COASTS

Coastal Publication No. 2

Renewable Resources Information Series

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RESEARCH PLANNING INSTITUTE, INC.

In cooperation with NATIONAL PARK SERVICE — USDI, and U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT

Renewable Resources Information Series
Coastal Management Publication No. 2

COASTAL RESOURCES MANAGEMENT GUIDELINES

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FOREWORD

Most countries recognize their coastal zones as distinct regions with resources that require special attention. Many have taken specific actions to conserve coastal resources and to manage coastal development. A few have created comprehensive, nationwide, coastal zone management programs that are fully integrated with other resource conservation and economic sector programs. There is a current trend to move toward more comprehensive and integrated coastal programs. Because comprehensive programs must, nevertheless, be organized to address specific development projects and specific conservation needs, this guidebook is designed to provide specific guidelines for management of projects. In this ground-breaking effort, the authors have provided an interim guidebook which should both benefit countries whose problems are urgent and stimulate comment toward a more complete future version of the guidebook.

This guidebook is one in a series of publications being produced for the Agency for International Development (AID) by the National Park Service (NPS). Its purpose is to provide expert guidance in planning and management for sustainable coastal development and for the conservation of coastal resources. In addition to this book, produced by Research Planning Institute, Inc. (Contract No. CX-001-3-0050), the coastal series includes a casebook with eight case studies, a report on institutional arrangements for coastal resource management, and a condensed design aids booklet.

This coastal series is part of a wider publication and training partnership between AID and NPS under the "Natural Resources Expanded Information Base" project commenced in 1980 in response to a worldwide need for improved approaches to integrated regional planning and project design. The project is producing publications on arid and semiarid rangelands and humid tropic systems as well as on coastal zones. The publications and training components are dedicated to strengthening the technical and institutional capabilities of developing countries in natural resource and environmental protection and to providing other international development assistance donors with ready access to practical information.

While the presence of integrated planning and comprehensive management alone may not assure a sustained and ample yield from the natural coastal resources of any country, its absence will lead to their depletion. The opportunities for development based on excessive exploitation of natural coastal resources are rapidly fading. In a world of rapid population growth and diminishing natural resources, countries that fail to plan their economic development strategy in concert with resource conservation and environmental management may not be able to sustain progress in health, food, housing, energy, and other critical national needs. The future depends on development closely linked to resource conservation. In the coastal zone, the need for an enlightened approach is urgent.

In producing the coastal publication series for AID, we realize that we have, at best, provided a foothold for natural resource aspects of the new and rapidly expanding field of coastal resource management. Much important work idly expanding field of coastal resources management. Much important work lies ahead in many of the technical areas. We particularly recognize the need to provide specific natural resource working materials for regional planners and economic development planners. Also, there is a need for advice on protection of life and property against storms and coastal natural hazards. Equally important is advice to planners on the role for designated protected areas--reserves, parks, sanctuaries--in tourism enhancement, fish stock management, and critical area and species conservation. We hope the present series will provide a springboard for studies on these important matters.

Mr. Hugh Bell Muller directed the implementation of the "Expanded Information Base" project and Mr. John Clark managed the coastal components. We thank AID for supporting the project. We are especially grateful to Mr. William Feldman, Ms. Molly Kux, and Mr. William Rosebotough of the Office of Forestry, Environment, and Natural Resources of the Bureau of Science and Technology, for their continuing encouragement and their patience.

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PREFACE

Until the mid-1960s, the tropical coastal zone was considered to be largely a wasteland having only marginal value unless "reclaimed" for some use such as rice agriculture. With the exception of a few former European colonies, where limited forms of utilization and management of coastal resources became established government policy, the coastal zone in most tropical countries languished under benign neglect. Beginning in the 1960s, the ecological and economic values of coastal resources became firmly established through scientific documentation, and, in the United States, the recognition of value led to a promising national policy of coastal zone management (CZM) that was based on existing political/legal institutions to promote the protection of the coastal habitats. Elsewhere in tropical regions, the coastal resource base was being destroyed through overt exploitation for not only short-term economic gain but also as the secondary result of regional development schemes that through the diversion of fresh water, impacted the coastal zone.

In response to the events taking place in tropical third-world countries, local scientists and managers began seeking scientific and technical assistance on coastal zone issues. Among those that provided the initial assistance were UNESCO's Division of Marine Sciences, the Food and Agriculture Organization of the United Nations and the Agricultural Development Council, as well as many others. As a result of these early efforts, most of which continue, there is a relatively large cadre of young, knowledgeable coastal zone scientists and managers scattered throughout the world.

In the preparation of this guidebook, we, as authors, were faced with a philosophical dilemma over the approach to be taken. Should we take the relatively successful U.S. paradigm of coastal zone management and retrofit it to specific circumstances in tropical countries, or should we sensitize ourselves to the unique economic development needs of those countries and devise a wholly new paradigm? Because coastal zone management in the United States does not actively promote economic utilization of the resource base, we chose to seek a new approach. As a result, we elected to work on the assumption that resource utilization and management are desirable goals in many developing countries, and that when undertaken on an integrated plan based on sustained yield, they effectively encourage coastal resource conservation. By working from this assumption, we also accepted the corollary assumption that the goals of protection and restricted resource utilization, as in the U.S. model, were primarily inappropriate alternatives for most developing countries.

The resulting guidebook, subject to continuing refinement, outliens a variety of utilization options that can result in economic gains when implemented in a manner which conserves the resource base. It also provides resource conservation guidelines for activities that commonly take place in the coastal zone. Most of the material presented in the guidebook, particularly with respect to the utilization options, is necessarily based on the overseas experience of the authors because, with certain exceptions, there is a paucity of published reference material upon which the discussions could be based. Each of the utilization options or alternatives contains a general set of operational goals, or performance guidelines, which identify the major considerations associated with their successful implementation. Specific utilization procedures and methods must be developed in each region or country and must be based on local characteristics of the coastal zone, the socio/political background, and the potential economic value of an activity in a specified region.

Because the refinement of the guidebook is a continuing process, readers and users are encouraged to recommend changes and additions to either the sponsors or the authors.

We are indebted to wholesale contributions during editing by Mr. Random duBois (University of Chicago) and Jane G. Snedaker (Tropic House International); our contract officer, Mr. John Clark (NPS); and Mr. Jeffrey Goodson (AID).

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READER'S GUIDE

This book was written as a guide for people involved in the international economic assistance programs which affect the world's coastal renewable resources. They are, most often, planners, project managers, development officers, and consultants who envision that our coastal areas can be developed while our resources remain renewable.

This guidebook covers 22 specific topics on the major coastal systems and the development of their resources and has been divided into two sections.

When scanning this book for use as a reference guide, it is recommended that the reader first refer to the appropriate major resource system in Managing Coastal Resources (Part I), and then proceed to the appropriate developmental section listed in Managing Coastal Development (Part II). Figure 1 presents the contents of both sections according to coastal landforms and water bodies.

Part I, Managing Coastal Resources, gives descriptions of five major coastal systems and their associated resources. The five systems covered are (1) coral reefs, (2) mangrove ecosystems, (3) beach systems, (4) estuaries and lagoons, and (5) seagrass beds. Each of these coastal systems is introduced by evaluating the ecological and economic benefits provided to man. Examples of previous management of the system are given so as to provide insight with regard to specific problems that have already been encountered. Sensitivities of the resource system are emphasized, and case examples are provided where there have been conflicting interests between the system/resource and the development activity.

Part II, Managing Coastal Development, covers 17 topics on developing coastal resources and the conservation problems that are faced when coastal development occurs. These 17 developmental resources have been grouped into the following economic categories: agriculture, fisheries, forestry, energy, transportation, urbanization, and industry. Each of the 17 topics begins with an overview and description of the coastal development activity. Again, case study examples are given which reveal how the development activity has already had, or has the potential to cause, a damaging or deleterious impact on the major coastal system. Specific suggestions are made for each development activity regarding site selection, project design, operational

Modules →

PART I — PART II

Water Bodies and Landforms	Coral Reefs	Mangrove Ecosystems	Beach Systems	Estuaries and Lagoons	Seagrass Beds	Coastal Agriculture	Upland Agriculture	Coastal Aquaculture	Capture Fisheries	Mangrove Forest Harvesting	Fuelwood and Other Renewable Resources	Oil and Gas Operations	Coastal Power Generation	Ports, Channels, and Harbors	Roads, Rails, and Bridges	Shore Protection	Waste Disposal and Disease Control	Coastal Recreation and Tourism	Water Resource Development	Industrial Siting	Coastal and Marine Mining	Salt Manufacture
Islands	●																	●		●	●	
Nearshore Waters	●								●					●			●	●		●	●	
Open Coast	●		●			●			●					●		●	●	●		●	●	
Barrier Islands			●											●	●			●		●	●	
Lagoons	●	●		●	●	●	●	●	●	●	●	●	●	●	●		●		●	●		●
Deltas		●	●			●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●
Estuaries		●		●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●		●
Coastal Wetlands		●		●		●	●	●	●	●	●	●	●	●	●		●		●	●		●
See page numbers	11	23	39	49	59	73	79	87	95	103	115	125	133	141	149	157	167	171	177	187	191	201

FIGURE 1. Matrix of coastal waters and landforms covered in each module.

techniques, and other applications, so as to conserve the renewable resources for future use while deriving the benefits of technology.

Guidelines are presented in both sections for each of the 22 specific topics with the intent that they will be regarded as actual management advice for the conservation of our coastal resource systems. As shall be seen, some of the guidelines will stress that sound management sometimes involves factors that are not even directly related to the coastline; for example, clearing for agriculture in the watershed of a coastal stream or improper soil conservation in upland agriculture must take into consideration the manner in which these activities will affect the downstream systems.

Most topics have been cross-referenced by a "See Also" note, which guides the reader to other sections in the book where the topic is relevant. This convenience was added to insure that the reader will comprehend the topic with the awareness that a change in one vital component of a major resource system can affect the system as a whole. For example, when considering a development activity in or near estuaries and lagoons, it would be prudent to refer to the information regarding mangroves since they are often a critical component of estuarine and lagoonal systems. If coastal and marine mining is to be considered as a coastal development activity, the information regarding coral reefs and seagrasses would give an insight as to the manner in which these major systems and their associated components are affected, since they are often damaged or removed. References have been supplied at the end of each topic discussion.

Additional information for developing the coastal zone can be found in the methods book entitled, Resource Inventory and Baseline Study Methods for Developing Countries. This manual, prepared by the American Association for the Advancement of Science (AAAS), is referred to by section listed in Figure 2. These are aquatic ecosystem components that should be monitored when developing along the coast, as recommended by the AAAS manual according to the information needed for coastal development planning. The AAAS manual describes aquatic ecosystem components which are recommended for collecting baseline data and monitoring in the case of specific project actions.

Modules →

PART I — PART II

MATRIX OF AAAS METHODS FOR EACH MODULE

	Coral Reefs	Mangrove Ecosystems	Beach Systems	Estuaries and Lagoons	Seagrass Beds	Coastal Agriculture	Upland Agriculture	Coastal Aquaculture	Capture Fisheries	Mangrove Forest Harvesting	Fuelwood and Other Renewable Resources	Oil and Gas Operations	Coastal Power Generation	Ports, Channels, and Harbors	Roads, Rails, and Bridges	Shore Protection	Waste Disposal and Disease Control	Coastal Recreation and Tourism	Water Resource Development	Industrial Siting	Coastal and Marine Mining	Salt Manufacture
1. Physical Properties																						
a. Climate		•	•	•		•	•	•		•												•
b. Precipitation	•	•		•		•	•	•		•							•					•
c. Surface water	•	•	•	•		•	•	•		•			•	•	•		•		•			•
d. Ground water		•		•		•	•	•		•			•	•	•		•		•		•	•
e. Tides and wave action	•	•	•	•	•			•	•	•		•	•	•	•	•	•		•		•	•
f. Currents and circulation	•	•	•	•	•			•	•	•		•	•	•	•	•	•		•		•	•
g. Temperature	•	•		•	•			•	•	•		•	•	•	•	•	•		•		•	•
h. Salinity	•	•		•	•	•		•	•	•		•	•	•	•	•	•		•		•	•
i. Density and stratification	•			•	•			•	•	•		•	•	•	•	•	•		•		•	•
j. Light and transparency	•			•	•	•	•	•	•	•		•	•	•	•	•	•		•		•	•
2. Chemical Properties																						
a. Dissolved gases	•	•		•	•		•	•	•	•		•	•	•	•		•		•		•	•
b. Total dissolved solids	•	•		•	•	•	•	•	•	•		•	•	•	•		•		•		•	•
c. Particulates	•	•		•	•	•	•	•	•	•		•	•	•	•	•	•		•		•	•
d. pH	•	•		•	•	•	•	•	•	•		•	•	•	•		•		•		•	•
e. Conductivity	•	•		•	•	•		•	•	•		•	•	•	•		•		•		•	•
3. Biotic Properties																						
a. Benthos		•	•	•	•			•	•	•		•	•	•	•	•	•		•		•	•
b. Plankton (zoo- and phyto-)				•	•			•	•			•	•	•	•	•	•		•		•	•
c. Fish and fisheries		•	•	•	•	•	•	•	•	•		•	•	•	•	•	•		•		•	•
d. Littoral vegetation		•		•	•	•	•	•	•	•	•	•	•	•	•	•	•		•		•	•
e. Periphyton		•		•	•	•		•	•	•		•	•	•	•	•	•		•		•	•
f. Microbiota		•	•	•	•				•			•	•	•	•	•	•		•		•	•
4. Functional Properties																						
a. Nutrient cycling		•		•	•	•		•	•	•		•	•	•	•	•	•		•		•	•
b. Primary productivity		•		•	•	•		•	•	•		•	•	•	•	•	•		•		•	•
c. Secondary productivity		•		•	•	•		•	•	•		•	•	•	•	•	•		•		•	•
d. Eutrophication		•		•	•	•	•	•	•	•		•	•	•	•	•	•		•		•	•
e. Ecosystem indices		•		•		•		•		•			•	•	•		•					
f. Water balance		•		•		•	•	•		•			•	•	•		•					•

FIGURE 2. Matrix of AAAS methods for each module. (Source: Ref. 1.)

CONTENTS

INTRODUCTION

Conservation is a justifiable goal in that the numerous natural assets which benefit local societies stem from the diverse kinds of coastal zone ecosystems that exist. However, if economic development is perceived to be a precursor to the social advancement, welfare, and harmony of men and nations, the coastal resources must be utilized so that they can be simultaneously maintained. This addresses a motive regarding economics, which seems to maximize the use of natural resources, while at the same time maximizing the profits that could be derived from the resource utilization.

Coastal areas and their development are unique since they occur at the interface of land and sea and are strongly influenced by both. Certain coastal area development activities, such as extensive landfilling and extensive development of watersheds, are relatively irreversible transformations which drastically alter the land/sea interface. In contrast, most of the development activities addressed in this guidebook are not irreversible, since proper planning may enable even the most damaging effects to be assimilated by natural processes in nearshore waters. These natural forces, such as tides and salinity gradients, control all aspects of the coastal zone, including the distribution of ecosystems, the mode of their utilization, and the extent of developmental impact upon coastal resources (Figure 3). Throughout this book, two basic concepts are woven which emphasize the ability of coastal systems to assimilate the impacts of coastal development; they are conservation and diversity.

Conservation is the wise use of resources; in other terms, it is the prevention of waste. In coastal area conservation, planning is vital when these factors are recognized: (1) the potential does exist for using the natural forces at the land/sea interface and within nearshore waters as well as for conserving the renewable natural resources; (2) the economic importance and contribution of coastal resources can be measured; and (3) a variety of successful, simple, and economically feasible options have resulted in the sustained use of coastal resources which would be otherwise depleted by the destructive effects of unplanned coastal area development. Conservation also leads to the maintenance of diversity.

Diversity, to an ecologist or a natural resource economist, is a measure of the richness and resilience of a coastal resource based upon an evaluation of the number of species functioning within the ecosystem. In general, the

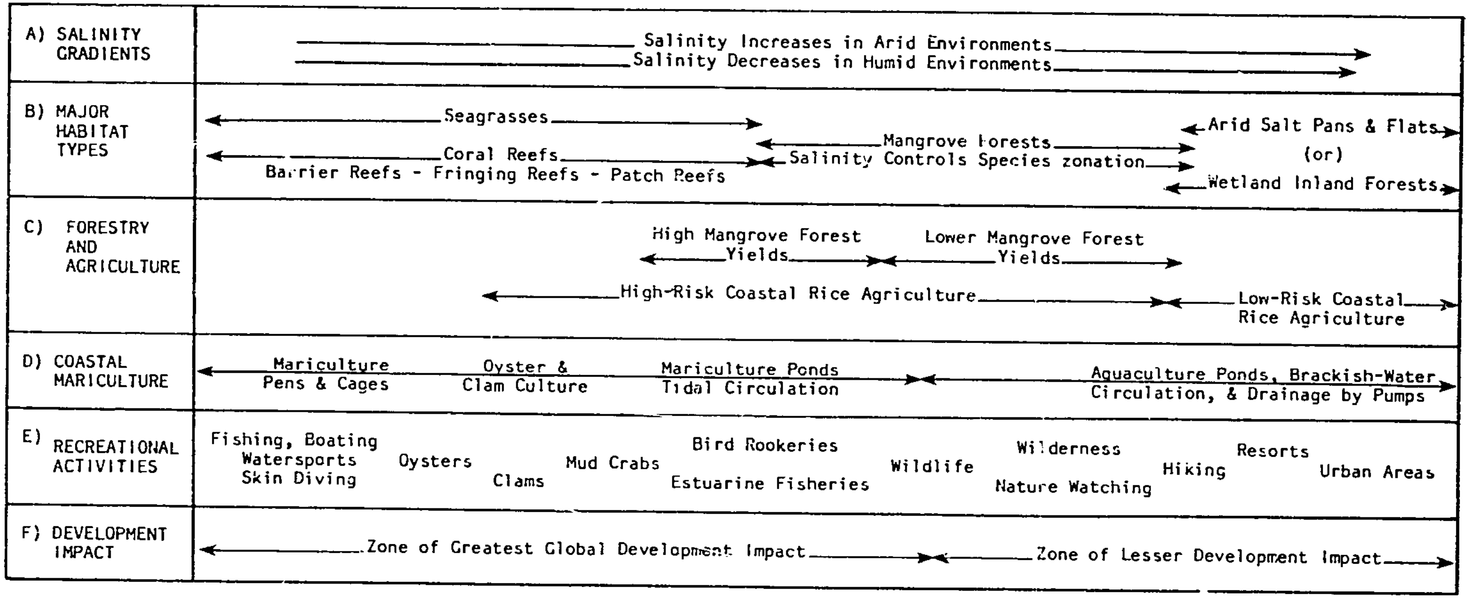

FIGURE 3. General interrelationships among selected coastal processes, natural habitats and human activities.
A) In arid environments, soil salinity is higher in inland areas, whereas in humid environments, freshwater runoff results in reduced soil salinity.
B) The spatial distribution of habitats and dominant organisms conforms to the broad gradients in topographic elevation, tidal flooding, and salinity.
C) Forest and agricultural yields, as well as economic risks, also tend to be correlated with their location in the coastal zone.
D) Different forms of mariculture are practiced in the coastal zone although there is an increasing tendency to convert intertidal habitats to open ponds.
E) Man is attracted to different portions of the coastal zone to obtain a variety of marine products and for purely recreational purposes.
F) In general, plant/animal community sensitivity increases toward open water, and these nearshore areas tend to suffer the most from unwise development practices that do not perpetuate natural habitat conditions.

more diverse the system, the more resilient it is to damage from coastal development. Maintenance of species diversity through conservation is a technique which positively affects the resilience of a given coastal resource. In this sense, the species within the systems comprise genetic resources providing resilience to other coastal resources impacted by coastal area development.

When planning for the conservation or development of coastal resources, it is essential to consider both direct and indirect effects of any activity on all adjacent systems. "Integrated planning" for resource development and utilization embodies the concepts of sustained utilization along with obtaining the greatest yield from the best multiple uses of the resource within a framework that plans for both long-term and multisectoral use. These concepts insure that resource development and utilization schemes meet their intended goals while minimizing the possibilities of creating a secondary effect on an adjacent system which causes costly problems (economic, social, or political). Integrated planning as described above is a relatively new term which expresses a process that has a long history of success among cultures forced (for simple survival) to make critical, natural resource decisions. An example of integrated planning is described in detail later in this section.

In most parts of the world, renewable coastal resources tend to be economically limited. Over any time period, the economic demand for a given resource will commonly exceed the supply, be it arable or developmental land, fresh water, wood, or fish. To insure that renewable resources remain available to future generations, resource management has as one of its major goals the sustained utilization of natural resources. The criterion for sustained utilization is that the resource not be harvested, extracted, or utilized more than that amount which can be either produced or renewed over the same time period. In essence, the concept of sustained utilization specifies that the resource is a capital investment with an annual yield; it is therefore the yield that is utilized and not the capital investment which is the resource base. By preserving the resource base, annual yields are assured in perpetuity.

The concept of greatest yield from the best multiple use takes into view that specific resource systems (sometimes treated as isolated systems) are always components of a larger ecological system that contains many other resources with economic and social values. Also taken into account is the fact that component resource systems naturally tend to be highly integrated and dependent upon one another. For example, in many parts of the world, fresh water is considered to be a limited resource for agricultural and domestic use. In the recent past, water development specialists tended to allocate water usage based on the most obvious economic and domestic demands, but failed to take into account the role of fresh water in the maintenance of coastal estuaries and their fisheries (e.g., the Nile watershed in Egypt and the Indus watershed in Pakistan). The greatest yield that can be obtained from the best multiple-use concept requires that all actual and potential uses for the resource utilization scheme be determined so as to insure that the sum of the opportunity costs is minimal. Opportunity costs represent the value of those lost options (or opportunities) that would otherwise be derived from using other resources, as opposed to committing one resource for an exclusive use. For example, in determining the allocations of fresh water for either irrigation or fishery maintenance, if the use of fresh water is exclusively for irrigation, then this imposes an opportunity cost from fisheries which equals the annual income which could have been obtained but is now lost due to its collapse (e.g., the sardine fishery in Egypt and the hilsa fishery in Pakistan). By taking into account all actual and potential uses of resources, it is possible to determine the greatest potential yield from the best multiple uses that would result in the smallest opportunity cost possible.

Figure 4 illustrates the Tji Tarum (new name, Cituram) estuary of Java, as an example which demonstrates the principle of sustained utilization and greatest and best multiple resource use. It also demonstrates that sound planning can be accomplished and not be dependent upon technological sophistication or bureaucratic guidance. In the Citurам area, all natural and human resources are integrated in a socioeconomic utilization scheme that strives for harmony and multiple, but yet long-term, sustained yields. In Figure 4, the estuarine area (A) is a fishery resource which is ecologically dependent upon, and supported by, the adjacent mangrove fringe forest which is a zone of mixed-species mangroves (B) that serves as a source of small-size wood for a variety of domestic uses. Located immediately inland from the mixed mangrove forest are the villages of the local residents (C) which front the inland tidal channels and waterways (D). The network of

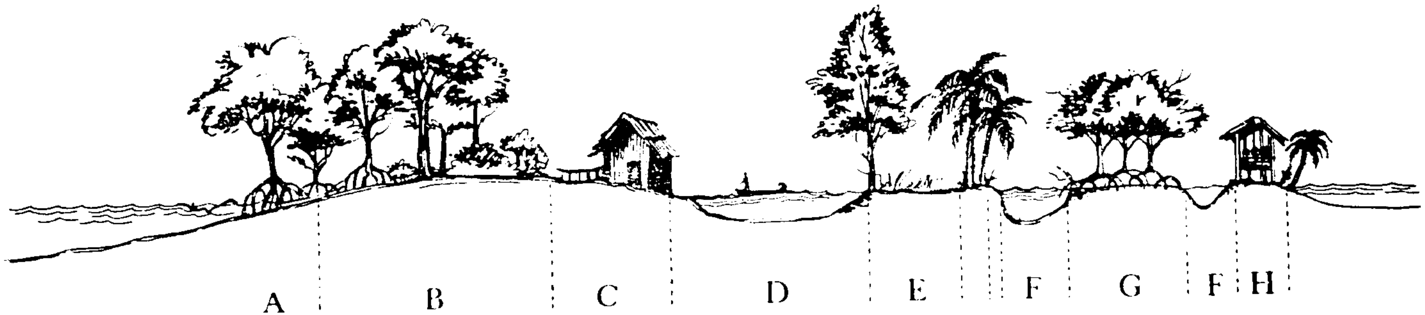

FIGURE 4. Example of subsistence-level utilization (see text for key to letters).

interlinking, brackish-water channels serves as the major transportation route within the Cituram area. Interspersed within the area are agricultural sites (E) which produce rice, sugarcane, coconut, and other minor crops. Alternating with the agricultural fields are aquaculture ponds (F) whose banks are stabilized with grasslike sedges for protection against erosion. These ponds are used to produce fish and shrimp, and pond populations are nutritionally supported by the adjacent mangrove forests (G) via the introduction of leaf litter and detritus into the ponds. These mangrove forests exist as managed plantations which yield timber and wood products that are used locally or sold. Sheep, which provide both protein and wool, are raised in elevated cages (H) and are fed green fodder which is harvested from the mangroves, along with other vegetation such as shrubs and certain local grasses. The perpetuation of the human community and its varied natural resource base is wholly predicated on the long-term planning for sustained, multiple resource utilization.

Throughout the book, we have referenced various case studies. These are the case studies appearing in Publication No. 3 in this series.

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PART I - MANAGING COASTAL RESOURCES

I. MANAGING COASTAL RESOURCES

Coastal areas contain major natural and economic resources which, in many regions of the world, are either not utilized or are utilized in such a manner that the economic benefits are not optimized to the fullest potential. Countries that have extracted economic gain from their coastal resources have employed various strategies. For example, Holland has converted its coastal lowlands to agriculture and human habitation; Bangladesh relies on the management of the Gangetic delta as a continuing source of pulpwood, domestic timber, and food products; the island state of Singapore has identified its coastal zone as a focal point for economic development which is based on shipping and commerce. While a few countries have elected to develop their coastal environments based on sound assessments and plans, other countries have not and, as a result, have witnessed the loss or deterioration of these resources as well as the loss of the long-term economic benefits that could be derived from them. In many instances, this loss or deterioration is due to secondary impacts which can result from other local development projects if the long-term planning of natural coastal resources is not adequately considered.

Five major coastal resource units are considered in the following sections--coral reefs, mangrove ecosystems, beach systems, estuaries and lagoons, and seagrass beds. Here we take the following points of view: (1) impacts on these resources should be thoroughly considered before development projects are approved; (2) each resource unit should be considered a subecosystem and impacts on the broader coastal ecosystem of which it is part should also be known.

CORAL REEFS

Description of the Resource and Habitat

Coral reefs occur along shallow, tropical coastlines where the marine waters are oxygenated, clear and warm, and free from suspended sediments, excessive freshwater runoff, and pollutants (Figure 5). The actual reef consists of a large and rigid structural mass of calcium carbonate formed by the cemented skeletal remains resulting from the successive growth and development of hermatypic corals (i.e., reef-building corals). Although corals are colonies of small animals, each living unit of the hermatypic corals contains algal populations within its own tissues which are capable of photosynthesis, thus providing an energy source for both the coral and the algae. The corals themselves are relatively slow-growing colonies of animals with growth rates ranging between one-tenth and ten centimeters per year in length. The large and diverse animal populations associated with the reef are supported both by the net primary production occurring on the reef and by the organic materials (including plankton) that are continually brought to the reef by marine currents.

Distribution

For most coral species, reef development occurs at seawater temperatures in excess of 20 degrees Celsius, though reefs are known to occur in waters with temperatures as low as 16 degrees. As a result, most coral reefs are found in the tropics and at higher latitudes where there are warm ocean currents (e.g., the Bermuda, the Florida Keys, and parts of the Great Barrier Reef off eastern Australia). The areas of greatest coral reef development are in the western Pacific and Indian Oceans. Lesser-developed reef systems occur off the western coast of tropical Africa and in the western Atlantic Ocean, notably the Caribbean Sea and Bahama Island region. Elsewhere along tropical coastlines, upwelling cold water, freshwater river runoff, and/or a lack of suitable substrate preclude the presence of reef-building coral animals. However, isolated corals and small groups of corals may be found scattered throughout tropical, shallow waters in association with other kinds of benthic (bottom) marine communities.

Hermatypic corals are found growing actively on the reef crest and face where the reef is growing seaward and toward the surface. Though not

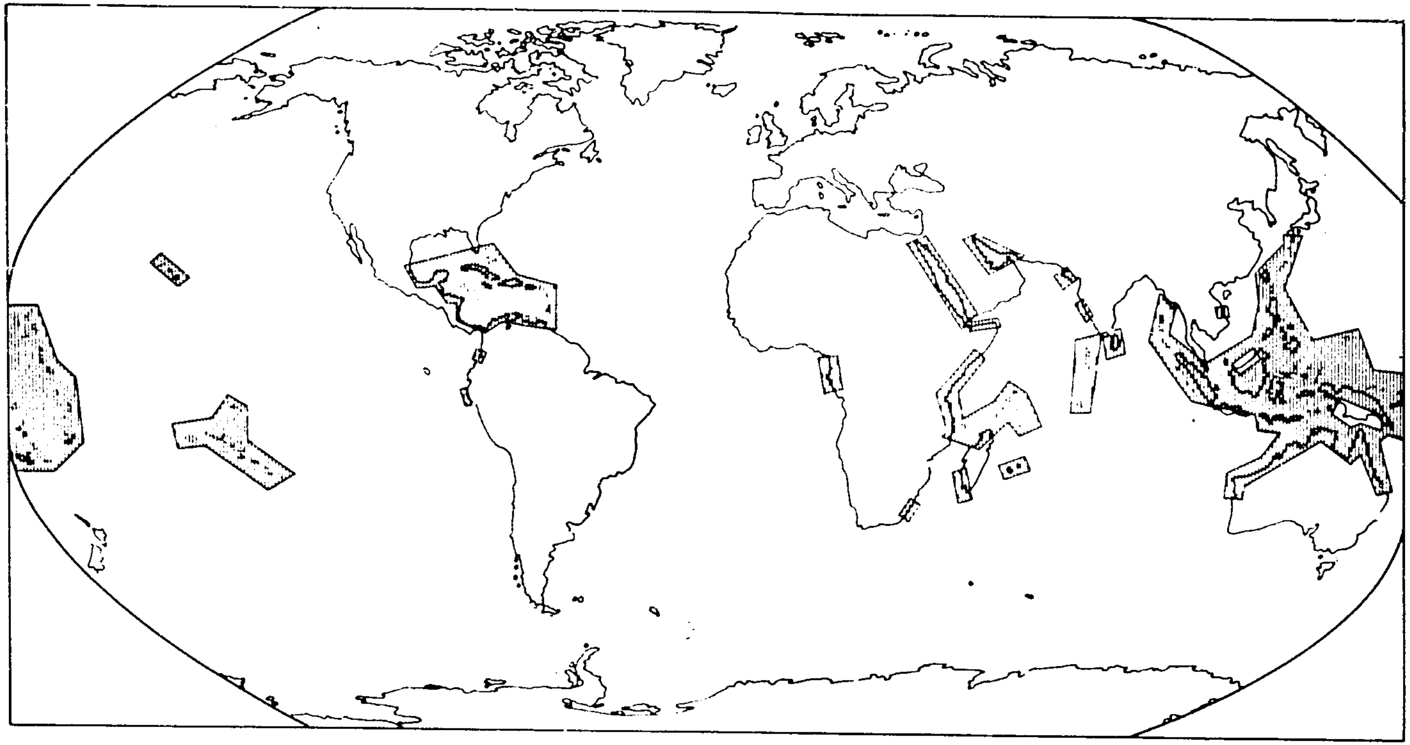

FIGURE 5. Geographical distribution of the world's coral reefs. (Source: Ref. 1.)

responsible for the formation of reefs, the nonhermatypic corals may still be valuable as substrate and may provide the basis for diverse and productive communities. These species are found both inshore and in deeper waters and often are valuable in the formation of sediment substrates, including beaches and shoals.

