decks is likewise seen to further enhance or boost the potential of our coastal parks.

Seaside Resorts in Singapore: A Geomorphological Perspective

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Abstract

A number of seaside resorts have been established in Singapore to meet the local demand for places to go to for a seaside holiday. On Sentosa, a resort hotel is currently undergoing development. Other offshore islands are also being considered for resort development. A geomorphological evaluation shows that the beaches fronting the local seaside resorts are insufficiently developed so that measures have to be taken to improve and maintain these beaches. In developing resorts for the tourist market, the local coastal environment has to be improved in order to compete with the other seaside resorts in neighboring countries.

Introduction

The idea of staying near the sea for purposes of pleasure or a holiday has an almost universal appeal. In the Old World, there were many well-known seaside resorts for both local residents and tourists. Today, a variety of seaside resorts has been developed worldwide for tourists; they range from small-scale units offering minimum facilities to luxury enclaves with a wide range of facilities and services. And in many Third World countries in the tropics, the development of seaside resorts for tourists has become a significant aspect of their tourism development plans.

Even in Singapore, where the coast is accessible within an hour from any inland location, the idea of staying at some seaside accommodation for holiday purposes has an appeal for the average local resident who lives in an apartment. Before coastal reclamations destroyed many of the natural beaches, holiday bungalows were available for certain categories of civil servants at Changi, Tanah Merah and Tanjong Rhu. Also available were some bungalows owned by commercial companies and statutory boards at Loyang and several small seaside hotels at Pasir Ris, Tanah Merah, Katong and Pasir Panjang. However, as a result of large-scale reclamations, seaside accommodations for pleasure purposes are presently restricted to Pasir Ris-Loyang, Changi and the East Coast. In Changi, there is one hotel within walking distance of the beach; another is under construction on Sentosa. Other offshore islands are also being considered for resort development.

While these seaside resorts have been discussed in the context of coastal recreation in an earlier paper (Wong 1989b), this paper has for its objectives the presentation of the spatial patterns of seaside resorts and their evaluation from a geomorphological perspective. The coastal geomorphological environment provides the basic setting for any seaside resort. For example, within the coastal environment, it is important to consider its character, the magnitude and frequency of coastal processes especially those giving rise to coastal erosion, the extent of a setback from the coastline, and the impact of the resort on the environment.

Spatial Patterns

Our seaside resorts located at Changi, the East Coast Park and the Pasir Ris-Loyang coast show a distinctive spatial pattern of distribution on the main island. Sentosa also has a number of holiday bungalows.

The East Coast Park's chalets could be considered as the first seaside resort to be developed to meet the popular local demand for a seaside holiday retreat. The first phase of its development was completed in the early 1970s and consisted of 110 single-storeyed units. Its success led to the development of an adjacent second phase of 59 double-storeyed units in 1981 (Fig. 1). The popularity of this resort is due not only to its beach but also to its easy access to and availability of a wide range of recreational facilities. The resort is currently being upgraded.

Changi is the government's main seaside holiday area. It contains some 40-odd bungalows which were refurbished several years ago. To encourage better utilization of the area, the period allocated for holidays in Singapore was increased in 1985 from one to two periods per week. Within this area are 8 chalets at the Changi Sailing Club and 17 guest rooms in a new extension block of the

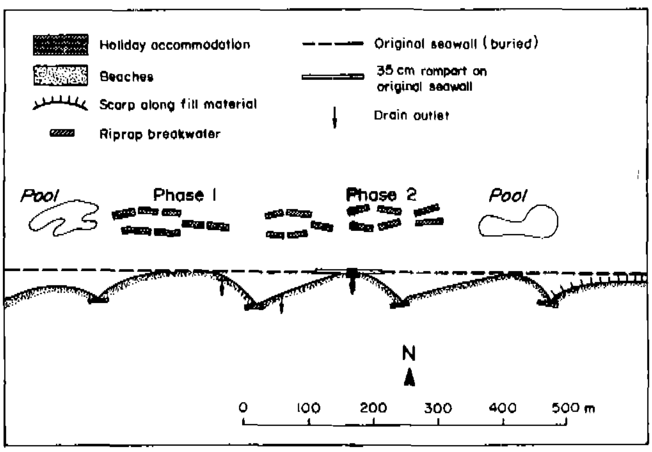

Fig. 1. The East Coast Park chalets.