Structural Types

Coral reefs are recognized as occurring in a number of major morphological, or structural, types. Fringing or shore reefs are the most common and widespread of the reef structural types. They occur in the nearshore environment and are best-developed along rocky coasts of uplifted continental coastlines and islands as well as along shores of exposed limestone islands where there is a firm substrate. Their inshore distribution renders them susceptible to coastal activities, more so than other reef structural types. Fringing reefs are nearly always found below the low-tide level, but extensive intertidal exposure forming broad tidal flats is known to occur in areas where there are moderate to large tides. Fringing (or fringe) reefs are often simply veneers of reef organisms that cover some type of hard, nonreef material. Elsewhere, such as on the island of Oahu in Hawaii, fringing reef may itself be hundreds of meters deep, reflecting land subsidence or sea-level rise. One of the largest fringing-reef formations is adjacent to the shoreline of the Red Sea which is noted for the absence of freshwater and sediment runoff. Patch reefs are associated with shallow coastal waters and are isolated and discontinuous patches of fringing reefs often occurring in depositional environments (e.g., adjacent to deltas, where otherwise, favorable conditions exist). Barrier reefs are linear, offshore-reef structures that run parallel to coastlines and arise from submerged shelf platforms; the water area between the shore and the reef is called a lagoon. The world's largest barrier reef, the Great Barrier Reef, occurs off the Queensland coast in Australia and is actually a complex of many different reefs of different shapes and sizes; for example, the scallnped seaward rampart gives rise to a morphology known as a ribbon reef. Other large barrier-reef systems occur in the South Pacific, such as off New Caledonia and north of the islands of Fiji, Viti Levu, and Vanua Levu, and in the western Caribbean off Belize. Atolls are circular or semicircular reef systems that may arise from a deep-sea platform (deep-sea atolls) or from a shallow-shelf platform (shelf atolls). Most deep-sea atolls occur within the Trade Wind belt and are most common in the Pacific Ocean; however, they are also present in the Indian Ocean. Similar, but less-developed examples are found in the Caribbean region.[1]

Productivity

Coral reefs are one of the most productive ecosystems in the world in terms of the support and maintenance of a large animal biomass (quantity of living matter). Although the gross primary productivity of the reef producers is equivalent to that for most productive plants, the reef system is also adapted to utilize a variety of organic and inorganic materials brought to the reef by water currents and by the diurnal migration of reef and nonreef species. Although the coral reef appears to be a discrete and self-contained ecological system, its productivity is wholly maintained by the characteristics of the surrounding environment. In this regard, the basis for the high productivity of the coral reef ecosystem is a result of the production of the reef itself, together with its surrounding and supporting environment.[2] It is this level of productivity which is the basis for sustaining the reef's characteristically high diversity and abundance of fish biomass (estimates between 490 and 1450 kilograms/hectare).[3]

Linkages

The coral reef ecosystem has a variety of useful roles, all of which have a relevant and positive influence on associated coastal habitats. The most prominent role is the provision of a diverse habitat for a large number of sessile and mobile organisms. In this regard, one notable feature is the large proportion of species that live within the reef system but forage and feed in contiguous areas on a diurnal cycle. Conversely, many nonreef species visit coral reefs at periodic intervals for the purpose of foraging and preying upon coral reef inhabitants. The coral reef ecosystem is thus both a habitat and source of nourishment for many species typically found in the coastal areas dominated by reefs.

Although the coral reef ecosystem is dependent upon the seawater's having superior water-quality characteristics, the reef itself plays a role in maintaining the quality of local waters. Water currents that circulate over and within a coral reef are "filtered" as the reef system takes up and utilizes a variety of inorganic minerals, oxygen, organic detritus, and plankton. The outflowing water carries small concentrations of metabolic wastes away from the reef as well as planktonic larvae that are dispersed into other areas.[2]

Coral reefs tend to be positioned perpendicularly to the mean direction of wind-generated swell currents flowing over the reef. Depending on the reef's proximity to adjacent coastal areas, this characteristic can serve to weaken incoming waves, thus minimizing erosion and coastal hazards behind the reef. This creates a lagoon and a protected coastal environment (Figure 6).

Uses

Coral reefs have a large variety of direct and indirect uses that benefit man and society. Among the dominant and most valued uses are the large yields obtained from marine fisheries supported by the reef system, which are estimated to be as high as five tons/square kilometer. This yield is not limited to the fishes and crustaceans actually harvested from within the reef system, but also includes a larger variety and quantity of organisms caught elsewhere but whose existence is dependent upon the reef. For example, an examination of the stomach contents of tuna being caught off New Caledonia indicated that 58-73 percent of the tuna's fish intake was of coral reef origin.[3] Catches from coral reefs often comprise a significant portion of the local fisheries. A survey of the total fishery catch of western Sabah (Malaysia) indicated that reef fishes comprised nearly one quarter of the total fishery catch of the Kudat and Kota Kinabulu areas.[3] The actual contribution of fishery catches from coral reefs may be highest in areas where subsistence fishermen literally live off the reefs, such as occurs in many areas of the world including the Laguna de Chiriqui (Panama) and many parts of the Philippines. In most cases, the catches of the subsistence fishermen rarely reach the records of their respective fishery offices.[4]

Mining of the living coral reef and back-reef areas is still common in many parts of the world. Coral mining has been documented as a source for lime production in Mauritius and India as well as a source of construction material in Indonesia.[5,6,7]

Some of the more valued, but less recognized, uses include their importance in the promotion and development of income-earning tourist industries. In many countries, the aesthetic and recreational aspects of coral reefs may

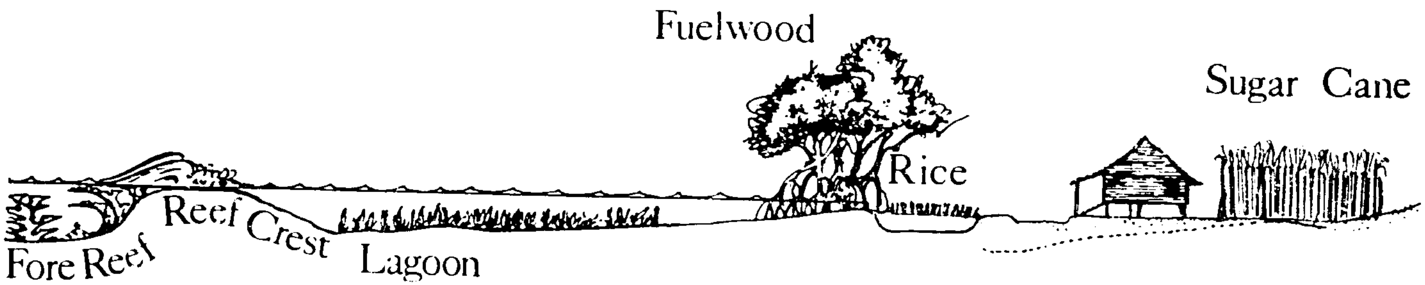

FIGURE 6. Coral reefs can serve as a buffer against storm waves thus protecting the shoreline and coastal lands, crops, houses, and human life.

support major tourist industries that are aimed at divers and fishermen, as well as others, who value the presence of coral reefs for recreational purposes.

Certain coral harvesting takes place for species with precious or semi-precious jewel value and for species with an aesthetic appearance of interest to tourists. The market for these coral species is often quite lucrative and almost exclusively export-oriented. In the Philippines, for example, local markets for corals compromise a very small portion (10 percent) of the total market, with foreign exports (primarily to the United States, Europe, and Japan) making up the much larger share (90 percent). In 1977, Philippine coral exports accounted for over US$2 million, with a wholesale market profit of 10-20 percent.[8] Recently, a partial ban on coral collection was implemented in the Philippines, since the tangle and drag nets of foreign fishermen were causing significant and increasing degradation to the reefs.

Problems

Corals and coral reef ecosystems occur under a rather well-defined set of environmental conditions which are mostly associated with shallow, continental shelf areas and island settings in tropical oceans. Maximum coral development requires clear transparent water, warm water temperatures, full-strength seawater, continual water circulation, an absence of excessive suspended sediments, and a suitable (i.e., hard) substrate.

As a result, coral reefs and coral reef organisms are extremely sensitive to (1) excessive freshwater inflows which reduce the ambient salinity; (2) waterborne sediments which interfere with the filtering action of the resident filter feeders; (3) temperature extremes beyond the thermal limits of the coral; (4) pollutants, such as agricultural biocides, which may enter local waters; (5) breakage, such as that caused by cyclonic storms and by boat anchors; and (6) excessive nutrient loading which may stimulate the excessive growth of competing algae which covers and kills the coral organisms or the bloom of phytoplankton which can shade the reef and reduce the rate of photosynthesis.

Due to the reef's role as a buffer of storm surges, coral reef mining serves to increase coastal erosion and coastal hazards.[8] One study of a coral reef that was partially destroyed from mining in Indonesia documented the resulting severe beach erosion which threatened local settlements and land-use patterns (Figure 7). A similar trend is reportedly in progress on the beaches of Minglanilla and San Fernando, Cebu, where the local people have been mining the fringing reefs for the manufacture of coral tiles.[8] The mining of coral is a particularly destructive use of the resource because the slow growth rates of most species render their status to practically nonrenewable resources.

A second major source of coral reef degradation is associated with mismanagement of upland areas resulting in high rates of sedimentation which effectively suffocate the coral.[8]

Losses of coral reefs also occur naturally, through severe storm damage and, in some areas of the tropical Pacific, by coral-eating starfish. It has been postulated that this biological agent could result in such severe reef loss so as to threaten the land, which is otherwise protected by healthy reefs, with the accompanying loss of life and property. However, coral reef predation by the starfish is now viewed as a natural and cyclical event that may actually help the reef system as a whole in maintaining its high productivity.

In addition to the previously cited causes of coral reef degradation, other actions affecting their well-being include the following: (1) siltation and sedimentation created by dredging, filling, and related construction activities; (2) degraded water quality which has resulted from changes in salinity and temperature, and the introduction of pollutants, including spilled oil, industrial wastewater, and domestic sewage; (3) discharge of large volumes of fresh water as may result from river diversion, domestic sewer outfall, and storm-water runoff; (4) destructive fishing practices which include the use of explosives, poisons, and nonselective traps; (5) overexploitation of selected coral species for use as ornaments and semiprecious jewelry in tourist markets; (6) collection of exotic species for sale in the marine aquarium market; and (7) tourist visits to reef systems which result in breakage from boat anchors and souvenir collection.

Guidelines

Coral reef ecosystems have a remarkable natural ability for self-maintenance and self-renewal in the absence of a disturbance when the basic habitat characteristics that favor coral reef formation are maintained. Like other natural ecosystems, the coral reef does not require overt or direct manipulation

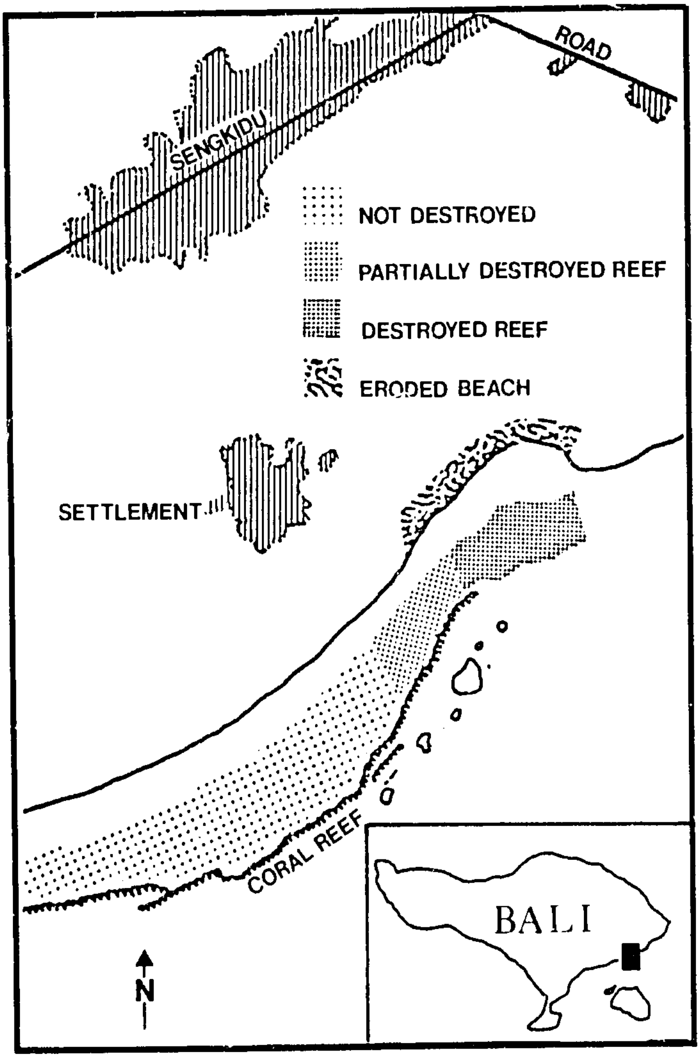

FIGURE 7. Beach erosion induced by coral reef mining. (Source: Ref. 7.)

by man for its sustained survival. However, since the actions that do threaten the existence of coral reefs are mostly man-caused, they are thus amenable to corrective action; this would result from integrated coastal activity planning which would take into account the sensitivities of corals and coral reefs. The guidelines below are those which are considered to be the minimal requirements for the maintenance and perpetuation of high-quality coral reefs.

1) Seek alternative sources of construction aggregate and calcium carbonate (for lime and cement) to prevent the mining and largely irreversible loss of these slow-growing living resources. Possible alternatives include mining nonliving corals, including the back-reef rubble zones and land-bounded Pleistocene reef, but these sources should be exploited with caution as they can serve a role as storm buffers and slow rates of erosion.

2) Do not undertake dredging or other activities that disturb the sediments and create silty water near or upstream from coral reefs. Where this is not possible, sediment containment measures should be considered (e.g., sediment curtains) and a monitoring program initiated which would serve to regulate mining activities to acceptable water-quality standards.

3) Avoid the introduction of pollutants and excessive nutrients into the reef environment. Proper siting of industries away from coral areas would minimize the risk of certain kinds of industrial pollutants. Likewise, ocean outfalls for the disposal of sewage wastewater should not be allowed to influence reef areas. Possible mitigation measures include treatment, settling and cooling ponds, and disposal in areas seaward of the reef.

4) Terminate the use of explosives and poisons as a means of harvesting reef fish. These methods are extremely destructive to slow-growing corals and to the reef community in general and may also pose a health risk for human consumers.

5) Set maximum limits on the annual harvesting of reef materials and associated fish and shellfish species. For each species of value, limit the yield to the maximum that can be sustained.

6) Promote and control tourism from the perspective that the coral reef ecosystems are invaluable national assets. For example, coral reef visitors should not be allowed to anchor boats on reefs or collect corals for souvenirs.

7) Avoid alteration of the ambient range of water salinities for the area. Disposal of brine wastes or drainage of salt ponds would raise the salinity, whereas the excess delivery of fresh water would reduce the salinity; both of these extremes should be avoided. This could be achieved through dilution techniques and regulating rates of discharge.

8) Avoid alteration of water temperatures from their known ambient range. To maintain the temperature range, heated discharge water should not be introduced into coral areas. Also, freshwater runoff is sometimes cooler than seawater, and exposure of corals to this runoff aggravates the effect of reduced salinity. The storage of discharge water in cooling ponds until ambient temperature is maintained is one solution to this problem.

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See Also: Coastal and Marine Mining (p. 191).

MANGROVE ECOSYSTEMS

Description of the Resource and Habitat

Mangroves are halophytic (salt-tolerant), woody, seed-bearing plants. They range in size from tall trees to small shrubs; worldwide, there are more than 50 species.[1] They are characterized by their common ability to thrive along sheltered, intertidal coastlines on sediments that are saline, often anaerobic, and sometimes acidic. Many of the individual species possess unique adaptations such as prop roots, pneumatophores (pencillike upright roots), lenticels (air holes), and viviparous propagules (seeds that germinate on the tree) that permit their existence in a relatively stressful environment (Figure 8). Although mangroves develop in a saline environment, they have the usual plant requirements for fresh water, nutrients, and oxygen. Salinity, existing in a gradient in the intertidal zone, exacts a metabolic cost on mangroves[1] but also serves to eliminate competition from nonhalophytic species. The variable patterns in topography, sediment type, and hydroperiod (seasonal period of saltwater/freshwater inundation), and salinity patterns determine the spatial distribution of the species and types of forest structure. Irrespective of the wide range in variation among the mangrove species and mangrove forest types, this ecosystem is economically and socially significant for its role in the existence and perpetuation of nearshore fisheries, the protection of coastlines, as a renewable resource, and as a location for permanent and temporary human settlements.

Distribution

There are some 24 million hectares of mangrove-dominated intertidal and supratidal land scattered throughout most of the subtropical and tropical countries of the world.[2] Because mangroves are sensitive to frost and freezing temperatures, the latitudinal limits are determined by temperature, with north/south extensions of the limits occurring only where warm coastal currents modify the climate (Figure 9).[3] Their dependence on the availability of freshwater runoff precludes mangroves from developing to their maximum potential in extremely arid areas, particularly where there is a "drying" effect from strong, prevailing winds. In a regional setting, mangroves are found along sheltered coastlines where wave activity tends to be minimal. Thus, mangroves tend to be the dominant intertidal plant community associated

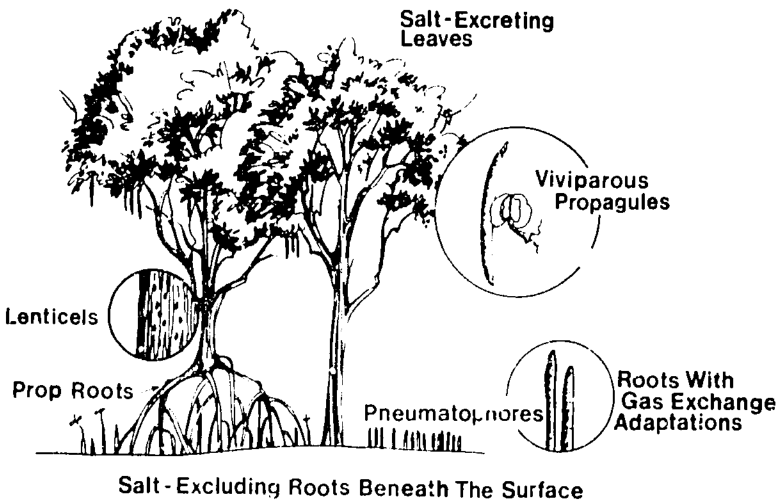

FIGURE 8. Mangrove species possess unique adaptations that permit them to exist in a stressful environment.

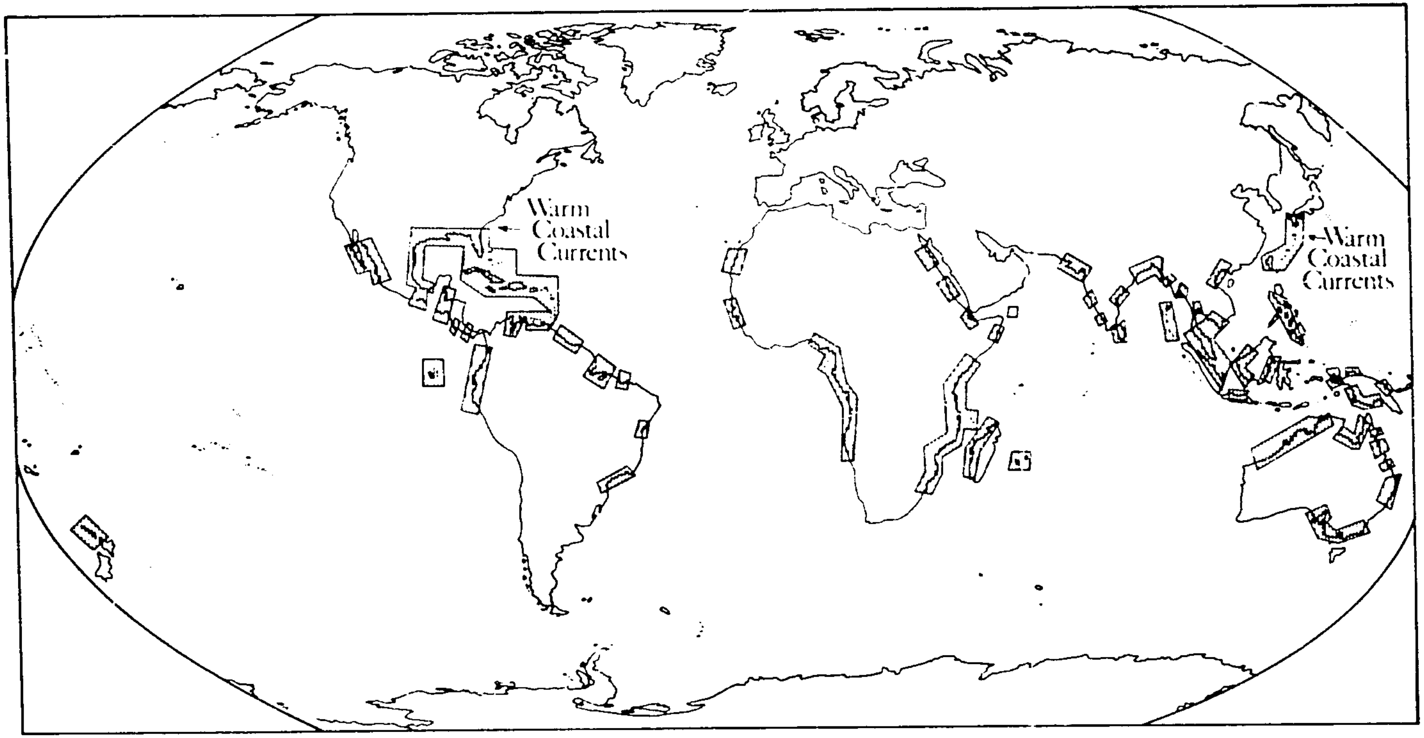

FIGURE 9. Geographical distribution of the world's mangroves. (Source: Ref. 3.)

with tropical estuarine, deltaic, and lagoonal landforms. The regions where mangrove forests reach their greatest extent are Asia and the Orient, followed by Africa and South America (Table 1).

Structural Types

The management of a mangrove forest is based on the structural and functional characteristics of the forest. Mangrove forest structural organization has traditionally been interpreted as the consequence of species zonation created by gradients in topography and soil salinity; each species dominates the zone to which it is best adapted. Although species zonation is frequently observed, the dominant influences on forest structure are more closely associated with differences in coastal landforms, patterns of surface-water flushing, and salinity. Five major forest-structure types are recognized: fringe, basin, riverine, overwash, and dwarf (Figure 10).[1] Fringe forests are situated along the slightly sloping shorelines of terrestrial mainland areas and larger islands. Often, they are exposed to open bays and receive moderate to light wave action. They are best defined on islands with elevations that prevent daily overwashing by high tides. Tidal motion is therefore restricted to an in/out pattern, which at any given point within the fringe forest may be manifested as a rise and fall of the water level. Flow velocities are so small that they do not flush large detrital debris into the adjacent waters on ebbing tides. Organic export from the forest interior occurs as particulate and dissolved labile materials. Basin forests occur in topographic depressions with relatively poor flushing. Inundating waters tend to accumulate in the depression and are seldom completely exchanged during a full tidal cycle. These forest types are often situated on the mainland in strandlike formations along the inland terrestrial drainages and in the centers of large islands. As such, they are exposed to less saline water for longer periods of the year as compared to the more coastal forests. Saline water flushing probably occurs during extremely high tides and storm tides. In humid areas, these forests often have a well-developed epiphytic flora dominated by bromeliads and orchids. Riverine forests occur in the floodplains of freshwater river drainages and are inundated with flowing water during periods of high rainfall and runoff. Studies have shown that this type may be one of the more productive structural types.[4] Overwash forests tend to occur on tidal flats and islands which are completely inundated and

TABLE 1. Regional distribution of mangrove forests (in hectares). (Source: Ref. 2.)

Asia and Orient	6,517,000
Africa	5,117,000
South America	4,105,000
North America	1,670,000
Oceania	1,515,000
Caribbean	962,000
Central America	888,000

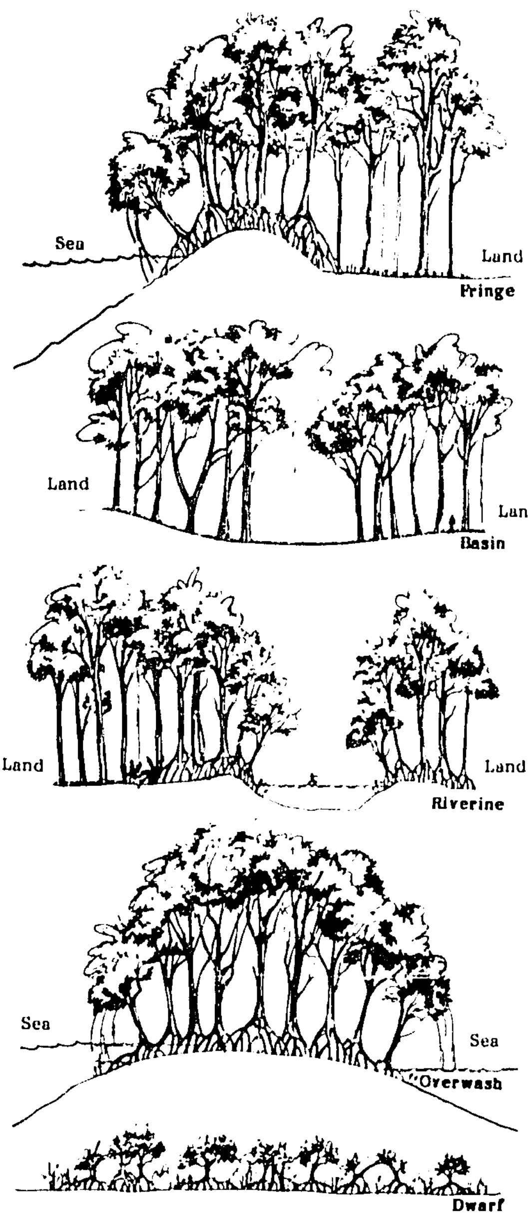

FIGURE 10. Five major mangrove forest structural types. (Source: Ref. 1.)

"overwashed" during most tidal cycles. Because incoming and exiting waters completely flush the islands, litter and organic debris do not accumulate. Dwarf forests occur where there are severe limitations on the growth and development of mangroves. Typically, they form a sparse, scattered community of shrublike mangrove species, seldom reaching two meters in height. Dwarf forests commonly occur in carbonate environments and in arid areas. Although each forest type performs the same functions (e.g., production, respiration, nutrient cycling, etc.), each has a different pattern and timing related to the specific environmental conditions which promote or restrict each function.

Productivity

Mangroves exhibit relatively high rates of gross primary productivity, up to 14 grams carbon/square meter/day, under favorable conditions.[1,4] Part of the organic production not used in respiration is accumulated as forest biomass and a significant fraction also goes to the production of leaf litter and woody debris. Although rates of productivity and biomass accumulation may vary by orders of magnitude, leaf litter production remains relatively uniform (i.e., between one and four grams carbon/square meter/day).[4] Highest productivities occur under conditions of moderate salinity, year-round warm temperatures, regular surface-water flushing, and exposure to terrestrial-water runoff.

Role in the Ecosystem

Mangrove communities have a variety of recognized roles in the larger ecosystem in which they occur (Figure 11). The most prominent role is the production of leaf litter and detrital matter which is exported, during the flushing process, to the nearshore marine environment. Through a process of microbial breakdown and enrichment, the detrital particles become a nutritious food resource for a variety of marine animals. In addition, the soluble organic materials which result from decomposition within the forest also enter the nearshore environment where they become available to a variety of marine and estuarine filter feeders and benthic scavengers. The organic matter exported from the mangrove habitat is utilized in one form or another, including utilization by inhabitants of seagrass beds and coral reefs which

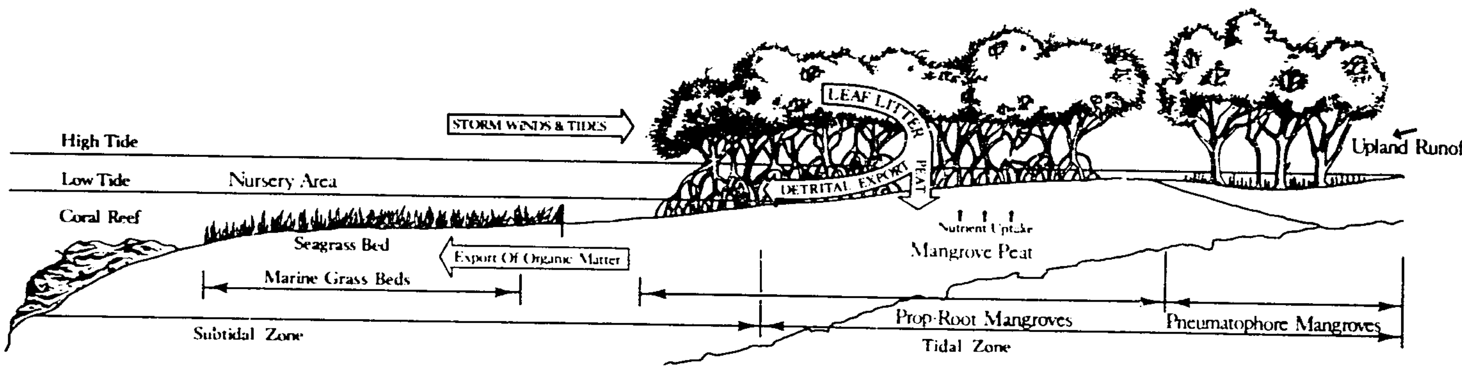

FIGURE 11. Beneficial roles of mangrove forests in the tropical coastal ecosystem.

may occur in the area. Whereas the role of mangroves in the production and maintenance of nearshore fisheries is an accepted fact, mangroves have other roles which are recognized in different parts of the world. In areas of annual cyclonic storm activity, the shoreline mangroves are recognized as a buffer against storm-tide surges that would otherwise have a damaging effect on low-lying land areas. Elsewhere, mangroves are noted for their ability to stabilize coastal shorelines that would otherwise be subject to erosion and loss. Probably one of their more important roles is the preservation of water quality. Because of their ability to extract nutrients from circulating waters, the eutrophication (excess nutrient enrichment) potential of nearshore waters is minimized. Also, the saline and anaerobic (no oxygen) mangrove sediments have a limited ability to sequester and/or detoxify common pollutants.[6] For example, some heavy metals are sequestered as insoluble sulfides, and certain organic pollutants are oxidized or decomposed through microbial activity.

Uses

In addition to the variety of mangroves' natural roles in coastal areas, the mangrove forest is a source of many different products having commercial and domestic importance (Figure 12). In many parts of the world, where direct dependency on local resources is the basis for survival, human populations heavily rely upon the variety of products that can be obtained from this habitat. In recent times, as resources have become scarcer, the mangrove habitat and forests have become recognized as resources for commercial utilization for such products as timber, pulpwood and chips, fuelwood and charcoal, honey production, and sundry domestic products. Where it is recognized that societal lifestyle and survival are dependent upon a functioning mangrove system, care is usually taken by the inhabitants to protect it. For example, in certain parts of Asia, relatively large human population centers exist within the mangrove forests on elevated platforms which include homes, shops, theaters, walkways, and small industries. It is the various uses of mangrove forest products and the plant and animal materials associated with them that lead to pressures concerning their utilization. Integrated planning, which involves simultaneous attention to all sectors and considers the maximum sustained yield of each resource, is an approach which is especially important in the management of mangrove forests.

FIGURE 12. In Bangladesh, a highly valued mangrove species (Sundri) is harvested on a sustained-yield basis to provide a high-quality wood for boat building, furniture, cabinet work, and home construction. Logs are transported by country boats to point of sale or use.

Problems

The tropical intertidal environment is relatively harsh for trees and shrubs in terms of salinity and waterlogging. Specifically, these substrates have the potential to become oxygen-depleted (anaerobic), hypersaline (greater than 40 parts per thousand), and highly acidic. Mangroves are able to express maximum growth and development under these conditions when there is a continual pattern of tidal inundation and surface-water circulation which causes an exchange and replacement of sediment water. Regular inundation supplies the required oxygen and nutrients, respectively, for respiration and gross primary productivity. Likewise, the outgoing water takes with it metabolic waste products generated by a functioning ecosystem. Low-salinity waters remove excess salts and alkaline materials, whereas saline waters neutralize soil acidity. Mangroves can, and do, grow on a large variety of substrate types (e.g., sand, silt, clay, rock, shell, coral, etc.). Mangrove growth in each type of substrate is dependent upon the water exchange process which maintains a suitable substrate for mangrove development. Equally important is the fact that the same salinity and waterlogging conditions which perpetuate the establishment of mangroves also serve to prevent the establishment of competing plant species which cannot tolerate these conditions.

In general, mangroves and the mangrove ecosystem are fairly resistant to many kinds of environmental perturbations and stresses. However, they are extremely sensitive to excessive siltation or sedimentation, cessation of flushing, surface-water impoundment, and major oil spills. These actions reduce the uptake of oxygen for respiration which results in rapid mangrove mortality. Alteration of factors that control substrate salinity patterns can induce a change in species composition; salinities in excess of 90 parts per thousand can lead to mass mortality. Salinity changes frequently result from alterations in the hydroperiod, freshwater inflow, and flushing patterns through such activities as damming, dredging, and bulkheading.[5]

A major problem that affects mangrove habitats results from man's desire to convert mangrove areas to residential, commercial, industrial, and agricultural developments (Figure 13). In addition, there is an increasing demand for forest wood products that results in the exploitative clear-felling of the forests. In these situations, the basic habitat and its functions are lost, and that loss is frequently greater than the value of the substituted activity. In general, these kinds of problems are generated by an

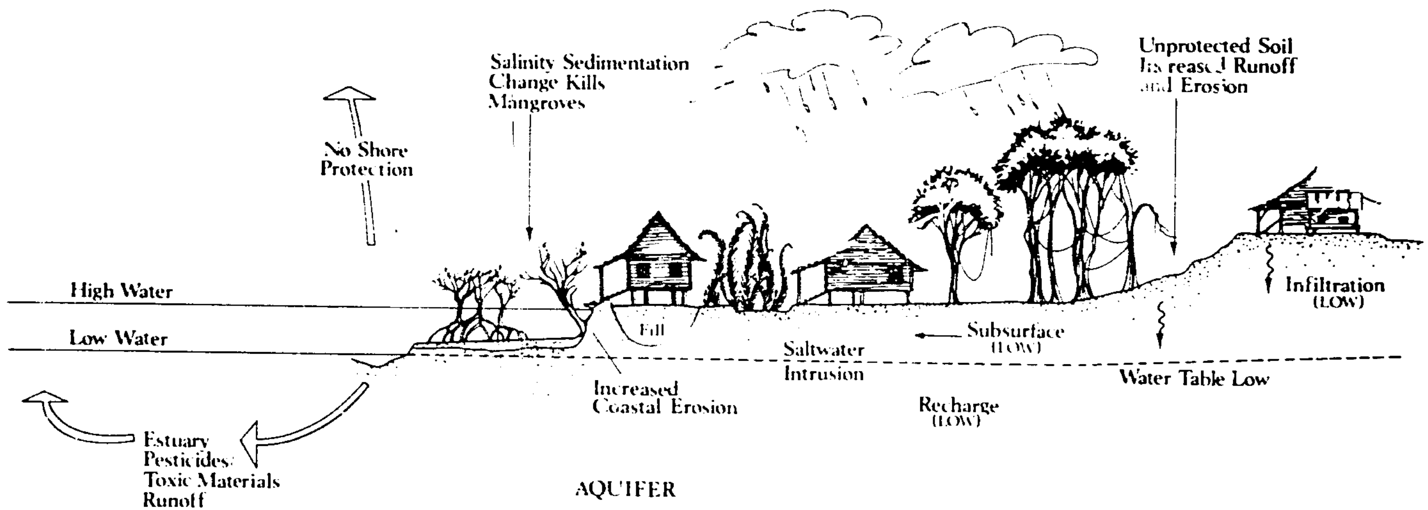

FIGURE 13. Coastal impacts associated with conversion of mangrove-forested areas.

unawareness of the natural values provided by a functioning system and by the absence of planning for integrated development that takes these functions and values into account as trade-offs (Figure 14).

Guidelines

Under the typical conditions of the tropical intertidal zone, mangroves exhibit abilities to rapidly colonize suitable habitats, to develop complex forest structures, and to be highly productive. However, they are extremely sensitive to factors which alter the prevailing hydroperiod, salinity regime, and physical/chemical properties of the substrate. Conservation of the ecosystem and its resources can be achieved most simply by preventing any significant change from occurring in these factors. It is important to recognize that many of the forces which can detrimentally alter these factors, with regard to the mangrove habitat, have their origins outside the mangrove ecosystem. Therefore, mangrove conservation and utilization depend wholly upon integrated planning that takes into consideration the habitat requirements of the mangrove ecosystem. Proposed developments and incidental actions that could affect the mangrove ecosystem should reflect the following planning and management provisions:

1) Maintain the topography and character of the forest substrate and water channels. Because the substrate is a key factor in the perpetuation of the mangrove forest, processes that might lead to excessive sedimentation, erosion, or alterations to the chemical characteristics (such as fertility) should be avoided.

2) Perpetuate the natural patterns and cycles of tidal activity and freshwater runoff. Coastal structures and water development schemes that have the potential to change the natural patterns should be designed to insure that those patterns are maintained.

3) Maintain the natural temporal and spatial patterns of surface and groundwater salinity. Reductions of fresh water by diversion, withdrawal, or groundwater pumping should not be undertaken if they affect the salinity balance of the coastal environment. Salinization also affects all of the other components of the coastal zone, including man.

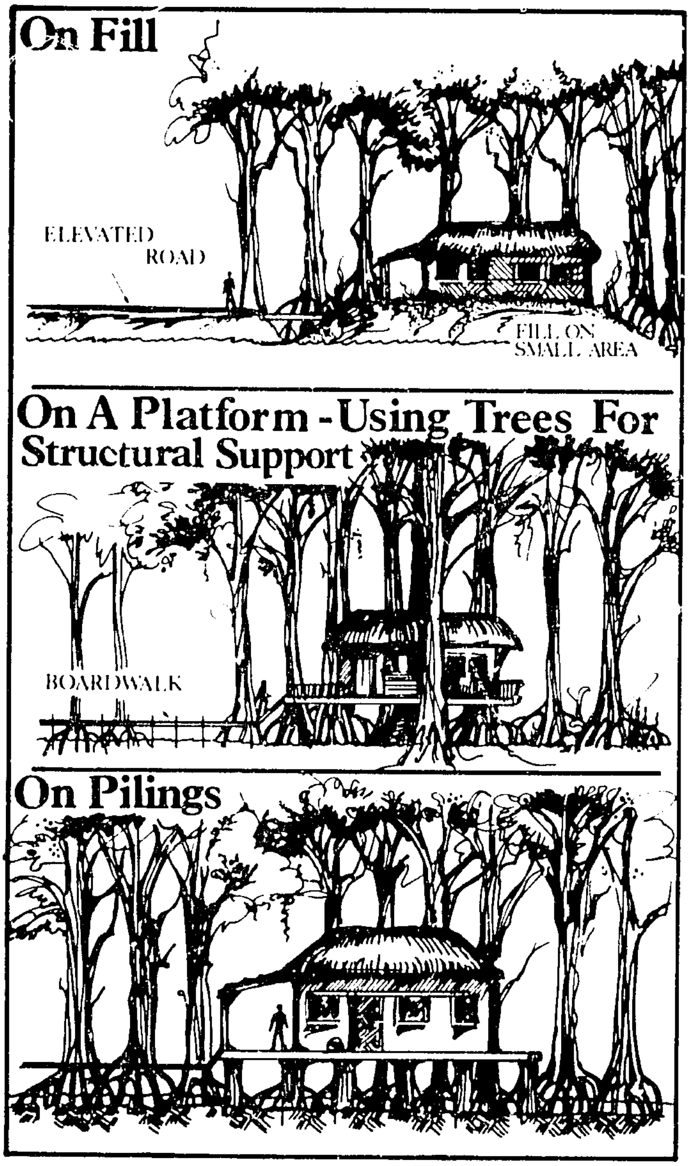

FIGURE 14. Dwelling construction within mangrove forests.

4) Maintain the natural equilibrium between accretion, erosion, and sedimentation. Coastal activities, which include construction, have the potential to alter the balance between accretion and erosion. Such activities should be evaluated for their potential impact on the mangrove environment prior to their implementation.

5) Set maximum limits on all harvesting to equal the annual production of the sought-after product(s). The current tendency is toward maximum harvesting for maximum short-term profit, without regard to the long-term potential for economic benefits. Cutting schedules should be based on rigorous plans that insure sustained yields and perpetuation of the ecosystem.

6) In areas subjected to potential spills, develop contingency plans to protect the mangroves from the damaging effects of oil and other hazardous materials.

7) Avoid all activities that would result in the impoundment of an area of mangroves. The cessation of surface-water circulation leads inevitably to the mortality of the trees.

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See Also: Mangrove Forest Harvesting (p. 103); Coastal Aquaculture (p. 87); Salt Manufacture (p. 201); Fuelwood and Other Renewable Resources (p. 115); Oil and Gas Operations (p. 125); Ports, Channels, and Harbors (p. 141); Roads, Rails, and Bridges (p. 149).

BEACH SYSTEMS

Description of the Resource and Habitat

Beaches consist of accumulated, unconsolidated sediments transported to shore and molded into characteristic forms by wave-generated water motion.[1] Beaches are located between the lowest seaward tide level and the inland limit of the average highest storm waves, exclusive of catastrophic storm events.[2] The landward limit is usually defined by a coastal cliff, a foredune ridge, or, where man has altered the coastline, through placement of some physical structure. It is important to realize, however, that the changes on a beach are responses to processes acting far outside the limits of the beach itself. Of special importance are offshore shoals and currents, as well as inland dune systems which exert controls on the erosional and depositional cycles of beaches.

The unconsolidated sediments forming the beach range in size from rock fragments to fine-grained sands and mud. Beaches are not stable entities, but rather, are dynamic landforms, constantly subjected to forces that promote erosion and/or accretion. Differences in beach form (or type) and position reflect the local balance or imbalance between deposition (or accretion) and erosion (or loss). On a worldwide basis, there is a general belief that erosional forces (natural and man-induced) tend to dominate the accretional (or depositional) forces. This is concomitant with a loss of beaches and beachfront in many parts of the world.

Distribution

There is no comprehensive synthesis of the world distribution of beaches although they occur to a greater or lesser extent in all regions. In general, however, beaches occur wherever there are (1) a flat to moderately sloping, nearshore coastal shelf; (2) a source of unconsolidated materials; and (3) forces, such as tides and waves, that shape and maintain a beach. The form of the beach in any specific region of the world will vary according to differences in these three basic characteristics. The dominant characteristic, however, is the wave climate (i.e., seasonal frequency, amplitude, and wave length, or distance between two successive waves).[1]

Beach Types

While beach classification is difficult because of the complexity of beaches and the underlying processes which result in their formation, there exist three beach "types" (Figure 15) which are commonly recognized as distinct geologic units.[3] The first type consists of a straight or curvilinear stretch of sand enclosed by rocky headlands separating inland areas from coastal waters. These beaches often are only thin veneers of sand overlying beach rock. These are considered "young" beaches in terms of geologic time. As the headlands erode, the continuing accretion of sand forms a spit or baymouth bar representing the second common beach type. The third beach form consists of the termination of an offshore barrier island.

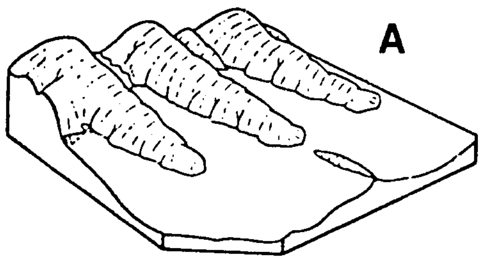
Beaches can also be classified by their composition. Typical beach types would include cobble, pebble, sand, and mud. The general composition of beach materials tends to vary with latitude, but the processes that create and maintain beaches throughout the world are similar. In tropical regions, the usual materials are carbonate sands composed of coral and algal fragments, shells, and carbonate precipitates.

Productivity

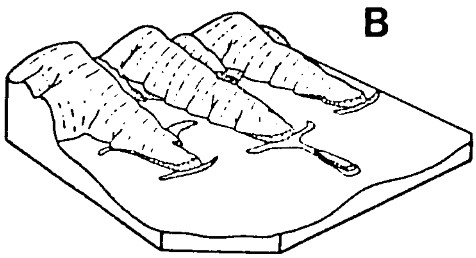
Although beaches appear to be sterile and devoid of significant life, there is an unusually large number of plant and animal species whose existence is dependent upon the beach and its dynamic processes. A beach's productivity will vary dependent on the interrelationships between a number of factors including its dynamics (depositional or erosional), grade, wave energy, water retention ability, and presence of organic material.[4] For a moderately exposed sand beach, productivity has been calculated to be 5 grams of carbon/square meter/year.[5] Where beaches are fine grained and the quantity of organic material is greater, this figure would increase. Most of a beach's productivity is attributable to organisms transported from outside its boundaries.[4]

Role in the Ecosystem

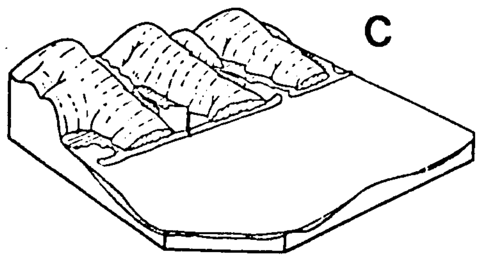
The major sources of a beach's primary production are diatoms and other phytoplankton and living marine vegetative debris transported by the tides.[4] This material and its subsequent bacterial decomposition together with other



Curvilinear beaches separated by rocky headlands



Formation of spits and bay-mouth bars



Development of offshore barrier islands

FIGURE 15. Sequence of beach "types" developed through time. (Source: modified from Ref. 3.)

organic material (much of it of terrigenous origin) provide the energy base to support the beach's diverse populations of deposit and filter-feeding consumers. At the highest level of the food web, beaches serve as energy sources for many species of coastal birds and fish. Despite the complexity of the beach trophic pyramid, the outside introduction of its primary producers has made its status as a discrete ecosystem tenuous and argues for the inclusion of those additional areas primarily responsible for the supply of these outside producers (i.e., adjacent rocky shores and coastal systems) to satisfy the criteria of ecosystem designation.[4]

Uses

Beach sand serves as one of the world's major sources of construction aggregate. It is a basic material in developed and developing country alike and, because of its low unit value and high unit of transport cost, in the absence of an economically viable alternative, will likely continue to serve as a source of construction material at sites in proximity to the coast. This use of beach sand is particularly critical in the shelf-poor insular countries where alternative sources of aggregate are scarce.

A second indirect use of beach sand is for the mining of placer deposits. These minerals and heavy-metal ores, when concentrated in beach sands in commercially exploitable quantities by the mechanical sorting action of coastal waves and currents, often portend the initiation of mining activities.

Finally, the value of tropical beaches as tourist attractions has been increasingly recognized in the last two decades resulting in new significant sources of revenues.

Problems

The existence of beaches depends upon two critical factors: a source of materials to replace the sand naturally lost through erosion, and a mechanism (such as longshore currents and waves) to replenish the beach and maintain the site-specific beach profile. Beaches are, in fact, temporary landforms that are constantly undergoing changes in the erosion/deposition equilibrium which, over the long term, tends to be balanced within a region. In the absence of source materials, the material losses due to natural erosion are not replaced and the beach loses its accumulated mass and areal extent. In the absence of longshore currents and wave action, there is no mechanical force(s) for the transport of sedimentary materials and their molding into a typical beach profile.

To better understand this erosion/deposition equilibrium, the concept of a "sand budget" was devised (Figure 16). By dividing the budget into credits and debits, the net difference manifests itself on the shoreline as either a source of deposition or erosion. For a more thorough discussion of the concept and the physical forces it attempts to describe, refer to the Coastal Erosion and Marine Mining Case Studies.

There is a general opinion among coastal geomorphologists that, on a worldwide basis, erosional processes tend to dominate depositional processes in the absence of other mitigating factors. Typically, activities which affect the source and transport of beach-building materials accelerate the erosional balance. Among the more commonly cited factors promoting beach erosion are (1) river dams, barrages, and diversions that either trap sedimentary materials, thus preventing their entry into the coastal zone, or reduce the river water's transport power; (2) poorly designed coastal engineering works that alter longshore currents or wave forces and lead to undesirable erosion and deposition patterns; and (3) coastal dredging and dune mining projects that remove beach-building materials from the longshore transport processes, thus starving downstream beaches.[1,7]

Sri Lanka represents an example where both man-made and natural processes affecting the coastline have resulted in widespread erosion (Figure 17). About 80 percent of the coast consists of natural sandy beaches, one of the nation's more vital mineral resources. Severe erosion problems have resulted from (1) the mining of sand and coral from coastal areas; (2) the building of training works and fishery harbors that impair longshore sediment transport; and (3) the construction of groins and seawalls which adversely affect neighboring areas. In one area where coastal erosion attributable to coral mining has been particularly severe, the loss of over 300 meters of beach at a cost of US$3 million has occurred over the last 50 years.[9] Causes of coastal erosion can also be material. These include such physical processes as monsoon-generated waves and the migration of tidal inlets, as well as biological factors such as the exposure of the shoreline following reef destruction by coral-eating starfish.

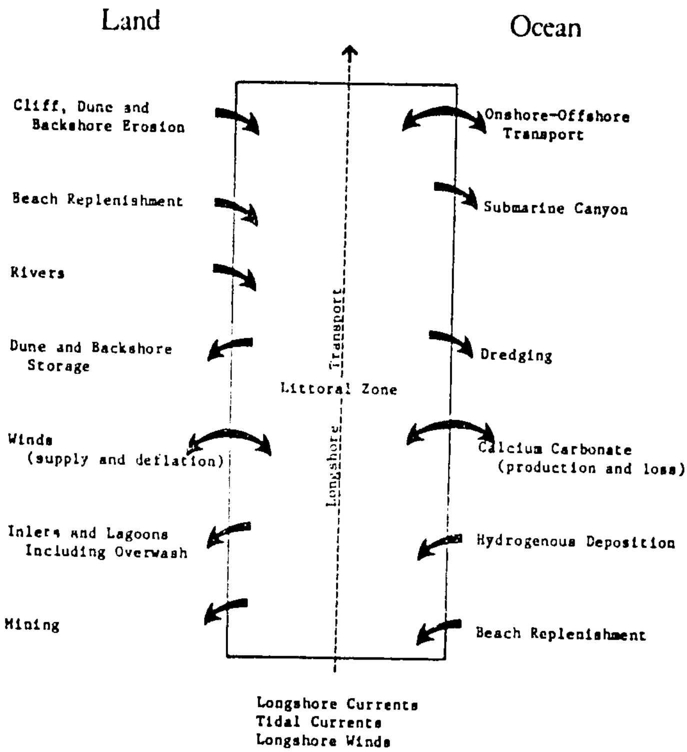


FIGURE 16. Sources of credits and debits to the littoral sand budget. (Arrows indicate mean net transport of sand). (Source: Ref. 6.)

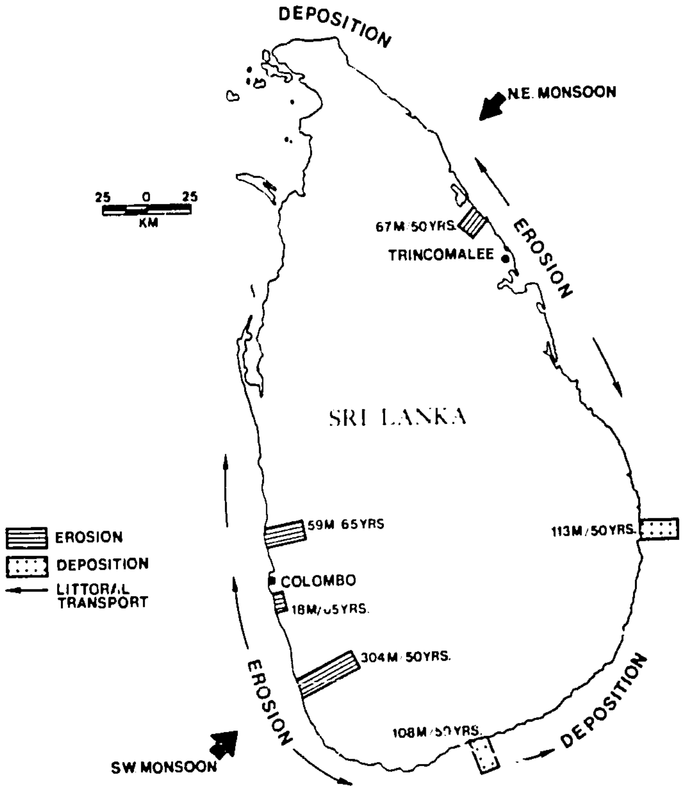


FIGURE 17. Coastal processes and beach erosion/deposition trends in Sri Lanka. Note influence of monsoons on erosion. (Source: Ref. 8.)

Guidelines

Under the typical conditions of the tropical intertidal zone, beach systems develop rapidly in favorable areas and have a remarkable natural ability for self-maintenance and self-renewal (e.g., following a disturbance) when the basic habitat characteristics that favor beach formation are maintained. However, they are extremely sensitive to factors which alter their sand sources, nearshore currents, and wave regime. Conservation of the system and its resources can be simply achieved by preventing any significant change from occurring in these factors. It is important to recognize that most of the forces which can detrimentally alter these factors with regard to the beach habitat have their origins outside the beach system. Therefore, beach conservation and utilization depend wholly upon integrated planning that takes into consideration the habitat requirements of the beach ecosystem.

Like other natural ecosystems, the beach does not require overt or direct manipulation by man for its sustained survival. However, since the actions that threaten the existence of beaches are usually man-caused, they are thus amenable to corrective action such as would result from the integrated planning of coastal activities which takes the sensitivities of beaches into account. The guidelines below are those which are considered to be the minimal requirements for the maintenance and perpetuation of beaches:[1]

1) Understand the natural beach system before it is altered. Site-specific studies may be required at many localities to insure wise planning decisions.

2) Develop a setback line before construction begins.

3) Where a major obstruction to longshore sand transport is built, such as a large harbor, allow for an adequate sand-bypassing system.

4) Where possible, use soft solutions, such as sand nourishment or diversion of channels, rather than hard solutions, such as revetments or seawalls, to solve beach erosion problems.

5) Maintain a prominent foredune ridge.

6) If a beach is valuable for tourism, recreation, or wildlife habitat, do not mine the sand from dune, beach, or nearshore.

7) Do not panic after a storm and drastically alter the beach. Whenever possible, let the normal beach cycle return the sand.

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See Also: Shore Protection (p. 157); Coastal and Marine Mining (p. 191).

ESTUARIES AND LAGOONS

Description of the Ecosystems

The subject here is coastal embayments, protected water bodies that have limited access to the open sea. It does not include open bays and sounds. There is some ambiguity in the terms "lagoon" and "estuary", particularly as applied to areas where infilling of coastal physical land forms is occurring and/or has occurred in the past.

(1) Coastal lagoons can be technically defined as depressions below mean high high water which maintain either temporary or permanent connections with the sea.

(2) In contrast, estuaries are considered to be semienclosed bodies of water which are connected to the open sea and whose waters are diluted by freshwater drainage.

(3) The major distinctions between the two appear to be (a) the degree of access to the sea often determined by the presence of an offshore bar characteristic of most lagoons and (b) the amount of fresh water received.

Day (1982) summarizes the differences as follows: ". . . an estuary is commonly considered as the mouth of a river while a coastal lagoon is an embayment separated from the coastal ocean by barrier islands." Day recognizes that the two are similar ecologically so that ". . . we can speak of a lagoon/estuarine environment."[1] But it should be noted that the "lagoons" formed by coral reefs are quite different and are not included in this discussion.

Distribution

Estuaries exist in many areas throughout the world with their notable absence in the arid/semiarid regions where major rivers are few and discharge is erratic. In contrast, lagoons are known to exist worldwide and are estimated to occupy approximately 13 percent of the world's coast[2]. Areas of particularly extensive lagoon/estuarine environment include the Atlantic and Gulf of Mexico coasts of the United States, Brazil, West Africa, Napal, the southern and eastern shores of the Indian Ocean subcontinent, southwest and southeast Australia, and the Nile Delta.

Classification

Coastal lagoons have been classified into four basic types of which three are distinguished by their degree of access to the sea (Figure 18). The first type, the lagoon, is characterized by high accessibility and is primarily influenced by the combination of coastal currents and river flow. Partly closed lagoons are often the result of a coastal current predominating over other forces, often contributing to the formation of an offshore bar(s). Closed or "barred" lagoons are formed primarily due to the influence of the coastal wind regime and longshore drift. (See Beach Erosion and Sand Mining Case Studies). The fourth type of lagoon is highly tidally influenced and approximates many estuaries in its physical appearance.

While the lagoonal classification scheme is based primarily on the degree of accessibility to the sea, estuarine classification approaches have employed either geomorphological or physical process-related characteristics as criteria. As an example of the former, four primary subdivisions have been proposed. Drowned river valleys refer to estuaries which were formerly river valleys in the last glacial period when the sea level was approximately 100 meters lower than it is today. Fjords refer to coastal features which have been formed by glaciers and are characterized by a U- or V-shape in cross-section and deep basins. The bar-built estuary is a third type which corresponds closely to its lagoons' counterpart with the degree of access to the ocean representing the subjective criterion separating the two. Fourth are estuaries formed by tectonic processes such as those water bodies with freshwater inputs formed by subsidence or coastal faulting.

The above classification notwithstanding, possibly the most widely recognized scheme identifies three basic estuarine types representing three points on a continuum-of-salinity regime.

The first, termed a stratified estuary, is characterized by a well-defined boundary between fresh and saline waters and is most likely found where a large ratio exists between freshwater outflow and tidally influenced salinity intrusion. The second type occurs where tidal mixing is sufficiently vigorous to prevent this salinity stratification, and a well-mixed or homogenous water body results. The third and most common type of estuary is the partially mixed estuary which maintains an intermediate salinity stratification regime.

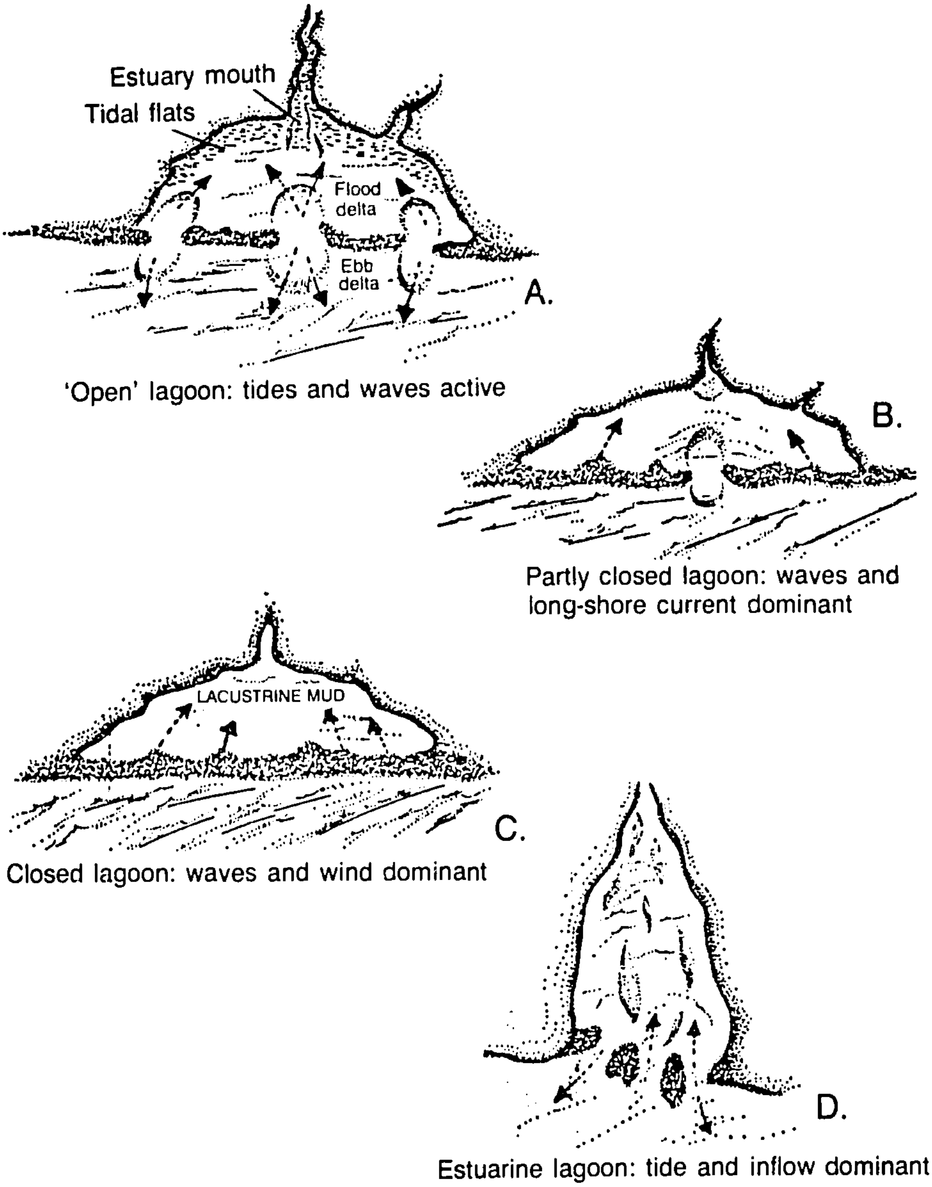

FIGURE 18. Classification of lagoon types: (a) "open"; (b) lagoon in process of formation; (c) closed or "barred" lagoon; (d) estuarine lagoon. (Source: Ref. 1.)

Productivity

Both estuaries and lagoons maintain exceptionally high levels of productivity, comparable as a whole to coral reefs and seagrass beds (commonly ranging in value between 10 and $25x10^3$ $Kcal/m^2/year$). Productivity values will vary according to dominant primary producers, latitude, time of year and certain critical, limiting, physical and chemical inputs entering the ecosystem. Among the more important underlying factors which explain these high production levels are (1) the key role of fresh and marine waters in providing and renewing nutrients, organic material, and oxygen; (2) solar radiation which is maximized as an energy source because of the characteristic shallow depths of these areas; and (3) the high mixing rates which assist gas exchange, nutrient circulation, and waste removal (Figure 19).

The entire dynamic balance of the estuary revolves around, and is strongly dependent on, water circulation. Vertical and horizontal water circulation transports nutrients, propels plankton, supports and spreads "seed" stages (planktonic larvae of fish and shellfish), flushes away the wastes of animal and plant life, cleanses the system of pollutants, controls salinity, shifts sediments, mixes water, and performs other useful tasks. The specific pattern of water movement found in the estuarine portion of any coastal system is a result of the combined influences of runoff volume, flow velocity, tidal action, wind, and to a lesser extent, external oceanic forces.

Uses

Due to the semienclosed nature (protected) and high productivity that is characteristic of the lagoon/estuarine environment, these coastal water bodies have sustained human usage dating back to prehistoric periods. Some of the earlier uses certainly consisted of food and salt production. In addition to the continuation of these uses, modern-day lagoons and estuaries serve purposes of navigation, waste disposal, mariculture, recreation, and residential development. Besides these direct "exploitative" uses of these water bodies, some lagoons have been drained for purposes of agricultural production, most notably in land-scarce areas such as the Netherlands.