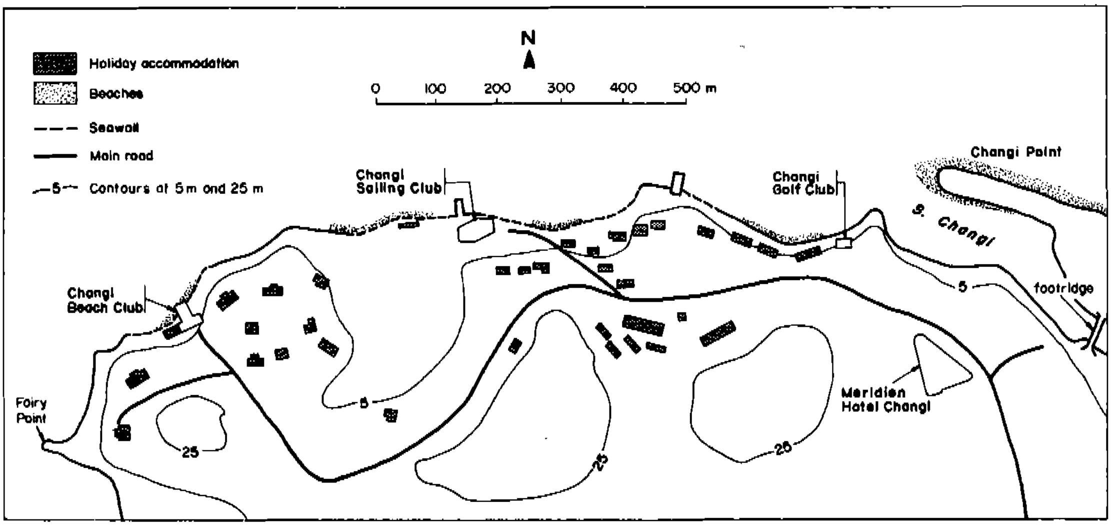

Fig. 2. The Changi resort area.

Changi Beach Club, formerly known as the Changi Swimming Club. Later additions in December 1985 were 12 chalets for the Singapore Armed Forces (SAF). Outside this government holiday area is the Meridien Hotel Changi which has easy access to the popular Changi Beach (Fig. 2).

The Pasir Ris-Loyang coast has recently become the major area for seaside resorts for the local population (Fig. 3). In 1973, the People's Association, which is the government's premier community development agency, built the Pasir Ris Holiday Flats which then fronted the natural beach at Pasir Ris. To the west of these holiday flats were eight units belonging to the Telecommunications Authority. Along Pasir Ris Road, the residential bungalows were bought by private companies and statutory boards for holiday purposes. Along Jalan Loyang Besar, the holiday bungalows, which were the earliest to be established in this area, lost their sea frontage when the coast was reclaimed from Sungei Loyang to Pasir Ris Beach between 1978 and 1980. On the reclaimed land at Loyang, the government built one lot of 37 bungalows in 1984 to increase its pool of holiday bungalows. To the west and also on the reclaimed land, the Urban Development & Management Company (UDMC), a government private limited company, established the Pasir Ris Resort consisting of 94 single-storeyed units and 92 double-storeyed units. This resort was opened in December 1987. Further west is the 396-room Pasir Ris Resort which is owned by the Singapore Labour Foundation. It was opened in October 1988. Although this resort has no access to the coast, it has a wide range of facilities.

On Sentosa, a number of holiday bungalows belonging to the Sentosa Development Corporation are leased for long periods to companies and statutory boards. For example, from late 1978 until its closure in March 1987, the Apollo Sentosa Hotel operated as a resort hotel and subsequently as a holiday chalet until December 1987. Today, on the same site, construction is in progress for a new 275-room resort hotel to be operated by the Beaufort International Hotels. It is scheduled to be ready by mid-1991. Like its predecessor, the resort has no direct access to the beach. However, another 320-room resort hotel to be built in March 1990 will have immediate access to the new beach near Fort Siloso.

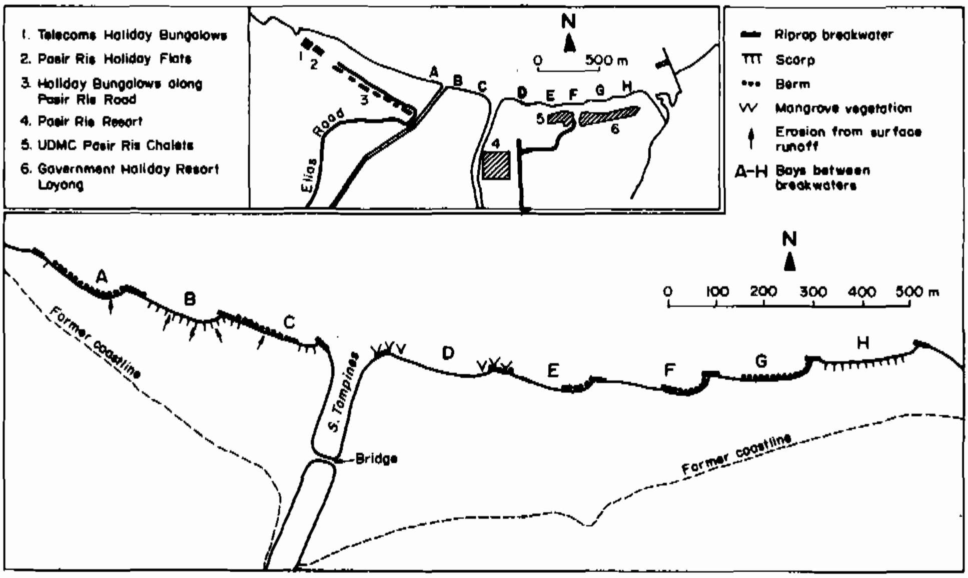

Fig. 3. The Pasir Ris-Loyang resort coast and bays A-H.

Geomorphological Evaluation

The seaside resorts in Singapore have the advantage of being in a low-wave energy environment and are therefore protected from strong wave attacks. But the beaches fronting them are poorly developed compared to those typical of seaside resorts in other parts of the tropical world. A geomorphological evaluation of these beaches is given below for each of the resort areas.

East Coast resort area

In the initial phase of reclaiming the east coast, a seawall was built to protect the reclaimed land. This idea was later dropped in favor of using a series of breakwaters as a protective measure. The breakwaters would act as headlands between which sandy bays would be formed. The East Coast Park chalets front three such bays (Fig. 1). A typical transect from the chalets to the beach shows the following main components: chalets, bicycle path, footpath, barbecue pits, seawall, backshore and foreshore.

Several aspects of the coastal environment have implications for the utilization of the beaches for recreation. As the coast retreats landwards, the seawall is exposed to wave action at the center of the west and middle bays. As the sea reaches the seawall, sand is thrown over the seawall and produces overwashes. To prevent the further ingress of sand and water over the seawall in the middle bay, a 35-cm high rampart has been added. Also, the swash marks which are common but important geomorphological features constitute and even contribute to the rubbish on the beaches. Moreover, the natural vegetation usually colonizes the backshore of the beaches but has been removed by the impact of pedestrian traffic. And the runoffs from heavy rainfalls occasionally cut channels across the backshore.

The chalets themselves can have a negative impact on the coastal environment, especially when their wastewater is discharged into the sea through one sump on the backshore of the west bay and two drain outlets in the middle bay. The negative impact of pedestrian traffic has likewise been felt on the backshore vegetation in the west bay, and particularly in the middle bay, which is now bare. While there is less impact on the beach vegetation in the east bay, bare ground is common around the barbecue facilities. This has been covered with granite chips to stop its further erosion. Bare areas also appear under well-shaded trees.

Changi resort area

This resort area stretches from the mouth of Sungei Selarang to the mouth of Sungei Changi and is dominated by four low hills. In general, its beaches are poorly developed or nonexistent with seawalls protecting the coast in a number of stretches including the sandy ones. The beaches are restricted mainly by the bays and a low straight stretch at the Changi Sailing Club (Fig. 2). The only decent stretch of beach is Changi Beach which is outside the resort area and on the seaward side of the spit.