A second critical factor is salinity. In estuaries, the salinity gradient starts with a high concentration in the ocean decreasing inward through the estuary before dropping to zero at some distance up estuarine

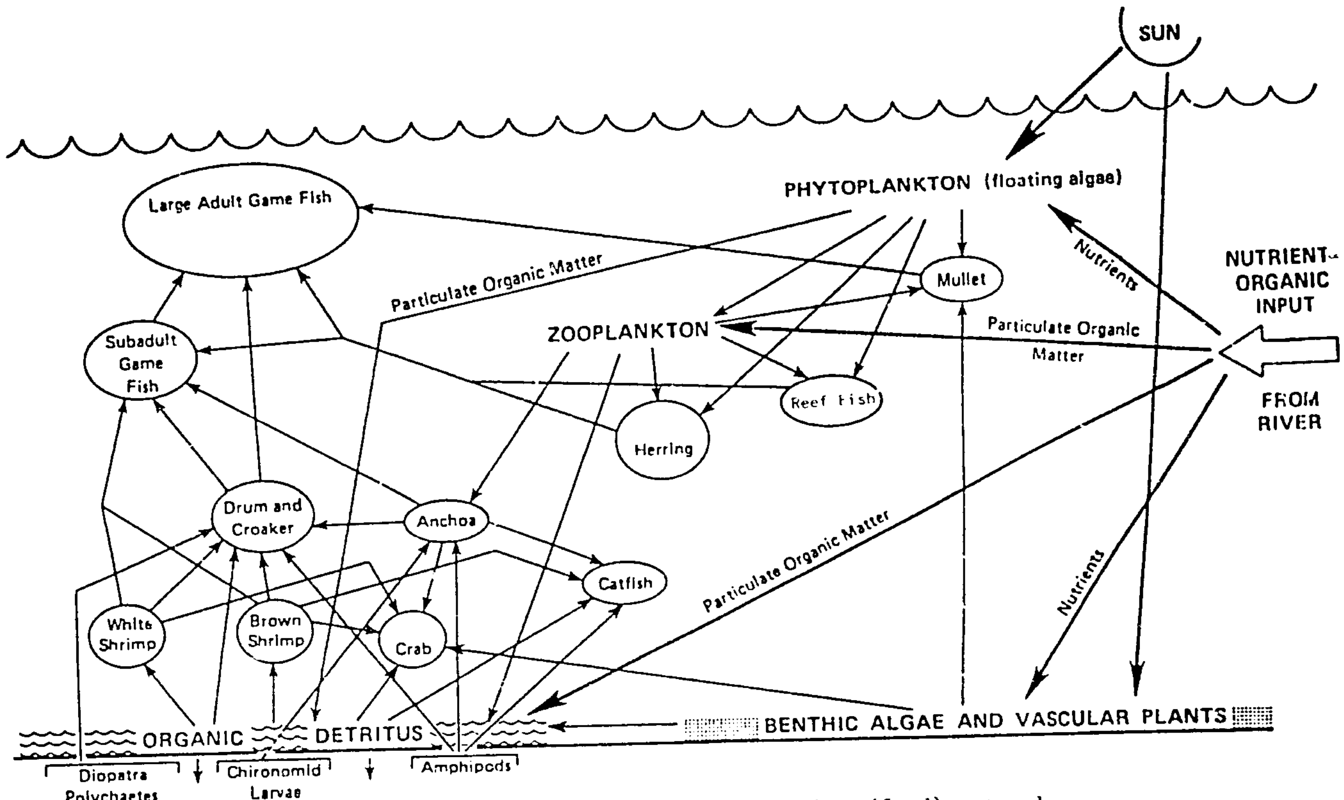

FIGURE 19. The complex estuarine trophic (food) network.

tributaries. Lagoons maintain a salinity near the ocean average or much higher if exchange with the ocean is limited and evaporation is high. As a result of the wide range and variation in salinity, these water bodies support a diverse assemblage of organisms which have each adapted to their respective levels of salinity tolerance. Whereas some coastal species tolerate a wide range of salinity, others require a narrow range in order to live and reproduce successfully. Still others require different salinities at different phases of their life cycles, conforming to regular seasonal rhythms in the amount of land runoff.

Also, the floors of coastal basins are important to the well-being of these water bodies. They provide the basic form and structure of the basins and govern the flow of water through them, as well as harboring the richest habitat areas of coastal water, exemplified by clam beds, coral reefs, submerged grass beds, and so forth.

Linkages

Lagoonal estuarine ecosystems play important roles including (1) providing a source of nutrients and organic materials to both coastal and freshwater areas through tidal circulation; (2) providing habitat for a number of commercially or recreationally valuable fish species which depend on the basin floor for protection and food; and (3) serving the needs of migratory nearshore and oceanic species which require shallow, protected habitats for breeding and/or sanctuary for their young (nursery areas).

Problems

Due to the intensive crowding of estuaries because of their utility as natural ports and harbors, demands have been placed on these systems which have created a variety of environmental impacts and a loss of estuarine resources. The effects of improperly planned development of estuarine resources create a variety of short- and long-term effects which represent economic losses and opportunity costs.

One major source of lagoon/estuary degradation is the continued usage as pollutant dumping grounds. Aside from outright fish kills and other dramatic effects, pollution causes pervasive and continuous degradation, evidenced by the gradual disappearance of fish or shellfish, or a general decline in the carrying capacity of the system. The most likely sources of pollution are chemicals or organic wastes. These contaminants create a hostile environment that drives away fish, prevents shellfish from reproducing, or undermines the food chain.

The increasing usage of many of these water bodies for transport of oil, chemicals, and other toxic materials, whether by ships, barges, pipelines, or railroads, presents a continuous threat to these fragile ecosystems. This is particularly true in the case of estuaries and lagoons because of their sluggish circulation which permits the presence of pollutants at a level which can cause damage.

In light of the importance of water circulation in lagoons and estuaries, activities that alter the configuration or composition of the basin floor can create disturbances that often have far-reaching effects. The major adverse effects stem mainly from dredging which is undertaken to create and maintain canals, navigation channels, turning basins, and harbors and marinas, as well as other activities such as laying pipeline or obtaining material for fill or construction.

A third problem which is increasingly threatening the well-being of these areas is the impoundment and/or diversion of rivers at upstream locations. When portions of the coastal watershed system are altered or short-circuited, the natural flow pattern is disrupted and estuaries may be overburdened by surges of fresh water. This not only disturbs the ecosystem, but also increases flood hazards. The most confined estuaries (particularly lagoons) need a maximum of protective controls: buffer strips above wetlands; control of sewage and storm-drainage effluents; safeguards against runoff of soils, fertilizers, and biocides from the coastal uplands; restrictions on industrial siting; and so forth.

Guidelines

Estuarine ecosystems have a remarkable natural ability for self-maintenance and self-renewal (e.g., following a disturbance) if the basic habitat characteristics that favor estuarine formation are maintained. However, these ecosystems are jeopardized by factors which permanently alter the prevailing salinity, current, and nutrient-cycling patterns. Conservation of the ecosystem and its resources can be achieved most simply by preventing any significant change from occurring in these factors. It is important to recognize that many of the forces which can detrimentally alter these factors have their origins outside the estuarine system itself (upland agriculture, river diversion). Therefore, estuarine conservation and utilization depend upon integrated planning and management that includes upstream management. With that in mind, the guidelines presented below are considered to be the minimal requirements for maintenance and perpetuation of lagoon and estuarine systems at high levels of function.

1) Achieve the highest practicable levels of waste treatment for industrial and municipal effluents released into lagoon and estuarine waters. Lagoon/estuary basins with restricted circulation are susceptible to extreme damage from urban industrial pollution. Through technology, nearly every kind of municipal and industrial waste can be effectively treated. Therefore, there is no technical reason to allow insufficient treatment. As an alternative, wastes can sometimes be piped offshore and safely diffused into deeper ocean waters. Both remedies are expensive and may therefore require considerable sacrifice; but in most cases the cost can be justified on a long-term basis.

2) Locate industrial facilities with a high potential for disturbing estuarine and lagoonal ecosystems away from estuaries. Industries with high waste output such as power plants with large estuarine water consumption, chemical plants with irremediable toxic discharges, and oil-transfer terminals should not be located on smaller, confined estuarine water bodies with poor circulation unless there is no practical alternative. If located on estuaries, those industries would require extensive treatment facilities.

3) Require control of storm-water runoff and other diffuse sources of pollution. Storm water is often more highly pollutant than sewage during the first 25 millimeters of each rainfall. Diffuse sources of pollution that affect lagoons and estuaries are septic tanks, dumps, landfills, and concentrations of boats. These sources may cause serious eutrophication of toxicity where the pollutants concentrate in confined estuarine water bodies. Settlement, treatment, or piping to offshore waters are possible solutions.

4) Avoid blockage of water circulation. Structures built in lagoons and estuaries should be designed so as not to significantly interfere with water flows. In particular, this applies to piers, docks, wharves, and bridge abutments. Specifically, the solution is to avoid locating structures at critical points in estuaries where important current flows could be affected, or if structures must be located in these locations, they should be elevated on piles, not built on solid fill.

5) Use care in the excavation or disposal of dredge "spoils". Select locations for the removal and deposit of dredged material to avoid adverse effects on vital habitat areas such as grass beds, shellfish beds, coral reefs, and productive basin-floor habitats. The season when dredges are allowed to operate, and their modes of operation, should be controlled to reduce the spillover of dredged materials into biologically productive areas.

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See Also: Mangrove Ecosystems (p. 23); Seagrass Beds (p. 59); Capture Fisheries (p. 95).

SEAGRASS BEDS

Description of the Resource and Habitat

Seagrasses are seed-producing marine plants (halophytes) that occur in shallow, nearshore, temperate, and tropical waters. They are able to reproduce by vegetative spreading in addition to the annual production and dispersal of seeds. As a benthic plant community, they are extremely productive and are associated with an abundance and variety of small fishes and invertebrates such as shrimp and crabs.[1] For these organisms, the seagrasses provide a habitat and source of food materials consisting of the leaves of the grasses, and the epiphytes (mostly algae) that live on the leaf surfaces as well as the microfauna and rich layer of microbes. The leaves and leaf detritus also represent a food resource for many other marine animals (e.g., certain reef fishes) that regularly visit seagrass areas for feeding and foraging on both the plants and their animal associates. Seagrass communities are also noted for their ability to trap and bind sediments which militate against the erosion of the shallow sediments.[2]

Distribution

The seagrasses dominate many of the temperate and tropical coastal environments of the world where there exists a suitable shallow substrate, having water of a high transparency and occurring in areas that are relatively free of strong wave action. As a result, they are seldom found in any great abundance near high-energy beaches, particularly in or near the surf zone, or in the deltaic areas of major rivers that carry high sediment loads. Their broad range is further attributable to the fact that seagrasses as a whole can tolerate wide salinity ranges which vary in concentration from that of almost fresh water to that of full-strength and higher (hypersaline) seawater.[2]

Different genera and species of seagrasses are found at different optimal depths. The observed distributional patterns result from differing competitive adaptations related to a complex set of environmental factors which include wave energy, currents, substrate turbidity, and light penetration. Most seagrasses occur within a depth range between mean low water and 30 meters.[2] In general, the larger and more well-developed seagrasses are found in greater depths, while the thinner bladed and more sparse beds are found associated with shallow subtidal or intertidal portions of the coast.

Structural Types

Seagrasses can occur in a variety of spatial and compositional patterns, such as extensive mixed or uniform meadows covering large areas, as small patches, or as dispersed, isolated plants. They have an ability to propagate by vegetative growth of the subsurface rhizome system. Thus, they tend to have the growth form of a terrestrial sod grass as opposed to that of a bunch grass. Seagrasses thrive where deep, soft sediments are found, although individual plants will survive in areas with very little substrate (Figure 20). This, more than other factors, is responsible for their structural formations, or the shape of the seagrass bed itself.

Productivity

Seagrasses represent one of the most highly productive, tropical marine ecosystems. Dry-weight values of gross primary productivity have been estimated as high as 8 grams carbon/square meter/year[1]. High productivity is associated with both seagrass growth and the production of plant epiphytes attached to the leaf surfaces. In addition to these sources, seagrass-system productivity is augmented by contributions from benthic micro- and macroalgae, phytoplankton, and shore-based vegetation.[2] As means for comparison, productivity levels for two common genera have been determined to be higher than values calculated for corn and rice cultivation in the United States.[2]

Linkages

Figure 21 illustrates that the dominant contributions of a seagrass community are in the habitat it provides for a variety of resident animals and the organic production which provides a food resource for both permanent and temporary residents. In addition to the food resource value of the seagrasses and their epiphytes, the small resident fishes and invertebrates serve as a food source to larger marine animals found in adjacent waters. During winter dieback periods (in temperate regions) and during annual storm events, seagrass leaf blades break off and are transported from the system in mass. This material, when collected in windrows on beaches or in the intertidal zone, becomes a food substrate and habitat for small invertebrates during the period of decomposition and breakdown. Other masses of leaf material that are swept into deeper offshore areas also have a role in the nutrition of

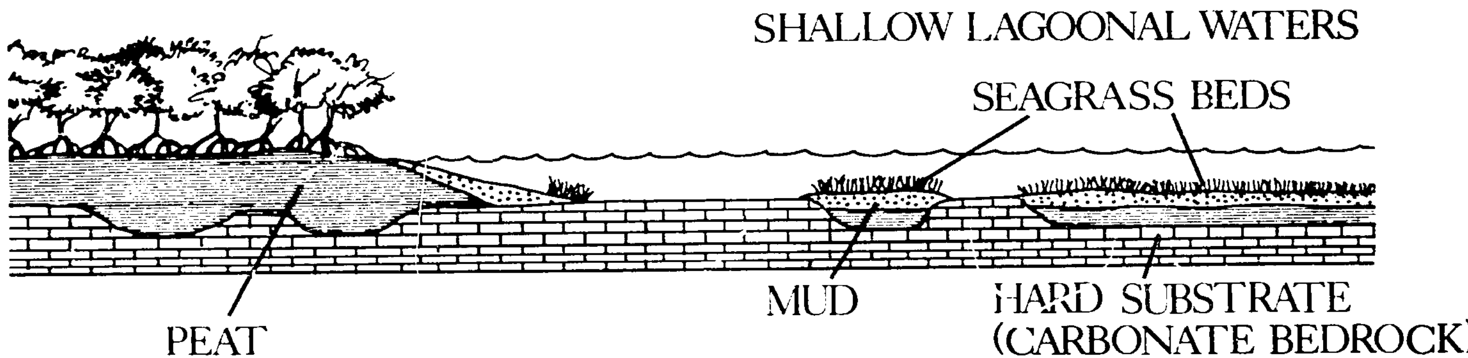

FIGURE 20. Substrate control of seagrass beds.

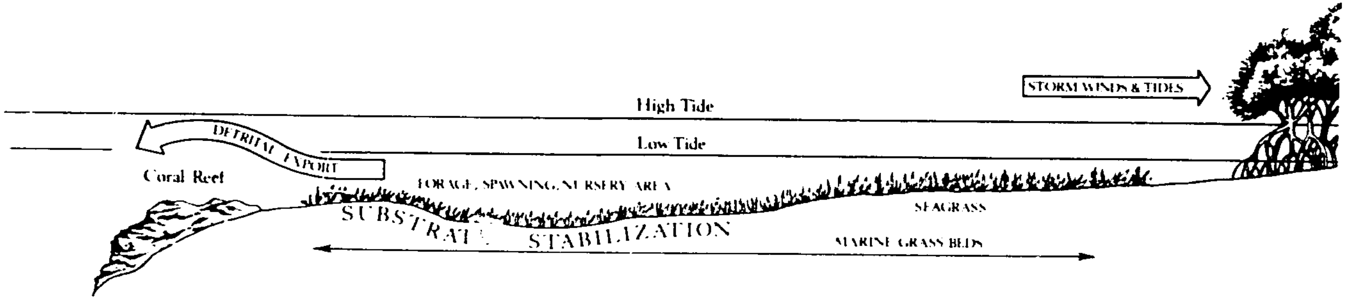

FIGURE 21. Beneficial roles of seagrasses in tropical coastal waters. Seagrass beds hold the substrate, provide special sanctuary for the young of many fishes, provide food for grazers (parrot fish, conch), and export particles of detritus (plant material) to be eaten by many smaller organisms in the food chain.

other marine organisms. Another well-recognized role is one that is associated with the rhizome system whereby loose sediments are consolidated and held into place, particularly during storm events.[2]

Uses

While seagrasses have no major economic or commercial uses, they have been reportedly used as a source of green manure (fertilizer), chemicals, and fodder.[3] The primary uses and subsequent value of seagrasses reside in their roles in providing a major habitat and food resource for nearshore fisheries, marine reptiles and mammals, and coastal stabilization.[3]

Problems

The basic habitat requirements for seagrasses are a shallow, soft substrate and water of high transparency. In addition, they require circulation of the overlying water which delivers nutrient and substrate material and removes metabolic waste products. In the regions in which they do occur, seagrasses do not develop in shallow areas that are exposed at low tide, although they can survive brief exposure during periods of exceptionally low tide. Because of their requirement for a relatively high light intensity, they are limited to water depths that do not exceed 20 meters unless the overlying water is extremely clear and transparent[4]. They are commonly associated with coral reef communities because of their similar requirements for water of superior quality. Conversely, they are only rarely found occurring contiguously to mangrove ecosystems because the dark, organic-stained waters flushed therefrom on falling tides can limit photosynthesis. Although seagrasses are a relatively hardy group of plant species, they are extremely sensitive to excessive siltation, shading, water pollution, and fishing practices that use bottom trawls which scrape the beds.[5] Siltation and shading reduce ambient light levels in the water, resulting in a lowering of the rate of photosynthesis or, in extreme cases, completely inhibiting it. Certain pollutants in water have toxic effects on the growth and development of not only seagrasses, but also many of their animal associates. They are also sensitive to hot-water discharges and are usually eliminated from areas subjected to effluents from power plants.[6] For reasons that are not clearly established, seagrasses only slowly, if at all, revegetate areas that have been dredged.[7]

Typically, when a seagrass community is eliminated. its marine animal associates also disappear from the area.

The major problems that affect seagrasses throughout the world are their destruction through widespread dredge and fill activities, and water pollution which includes brine disposal from desalinization plants and oil production facilities, waste introductions around industrial facilities, accidental spills of petroleum and petroleum products, and thermal discharges from power plants. The loss of seagrasses is also indicative of a significant loss in marine animal production, primarily because of habitat destruction.[6] In many areas, the disappearance of seagrass communities is only noted by local fishermen because, unlike mangroves and coral reefs, seagrass communities are not visually obvious to most observers.

Guidelines

As with all biological systems, seagrasses and their associated fauna have a natural ability to survive and perpetuate by themselves under the normal, or typical, environmental conditions defining their habitat. Management guidelines thus reflect the simple need to preserve those conditions. Actions initiated in the coastal zone should therefore take into account and incorporate the following guidelines:

1) Dredging and filling should generally be avoided in areas that are dominated by seagrass beds. When these activities take place in contiguous areas, care should be taken to insure that silt is not transported into the seagrass beds. This can be achieved by the use of various devices called silt barriers and by a dredging strategy that insures that nearshore circulation and tidal currents move the silt away from seagrass areas.

2) Proposed coastal engineering works (e.g., harbor jetties, piers) that significantly alter circulation patterns should be designed to prevent or minimize either erosion or deposition in nearby seagrass areas. The actual structural design should be based on the specific local circumstances.

3) Present liquid-waste disposal procedures should be reviewed and modified where needed to prevent deleterious wastes from entering seagrass areas.

Such wastes include industrial effluents, thermal and brine discharges, bilge water pumping, and urban runoff. In most instances, the alternatives would include selection of different areas for disposal, specifically, the location of pipe outlets.

4) Trawling practices and other damaging capture fishery activities should be modified to minimize damage to seagrass beds during fishing operations. The most effective means would be to ban bottom trawling from the seabeds where seagrass meadows occur.

5) Water diversion schemes which would alter the natural salinity regime should take into account the effect on seagrass communities and their associated biota. Maintenance of salinity within acceptable ranges can be achieved through an appropriate scheduling of water release.

6) Measures should be taken to prevent oil spills from contaminating seagrass communities. This can be achieved through siting measures, a monitoring program, and the development of an oil spill contingency plan.

7) Seagrass beds should be identified and mapped in a resource inventory before any of the above kinds of projects and activities are approved.

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See Also: Coastal and Marine Mining (p. 191); Ports, Channels, and Harbors (p. 141).

PART II - MANAGING COASTAL DEVELOPMENT

II. MANAGING COASTAL DEVELOPMENT

This section presents guidance for management of coastal developments. The object is to suggest--for each of the 17 different types of development--ways to improve site selection, project design, and/or operational technique, so as to best conserve renewable natural resources of the coast. It is directed toward finding the right balance between the quick payoffs of development and the longer term payoffs of conservation. In general, well-planned development will add to the general prosperity of a coastal region, while poorly planned development will sooner or later have a negative effect.

As many of the following guidelines will show, managing coastal development may involve events far distant from the coast; for example, clearing for agriculture in the watershed of a coastal stream or improper soil conservation in upland agriculture. Therefore, coastally oriented planning must consider the effects of several types of upland projects for the sake of coastal resource conservation.

Management advice specific to each development type is given as guidelines at the end of the module. Management advice of a more general nature is given below in the form of a checklist of five general coastal management goals. Each coastal development initiative should be reviewed first in the light of these goals before it is reviewed in the light of the guidelines for the specific development at hand.

1) Do the plans and studies for the development initiative recognize potential effects upon coastal renewable resources and provide measures for their protection?

2) If the development initiative is in an upland watershed, is due consideration given to the effects upon downstream coastal resources caused by alterations in river flow or water quality?

3) Is consideration given to maintaining the physical condition of the land/sea transition as well as to identifying and protecting critical ecological areas, such as wetlands, seagrass beds, fish/shellfish nursery areas, etc.?

4) Are suitable precautions taken to avoid the discharge of pollutants and excessive nutrients into coastal waters, such as industrial wastes and municipal sewage?

5) Is sufficient attention given to maintaining the following:
   - ° Ambient-water salinities.
   - ° Ambient-water temperatures.
   - ° Natural patterns of tides and water circulation.
   - ° Natural patterns of freshwater inflow.
   - ° Existing clarity and transparency of water.

AGRICULTURE

COASTAL AGRICULTURE

Introduction

As the world's inventory of potentially developable, arable land decreases, there is a compelling need to reclaim and develop marginal land for agricultural purposes. Frequently included in the latter category are the coastal intertidal areas that are mostly mangrove forest habitats though lagoons, marshland, and peat soils are also targets for conversion (see Indonesia Case Study). Although many soil surveys identify these sediments as marginal, submarginal, or unsuitable for agriculture, limited success in rice cultivation (e.g., Africa and Asia) has prompted the further conversion of these habitats to agricultural uses. Rice is the preferred crop because it can tolerate flooding and waterlogging and has a moderate salinity tolerance. But many new crops are grown in tidally influenced areas, e.g., 115,000 of the 250,000 hectares of tidal swamp under cultivation in Indonesia are planted in fruit trees, vegetables, "industrial" crops, and "palawijz" (secondary food crops).[1]

Problems

In parts of Africa and Asia, rice has been successfully cultivated for centuries on the landward fringes of the mangrove zone.[1] Current agricultural development practices, however, tend to emphasize the lower, more inundated parts of the mangrove zone. In practice, an area of mangroves is cleared, diked (bunded, empoldered) to prevent tidal flooding, and drained (Figure 22). Rainfall and/or freshwater flooding reduces the salinity by leaching and draining the accumulated salts. Lime or gypsum is sometimes applied in an attempt to prevent the soil from becoming acidic. Under the most ideal conditions, rice yields of 2-4 tons/hectare/year are obtained, but more usually, the yield is 1-2 tons.[2] When rice yields fail to justify the initial investment and annual operation costs, the fields are abandoned. After abandonment, recovery of the area to a beneficial state in most cases would be slow unless dikes are broken and the fields reopened to introduce full flushing.

There are two classes of problems associated with the agricultural use of the coastal environment. The first is embodied in the term, reclamation, in that it implies that a resource is wasted unless something is overtly done

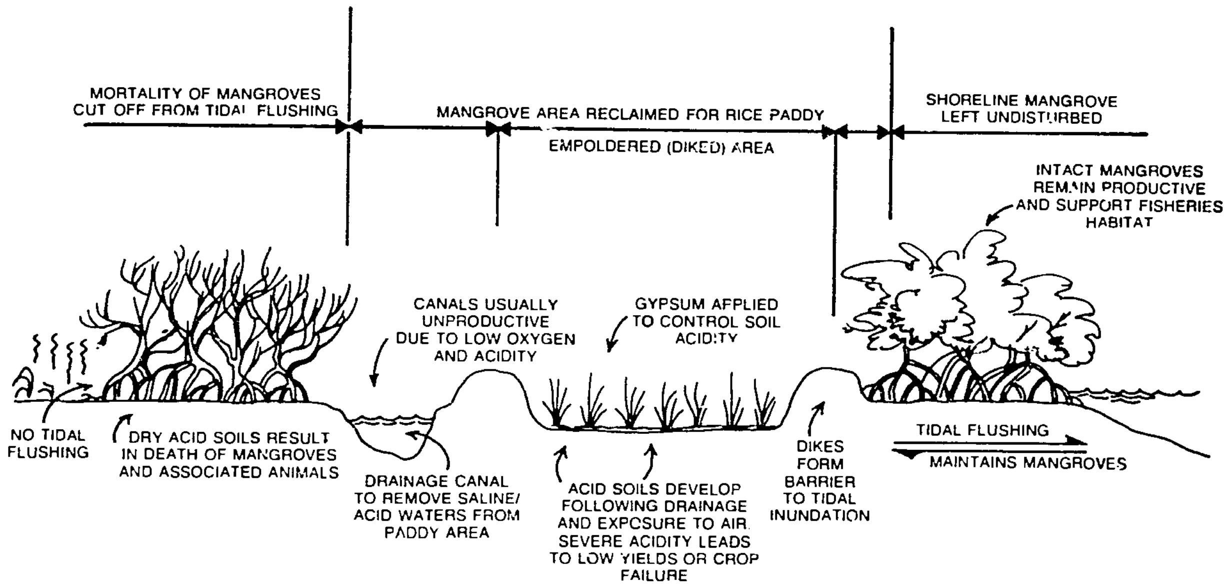

FIGURE 22. Intertidal mangrove habitat converted to rice paddy agriculture. Mangrove forest areas are clear-felled and empoldered (diked) to prevent inundation by saline tidal water. The empoldered area is then leached with freshwater (from rainfall or freshwater irrigation) to remove excess salt and the acids which form following drainage and exposure to the air. When acid sulfate soil formation cannot be controlled by leaching and the application of gypsum, crop yields are reduced and there is a high risk of total crop failure. The total impact of empoldering exceeds the actual area that is converted because inland habitats, cut off from the beneficial influence of tidal flushing, become stressed and eventually deteriorate. Conversion of intertidal areas to agriculture represents a poor land use in areas of potential acid sulfate soils as a result of the poor economic return and the loss of the natural resource base.

to capture the benefits of that potential resource, namely, arable land. The concept intrinsically ignores the fact that nearshore habitats and resources have economic and social value in their natural states. Not only is reclamation not required in order to receive economic benefits, it obliterates them for the most part. Commonly, the conversion process itself not only affects the actual area converted, but also interrupts the flow of surface water which is required for the maintenance and survival of the remaining natural areas unless provisions are made to preserve the natural hydrologic pattern. In addition, areas where hydrological alterations are proposed should be limited in size to that which will actually undergo agricultural production.

The second class of problems concerns the low probability of success in converting coastal sediments into agricultural soil and in having it suitable, particularly, for rice production. In general, only areas above mean sea level should be considered for conversion, thus minimizing agricultural losses caused by exceptional flooding and salinity intrusion. Still, few regions of the world are exempt from cyclones, tsunamis, and other potentially catastrophic climatic events, and in this regard, meteorological and tidal records should be used to set the elevation of the protective dikes above the flood level predicted for major storms or tidal surges.

In general, the sediment fertility and microhabitat conditions promoting the high productivity of mangrove forests are lost when the forest is cleared and the previously wet soil is exposed to the air and allowed to dry. Among the soil's chemical processes that occur is the rapid oxidation of pyritic sulfur (iron sulfides) which forms sulfuric acid, causing a low soil pH. Such soils are called acid-sulfate soils.[3] Under this condition, lime or gypsum may be applied to raise the soil pH to a level suitable for plant growth, but the practice is not always successful. On weakly acidic soils, this practice may work. On strongly acidic soils, however, this practice may be impractical because of the unique amount of lime of gypsum materials necessary to neutralize acidic soil conditions. Also associated with the progressive change in soil conditions and drop in pH is the creation of toxic levels of aluminum.

Metals, such as iron (which is normally present in high, but unavailable, concentrations in mangrove sediments), are released and may also reach toxic levels which could affect agricultural production. In contrast, however, such altered soils frequently exhibit deficiencies of phosphorus and zinc, both of which are mineral nutrients required for plant growth. As a result, fertilizer requirements increase after the original stock of nutrient has been utilized in plant growth.

Other prominent problems associated with rice production on former mangrove sediments include lodging, disease and insect damage, flood damage, and drought and salt injury during the dry season. Although these problems affect many different types of agricultural crops, they seem to exhibit a higher incidence on reclaimed mangrove sites. The failure of many large reclamation schemes in Africa and Asia has been attributed to acid sediments and excessive flooding, both of which are symptomatic of either poor site selection or the lack of feasibility tests for the proposed sites.[4,5] Also, in some areas, rice culture ponds at low elevations too close to the water are endangered from sea storm flooding, loss of crop, and washout of dikes.

From an economic viewpoint, coastal soils that are normally marginal for efficient agricultural production can be converted to agriculture in a manner that insures both production success and minimal loss of associated habitats and resources. This requires acceptance of the fact that not all coastal soils have the same amenable characteristics and that the habitats to be reclaimed may offer greater economic and social values when left intact. Prior to the actual reclamation of marginal lands, feasibility studies should be undertaken to insure that the investment is justified and that the opportunity costs are minimal.

All parties to the expansion of agriculture at the expanse of mangrove forests and other critical coastal resources must account for the trade-off being made. Mangroves support fisheries, protect the shoreline, purify water, and produce dozens of valuable products. The extent to which these values are lost in preemption for rice culture, particularly, should be known and accounted for. In this regard, the following advice from studies in Indonesia[6] is appropriate (also see specific subsections on mangroves in this book):

> Converting mangrove ecosystems to agricultural lands or single purpose lumber concessions will usually result in a net loss of export dollar earnings, protein production, and perhaps employment. Analysis can and should proceed before irreversible momentum gathers for exploitation. For that analysis managers should consider the following points about mangroves: (1) Many developed and underdeveloped fisheries are entirely dependent on mangrove ecosystems. This dependence seems to be especially pertinent for penaeid shrimp stocks captured far from the mangroves. (2)

Mangroves protect shorelines against waves, tides, and storms. Agriculture ponds and lumber harvest should therefore not occur within 500 m, or further, of the coastline in order to preserve them. (3) Mangroves provide a vast array of products and services to the local villages. (4) Mangroves are generally self-sustaining and require little, if any economic management to be sustained.

Guidelines

It can be expected that the demand for new agricultural land will continue to increase and that more and more marginal lands in the coastal zone will be the focus of attempts at reclamation for agricultural development. Although some of the potential land is suitable for agricultural conversion, the majority of it may not result in profitable or cost-justified levels of agricultural production. With proper feasibility studies and resource inventories to guide the selection of land to be reclaimed, and with protocols to protect and retain critical parts of the supporting natural systems, the ratio of success to failure can be expected to improve significantly. In doing so, the value of the agricultural yields obtained from the conversion could justify the loss of valuable natural habitat from which it was converted. The following guidelines stress these points:

1) Potential acid-sulfate soils should not be developed, but instead should be left undisturbed along with their natural vegetation. The risk of obtaining a low yield or an absolute failure does not justify the destruction of the resource base.

2) Flooding should be restricted to the actual area in agricultural production. The hydrologic cycle in contiguous and adjacent areas should remain undisturbed to the maximum extent possible. The benefits of minimizing the destruction of other natural resources and habitats should be considered prior to their destruction, e.g., in order not to destroy other natural resources and habitats.

3) In general, areas considered for conversion to crop cultivation should be above mean sea level, and if flooding from sea storms is a problem, they should be placed inland far enough to prevent storm flooding and dike washout.

4) Drainage canals should be constructed in such a way as to minimize the leaching and removal of saline, acid water from the converted area, and the drainage waste should not directly enter mangrove estuarine areas.