The poor condition of these beaches and the use of seawalls to protect the land from erosion along the Changi resort area constitute severe limitations on the enjoyment of holiday makers. At high tide, the waves virtually reach the seawalls because the beaches do not have the backshore. At the Changi Sailing Club, overwashes are common in front of the chalets. At the Changi Beach Club, swimming is confined to an area fenced in by a boom within the small bay. It is generally possible to swim only at high tide as a muddy terrace is exposed at low tide.

Attempts to overcome coastal erosion and the lack of beaches in this area can be seen in the development of the SAF Holiday Chalets which consist of three blocks immediately to the west of the Changi Golf Club. To protect the coast on which these blocks are sited, an almost vertical wall of about 6 m high of permeable prefabricated concrete slabs was constructed. Immediately seaward of this wall is a narrow artificial backshore which is landscaped with coconut trees, but which can still be easily reached by strong waves. The foreshore is equally narrow.

Apart from the unfavorable impact of seawalls on the beaches, particularly on the stretch along chalets B to F up to the Changi Sailing Club, drain outlets also have a negative effect on the beaches. These outlets are found west of chalet D and in front of the SAF Holiday Chalets.

Pasir Ris-Loyang resort area

The reclaimed land here, like that in the East Coast, is protected by a series of riprap breakwaters which have given rise to three bays (A-C) west of Sungei Tampines and the five bays (D-H) between Sungei Tampines and Sungei Loyang. A subsequent phase of reclamation to the west of bay A is also protected by breakwaters where the formation of a beach is in progress.

Beach formation has been slow along this reclaimed coast in the sheltered environment of the Johore Strait for the surveys in May and June 1984 indicated the presence of active scarps and abrasion ramps in all bays (Chew et al. 1987). However, beach formation has, since then, improved. The surveys in October 1989 indicated the presence of an abrasion ramp only in the middle of bay D and scarps in bay H, the greater part of bay B, both ends of bay C, and the western extremity of bay A. Except for their western ends, better developed beaches are in bay A where a wide berm can be found at the eastern end and bay G where a berm can be found along almost its entire length (Fig. 3). On the other hand, beach vegetation *(Ipomoea pescarpae)* has colonized the middle part of bay F and mangroves in the area seaward of the breakwaters which forms bay D. These bays are suitable for swimming only at high tide as a terrace is exposed at low tide.

For bays E to H, the impact of pedestrian traffic is less than in other bays as the number of holiday makers here is much lower than that in the East Coast Park Chalets. But at bays A to C, which are in front of the park facilities for children and the holiday chalets on Pasir Ris Road, the impact of pedestrians is more evident. In the middle part of bay B, erosion by surface runoff is particularly evident. Also, the high water table particularly at bays D to H leads to backwearing of the fill material.

The government- and UDMC-owned resorts are sufficiently set back from the equilibrium planforms of the bays. The perimeter fence of the government resorts is more than 50 m from the shoreline at its narrowest point. Moreover, there is a sufficient setback land for a park with a bicycle track, footpaths and a number of barbecue pits along the coast. To prevent its erosion, the area around each barbecue pit has been cemented.

Sentosa

Beach improvement measures taken on Sentosa are a clear indication of the importance of good beaches for successful beach resorts. Along the island's southwestern coast, a swimming lagoon was first constructed and completed in 1974; this was followed by a boating lagoon the next year. However, many environmental problems were associated with the swimming lagoon: the presence of cerithid shells which generate wastes, the deterioration of the beach due to pedestrian impact, erosion from surface runoffs particularly near beach structures, and lack of beach vegetation. The problem of cerithid shells was recently tackled by pumping out the seabed sediments.

The Sentosa Development Corporation (SDC) has likewise undertaken a program of lagoon and beach improvements aimed at developing the entire 3-km southwestern coast from Tanjong Beach to Siloso Beach into one of the best in this region. Commencing in mid-1988, the works included the addition of reclaimed land to create three bays along the coast; the construction of new revetments to protect the reclaimed land; the development of new beaches in the three bays; and the formation of sand keys to connect the revetments to keep the water level in the bays at least a meter deep during low tide (Fig. 4). These improvements have been carried out in phases: I (mainly in Siloso Beach) to be completed in April 1990, and II (in Tanjong Beach) and III (in the Central Lagoon), in January 1991. As of October 1989, all revetments, except those in the Central Lagoon, have been completed. The beach improvement in Siloso Beach is almost complete, while that in Tanjong Beach is yet to commence. These beaches in the three bays will be the main attractions for the holiday makers to this coast.

Meanwhile, preliminary observations indicate that a wider backshore or strip of sand is required for the Siloso Beach to reach its equilibrium alignment between the two widely spaced revetments. To achieve this, the seaward convexities are likely to be removed. However, landscaped areas located in such sectors would risk being eroded. The equilibrium shape at both ends of each of the bays would also vary with the seasons. Thus, the variability of the planform should be determined or monitored early or at some time before any structure is put up on the backshore of these areas.

Discussion

While it is true that many factors have to be considered in the development of seaside resorts, the geomorphological evaluation of

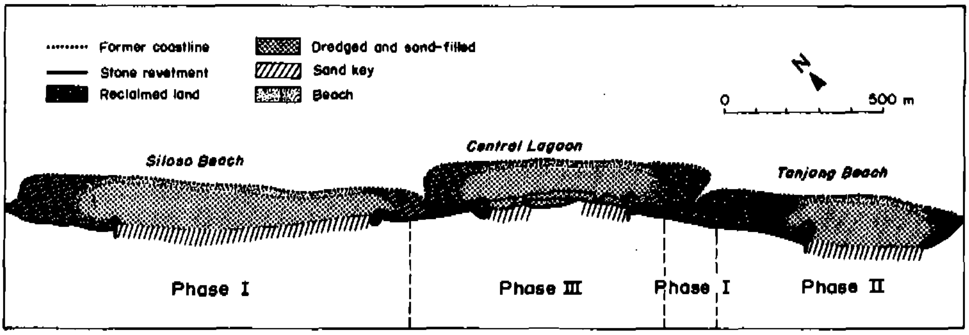

Fig. 4. Lagoon and beach improvement works by SDC.

seaside resort sites is perhaps the most basic and thus should be carried out at the first instance. The importance of such an evaluation of existing and potential beach resort sites has been demonstrated elsewhere (Wong 1988, 1989a).

As for the general opinion regarding existing seaside resorts in Singapore catering to the local residents, it was recommended that the beaches be improved and site-specific measures taken up only after a more detailed study of the beaches has been completed.

On the development of seaside resorts for tourists, contrary views have been expressed in the tourism development reports of the Ministry of Trade and Industry (MTI 1986) and Pannell, Kerr, Foster (1986). Moreover, there has been a lukewarm response to the call for developing resorts on other offshore islands apart from the resorts on Sentosa.

For the large-scale development of seaside resorts for tourists, it is important to know the physical potential of the coastal environment and then to develop it accordingly. In the case of Singapore, the coastal environment lacks clean and clear water, white beaches, good coral reefs and other natural coastal features that are synonymous with seaside resorts, although it can provide the infrastructural facilities and services required at any resort. Without the advantages of such a natural setting, our seaside resorts would not be able to compete on equal terms with the others in neighboring countries.

In a wider context, there are also various impact scenarios that can occur in seaside resorts with the future rise of sea levels. The United Nations Environment Programme (UNEP), for example, projected a 0.2 m rise by the year 2025 in the Southeast Asian region. In another UNEP project, a rise of 0.12-0.18 m by 2030 and then a rapid rise to 1 m by 2090 was projected. But whatever the scenario, the rising sea level would have an impact on future seaside resorts and other coastal tourism developments. Thus, the larger the tourism development is and the longer its return on investment, the higher is the risk imposed by a future sea level rise.

Based on the above discussion, it is evident that the present geomorphological evaluation of existing seaside resorts demonstrates the need for a better understanding of some aspects of their physical environment. It is hoped that, in the long run, this perspective will contribute to a more rational planning and development of seaside resorts for both the local and tourist populations in Singapore.

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The Aquarium Revolution and Underwater World Singapore

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Abstract

In the past, aquariums were generally publicly funded and considered largely as an educational experience. In recent years, advances in display technology have enabled aquariums to join the ranks of other leading leisure attractions with visitors numbering in the millions. Underwater World Singapore will be the first of this new breed of aquariums in Asia.