5) Assurance should be obtained by the designers that sufficient fresh water will be available during the dry season to sustain agricultural production during droughts. However, the dry season demand should not deplete groundwater supplies or promote salinity intrusion.

6) Should diked agricultural fields ever be abandoned, the dikes should be breached to allow for seasonal flooding and the regeneration of local vegetation.

7) A thorough inventory and evaluation of the benefits of natural mangrove forests or other coastal resources and a trade-off analysis should precede issuance of any permit or approval of funding for conversion of coastal areas to agriculture.

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See Also: Upland Agriculture (p. 79).

UPLAND AGRICULTURE

Introduction

Agricultural practices in upland areas are relevant to coastal resources wherever watersheds drain directly into coastal environments. Among the more serious upland land uses which affect coastal ecosystems are deforestation or devegetation of catchments which alter water and sediment runoff characteristics, chemical runoff associated with agricultural applications of fertilizers and pesticides, and water diversion. These sources are of particular concern to both the coastal user and manager. In most cases, a poor understanding of the underlying physical relationships connecting upstream and coastal components of a catchment inhibits finding ready solutions to coastal degradation. Further, failure to understand these linkages is often compounded by information gaps concerning upland land-use activities. Finally, even when data and potential solutions are in hand, the most existing legal and institutional mechanisms lack the flexibility to incorporate coastal considerations into the planning process. In the developing countries, many of these issues take on added importance as high population growth rates signify a continually increasing pressure on land resources, much of which are poorly structured for intensive human uses.

Problems

Agricultural activities in the upland portions of watersheds may cause impacts within the coastal environment through a variety of transfer mechanisms of which the most important is water (Figure 23). River water represents the primary agent for transporting nutrients, sediment and organic material to coastal waters and accounts f·· the principal source of fresh water required to maintain the salinity regimes of several of the previously described coastal ecosystems. Perhaps the most insidious of the coastal problems associated with upland agriculture concerns the withdrawal or diversion of fresh water. This serves not only to directly reduce these critical inputs but also leads to a host of secondary problems such as a decline in fishery production and increased salinization of lowlands.[1,2,3] In a related agricultural practice, the increased freshwater flow associated with stream canalization can also result in the altering of the coastal hydrologic regime, decreasing salinities and causing degradation of salinity-sensitive marine ecosystems.[4]

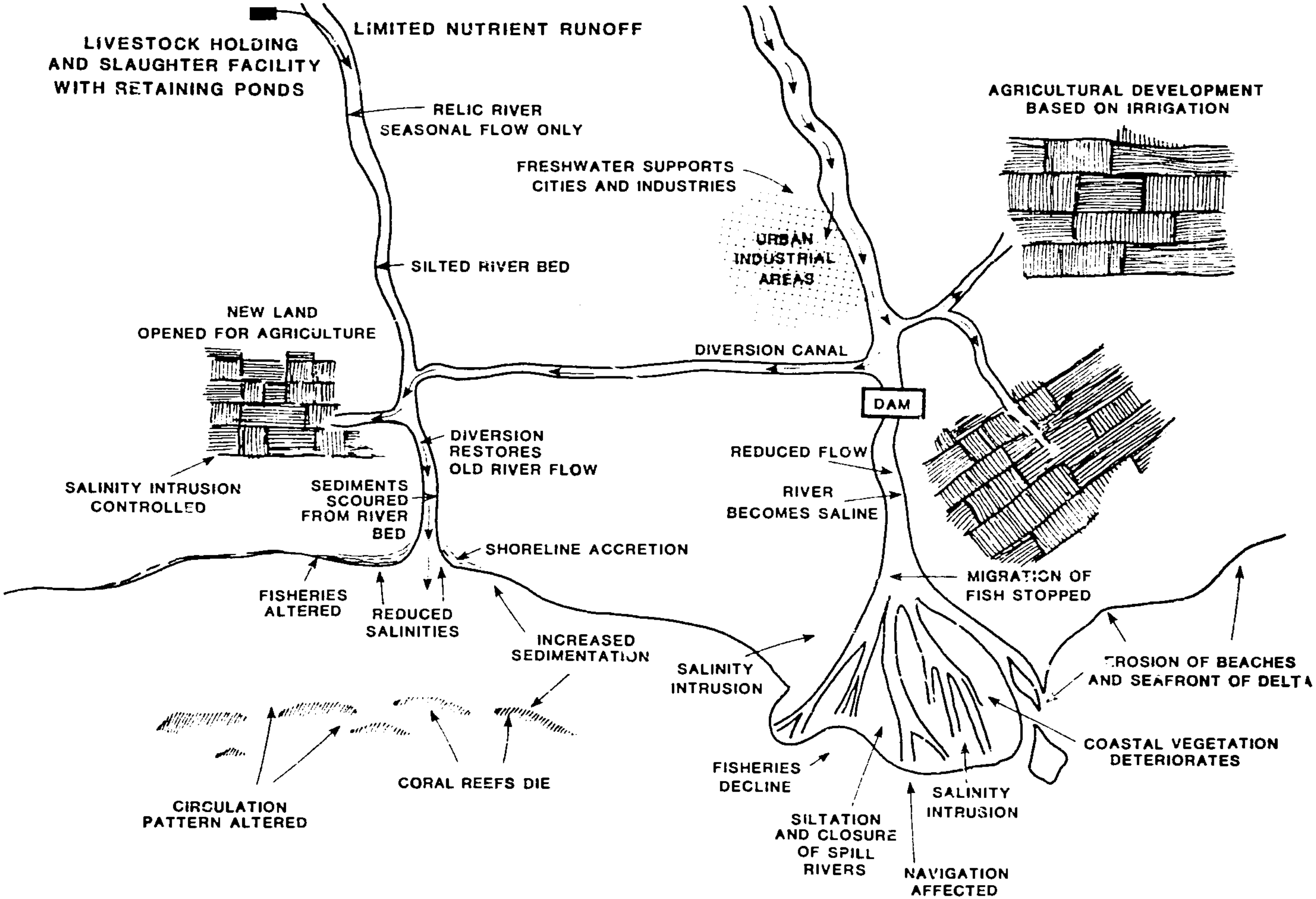

FIGURE 23. Impact of upland agriculture on coastal resources.

A second set of problems associated with upland agricultural land use concerns the application of deleterious chemical products to croplands to increase yields. The transfer of these toxic chemicals from the site of cultivation to the coastal zone may result in their interaction with natural processes, leading to impacts on the estuarine/marine organisms in the nearshore environment. When agricultural chemicals including pesticides, herbicides, nutrient fertilizers, and other soil amendments are introduced into marine food webs, deleterious changes in nearshore marine plants and animals may be promoted, eventually contributing to health hazards for local inhabitants who harvest fishes, crustaceans, and other food organisms from the affected area.[5]

Related to the transport of these toxic substances are the effects associated with increased sediment loading attributed to man-induced erosion. Soil loosened by cultivation or exposed while fallow often erodes and enters coastal areas, causing alterations and/or loss of habitat (particularly where sediment-sensitive organisms occur such as seagrasses and coral reefs).

A second major source of upland sediments results from poor land management which may include deforestation, overgrazing, and farming of overly steep hillsides. The conversion and destruction of forest cover serves to remove a major means of soil stability and retardant to freshwater surface runoff. In addition to these roles, forest systems serve to release moisture through evaporation, providing rain to other areas.[6] Their removal implies not only increased soil loss but appears to contribute to a rainfall reduction in adjacent areas, increasing the chances that aridity will further contribute to soil loss.

Stock grazing by cattle leads to soil compaction caused by trampling. In general, compacted soils have a low infiltration capacity and produce higher rates of watershed runoff. Also, because cattle consistently use the same small trails in their daily roaming, furrows are made in the soil which become channels for accelerated runoff during rains. On steep land, the channels may eventually lead to gully erosion. Frequently, when watersheds are grazed by goats, their efficiency in removing vegetation leads to aggravated problems of accelerated runoff and erosion. In general, the overall effects include alteration of the hydroperiod in the coastal environment and an increased rate of downstream sedimentation.

The coastal environmental and economic costs associated with poor upland land use were the subject of one of the case studies (Kenya River). The costs included coral reef die-off, declining water quality, bay infilling, tourism declines, and possible declines in fishery production.

Probably the best documented case of coastal and marine impacts attributal to catchment modification is in Kaneohe Bay on the northeastern coast of Oahu, Hawaiian Islands. The bay which measures 55 kilometers with a coastline length of 8.8 kilometers with a total catchment of 46 kilometers coral degradation resulting from human-related alterations in the watershed which may have occurred as early as the latter part of the last century when overgrazing of steep hillsides increased erosion and downstream sediment loads.[7] Since that time, the bay either directly or through catchment modifications has been subjected to a number of intense and diverse sources of stress including dredging, increased freshwater runoff and human sewage.[8] The combination of sewage effluents and land conversion for farming and development, as well as other factors, resulted in the severe deterioration of marine habitats in the bay. Various forms of marine life disappeared from portions of the bay, and coral reefs were killed and later overgrown by fleshy algae (due to increased nutrient levels in the bay). Plankton blooms also appeared because of high nutrient levels, contributing to the deterioration of water quality.[8] Only when expensive, corrective measures were implemented, the deterioration of the bay stopped and the long process of recovery begun.

In addition to the upland agricultural sources of coastal degradation, other development activities which have the potential to affect coastal environments include industrial outfalls affecting water quality and coastal temperature regimes, dam construction reducing natural levels of sediment and nutrient downstream concentrations, and intensive plantation exploitation of lands.

Guidelines

It is important to recognize that most of the forces which have led to the destruction of coastal resources in the past have had their origins from outside the ecosystem[2] and that upland agriculture is perhaps the classic case of impacts from areas which are remote from sensitive coastal systems. Therefore, in the case of upland agriculture, the conservation and sustained utilization of coastal resources depend upon the effective use of multisectorial, integrated planning techniques. Before agricultural activities take place, the downstream coastal ecosystems and their dependence upon the freshwater sources which they share with the upland agricultural practices should be understood. Site-specific studies may be required at many localities. Dealing with the effects of upland agriculture on coastal resources requires careful study which may be costly. But, these costs are usually minimal when compared to the loss of coastal resources which results from poor planning. The best time to deal with the potential coastal effects of upland agriculture is in the planning phase, not after the development activity has already damaged the resource. The guidelines below are those which are considered to be the minimal requirements for the maintenance and perpetuation of coastal ecosystems potentially affected by upland agricultural practices.

1) Avoid agricultural practices, as well as dredging and poor erosion control, which can introduce pollutants and excessive nutrients into rivers leading directly into coastal areas and to critical and sensitive coastal resources. Where poorly managed lands have resulted in eroding soils, consider the use of check dams, bench terraces and cutoff drains as possible means of slowing rates of soil loss. Alternative land management techniques for future land development include reforestation, controlled grazing, and improved cultivation.

2) For upland agricultural practices, maintain ambient-water salinities at a relatively constant level with downstream coastal waters. The excess (or deficit) delivery of fresh water reduces salinity and should be avoided. This can be accomplished with water control structures, including dams which may be used to regulate flow to simulate certain natural conditions, a practice which has been used effectively in some areas.

3) Adopt agricultural practices which maintain the ambient-water temperatures reaching coastal waters by use of retaining ponds. Avoid the introduction of significant heated discharge or cooler freshwater discharge into restricted coastal areas. Remember that changes in temperature may aggravate the stresses of altered salinities that have resulted

from excessive hot or cold water discharges which have resulted in localized degradation of costal environments.

4) Maintain agricultural practices which maintain the natural clarity and transparency of the water. Activities associated with agriculture (including dredging or soil erosion) that disturb the sediment and create silty water should not be undertaken near, or upstream from, sensitive coastal resources.

5) Maintain the natural temporal and spatial patterns of surface- and groundwater sources. Reductions of fresh water by diversion, withdrawal, or groundwater pumping should not be undertaken if they are expected to have an effect on the salinity balance in the downstream coastal environment. Especially important is the avoidance of irrigation or diking control projects which alter the naturally occurring hydroperiod. Special consideration should be given to migrating fishes which may be stopped from migrating upstream by such structures. (See "Water Resource Development" section for additional guidelines).

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See Also: Coastal Agriculture (p. 73).

FISHERIES

COASTAL AQUACULTURE

Introduction

Aquaculture is a term that describes a variety of management procedures designed to increase the production of living aquatic resources beyond that which is normally available from harvesting wild stocks. On a worldwide basis, it accounts for approximately 15 percent of the 60 million metric-ton harvest of aquatic animals (see Mariculture Case Study). The practice of aquaculture in the coastal marine environment is often termed mariculture and is a promising economic enterprise accepted and implemented on a worldwide basis. Depending upon the form and the plants or animals produced, mariculture provides a source of locally available protein and generates a significant source of hard foreign-currency earnings.

In spite of its promise, there is a high rate of failure for the pond system, which is accompanied by the unacceptable loss of coastal resources which could have had a greater value under another economic scheme. An examination of the successes and the failures shows that a properly sited and managed pond enterprise is a promising business venture compatible with the protection of the supporting natural resource base. Investors place great emphasis on maximizing the individual pond yield rather than developing extensive land tracts with many lower-yielding ponds.

Classes of Mariculture Operations. The many forms of mariculture operations can be described in terms of the level of financial investment and the corresponding intensity of management (Figure 24). In the least expensive and simplest form, termed open-system mariculture, the plants and/or animals of interest are confined within a naturally productive area by cages or pens or within areas enclosed by nets to prevent predation or escape of the animals of interest (example, the Acadja fisheries in Benin). The production of nonmobile animals such as oysters may be enhanced in this type of system, simply by providing special substrate for attachment and by preserving the natural water quality.

When greater management control is required, ponds are typically constructed in the intertidal littoral zone and stocked with the desired species. The cost of this type of "extensive" mariculture is minimized when natural tidal exchanges are utilized to freshen the pond water and when naturally occurring larvae in the incoming water are captured and maintained

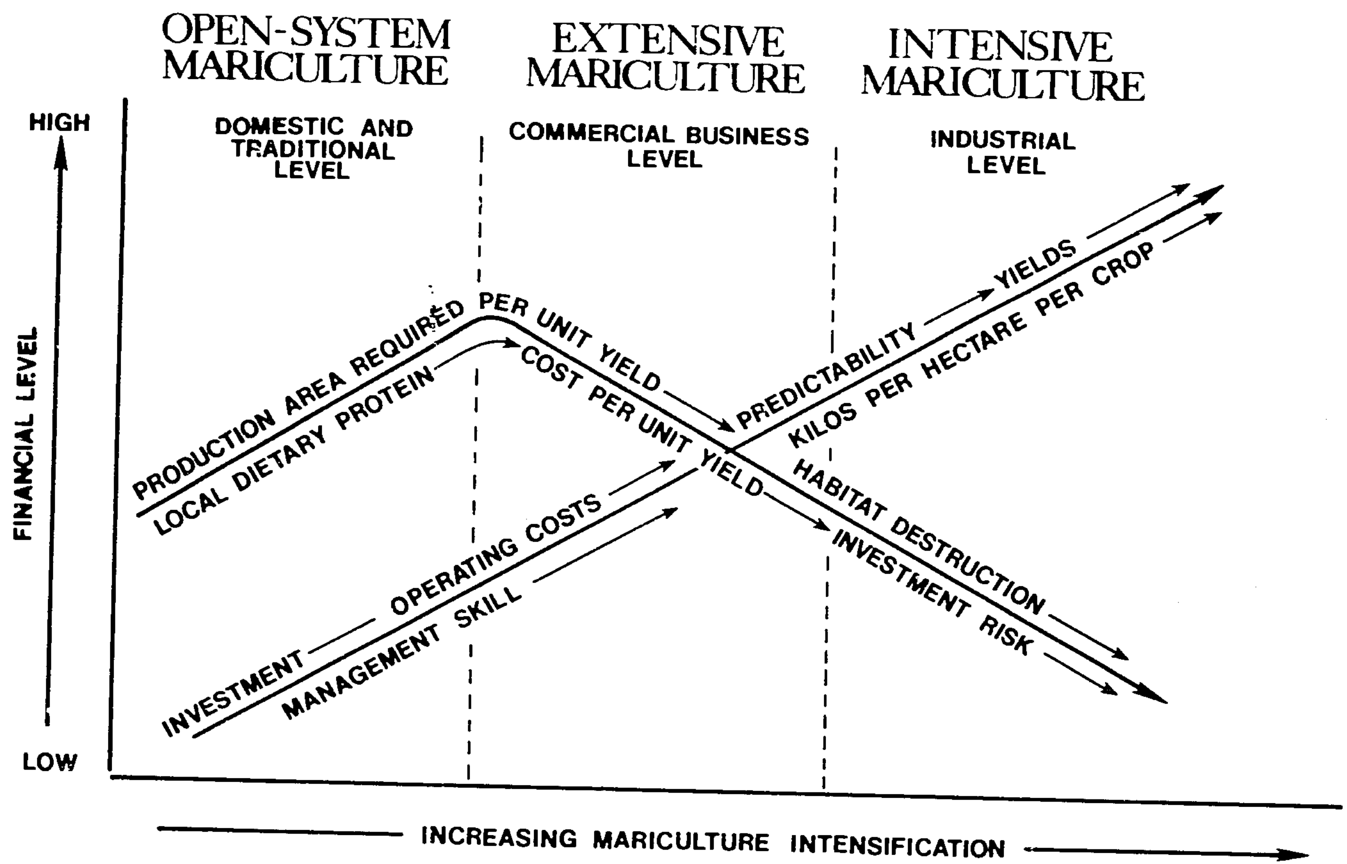

FIGURE 24. Intensity and financial level of associated types of mariculture.

within the pond for subsequent growth and harvesting. Although operational cost is minimal, extensive mariculture operations require large areas for pond construction and are wholly dependent upon the varying availability of larval and juvenile stock. As a result, they tend to be highly destructive to the natural environment and produce low and varying annual yields (example, the Chokaria Sundarbans in Bangladesh). Low-producing ponds (a few hundred kilos per hectare) may be abandoned after several years.

"Intensive" mariculture requires less space for the construction of ponds but requires a greater investment in terms of better constructed ponds, large pumps for water exchange and, in some instances, artificial feeding during the grow-out period. Yields from intensive mariculture operations tend to be significantly higher (several thousand kilos per hectare) and more predictable from year to year, particularly when the juvenile stock can be easily obtained (e.g., milkfish in the Philippines).[1] When pond operations depend on the local capture of larvae for pond stocking (e.g., larval shrimp in Ecuador and Panama), yields are significantly affected from the year-to-year variation in the availability of the seed stock.

In mariculture, the level of capital investment and intensity of management are economically justified only when the crop has a high market value such as that for large shrimp or prawns, or such finfish species as pompano and promfret. Such high-value species represent important sources of foreign earnings but do little to increase the level of protein in the diets of local people.[2]

Problems

The current high demand for marine protein, both for local consumption and foreign export, has led to the expansion of existing mariculture operations and the development of new operations in many parts of the world. As reports become available, however, it is apparent that not all mariculture operations are economically justifiable, particularly in terms of the destruction of the natural resource base.[3] Some of the more common problems which are sometimes overlooked by investors, financial support institutions, and owners/operators fall into two distinct, but related categories: pond siting and pond management.

Figure 25 illustrates that the major problems associated with pond siting include the direct removal of wetlands, the development of acid-sulfate

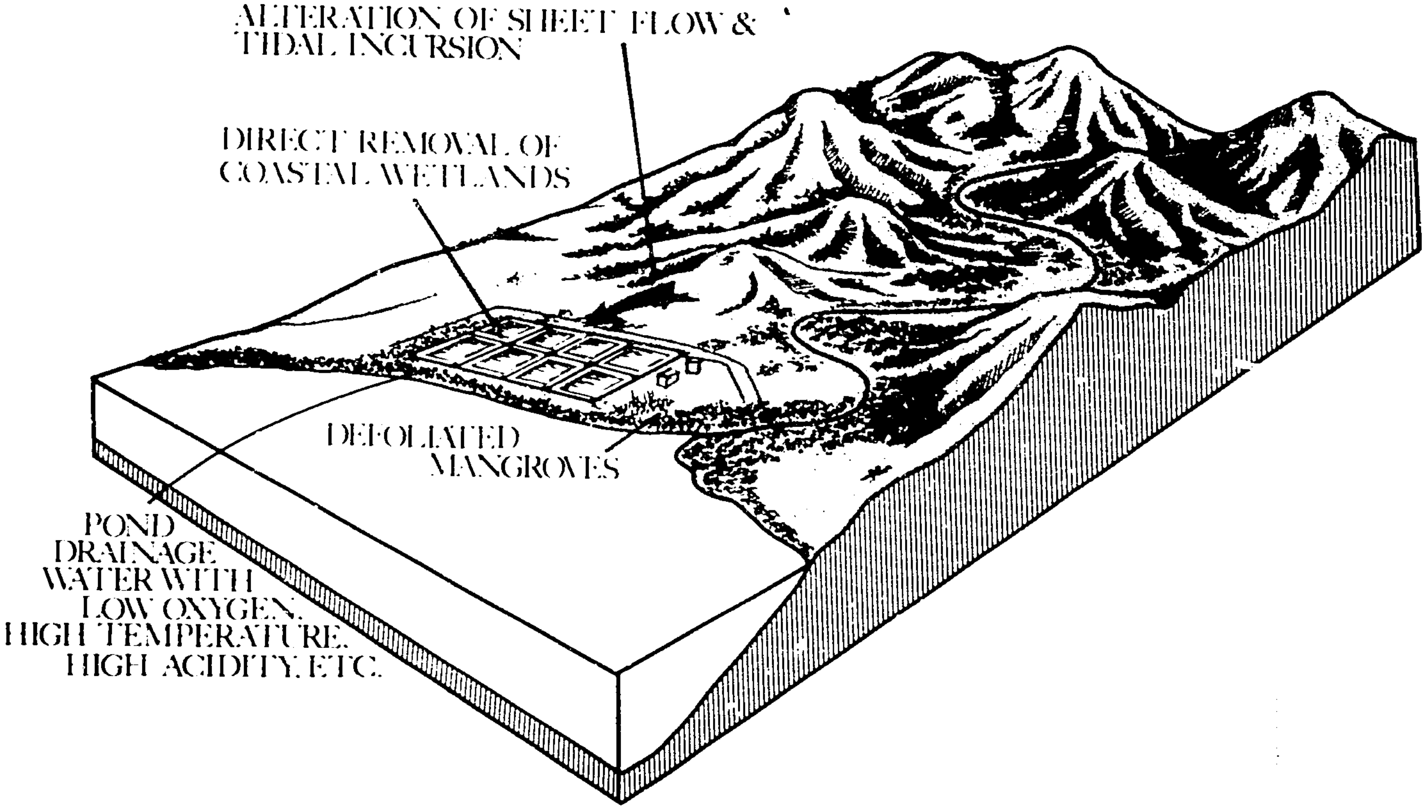

FIGURE 25. Environmental effects of aquaculture operation in nearshore coastal resources.

sediment conditions, inadequate to poor flushing of ponds, and local depletion of larval and juvenile organisms for pond stocking. Acid-sulfate soils develop when previously waterlogged sediments, rich in pyrite and organic matter, are exposed to the air or oxygen-rich water. The chemical reactions that occur result in the formation of sulfuric acid which, in an enclosed pond, creates an unsuitable environment for the survival and growth of aquatic organisms. The problem is aggravated in situations where there is inadequate pond-water exchange or flushing, which otherwise would remove the acid water and replace it with clean water.

Inadequate renewal of pond-water permits other potentially toxic conditions to develop in the pond (e.g., high temperatures and low oxygen). In the Philippines, for example, poor siting of milkfish ponds, coupled with inadequate corrective management, frequently results in the decline of yields and in pond abandonment. Following abandonment, the pond operators clear new areas for new pond operations. The cycle of repetitive land clearing, pond construction, and abandonment is termed "shifting aquaculture" and, like its terrestrial counterpart--shifting agriculture is equally destructive to the sustaining resource base. Usually, ponds are developed in areas which constitute the natural habitat for the organism of interest (e.g., mangrove estuaries and shrimp) with the belief that larval and juvenile shrimp will be available for pond stocking. Whereas this may be true in most cases, the absolute availability of a larval stock is highly variable on a year-to-year basis. Also, in areas of extensive pond operations, the competition for larvae can lead to overexploitation and a reduction in the total available stock (e.g., Ecuador).

With respect to pond management, there are two critical limitations on production and yield: excessive predation and low in-situ primary production or availability of detritus (particles of dead plant matter). Predation is a serious problem when ponds are not completely cleaned out and drawn down at the time of harvesting, thus allowing captured predators to remain in the pond. Also, pond stocking that is based on free entry of juveniles followed by closure of the access also permits potential predators to enter. The presence of just a few large predators can completely destroy the growing stock in a grow-out operation.

The problem of low in-situ primary productivity is significant in the sense that the final yield is proportional to the availability of food during the grow-out period. In most instances, where all other pond conditions are favorable, the yields can be dramatically increased by supplemental feeding and/or fertilization. The former provides a direct food source, whereas the latter stimulates phytoplankton and attached-algae production (and the formation of detritus), both of which benefit the species retained in the ponds for grow-out. Supplemental feeding or stimulation of in-situ production is a superior technique that can produce high yields while reducing the need to construct additional ponds simply to maintain the viability of an economic marketing constraints enterprise. In many instances, in the absence of techniques promoting higher yields, unmanaged pond yields do not justify either the loss of habitat or capital investment associated with pond construction.

Guidelines

Proper pond siting and subsequent intensive management helps to insure a suitable economic return for the investor/operator, in part through a reduction in the need to convert large coastal areas to ponds for extensive mariculture (Figure 26). It also significantly reduces the risk of pond failure and abandonment. In essence, good siting and management protocols are the bases for both a long-term, profit-generating enterprise and the conservation of the natural sustaining resource base. The following guidelines serve to optimize pond yields relative to the protection of the resource base:

1) International donors and lending agencies should give preference to improving the efficiency of existing mariculture enterprises as opposed to converting new coastal areas to extensive mariculture pond systems. Approval requirements should also include a demonstration that the proposed site is, in fact, suitable for a sustained-yield production pond.

2) The approval and development of mariculture activities should be based on national or regional plans that identify critical resources and conflicts with all other actual or potential resource uses. Such plans should include the protection of coastal habitats for sustaining capture fisheries, supporting tourism, and maintaining a high level of ecological functions.

3) Pond-siting protocols should include performance requirements for the protection of the natural habitat surrounding the ponds; specifically,

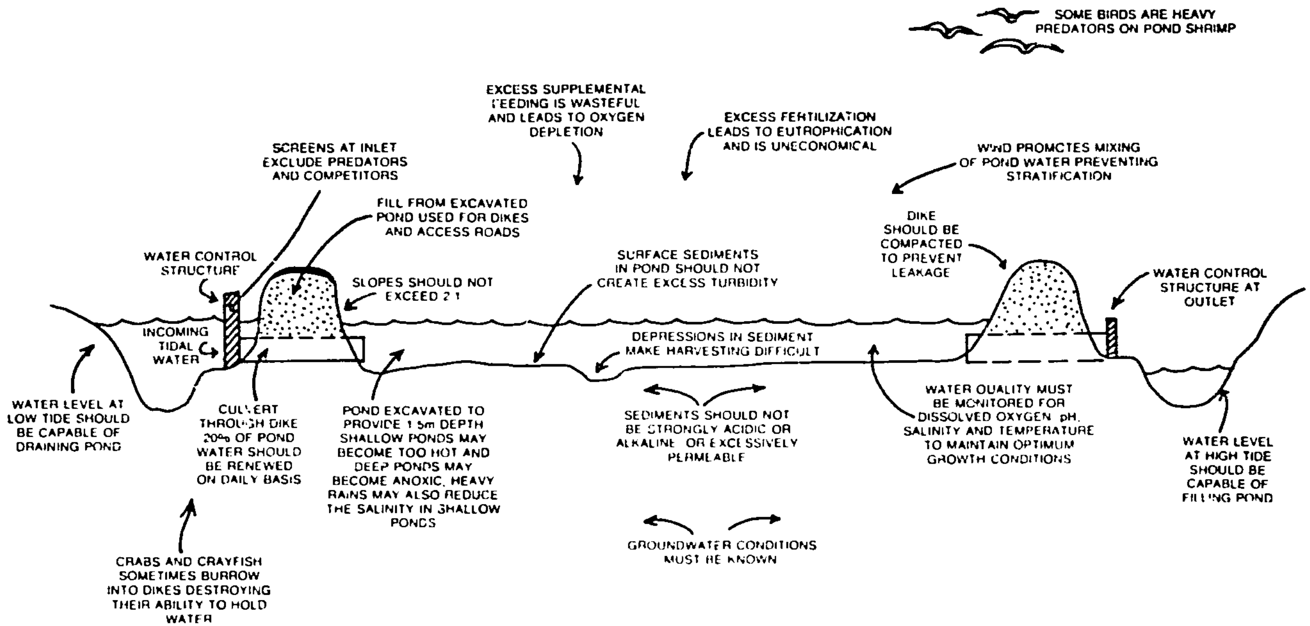

FIGURE 26. Siting and management of coastal mariculture (shrimp) ponds. The economic success of mariculture ponds depends wholly on the initial siting of the ponds and their subsequent management. Promotion of these goals also insures that the most use is made of the finite intertidal zone and that new areas are not converted to ponds because of low yields in existing pond systems. Siting and management are complex problems that must be resolved by experienced pond managers and not left to the trial and error process typically used by first-time entrepreneurs. This figure illustrates only some of the critical factors that must be considered when siting and managing a shrimp grow-out pond for the optimum yield. In general, only a small portion of the coastal zone is suitable for mariculture; unsuitable sites and poor management lead to economic problems and the unnecessary waste of a valuable natural habitat.

natural patterns of surface-water flow (i.e., surface-water runoff, tidal ingress and egress) should not be interrupted.

4) In mangrove areas, the ponds should be located inland from the mangrove forests. When available, areas defined as salt flats or salt pans are preferred sites. Frequently, pond yields are greater in these areas than in mangrove forest areas which have been converted to pond systems. A wide buffer of natural mangrove forest should be left between the pond sites and open waters.

5) In managed pond systems, an increased (above that normally believed and practiced) stocking of animals for grow-out is usually feasible. In addition to natural tidal exchanges and/or large volume pumps to increase water exchange and renewal, other management tools available for sustaining high production include (1) the monitoring of water-quality conditions and the regulation of pond-water renewal on an as-needed basis; (2) the fertilizing of pond waters to stimulate high rates of primary production and detrital formation for feeding purposes; and (3) the use of artificial food supplements for accelerated growth.

6) Whenever a pond or system of ponds is forced to be abandoned, the impoundment dikes should be breached to permit the pond area to recover to its former status.

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See Also: Mangrove Ecosystems (p. 23); Mangrove Forest Harvesting (p. 103).

CAPTURE FISHERIES

Introduction

The declines in the catch of many of the world's coastal fisheries can be attributed to two major sources: (1) problems related to overexploitation; and (2) environmental problems such as habitat removal and pollution. The subsequent discussion and guidelines presented below deal mostly with environmentally induced problems.

Since fishery resources depend heavily upon estuarine and coastal waters, the degradation of these environments can often be linked with the subsequent reduction in capture-fishery yields. Among the sources of environmental degradation which have been implicated in the reduction of capture-fishery productivity are logging, agricultural practices, sewage and industrial waste, coal mining, land reclamation, urbanization, aquaculture, and the removal of wetlands.

Problems

In general, these practices lead to changes in ambient-water quality including salinity and temperature; important environmental parameters for many species dependent on critical nearshore areas for spawning, nursery, and forage (Figure 27). Specifically, changes in salinity can result from the disposal of brine wastes or the drainage of salt ponds or industrial processes. Similarly, temperature increases can occur from heated discharge water from process plants. Other human activities which can affect coastal water quality include dredging or other activities associated with a growing urban development sector located near or upstream from critical fishery habitat which can disturb sediments and create silty water leading to regional impacts; industrial processes introducing pollutants; and sewage wastewater outfalls which create major influences in areas critical to fishery resources.

These developmental practices may also alter the natural patterns and cycles of tidal activity and freshwater runoff in areas which are critical to fishery resources. Spawning and young finfish and shellfish often rely upon freshwater runoff (anadromous fishes) and tidal cycles (penaeid shrimp) for their migratory behavior, which is critical to their survival.

Coastal structures and water development schemes have the potential to change natural patterns and can damage local fishery resources.

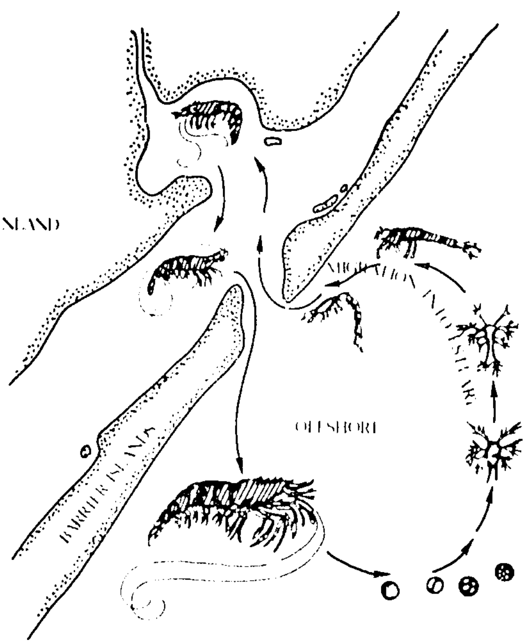

FIGURE 27. The value of estuaries to fisheries.

Finally, both inland and coastal area development which results in excessive sedimentation, erosion, or changes in the chemical characteristics of the substrate can lead to the loss of critical habitat of many fishery resources (see Kenya River Case Study).

A specific example of inland development activities which have affected coastal fish stock is the construction and operation of the Aswan High Dam. As a result of alteration of the salinity regime and reduction of nutrients in the species nursery grounds,[1] this project led to the complete destruction of the herring fishery located at the mouth of the Nile River.

The increase in world value of petroleum products has signified another source which threatens critical fishery habitat. In several regions (e.g., West Malaysia, Brunei, the Java Sea, and Ecuador), rapid development within the petroleum sector has created potential for conflict between petroleum and fishery industries. This situation is especially apparent in Ecuador where the discovery of oil in the sparsely populated Amazon Oriente generated a major shift in the economy. The activities which followed included the construction of a 300-mile trans-Andean pipeline from the Oriente to the port of Esmeraldas. Petroleum-export revenue increased from US$61 million in 1972 to over US$1,000 million in 1979. This signified an increase in share of export dollars from 19 to 50 percent within seven years. During the same time period, fish exports increased in value until 1982, where they ranked third in value of the nation's exports, immediately following petroleum. The coincidental rise in the importance of these two resources and the potential for conflict has resulted in a focus on national oil spillage prevention.[2]

Fisheries themselves case habitat damage in certain circumstances. FOr example, use of dynamite for capturing reef fishes is often destructive to the reef. Also, nets and trawls towed over the bottom can damage grass beds, coral reefs, and other habitats (Figure 28).

Guidelines

It is important to recognize that most of the forces which have led to fishery catch reduction have been due either to overfishing or to impacts derived from coastal and inland area development in areas outside critical habitats for fishery resources. Therefore, fishery conservation and sustained utilization of fishery resources should take into consideration both the maximum sustained yield of each fishery as well as the critical habitat requirements

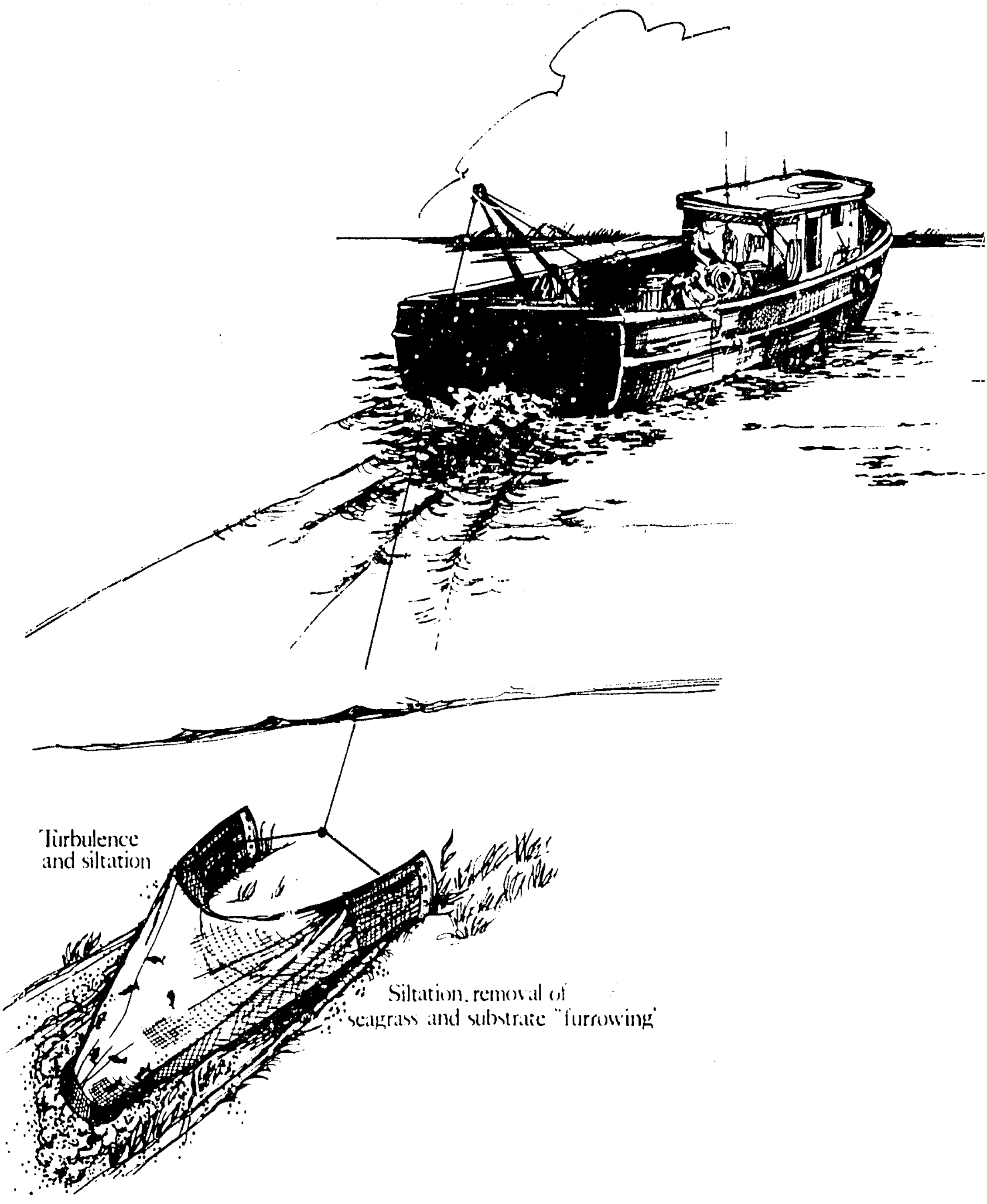

FIGURE 28. Fishery impact to seagrass beds.

of each species in the fishery. Sustained production of fishery resources requires the inclusion of these areas within the management context to safeguard critical habitat required for their survival. The guidelines below are those which are considered to be minimal requirements for the maintenance and perpetuation of marine capture fisheries. Many of these guidelines are developed in further detail in other sections in the document determined by the primary development activity affecting the change.

1) Avoid changes in ambient water salinities and temperatures, especially in critical areas such as spawning, nursery, and forage areas. Disposal of brine wastes or drainage of salt ponds would raise salinity, whereas the excess delivery of fresh water would reduce salinity; thus, these practices should be avoided. To maintain the ambient temperature range, the use of cooling ponds is advisable. The ambient salinity regime can be maintained through dilution of briny discharges; conversely, the impacts of high quantities of freshwater discharge can be mitigated through controlling and slowing the rate of discharge over time.

2) Avoid changes in the natural clarity and transparency of the water in areas which are critical for fishery resources. Dredging or other activities that disturb the sediments and create silty water should not be undertaken in locations that are near or upstream from critical fishery spawning, nursery, or forage grounds. Where required, impacts can be mitigated through use of silt curtains and limiting activities to periods characterized by advantageous currents.

3) Avoid the introduction of pollutants and excessive nutrients into environments which are critical to fishery resources. Proper siting of industries away from these areas would control effluent composition and discharge rate, thus minimizing the risk of certain types of industrial pollutants. Likewise, ocean outfalls utilized for the disposal of sewage wastewater should not be allowed to influence areas critical to fishery resources.

4) Avoid changes in the integrity of the land/sea interface, as well as the topography and character of the substrate in areas critical to fishery resources; the coast and nearshore substrates are often utilized for spawning and for sheltering young and juvenile finfish and shellfish.

Likewise, coastal and inland area development resulting in excessive sedimentation, erosion, or changes in chemical characteristics of the substrate should be avoided.

5) Avoid changes in the natural patterns and cycles of tidal activity and freshwater runoff in areas which are critical to fishery resources. Spawning and young finfish and shellfish often rely upon freshwater run-off (anadromous fishes) and tidal cycles (penaeid shrimp) for their migratory behavior, which is critical to their survival. Coastal structures and water development schemes that have the potential to change the natural patterns should be modified to insure that those patterns are maintained.

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See Also: Mangrove Ecosystems (p. 23); Estuaries and Lagoons (p. 49).

FORESTRY

MANGROVE FOREST HARVESTING

Introduction

Coastal mangrove forests are a significant source of wood and wood products for both domestic and commercial uses. Mangrove forest products are a major subsistence source of construction materials and fuel for coastal populations. In some countries, mangrove forests have been managed on a rotation basis for economic benefit since the nineteenth century. Mangrove forest management is based on standard silvicultural practices, modified to protect the fragile coastal habitat, thus guaranteeing long-term economic yields. Avoiding exploitative harvesting of large, mangrove forest areas will reduce a variety of environmental impacts and prevent the loss of productive potential over the years required for forest regeneration.

Mangrove forests are recognized as having an essential role in sustaining estuarine and nearshore ecosystems and therefore are a key factor in maintaining high fishery yields (see "Mangrove Ecosystems" subsection). For example, researchers in different areas of the world have established that shrimp yields are proportional to the local abundance of mangroves which support the fishery. Estimates suggest that 1 hectare of mangroves contributes to an annual yield of 870 kilograms of shrimp, which in many areas is a source of valued foreign exchange.[1]

In addition, mangroves provide other valuable services such as water purification, shoreline stability, and protection of life and property against sea storms. For example, in areas subject to catastrophic cyclonic storms (e.g., around the Bay of Bengal, the Caribbean, and many areas in Oceania), mangrove forests are recognized for the role they play in minimizing storm-surge damage and destructive flooding. In heavily populated areas throughout the world, good coastal water quality is associated with mangrove forests and the role they play in trapping nutrients and sequestering certain toxic pollutants.

Mangrove forest species can be utilized for a variety of purposes which include high-quality lumber, large poles and durable construction timber, pulp for paper and cellulose, and fuelwood and charcoal. Thus, mangrove forests have an economic value that can be derived on a long-term basis similar to most other types of managed forests. Good management which places emphasis on appropriate harvesting and extraction procedures perpetuates the forest for coastal protection especially during periods of severe storm activity. The following uses are documented:[2]

FUEL: Firewood (cooking, heating), charcoal, and alcohol

CONSTRUCTION: Timber, scaffolding, heavy construction (e.g., bridges), railroad ties, mining pit props, boat building, dock pilings, beams and poles for buildings, flooring, paneling, thatch and matting, fence posts, water pipes, chipboard, and glues

FISHING: Poles for fish traps, fishing floats, wood for smoking fish, fish poison, tannins for net and line preservation, and fish-attracting shelters

TEXTILES AND LEATHER: Synthetic fibers (e.g., rayon), dye for cloth, and tannins for leather preservation

FOOD, DRUGS, AND BEVERAGES: Sugar, alcohol, cooking oil, vinegar, tea substitutes, fermented drinks, dessert toppings, condiments from bark, sweetmeats from propagules, cigar substitutes, and vegetables from propagules, fruit, or leaves

HOUSEHOLD ITEMS: Furniture, glue, hairdressing oil, tool handles, rice mortar, toys, matchsticks, incense, and decorative carvings

AGRICULTURE: Fodder and green manure

PAPER PRODUCTS: Paper of various kinds

MISCELLANEOUS PRODUCTS: Packing boxes, wood for smoking sheet rubber, wood for brick kilns, and medicines from bark, leaves, or fruits

OTHER NATURAL PRODUCTS: Fish, crustaceans, shellfish, honey, wax, birds, mammals, reptiles and reptile skins, and other fauna

Problems

Due to the worldwide demand for wood and wood products, local economic demands may result in the overexploitative harvesting of large areas of mangrove forests. This creates a variety of environmental impacts and a loss of potential productivity over the years required for forest regeneration. Large-scale clear-cutting (or clear-felling) of mangrove forests is perceived to represent an economic means of rapidly exploiting large coastal forest areas for their timber reserves. Improperly conducted forest clear-cutting and extraction operations create a variety of short- and long-term effects which represent economic losses, high opportunity costs and, frequently, the loss of human life. The excessive clear-cutting of large forested areas creates a variety of coastal effects, including the exposure of organic sediments to rapid oxidation and subsidence which permits terrestrial runoff and tidal incursions to accelerate surface erosion (Figure 29).

This has a profound effect on associated nearshore communities such as seagrass beds and coral reefs.[3] Exposed and oxidized sediments present poor substrate conditions for propagule establishment and forest regeneration, and delayed recovery of a production forest represents a long-term economic loss. In addition, sources of colonizing propagules (seedlings) may be limited by the loss of extensive areas of parent trees. Although nearshore fisheries may be stimulated by the initial pulse of eroding organic debris and dissolved organic matter from decomposing slash (harvesting debris), the subsequent losses of habitat and detrital production are presumed to result in significant shifts in marine species assemblages and/or a loss in fishery yields. Coastal and estuarine environments receive the unfiltered materials in terrestrial runoff that under certain circumstances can be considered pollutants (Figure 30). In areas subject to cyclones, typhoons, hurricanes, and tsunamis, the loss of the coastal buffer and the resulting tidal surges are translated into the loss of human life and property.

Mangrove forests represent a major economic resource that is frequently lost through exploitative clear-felling. Abusive clear-felling not only destroys economic potential, but also places environmental impacts on other nearshore ecosystems which may represent a valued resource.[3] This contrasts greatly with properly managed, sustained-yield and harvesting practices, such as block cutting, which produce economic benefits of local and regional significance. Exploitative clear-felling creates environmental damage and

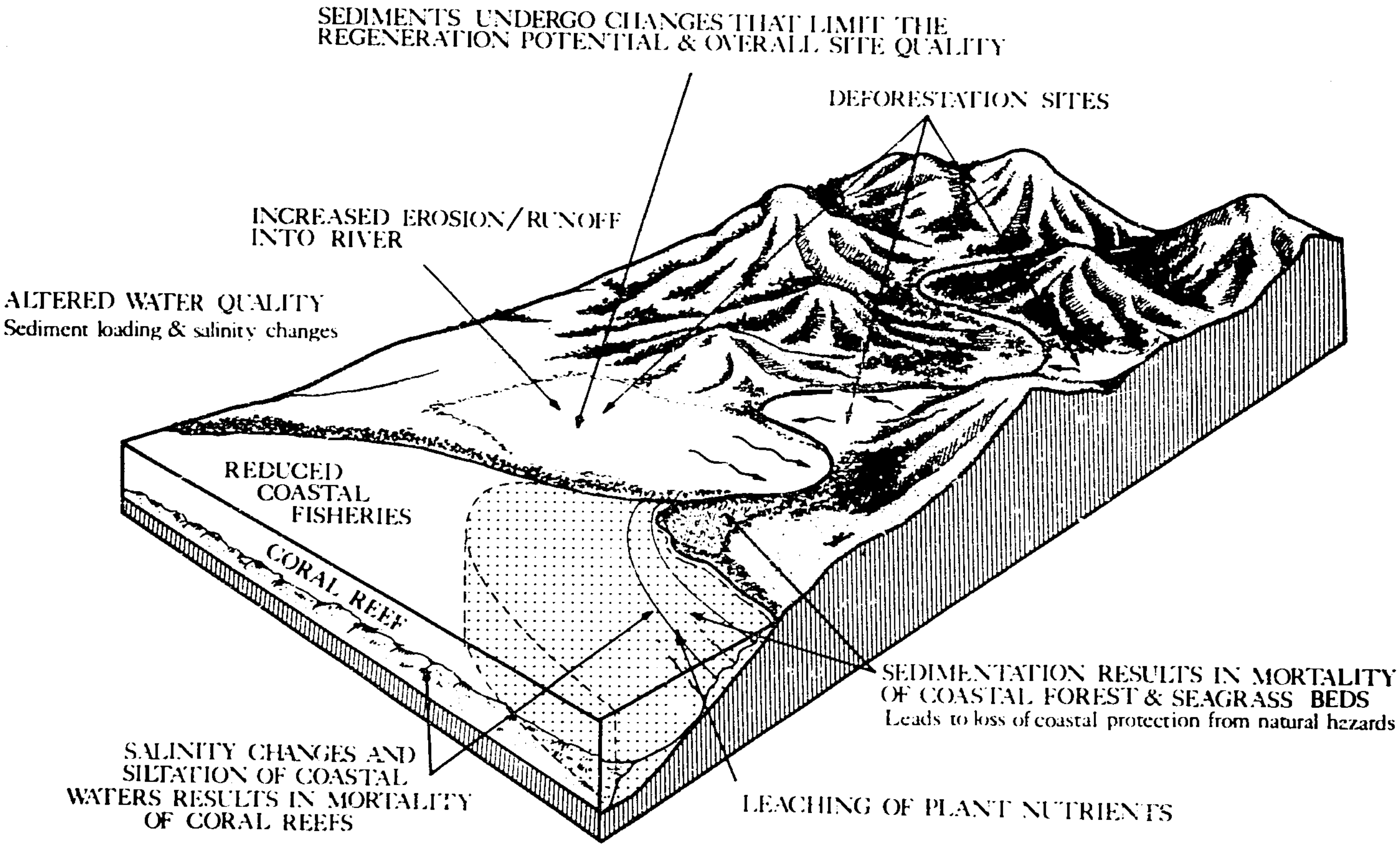


FIGURE 29. Coastal effects of excessive clear-cutting.

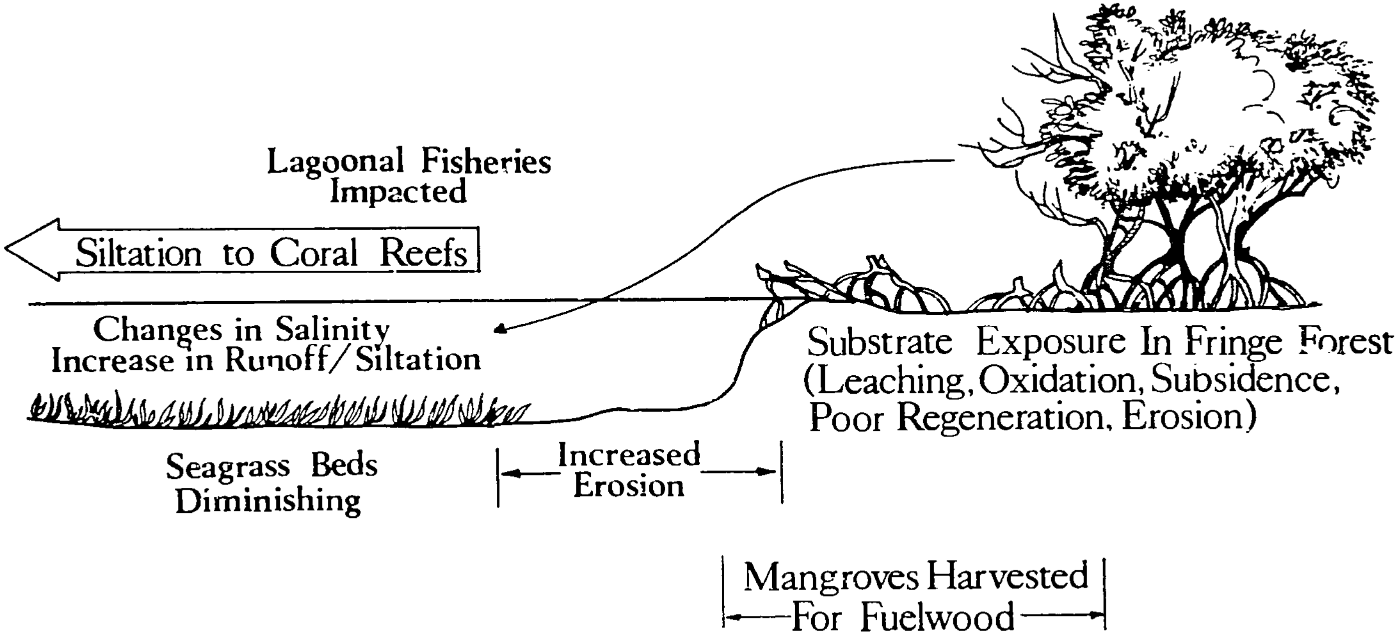


FIGURE 30. Environmental effects of clear-cutting on nearshore coastal resources.

depresses the rate of forest regeneration. The alternative is integrated forest planning. (Figure 31).

Management Solutions. Many of these problems can be mitigated through the development and implementation of an effective mangrove management program. In order to perpetuate sustained-yield harvests of mangrove trees, it is necessary to establish growth and wood production rates as a basis for setting harvest schedules. In general, total harvest from an area is set equal to annual production; harvest in excess of annual production proportionately reduces the productive potential for future harvests. Typically, mangrove harvest rotations range from about 20 to 40 years, depending upon the intended use of the wood. Thinning and improvement cutting may take place during the period to increase the yield and quality of the timber. Under a 20-year rotation, the maximum harvest area is 5 percent of the managed forest area; a 40-year rotation is equivalent to 2.5 percent of the management area. The relatively small size of the maximum allowable cut sometimes encourages a desire for excessive harvesting; the opportunity cost is measured in terms of the loss of future harvests.

The best-managed commercial forests are those of the Asian region where many decades of experience have led to rigorously defined management and harvesting protocols. (For examples, see management plans of Refs. 4, 5, 6). In other areas, where there is no historical precedent in mangrove forest management, sustained-yield harvest schedules have revealed unanticipated problems of an institutional nature. One of the more-widely-known managed mangrove forests is the 40,000-hectare Matang Forest in Malaysia. The management plans were initially established during the British colonial period, but have been continually upgraded through trial and error and through a variety of practical research programs. As a result, the Matang Forest is managed on a 30-year rotation and is presently in its third rotation.[2] Although there are competing land-use pressures (e.g., conversion to shrimp ponds), silvicultural research in Malaysia is a continual process which inevitably will lead to new and better forest management decisions.

An important component of the management plan is the method selected for harvesting the resource. There are a variety of methods and procedures for mangrove timber harvesting and extraction that can be adapted and utilized under a variety of site-specific conditions. The following two contrasting

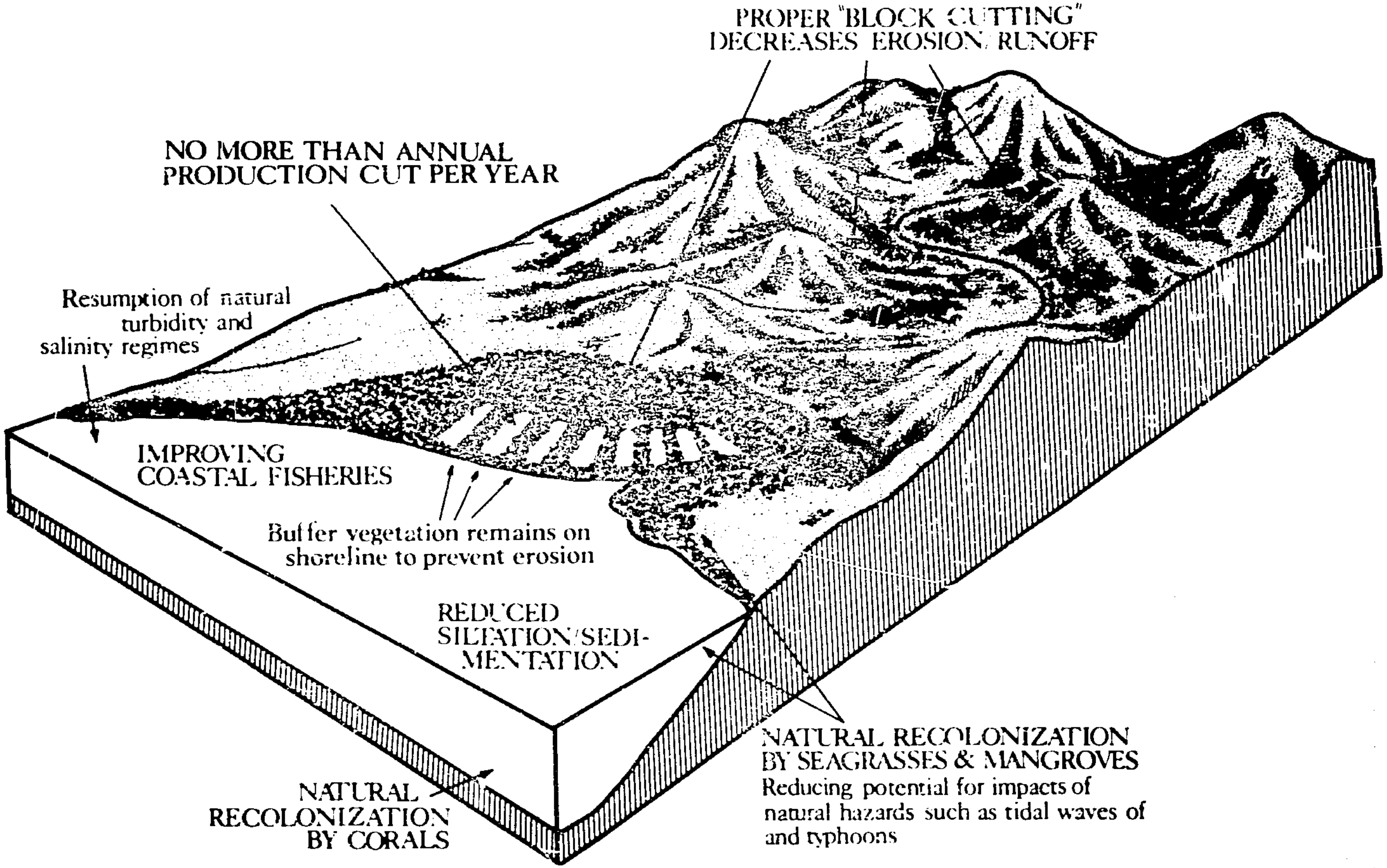


FIGURE 31. Results of integrated forest planning on coastal resources.

examples are presented; they have been proven to be cost-effective and, when properly conducted, present no long-term environmental damage.[7]

Method 1. The use of small, temporary canals is employed in parts of Malaysia for the extraction of small timber and poles. Following extraction of the timber, the canals are filled to reestablish the former topography and flushing pattern, thus encouraging a rapid regeneration of the forest (Figure 32).

Method 2. Alternatively, rough-sawn boards can be used for small roadways over which the harvested wood is removed on small, wheeled carts or wheelbarrows. This is minimally damaging, and the boards can be successively used during the harvesting process. Both of these example techniques are labor-intensive and thus provide a variety of local employment opportunities (Figure 32).

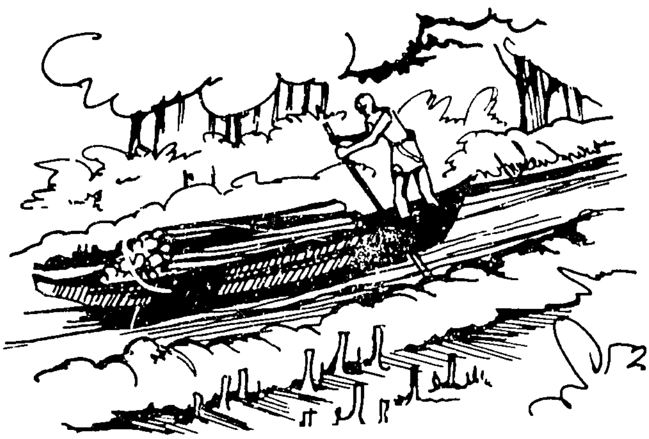
Guidelines

The clear-cutting (or clear-felling) of mangrove forests according to well-defined harvest schedules represents an efficient means of obtaining relatively large volumes of wood and wood products. When conducted properly, care is taken to minimize site disturbance and provide a suitable habitat for natural regeneration.[3] Improperly conducted forest clear-cutting and extraction operations create a variety of short- and long-term consequences which represent economic losses, opportunity costs and, frequently, the loss of human life.

Mangrove forest resources have a relatively high economic value, although in many parts of the world, they are not utilized for economic purposes.[8] Mangrove forests managed for sustained yield can be viewed as a production forest offering many types of wood and wood products. Also, when managed properly (particularly during the harvesting and extraction phases), an important coastal habitat is preserved, while at the same time, economic benefits are being derived. Abusive or exploitative clear-cutting for short-term profit destroys the potential for future economic benefits and has a severe impact on the nearshore and offshore marine habitats. The following guidelines present a summary of management approaches:

1) The basis for the silvicultural management and scheduled annual harvesting of mangrove forests is developed from a site and forest type map

A



B

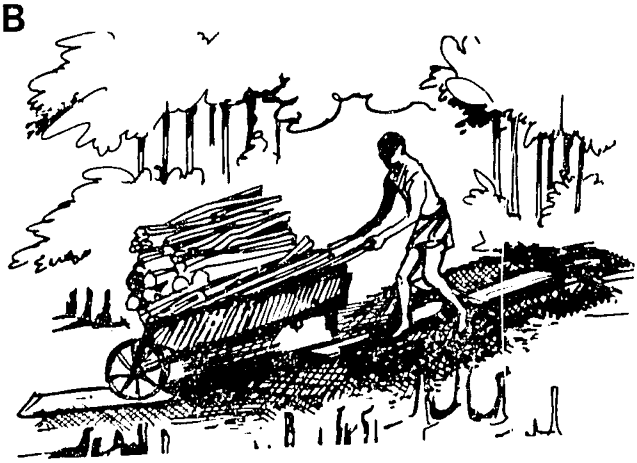


FIGURE 32. Two methods for the transportation of mangrove forestry products involving small-scale waterborne transport (A) and transport by wheelbarrow through the forest (B).

incorporating mensurational data on forest volume and forest growth rate. The silvicultural and forest measurement procedures are similar to those used in general forest management and are easily adapted for use in mangrove forests.

The general procedure treats the forest as the capital investment (as in financial investments) and the annual growth increment as the interest earned on that capital. Just as a good financial manager never uses the capital, only the interest, so do forest managers interested in long-term forest yield.

2) In order to set cutting schedules for long-term sustained yield, the mean annual net incremental growth is determined for the whole forest under management. This annual growth increment, measured in cubic meters, cords, units, or board feet of wood, sets the limit on the maximum allowable annual harvest. Several mangrove forests are under such continual management. This is especially true in parts of Southeast Asia, where new forest measurement data are obtained at regular intervals in order to revise the estimate of the annual growth increment. This is frequently necessary because annual growth rates tend to vary from year to year according to changes in climatic conditions and related environmental trends.

Alternatively, in the absence of forest volume data, the allowable harvest can be estimated as a function of the preferred rotation age determined for the whole forest. The rotation age is the number of years required to harvest all forest areas one time which is equal to the number of years required for the trees to reach a specified size, girth, and/or height.

3) The most critical time in the management and utilization of mangrove forests is the period during which the harvesting and extraction of timber is taking place. This is because the felling and removing of trees tend to disturb the sediment substrate which promotes erosion and soil degradation. It is therefore necessary to plan the harvesting sequence and extraction procedures on a site-specific basis to minimize this impact. Minimal sediment disturbance permits the forest to regenerate and develop at optimum rates.