Introduction

Most of the world's conventional aquariums are found in cities by the sea or in communities with a marine tradition. This pattern of geographical distribution continues today and is reflected in recent aquarium developments, such as in the Seattle Aquarium, Copenhagen's Danish Aquarium, Hong Kong's Ocean Park, the Vancouver Aquarium and Townsville's Great Barrier Reef Wonderland.

While traditional factors continue to affect the location of aquariums, there are significant changes taking place in their character because of the influence of a number of public demand factors. For example, visitors want to get as close as possible to the creatures of the sea, which means breaking down the visible and physical barriers between the audience and the exhibit. Also, they increasingly seek a thrill or an "encounter" with a more true-to-life presentation of life underwater. They are more environmentally aware of the requirement for a good interpretation of the exhibits.

Moreover, an innovative aquarium today can draw a large number of visitors to the extent that it affects the entire community's local economy. An outstanding example of this took place in Monterey Bay in the USA following the opening of its aquarium. In its first year of operation alone, some three million visitors flocked to see the aquarium.

In the past, public aquariums have been generally funded or subsidized by governments or charitable foundations. However, in the last few years, changes in aquarium technology and the upsurge of interest in aquariums have made them potentially profitable business ventures.

The first aquarium in Singapore was funded from money donated by Mr. Van Kleef. The Van Kleef Aquarium is now run by the government through the Primary Production Department. The Coralarium on Sentosa is government-funded through the Sentosa Development Corporation (SDC). Both of these aquariums are traditional in style, with small window boxes into which the visitors can peer. The latest aquarium under construction in Singapore which utilizes some of the state-of-the-art aquarium technology is being developed by a private enterprise. The aquarium will be called Underwater World Singapore (UWS).

The Development of an Aquarium on Sentosa Island

In 1968, the Singapore Government commissioned the Dellingham Report on the Future Development of Sentosa, then known as Pulau Blakang Mati. This report, which was completed in 1970, stated that the island could be successfully developed into a leisure and resort island. Thus, SDC was set up by the government to undertake the development and management of the island. In 1980, the Pacific Area Travel Association (PATA) reviewed the Dellingham master plan and proposed an oceanarium to be added to the development. This was subsequently included in the Royston, Hanamoto, Alley and Abey review of 1985.

Next, a final site for the oceanarium-type development was selected on the coast next to Fort Siloso. The site was put on public tender in 1987. The tender was won by Marinescape Corporation (MC) of New Zealand which proposed an Underwater World (UW) facility using the same technology developed for its Auckland project. Thus, MC entered into an agreement with Underwater World International (UWI) of Perth, Australia, to finance and administer the development of UWS. After some delay due to a change in the shareholding at UWI, the main contractor commenced construction in June 1988. The project is due to be completed in March 1991.

The Underwater Worlds in operation to date in Auckland, Sydney and Perth (with the exception of Mooloobar Underwater World near Brisbane) are all cold-water aquariums. When completed, UWS will be the first tropical underwater world featuring a recreated coral reef with the compliment of over 200 species mainly from the Maldives, Malaysia and Indonesia. It will also feature a large shark and ray tank filled with tropical reef sharks and giant stingrays. Moreover, a curved acrylic tunnel, which is a moving walkway, will enable visitors to be surrounded by water and have close "encounters" with amazing marine animals as they glide past these creatures separated only by 6 cm of acrylic. Visitors can also step off the walkway and observe marine life at their leisure. There will also be displays of marine invertebrates, living corals and dangerous marine animals. A souvenir shop and food outlet are likewise planned.

To prepare visitors for their UW experience, there will be a short introductory audiovisual show in a theatrette. A fully equipped education unit manned by a full-time education officer will provide students of all ages the opportunity to learn more about the ocean, while trained guides will explain the exhibits.

There is also the possibility that UWS will be able to provide opportunities for research, using the quarantine and laboratory facilities of the National University of Singapore. In so doing, an aquarium of high caliber becomes not only a major tourist and leisure attraction, but also indirectly provides the public with an important educational and potential research facility.