4) In all harvesting activities, irrespective of the specific procedure, it is beneficial to avoid all cutting along shorelines and the banks of tidal channels and rivers. The cutting and disturbance of these habitats can lead to accelerated bank erosion and a corresponding degradation of water quality. The minimum width of the buffer strip can be estimated by multiplying the average tidal amplitude by 15. That is, in an area with a 1-meter tidal range, the untouched buffer would be 15 meters.

5) To the greatest extent possible, harvesting should be conducted by cutting in narrow strips or blocks perpendicular to the shore. The strips intermix with stands of uncut trees, thus avoiding large, continuous denuded areas and reducing sedimentation and excessive runoff. Care should be taken to leave an adequate seed source for regeneration. Planted stock can be used if rapid regrowth is desired.

6) During harvesting operations, typically only the large wood is removed; the branches, leaves, prop roots, etc., are left at the place where they are removed from the tree. It is recommended that the slash (harvesting debris) be cut and distributed over the cleared area to encourage regeneration and to prevent the slash from moving on successive tidal cycles and destroying regenerating trees. Care should also be taken to prevent the slash from becoming a barrier to the dispersal of mangrove propagules necessary for forest regeneration. In populated areas, there is also a possibility that the slash can be sold as domestic fuel.

7) Because of the wide variation of mangrove environments and mangrove forest types, and the presence of contiguous marine habitats (e.g., seagrass meadows, coral reefs, etc.), harvesting and extraction procedures should be designed to minimize environmental damage to nearby habitats and to maximize the potential for forest recovery.[3] To minimize extraction disturbance, logs, poles, and other wood products should be removed using small boats in temporary channels, skidded to a central inland point, and then from that single point to the transportation channel or, in the case of small-dimension timber and an adequate labor supply, carried out manually.

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See Also: Mangrove Ecosystems (p. 23); Mangrove Forest Harvesting (p. 103); Fuelwood and Other Renewable Resources (p. 115).

FUELWOOD AND OTHER RENEWABLE RESOURCES

Introduction

It is possible in many regions of the tropical world to meet local needs for green forage for domestic animals, liquid fuels, nonstaple food items, such as honey, and other such products from the natural resources of mangrove forests. The production activities would also provide jobs; with reasonable controls, the resource need not be degraded.

Fodder and Forage. Mangrove foliage is not a major source of fodder or forage material for livestock, but in certain arid parts of the world where rangeland is limited (e.g., the Middle East, Pakistan, India), it provides a green forage for both camels and cattle. Milk produced from dairy cows that are fed mangrove foliage is reported to be exceptionally high in butterfat content. Nutritionally, mangrove foliage is equivalent to the better forage species grown for grazing and stall-feeding. In addition, it naturally contains salt, iodine, and various trace minerals because of its growth in a coastal marine environment. Most forages are deficient in these minerals so they must be supplied from other sources. Although mangrove growth and development tends to be limited in climatically harsh arid environments, species adapted to the conditions happen to be the preferred species used for this purpose. Elsewhere in the world, mangrove foliage is used on a limited scale for domestic animals such as sheep and goats. Although overgrazing or overharvesting can be highly destructive to the mangrove habitat, the nutritional value of the foliage and its widespread use (in certain areas) makes it a forage resource that should be managed on a sustained-yield basis and protected from abuse.[1]

Mangrove foliage may be utilized as a domestic forage in two distinct manners. Foliage may be harvested in the mangrove forest and transported elsewhere for the stall-feeding of domestic animals. Alternatively, local animals may be allowed to graze directly on the foliage, as in the case of camels around parts of the Arabian Sea during the dry season. In Pakistan, for example, professional graziers bring camels from the Province of Sind into the Indus delta area where green mangrove foliage is available. The camels remain in the coastal areas from June until October, and the graziers must bring in fresh water at intervals for the grazing stock. It has also been found to be beneficial for chickens and a variety of other animals.

With suitable management practices, mangrove foliage can be safely and profitably used as forage in areas where grazing is limited.

Fuelwood and Charcoal. In coastal areas of the tropics, a major source of fuel is the wood from mangrove forests which may be used as a dry wood fuel or converted to charcoal. The intensity of the use ranges from scavenging as in the densely populated portions of India and Africa, to managed harvesting as in some Asian countries that produce wood fuel on a continuing basis. In areas where mangrove wood is relatively abundant, only branches and dead trees are utilized. In areas of scheduled harvesting, the slash (leftover small wood and branches) is used for fuel. But certain heavily populated areas where mangrove forests are limited, as in parts of Africa and India, all parts of the trees are used, including dried leaves. Yet indiscriminate, uncontrolled cutting seems to be the dominant practice throughout much of the world (Figure 33). In many areas, mangrove wood is made into charcoal (carbonized) using permanent or temporary kilns. Charcoal is usually preferred, compared to dried wood, because of its light weight and heating efficiency.

Charcoal is produced in tightly sealed kilns that allow only small flows of air to support the carbonization process. The kilns may be small, temporary, earth pits or large-volume, commercial retorts. Carbonization typically takes 30-45 days, but in some areas, a lower grade of charcoal may be produced within as few as 8 days. The first phase involves slowly burning the wood, followed by sealing the kiln and allowing the kiln to cool. The quality of charcoal can be varied by its placement within the kiln and the alteration of temperature and burning time. One cubic meter of wood will typically produce over 100 kilograms of charcoal. Prices vary according to the quality of the charcoal but, in general, range around US$3 per 100 kilograms (worldwide estimate). In general, species of the Rhizophoraceae (prop-rooted mangroves) are preferred for charcoal, although wood from the other mangrove species can also be converted to charcoal.

Alcohol, Sugar, and Thatch. The nypa palm occurs in coastal mangrove forest environments that have low to moderate salinity regimes. In these areas, nypa occurs on the inner portion of the intertidal zone where there is a significant source of fresh water from terrestrial runoff that creates a salinity regime favorable to the relatively salt-intolerant nypa palm. Natural

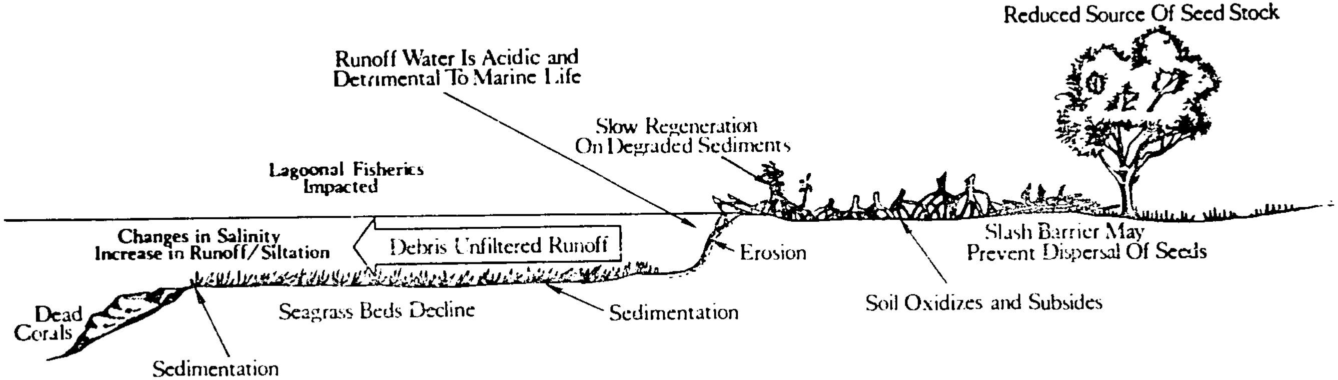

FIGURE 33. Environmental effects of overexploitation for fuelwood in nearshore coastal resources.

nypa forests are largely restricted to Southeast Asia and Oceania, but nypa has been introduced into West Africa (Nigeria). In optimum habitats in Southeast Asia, stands of nypa palm extend over thousand of hectares. Nypa fronds, when properly woven and stitched together, are used to make two-meter-long shingles for roofing material that will last from three to five years. In the Philippines, shingles are sold for US$7-$10 per hundred. The sustained-yield shingle production from a nypa palm forest approximates 15,000 pieces/hectare, making it a significant local industry. Locally, nypa has been extensively used as a major source of thatching for the roofs of dwellings and is managed for that purpose in some countries (e.g., Bangladesh and the Philippines).

The nypa palm, however, is also rich in a sugary sap (14-17 percent sucrose) that can be converted to sugar, fermented into vinegar, or fermented and distilled for the production of commercial-grade alcohol.[1] Although many species of plants are capable of producing a fermentative sap or liquid, the nypa palm is notable for its extremely high yields under managed conditions.

When the sap is used for the production of raw or refined sugar, yields upwards of 20 tons/hectare/year are obtained; this exceeds the production of sugar from other sources such as sugarcane, cassava, sweet potato, or coconut sap.

In Southeast Asia, yields of commercial-grade alcohol can range from 6,000 to over 15,000 liters/hectare/year. In certain countries, (e.g., Papua New Guinea and the Philippines), nypa alcohol is being considered for use in "alcogas" by blending it with gasoline.[2]

The production of sugar and alcohol from the nypa palm requires that the plants be managed as a plantation with specific management practices to maximize growth and, hence, yield of the sap. A producing plantation normally has fewer than 750 plants/hectare. A nypa palm usually matures within three to five years, during which time a 0.6-1.4 meter fruit stalk develops. Tapping typically begins in the fifth year of growth. The sap is obtained from mature fruit stalks, usually two per plant, by removing the fruit head. The severed end of the stalk is inserted into a container to collect the juice. Production is year-round which, in part, accounts for the relatively high yields as compared to other crop plants that have seasonal production characteristics.

One of the critical management practices required to initiate sap flow is called "gonchanging" which is the regular beating or kicking of the plant. At the beginning of the production period, the kicking of the plant is done once each week, progressing to daily for 10 days in the fourth month. During this time, the fruit stalk is progressively bent over for tapping convenience. For the first few weeks, sap flow is low (about 0.5 liters/palm/day), but increases to about 1.0 liter/palm/day for the life of the plant.[2] The collection containers are emptied once or twice each day. Nypa plantations managed for sap production cannot be used as sources of thatch; the removal of the green palm fronds results in lowered sap yields.

Honey and Wax. Honey is a traditional natural sweetener with a high cash or barter value, particularly in areas where refined sugar or substitutes are not available.[2] In most mangrove forests of the world, there are wild populations of honey bees that utilize the pollen and nectar of certain mangrove species for natural honey production. Some countries, such as Bangladesh and India, rely heavily upon local honey production. In the Ganges River delta, honey comes from the mangrove production forests and from associated areas dominated by other species of mangroves. There, the wild honey trees are cut down, or otherwise destroyed, to harvest the hives located in cavities within the trunk.[2] In India, some 2,000 people are employed as honey gatherers in an industry that yields approximately 170 tons of honey and 49 tons of beeswax per year. The production system is sustainable because of the large size of the area and the access limitations which, in some areas, may be attributable to a resident tiger population. In south Florida, some commercial hives are maintained within mangrove forests, and consumers report that "pure" mangrove-derived honey is of superior quality. The ability to maintain beehives in the forested coastal environment without major problems demonstrates its potential as a local industry in many parts of the world.

In the traditional mode, honey is obtained by locating a wild hive, killing the bees, and extracting the honey. In some areas (e.g., Africa), straw or clay pots are hung in the trees to provide a refuse for wild bees which, after colonization, are killed and the honey removed.[2] Honeybee populations can be managed for much higher and continuing yields by using any of a variety of simply constructed hives that provide areas for brood maintenance and honey accumulation. In its basic form, an artificial hive provides for honey removal without destruction of the bees. Inexpensive, advanced hive designs also permit the colony to be manipulated for controlling hive production.[1]

In many areas, mangroves produce nectar (used by bees to make honey) and pollen (food source for the brood) for only part of a year, thus requiring that alternative sources be identified for hive placement during the off-season. Care must be taken to insure that the honey is not contaminated with nectar from certain plant species which impart a bad taste to the honey. Although commercial hive operations in tropical forests can obtain yields upwards of 150 kilograms/hive, well-managed hives in mangrove areas appear to be able to produce 35-40 kilograms of honey/hive colony/season.[2] Whereas the absolute yields may be low by comparison, the development of a honey production industry in some mangrove areas can help to meet the dietary needs of local people and provide employment.

Problems

The growing degradation of mangroves resulting from the absence of adequate management is most commonly associated with direct exploitation as sources of fuelwood, charcoal, and tannin; construction materials; and conversion of lands for use for agriculture and aquaculture development activities. While less well-documented, there appears sufficient evidence to warrant concern for this abuse to sources of fodder and forage. Because of these pressures on the resource, there is a need to limit the amount harvested or grazed during a season to insure that sufficient mangrove growth stock remains to regenerate the same amount prior to the next grazing or harvesting season. In most areas, sustained-yield management is not presently practiced, and the annual consumption of green foliage (including growing shoots) exceeds the regenerative capacity. This one characteristic, overharvesting/overgrazing, may be the most important problem concerning mangrove resource utilization.

The extent to which human pressures have resulted in declining yields for nypa palm are unknown for lack of data. Despite these uncertainties, nypa palm, like other renewable resources, can be managed for sustainable yields, an approach which appears justified where the resource is extensive enough to warrant large-scale exploitation. Similarly, while little is known concerning the status of honey bees, the production from beehives may be threatened from two sources: the direct exploitation of mangroves (on which they depend) and their destruction for honey extraction. While the implementation of adequate mangrove management approaches described elsewhere in the document would appear to mitigate the impact of the threat formed until more data can be gathered on the ecology and status of honey bee production, the artificial maintenance of brood stocks remains the best sustainable management option for honey exploitation.

Guidelines

The following guidelines are presented separately for the individual subjects. Overall, the most important requirement is maintenance of sustained yields.

Fodder and Forage. In the absence of significant documentation concerning the use of mangrove foliage for fodder and forage, management guidelines are limited to the perpetuation of the mangrove growing stock.

1) The most important management guideline concerns the establishment of the maximum sustained yield that can be expected from the resource. Prior to promoting the use of mangrove foliage as a green fodder, the maximum sustained yield must be established.

2) In areas where mangrove growth and development are limited, it is recommended that a rotation system be used to prevent exploitation. Specifically, following a season of grazing, the grazed area should be excluded from further use until it has completely regenerated.

Alcohol, Sugar and Thatch. In the management of nypa palms for the production of sugar, alcohol, and thatch, the sustained availability of fresh water is the single most important criterion. Where nypa palm forests are extensive and the freshwater source is secure, those areas can be placed into a sustained production system.

3) The sustained-yield production of nypa palm requires that fresh water be normally available so as to maintain low salinities along rivers and drainages in the mangrove environment.

4) Nypa palms are pollinated by the fruit fly; thus, the use of pesticides must be prevented in plantation or natural palm-forest areas.

Honey and Wax. For the present, the lack of data concerning the management of bee colonies prevents their management for sustainable yields in their natural environment. This constraint forces harvesters to breed bees in artificial hives. However, the production of honey and wax is still dependent on the adjacent mangrove forest which serves as the principal source of nectar and pollen.

5) The destruction of bee colonies for honey and wax extraction should be discouraged in favor of development of artificial hives for maintenance of brood stocks, providing a means for sustained-yield production.

6) Alternative food sources to mangroves must be identified to support year-round production for the seasonal availability of nectar and pollen.

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See Also: Mangrove Ecosystems (p. 23); Mangrove Forest Harvesting (p. 103).

ENERGY

OIL AND GAS OPERATIONS

Introduction

The petroleum industry usually involves exploration, production, refining, and transporting in the regions of tropical OPEC nations, such as Nigeria, Venezuela, Ecuador, and Indonesia. This often creates perceived or real threats to the local fisheries and the conservation of coastal resources, including coastal wetlands. Oil spillages from well blowouts, tanker spillages, pipeline breaks, and offloading activities can create, and have created in the past, long-term damage to coastal resources. These spills can promote two types of damage: acute and chronic.

Problems

Acute spillages usually result from transportation accidents. This type of spillage has occurred along the coasts of Panama, Indonesia, Nigeria, and other countries which contain or are adjacent to oil transportation activities. For example, in the late 1970s, a tanker released thousands of barrels of crude oil into the Singapore Straits where it then moved ashore to impact a large mangrove forest, resulting in several hectares of dead and dying mangroves within a few months (Figure 34).[1] In the late 1960s, a tanker released several thousand barrels of crude oil onto the shorelines of Panama, which resulted in the mortality of mangroves and other coastal organisms.[2,3]

Another type of spill, that of offshore well blowouts, is less common, but has a greater magnitude of impact on the coastal environment. In Nigeria in 1981, an offshore well blowout of Nigerian crude oil resulted in the mortality of over 250 hectares of mangroves on the Niger delta (unpublished Research Planning Institute survey).[4] Acute spillages may also result from pipeline breaks; this may be especially damaging when the pipelines are adjacent to critical coastal resources such as freshwater and marine wetlands, fishery resources, and habitats of endangered and threatened wildlife. In Guam in 1982, over one million gallons of crude oil leaked from a pipeline into a large, freshwater/wetland area, causing a major impact to the wetland areas (unpublished Research Planning Institute report). Also affected was a local prawn aquaculture facility which shared its drainage system with the impacted wetlands.

A second type of spillage is termed chronic. This type is more commonly associated with shore-based refining and/or offloading operations and energy ports including operations which produce drilling mud effluents. For example, most embayed ports and harbors which handle petroleum products are likely to have detectable petroleum hydrocarbons in the water. Although the effect of low levels of petroleum hydrocarbons is usually not as devastating as an acute spillage, the potential for bioconcentration and uptake by marine organisms is great. In oil ports in Nigeria, South America, and Southeast Asia, oil operations and associated low-level pollution have led to changes in the species composition of the port area. Shellfish from these areas are known to accumulate hydrocarbons and other materials associated with the petroleum-industry operation of oil ports and harbors and thus to be rendered inedible.

Different coastal environments are differentially sensitive to oil spills (Figure 34). In general, the greater the degree of sheltering (outer, less-protected coasts versus lagoonal, more-protected shores) and the greater the grain size (boulder/cobble versus fine-grained sand), the greater the persistence of spilled oil on intertidal zones. Numerous spills have been reported to impact sand beaches in tropical areas with a minimum of damage. The greatest conflicts between coastal resources and the oil and gas industry have occurred in certain regions with large areas of coastal wetlands and coastal fisheries which have received acute spillages. The damages occurring from these spillages depend upon the type of mangrove forest which is impacted and upon the type and amount of oil which reaches the shoreline (Figure 35). The most sensitive are riverine and basin forests.

Oil spillages have also occurred over coral reefs, but the results have been less damaging than those seen with spillages in mangroves. For example, a tanker spill of crude oil in Palau in 1982 covered intertidal corals at low tide (unpublished Research Planning Institute account). On the rising tide, however, the oil was removed, and no subsequent damages were recorded. An oil spill on the Great Barrier Reef (Australia) in the 1970s also covered intertidal corals with oil, but no damages were reported in this case either. It appears that subtidal reefs are even less likely to suffer mortality from acute spillages. In 1976, a tanker foundered on a reef off the harbor entrance at Wake Island (in the North Pacific), releasing a large amount of low-viscosity oil onto a reef flat. No damage to the reef was reported.

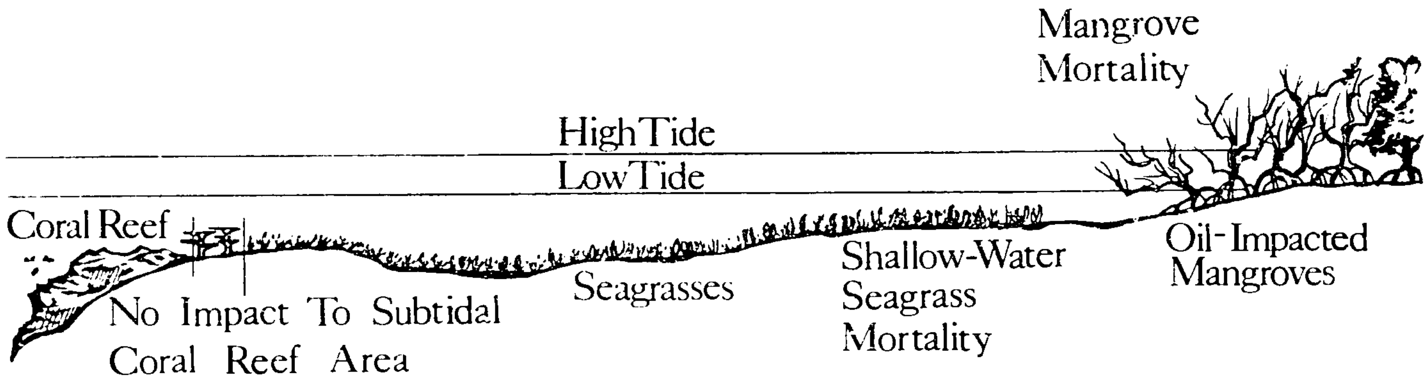

FIGURE 34. Simplified continental shelf profile with effects on coastal resources observed during past spillages.

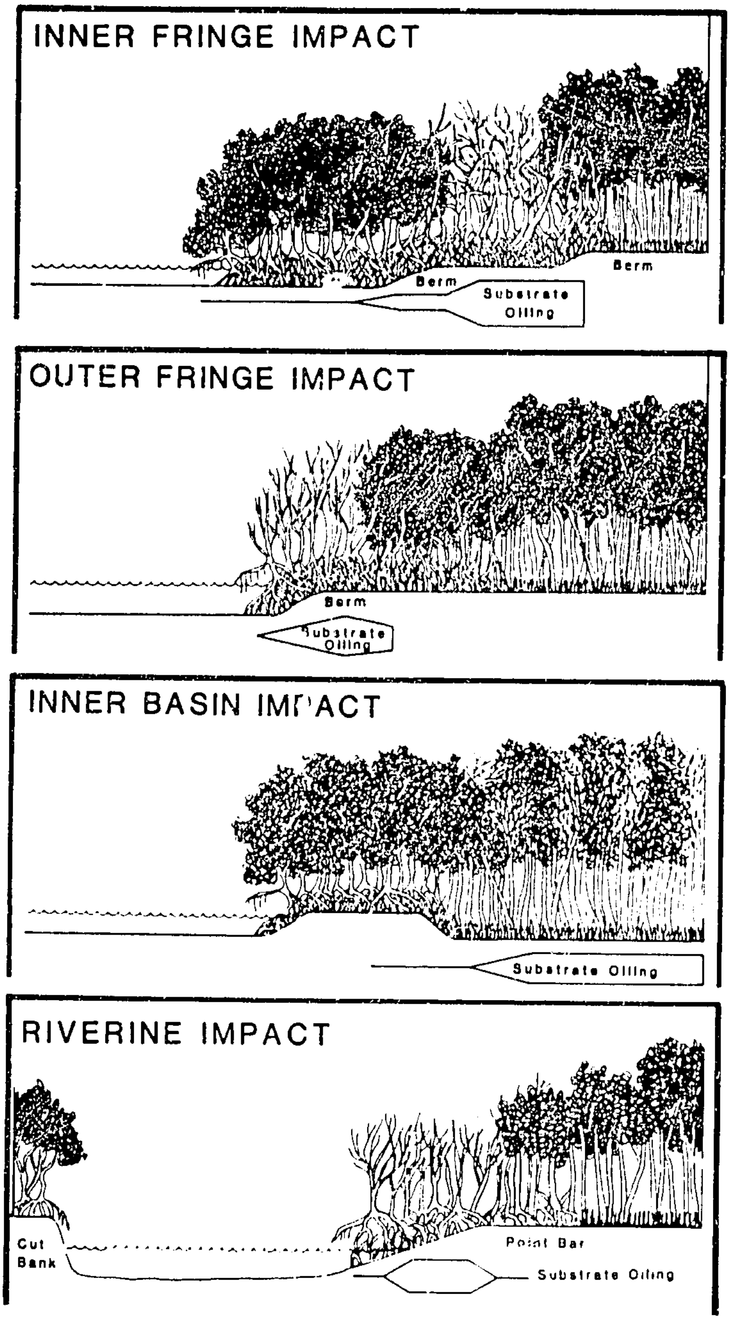

FIGURE 35. Oil damage to mangroves depends upon forest types.

However, over 2,500 kilograms of dead reef fishes (especially grouper and squirrelfish) were washed up on the beach after the spill, indicating damages to reef-associated organisms.

Oil spills have been observed to create small-scale damage to seagrass beds in Puerto Rico and Mexico, but effects were limited to (1) intertidal turtle-grass beds or to (2) areas impacted by oil which became weathered, sank to the bottom, and coated the surface and the substrate of the seagrass beds in a restricted area.

Oil operations also may potentially affect fishery resources, although the documentation of this is sparse. For the most part, quantified damages from oil spills to fishery resources have been to fishermen's boats and gear, to intertidal shellfish resources, and in lost fishing effort, although near- and offshore damages are speculated from studies conducted in temperate areas. In Nigeria, following an offshore well blowout, the gathering of shellfish in mangroves (oysters and periwinkles) was curtailed due to tainting of flesh and to mortality of the shellfish and the mangrove substrate upon which they were found. Numerous areas including the eastern Malay peninsula, the Java sea, and the coastal waters of Ecuador are currently under large-scale development for oil and gas production, creating apparent conflicts with local fisheries.[4]

In Ecuador, the discovery of oil in the sparsely populated Amazon Oriente generated a major shift in the economy. The activities which followed included the construction of a 300-mile trans-Andean pipeline from the Oriente to the port of Esmeraldas. Petroleum-export revenue increased from US$61 million in 1972 to over US$1,000 million in 1979.[4] This was an increase in percentage of export dollars from 19 percent to 50 percent within seven years. During the same time, total fisheries production tripled and, in 1982, ranked third in export, immediately behind petroleum. The importance of these fisheries has resulted in an oil spill contingency plan which focuses on oil spill prevention.

Well blowouts probably constitute the greatest potential for devastation and long-term damage by threatening coastal fisheries, wildlife, and coastal environmental resources. Chronic sources of pollution can taint the flesh of fish and shellfish in impacted areas.

Prevention of oil spills is the key with which oil and gas operations can blend with coastal environments and fishery resources. This involves creating a detailed contingency plan which provides the traffic patterns of marine petroleum transportation to and from ports and having the availability and deployment potential of spill response equipment and trained personnel available for immediate response to such a spill.

Guidelines

The key to reducing petroleum sector damage to coastal resources is in the prevention of of petroleum products spills. Under typical conditions of the tropical intertidal zone, most coastal ecosystems exposed to small amounts of oil pollution have a remarkable natural ability for self-maintenance and self-renewal (e.g., following a disturbance) when the basic habitat characteristics favoring their original formation and functioning are maintained. However, these same coastal ecosystems are extremely sensitive to factors which alter the prevailing water quality and substrate conditions. Conservation of the ecosystem and its resources can be simply achieved by preventing any significant change from occurring in these factors.

Oil and gas operations should perpetuate the natural patterns and cycles of tidal activity and freshwater runoff. Coastal structures and water development schemes associated with oil and gas operations often have the potential to change these natural patterns and should therefore be modified to insure that these patterns are maintained. The best time to deal with the environmental consequences of oil and gas operations in a given area is in the planning phase for all such activities, not after the operation is underway and has already begun to negatively influence natural coastal resources. The coastal resources which may be affected by oil and gas operations should be identified before these operations begin. Site-specific studies may be required at many localities. The interface between the land and sea is a dynamic, changing natural system. Dealing with this system requires careful study, which may be costly. But, these costs are minimal when compared to the coastal resource loss which results from poor planning. The guidelines below are those which are considered to be the minimal requirements for the maintenance and perpetuation of coastal resources adjacent to and receiving effluent from oil and gas operations:

1) Oil and gas operations should be conducted in a manner which (through proper siting and operation) minimizes changes to ambient-water

salinities, temperatures, and water clarity and transparency. These operations should avoid the disposal of wastes which would raise or lower the salinity and/or temperature of surrounding waters.

Dredging or other activities associated with oil and gas development that disturb the sediments and create silty water should not be undertaken near or upstream from coastal resources, especially coral reefs.

2) All operations should avoid the discharge of oil and grease into the marine environment, especially chronic, low-level discharges, which can be prevented through proper plant siting and through effective treatment of effluents. Ocean outfalls with untreated effluents are not acceptable means of discharging waste, since these effluents float and may return to shore with certain climatic conditions.

3) Oil and gas operations and siting should maintain the integrity of the land/sea interface, as well as the original configuration of coastal substrates, when constructing land- and sea-based pipelines, since the coast and nearshore substrate are key factors in the perpetuation of coastal resources. Operations and construction activities that might lead to excessive sedimentation, erosion, or alterations in the chemical characteristics of coastal sediments should be avoided.

4) A detailed contingency plan should be developed for potential spills in each harbor or other sensitive coastal area subject to spills.

5) Before a coastal operation is undertaken, a thorough evaluation should take place which, among other things, includes a modeling of the fate and effects of a "worst-case" spill which could result from the proposed operation. This should include a detailed evaluation of the anticipated damages to coastal wetlands and fishery resources which would result from a worst-case scenario.

6) Open-coast, deep-water ports are preferred for oil operations over embayments which are likely to contain an abundance of natural resources in a sheltered condition.

7) Cleanup of oil on oiled beaches and other coastal areas should commence only after all oil has impacted the shore. Natural cleanup or manual cleanup should be emphasized, while the use of heavy machinery or extensive substrate removal should be avoided.

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See Also: Ports, Channels, and Harbors (p. 141).

COASTAL POWER GENERATION

Introduction

Electric power-generation plants are often located in the coastal zone because of the large volume of cooling water that is required. In a coastal plant operation, seawater is used as the heat exchange vehicle for maintaining an efficient heat gradient within the power plant. Unless the plant is fitted with a closed-cycle cooling system, the hot water from the plant is discharged into the nearshore waters in an area distant from the intake area in order to prevent recirculation.

Problems

The problems associated with coastal power plants can be divided into two categories: chronic and accidental. The chronic problems involve the mortality to marine animals that are associated with the intake water and the discharge of that heated water. These include the disposal of fly ash for fossil fuel plants; the offloading of oil or coal; the use of chemicals to clean condenser tubes (heat exchange system) within the plant; and the presence of radioactive isotopes created by nuclear plants. Accidental problems include the spillage or dumping of fuels; the overheating of cooling water; and reactor accidents in nuclear plants.

The intake water which enters the power plant carries with it a large number of planktonic organisms (plants and animals), larval and juvenile marine animals, and those larger marine animals that track the flow of water (Figure 36). The smaller organisms entrained with the intake water are carried through the plant where the elevated temperature and rapid pressure changes cause mortality. The larger animals which cannot pass through the small diameter of the condenser tubing are "screened" or filtered out before entering the plant. Most of the dead animals impinged on the filter screens are removed and disposed of by plant operators. Power plants with long intake canals entrap various kinds of marine animals which, once in the canal system, are unable to escape; they are, in effect, removed from the local breeding population.