While the developers of UWS will be responsible to its shareholders for maximizing the profits, they too, like most aquarium developers, have an interest to promote all aspects of marine conservation. The facility will, therefore, be a great opportunity to demonstrate the wonders of the tropical seas to a large number of people, perhaps over a million every year. By increasing the general public's awareness and understanding of marine life, the developers will have taken a big step towards promoting practical conservation schemes such as the desirability of marine parks and the utilization of a choice waterfront location for this kind of development. In the case of UWS, it is a well-justified response to a growing demand for a new breed of aquariums in Asia.

Recommendations from the National Workshop on Urban Coastal Area Management of Singapore

1. The coastal area of Singapore comprising the waterfront land of the main island, offshore islands and territorial waters should be managed on an integrated, multisectoral basis for the maximum benefit of the nation as a whole, both in the short and long terms.
2. There should be a single agency responsible for the management of the entire coastal area. Alternatively, a consultative coordinating management body should be established. The PSA, which is already responsible for the overall management of port waters (covering 85% of the territorial waters), is a logical choice for such an agency.
3. Under the present practice, all major projects are to be approved by the Chief Planner who is responsible for the overall physical planning of Singapore including its coastal area. The options are to continue with this practice or to vest the authority to approve projects on a separate agency as suggested in (2).
4. Wherever necessary, an environmental impact assessment of new development projects should be undertaken to ensure that there are minimal and acceptable impacts on the coastal environment.
5. Coastal pollution should be minimized through careful monitoring of all sources of pollution and, wherever necessary, legislation should be passed to strengthen control and enforcement. Support is given to the Oil Spill Contingency Plans currently in operation, although additional efforts should be made to strengthen them and thus ensure their effectiveness in combatting the major oil spills that may occur.
6. Foreshore reclamation will continue to be undertaken to meet long-term needs for land space and it will proceed down to the 15-m level. The improved method of landfill currently employed is less likely to cause silting in the coastal waters. Nevertheless, continued efforts should be made to further reduce the level of silting.
7. The program to control hazardous substances, which has been implemented since 1985 and covers the control of their import, sale, use, transport and disposal, should be reviewed periodically and, where necessary, strengthened to prevent the accidental release of these materials into the coastal environment.
8. In line with similar protection programs for birds, marine life should be protected with due regard given to the need to provide legitimate recreational fishing plans. In this connection, current efforts to create artificial reefs, establish artificial seagrass as habitats for marine life, and restock fish and shrimp in the Singapore River should be encouraged.
9. Development on land, especially on elevated sites, should take into account the needs to preserve the vista and scenic beauty of the coast as well as to provide access to the waterfront and foreshore areas.

10. The natural scenic quality and the unique character of the coastal area should be conserved to enhance the quality of life for present and future Singaporeans.
11. A system has been implemented since the 1970s under MOE to assess the siting and control of pollution and waste disposal of industries to be located on coastal sites and islands after an evaluation of the environmental aspects has been made. A review of the present system to determine whether or not additional guidelines should be instituted is now under study.
12. While it is recognized that there is a severe shortage of dumping grounds (sanitary landfills) for the disposal of solid wastes on the main island, special care should be exercised to ensure that the pollution of coastal waters is minimized and that marine life is not adversely affected.
13. Adequate seaspace and access to and availability of waterfront locations should be provided to cater to marine sports and recreation for the general public on a national and long-term basis.
14. Support is given to the PSA "Master Plan for the Management of Port Waters" which has the objectives of optimizing the utilization of the limited seaspace, improving the safety of navigation and raising the efficiency of the use of marine resources for maximum benefits.
15. Support is given to URA's newly released "Master Plan for the Urban Waterfront at Marina Bay and Kallang Basin" which is designed to redevelop Singapore's urban waterfront. Support is also given to the creation of sandy beaches, parks and waterfront promenades and to the promotion of water-based activities.
16. Support is given to the programs by PRD to conserve natural habitats and establish coastal nature reserves, mangrove parks and bird sanctuaries.
17. Marine-based tourism should continue to be developed both for the local population and visitors. Due consideration should be given to ensure that the siting and design of tourism facilities are environmentally sound.
18. A marine conservation zone with a sanctuary to protect the valuable reefs and marine life in the Southern Islands area should be established. Wherever possible, other similar areas should be explored.

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