The heated discharge water creates a second set of problems for the coastal area which receives it. In a typical operation, the water that passes through a power plant is elevated 10 to 15 degrees Celsius above the

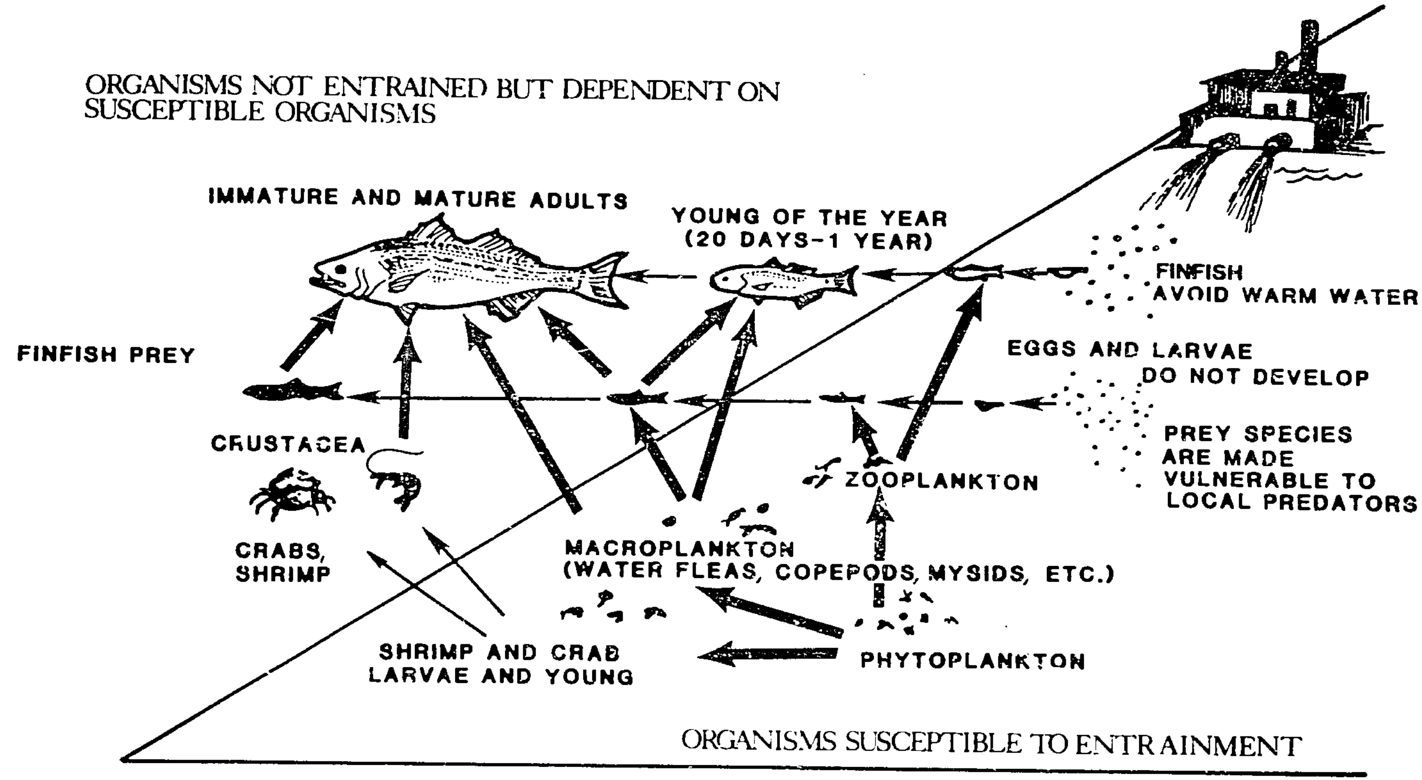

FIGURE 36. Potential power plant impacts involving organisms susceptible to entrainment and those not entrained, but dependent on entrainment-susceptible organisms. (Source: Ref. 1.)

ambient-water temperature at the intake. In warm-water environments, this rise in temperature is higher than the thermal tolerance limit for some marine plants and animals (in the localized discharge area prior to cooling). In general, that threshold is around 30 degrees Celsius. In the heated water discharge area, termed the thermal plume, the decline in water temperature with increasing distance away from the point of discharge results in a characteristic zonal distribution pattern of species composition and viability. Also at the point of discharge, there is frequently an area of scoured sediment which is swept away by the velocity of the discharge current. As the water moves away and its temperature progressively decreases, erosion lessens and sedimentation increases.

The discharge of thermally elevated water into shallow, low-flushed estuaries and lagoons probably causes the most harm to marine life because of the abundance of the highly susceptible planktonic life (including young stages of fish and shellfish). Generally, where the discharge of thermal pollutants occurs in deeper waters or in better-flushed coastal areas, the impact is lessened.

The thermal efficiency of a power plant is maintained, in part, by creating an efficient system for extracting excess heat in an elaborate condenser system and then disposing of the heat into the discharge water. The heat removal, or exchange, requires that the condenser tubing be clean; that is, not only free of sediment accumulation, but also of fouling organisms. This problem is usually handled by poisoning the organisms with such toxins as sodium hypochlorite. The reactive chlorine that remains in the discharge water causes mortality in the smaller marine organisms resident in the receiving waters.[2]

For fossil-fuel plants that burn oil or coal, deliveries of large quantities of fuel are made on a regular basis. During the offloading operation, there is usually enough leakage or spillage to degrade the water environment in the vicinity of the plant.

In nuclear plants, radioactive material which requires disposal is created through neutron activation. For those isotopes which exist in a gaseous form, disposal is usually accomplished through atmospheric venting. In liquid form, isotopes are slowly released into the discharge water so as to achieve a maximum amount of dilution. In either case, this disposal into the environment poses an unresolved problem that is associated with nuclear plants.

Other acute problems include accidents that are associated with excessively heated water, the release of pollutants[3] such as spilled oil, the escape of radioactive isotopes, and mass movements of migratory species into the water intake range.

Because the waste-discharge heat is a major problem associated with all power plants, various alternatives to once-through cooling have been developed in order to minimize the environmental impact. Among these alternatives are mechanical and forced-draft cooling towers and closed reservoirs from which cool water is withdrawn from the other end. Cooling towers tend to be very expensive, whereas the construction of large reservoirs for recirculating cooling water results in the conversion of large areas of natural habitats.

Under typical conditions in the tropical coastal zone, some plants and animals in the marine ecosystem are living at, or near, their thermal threshold and thus are living near the limit of their thermal pollution endurance.[3] Alternatively, in some situations, the waste heat could be used directly as a low-temperature process heat or, once stored in water, could be used as a low-temperature process water. If viewed as a resource, this surplus heat could be used for heating buildings, homes, mariculture ponds, and certain types of industries where low-temperature heat sources would be useful.

Guidelines

The major factor associated with minimizing the impact of power plants on a coastal environment is their location in relation to ecologically critical areas. Cooling water removal and return systems give rise to additional problems as do the various wastes that are released. The guidelines below are those which are considered to be the minimal requirements for the maintenance and perpetuation of coastal ecosystems which are located near, and receive effluent from, power plants.

1) Power plants should only be located in estuaries or lagoons if they are designed for closed-cycle cooling. Estuaries and lagoons are vulnerable to damage because of their rich planktonic life, shallow waters, critical nursery area functions, soft bottoms, and poor circulation. A poorly located plant can destroy significant amounts of planktonic fish, shellfish, and microorganisms and cause a general ecological blight around the plant.

2) Coastal power plants should be sited so as not to jeopardize ecologically critical areas. Siting criteria should include measures that avoid disturbance to habitats such as wetlands, seagrass beds, coral reefs, shellfish beds, and migration routes of estuarine and nearshore species.

3) When constructing land- and sea-based pipelines, power plant operation and siting should maintain the integrity of the land/sea interface, as well as the original configuration of the coastal substrates because of the role of coastal and nearshore substrate in the perpetuation of coastal resources. Operation and construction activities which could lead to excessive sedimentation, erosion, or alterations in the chemical characteristics of the coastal sediment should be avoided.

4) Power plant designers should concentrate on techniques that reduce the incidence of marine-life mortality caused by entrapment, screening, and entrainment. In some situations, this could be accomplished by diversions that would keep animals away from the intake. Entrainment is a more difficult problem to solve because the organisms are small enough to go through more screens. Those entrained in the cooling stream have no means of escaping. This problem can only be resolved by selecting a site on the open-ocean coast away from critical estuarine areas.

5) All operations should avoid the discharge of excess nuclear wastes and toxic substances into coastal waters, especially where they enter the food chain and could eventually be consumed by man. Buildup of low-level discharges can be prevented by proper plant siting (discharge to deep-moving waters) and by thorough treatment of effluents. Ocean outfalls with untreated effluents are unacceptable means of discharging waste, if then effluents return to shore under certain conditions of tide and wind.

6) Accidental problems can be minimized by implementing efficient maintenance programs and training personnel to be responsible for handling emergency situations. This includes contingency plans for pollution spills and exacting shutdown procedures in the event the cooling water system fails.

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See Also: Capture Fisheries (p. 95); Estuaries and Lagoons (p. 49); Ports, Channels, and Harbors (p. 141).

TRANSPORTATION

PORTS, CHANNELS, AND HARBORS

Introduction

Due to increasing importance of the worldwide waterborne-transport systems, and the concomitant need for improvement of deep-water ports, channels, and harbors, numerous natural resource impacts associated with this type of development in coastal areas have been documented. For both new port facilities and existing facilities which have undergone expansion, the magnitude of these problems is generally a function of the real or potential economic importance of natural resources at risk. Developing in these areas places a new set of demands upon the local economy and creates the threat of producing environmental impacts with short- and long-term effects that could represent economic losses and high opportunity costs, as well as threatening the livelihood of those persons who directly or indirectly depend upon the crucial natural resources. Poor design and operation of ports and associated facilities may exact a cost that exceeds the benefits gained from the industrial development and operation.[1]

Problems

The economic incentive is to construct or expand ports in accessible locations which minimize total land and sea transportation costs; the environmental incentive is to site facilities in locations which would minimize the loss of economic opportunities caused by the removal or degradation of existing natural resources. The ideal situation would be to integrate the priorities of both the developer and the natural resource specialist, thereby satisfying all who are dependent upon coastal resources in one way or another. Coastal resource considerations in port development can vary tremendously depending upon the nature of the resources. The need for site-specificity in considering these variables is highlighted in the following example.

Recently, two very different ports were constructed in northwest Panama.[2] One was located on the Pacific Coast (Figure 37), while the other was situated on the Atlantic (or Caribbean) Coast (Figure 38). The respective ports lie at each end of the trans-Panamanian pipeline, which was constructed as an economic means of transporting crude oil from the Alaskan northern slope to the eastern United States market. Presently, a Pacific port (Puerto Armuelles) serves about 20 supertankers a month which offload approximately

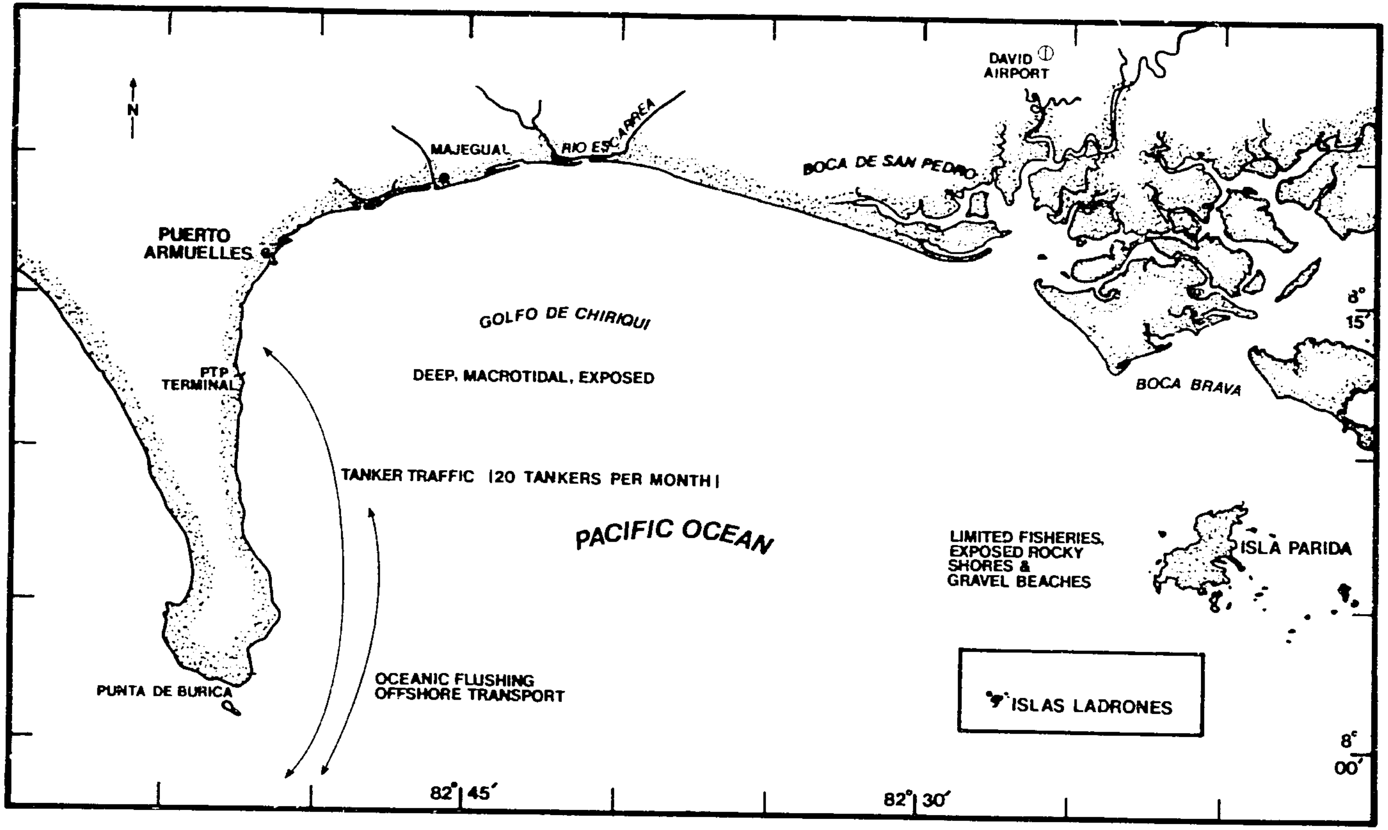

FIGURE 37. Puerto Armuelles, Panama (Pacific deep-water energy port).

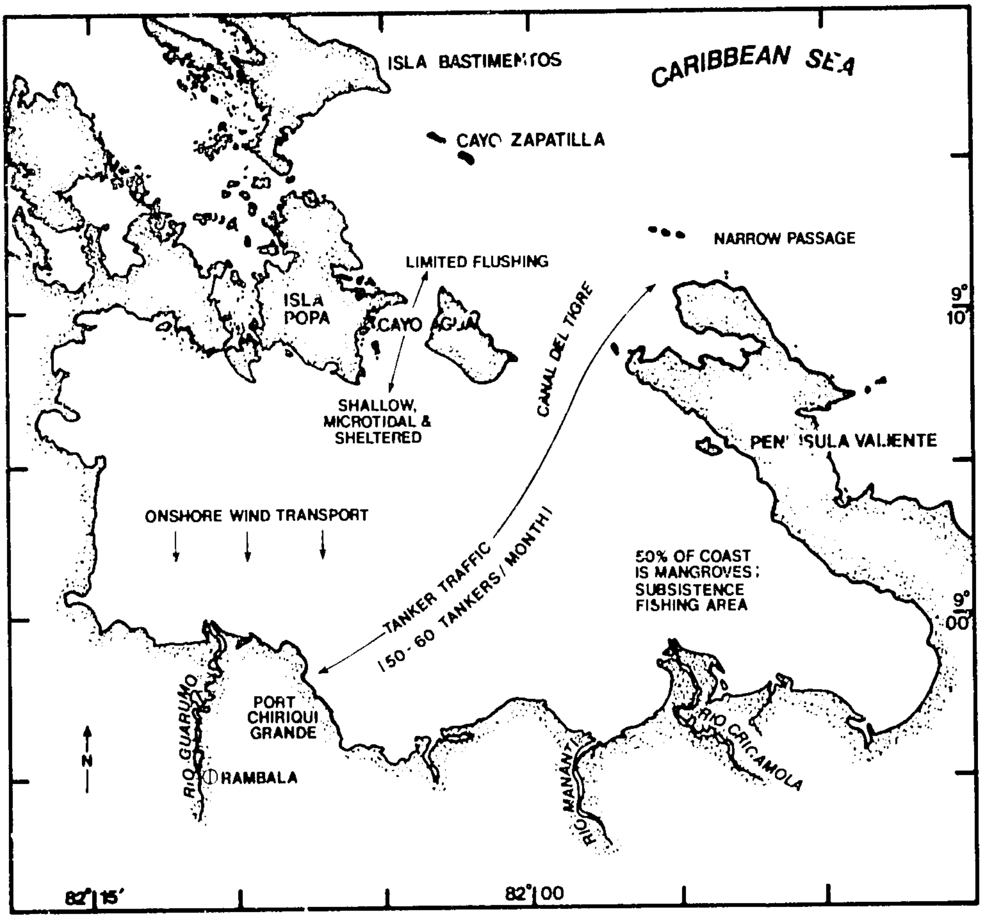

FIGURE 38. Laguna de Chiriqui, an environmentally sensitive energy port in western Caribbean Panama.

700,000 barrels of oil per day; this oil is then pumped via the pipeline to the Atlantic port terminal (Rambala). Here smaller tankers, carrying an average capacity of 365,000 barrels, pick up the oil and transport it to the eastern United States. About 50-60 tankers per month use the Atlantic terminal.

The biological and physical characteristics of the two ports vary tremendously. The Pacific port is deep and well flushed, has predominantly offshore water and sediment transport with deep ocean currents, is macrotidal, has high wave energy and exposed rock shores, and is not immediately adjacent to biologically critical wetlands or fishing areas. The Atlantic port is much more environmentally sensitive since it is very sheltered and shallow, has limited flushing capacity and is nearly landlocked, has predominantly onshore winds, is microtidal, has mangroves along over 50 percent of its shorelines, and supports a critical, subsistence finfish and shellfish fishery. Clearly, between the two port developments, the port which warrants the most concern regarding potential impacts from oil spills, dredge and fill activities, changes in dissolved oxygen and other water quality parameters, and impeding migrational patterns of commercially important marine species is the Atlantic port site.

Major categories of impacts associated with port development include dredging and filling of channels and berths; wetland modifications of proximal terrestrial systems of significant important species; changes to hydrological circulation as it affects sedimentation budgets, water quality, and biotic and abiotic transportation patterns; water quality impacts associated with sustained increases in effluent levels and aperiodic spills of hazardous materials; water quantity impacts associated with increased port requirements for fresh water; and secondary socioeconomic impacts associated with increased employment, increased population influx rules, and shifts in the makeup and economic base of the region.

On a different scale, development of marinas for smaller craft may take on major proportions in order to meet the recent increases in need for mooring and berthing facilities for small craft in isolated LDC locations. Large marinas have been developed, for example, in or near ports throughout the Caribbean, Central America, and South America. Marinas for smaller craft may moderately alter large areas of the land/sea interface and change the configuration of the nearshore substrate in a manner detrimental to local fishery practices, but they are often the site where the fishing fleets are based and therefore are essential to the industry. In general, the operation of smaller vessels is less detrimental to the marine environment because of the relatively low levels of oil, grease, and other discharge materials which are associated with them and because of the generally lower areal extent of land modification. Adverse impacts to natural resources due to land alteration and effluent increases may also be more than offset by increased access to commercially important species and by increased sustainable harvests.

Guidelines

Under typical conditions of the tropical coastal zone, most coastal resources exhibit the ability to rapidly colonize suitable habitats near ports, harbors, and coastal waterways; develop complex structures; and be productive under these conditions. Coastal ecosystems have a remarkable natural ability for self-maintenance and self-renewal (e.g., following a disturbance) when the basic habitat characteristics (e.g., substrate type, water quality parameters, and nutrient quality and quantity) which favored their original formation are maintained. However, they are extremely sensitive to factors which alter these conditions. In order to maximize economic benefits and minimize economic costs and risks, planning of port, harbor, and water improvements should seriously consider how those modifications will affect the physical, biotic, and socioeconomic environments of the port and surrounding areas.

1) Port improvements should be sited and designed in a manner which minimizes changes to existing water quality parameters, especially salinity, temperature, dissolved oxygen, nitrogen and phosphorus concentrations, organic constituents, and transparency of the water.

2) Waste disposal sites, rates, and compositions should be carefully evaluated by engineering, water quality, and natural resource specialists to minimize adverse impacts to human health and important biological resources. This includes both organic and inorganic materials, as well as discharges to water with high temperature or salinity characteristics.

3) Dredging operations should consider impacts of depressed dissolved oxygen levels in deeper channels on commercially important demersal or benthic species, as well as the effects of turbidity on sensitive

species or habitats such as seagrass beds and coral reefs where deposition of suspended sediments will occur. This normally requires an understanding of basic species composition, ecological requirements and migrational patterns, and basic hydrological circulation patterns.

4) Dredge spoil disposal on upland sites is usually preferable to disposal in nearshore or offshore areas, but evaluation of alternatives and economic/natural resource tradeoffs usually permit identification of an optimal disposal scenario. Disposal is normally most advisable where biotic production is low and water circulation impacts are minimized. Where industrial facilities produce persistent constituents such as heavy metal effluents, basic bioassay/bioaccumulation and spoil toxicity studies may be necessary prior to disposal site selection.

5) Ports, channels, and harbors should maintain the natural equilibrium between sediment accretion and erosion. Coastal dredge siting and configuration (e.g., jetties, groins, breakwaters), filling and disposal activities, as well as structure, can result in dramatically elevated economic costs for maintenance by altering the balance between accretion and erosion. The tradeoffs involved may not always be so readily apparent, however. For example, reduction in channel width to reduce spoil volumes may result in more adverse impact by reducing the ship transit safety factor and increasing spill probability rates.

6) Ports and harbors should be placed in areas with the highest available flushing rates, and the access channels should be designed to minimize water circulation changes and creation of a stagnant water column.

7) Ports, channels, and harbors should be sited so as to avoid critical coastal resources to the extent practicable. Routing around coral reefs and extensive mangrove forests minimizing the size of channels and the quantity of dredge spoil and minimizing impacts to water circulation patterns can greatly decrease direct and indirect economic costs.

8) Ports and harbors should incorporate facilities which allow for effective handling of sewage and industrial waste.

9) Dredging and offshore disposal operations should be timed so as not to coincide with critical periods of migration, spawning, or nursery activities of important commercial fishery species which may be affected by

the activity. Dredge types should be selected keeping in mind the different kinds of adverse environmental impacts which may result. Impacts may vary considerably between cutterhead, clam shell, burket, and hydraulic dredges, for example, depending upon substrate types, water quality conditions, and biota.

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See Also: Shore Protection (p. 157).

ROADS, RAILS, AND BRIDGES

Introduction

Industrial, commercial, and residential development in coastal lowland environments necessarily requires overland transportation facilities such as roads, railways, and bridge structures which are often over areas of open water. The transportation network links the development(s) to inland areas and to local ports and harbors. In general, construction costs in coastal lowlands are more expensive than in upland areas because of the usual presence of soft, nonload-bearing sediments and the potential threat of storm damage, flooding, and washout. During the construction of roads and railways, the soft sediments, usually organic in nature, are excavated; the procedure is termed "de-mucking" (Figure 39). The hole is then backfilled with fill such as sand, gravel, or aggregate in order to provide a solid foundation that will not settle under the load of road vehicles or trains. To minimize the potential damage from storms, the elevation of the road or rail surface is usually raised and the foundations are strengthened with additional fill. Permanent high-use road and railway foundations may be further strengthened with fill, rock, or concrete.

In the better designs, the existing tidal creeks and channels are bridged and left open to permit a natural flow of water and to relieve storm-surge flooding. However, because bridges are significantly more expensive to construct than roads or railways placed on solid fill, the number and size of bridges are kept to a minimum in the design process. It is not uncommon to find that the roads and railways which are constructed on fill are located in large shallow-water areas, since expensive bridges would be impractical. When bridges are used, they are typically constructed by using prestressed, reinforced, or poured concrete, because exposed iron and steel rapidly rust and corrode in a marine environment. In general, the construction of roads, railways, and bridges in coastal lowlands is justified on the basis of the economic development that they facilitate.

Existing engineering protocols could be used to minimize both the economic costs and the opportunity costs associated with the damage which occurs to the local natural resources.

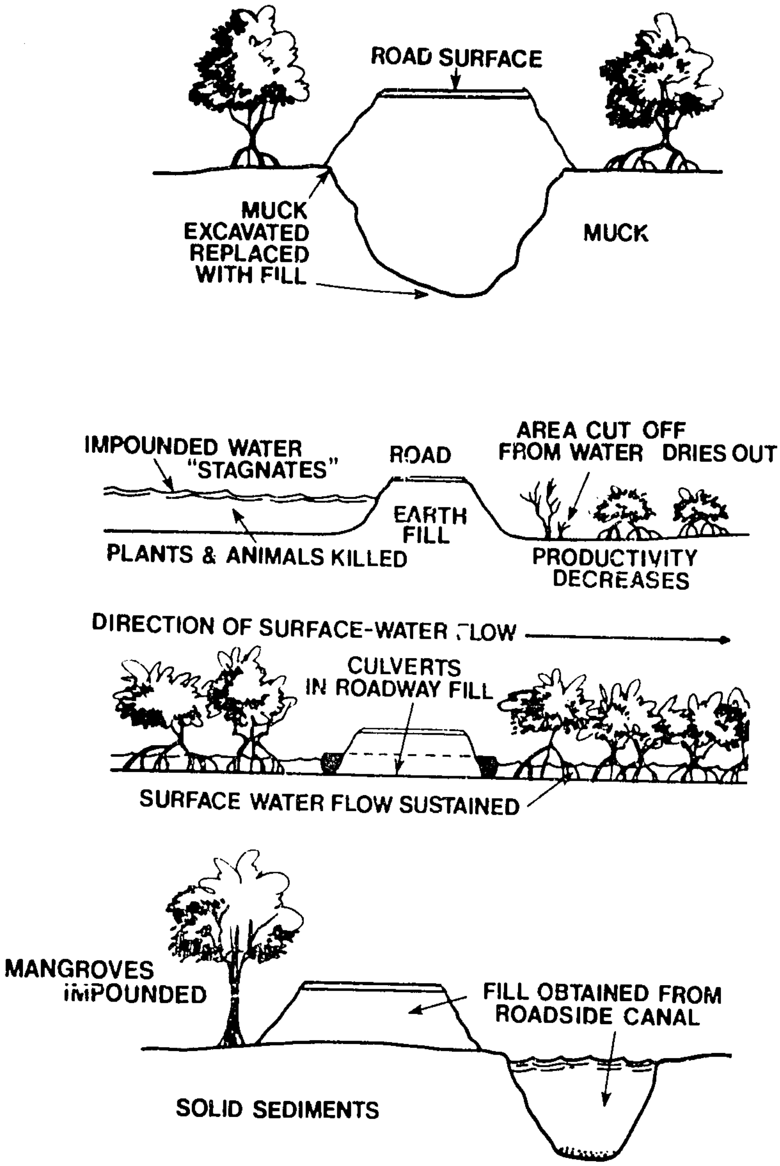

FIGURE 39. Four different road construction techniques, each with different environmental effects.

Problems

The most significant problem associated with roads and railways in the coastal environment is that they cause the partial or complete impoundment of natural areas that are normally maintained by tidal flooding and surface-water circulation. The complete impoundment of an area by barriers to water flow results in the rapid mortality of plants and animals through stagnation of the entrapped water or through the desiccation of an area that no longer receives an inflow of terrestrial freshwater runoff or tidal water.[1] More commonly, an area is only partially impounded, in which case, mortality does not occur; rather, the impounded area slowly deteriorates over time, diminishing productivity. The "barrier effect" also interferes with the natural migration patterns of many kinds of local species (Figure 40).

The fill material used in the construction is associated with two specific problems related to its source and the leaching that occurs when it is in place aboveground. There are two sources of roadfills: earth materials from upland areas, and dredged materials from the marine environment. In both situations, there are environmental impacts associated with the removal of materials at the point of origin. Sometimes, when the on-site sediments are suitable, the fill materials are taken from alongside the roadway which results in an open-water canal paralleling the route. Whereas the environmental impact of the excavation is locally confined to the site of construction, the presence of a canal alongside a road presents a critical hazard for road travelers. In the event a vehicle runs off the road, it enters a deep-water canal; victims trapped in the vehicle frequently are unable to escape and subsequently drown.

The second problem associated with the fill used to construct roads and railway foundations is the composition of the mineral components. In highly developed areas, for example, the fill used may be the dredge spoils obtained from the maintenance dredging of navigable waterways. It is not uncommon for such dredge spoils to contain a variety of the pollutants which have accumulated and persisted in the waterway. When subsequently used as a fill, these materials erode and leach out of the fill into the contiguous environment.[1] Even when the fill is free of pollutants, the leached mineral components alter the mineral composition and mineral ratios in the contiguous areas where they accumulate. Extreme changes in the mineral composition of the sediments can alter the productivity because of their effects on soil fertility.

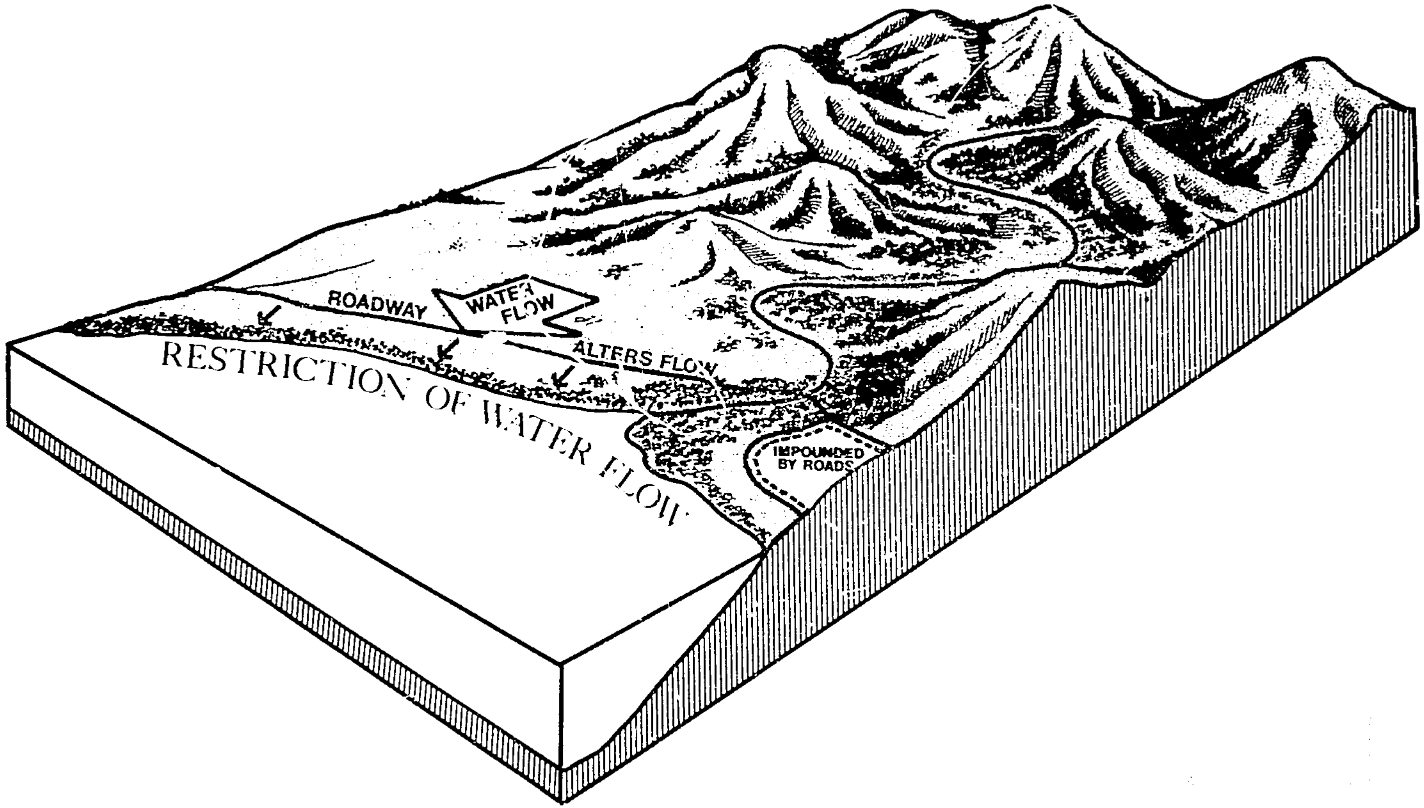

FIGURE 40. Coastal problems associated with roads.

A common problem that has an economic impact occurs when the design of transportation structures and the selection of the materials to be used are inadequate for use on a soft sediment base. For example, when vehicular and rail weights exceed the design capacity for the foundation, slumping and settling occur. Also, improperly formed and placed concrete with steel reinforcement can result in internal corrosion and loss of strength in the construction components. Frequently, these kinds of structural failure problems occur when the designers and engineers have minimal experience with the technical difficulties associated with marine engineering.

Guidelines

1) Road, railway, and bridge design requirements should include engineering provisions for the maintenance of natural surface-water flow characteristics according to specific performance standards. This is frequently achieved at minimal cost by the extensive use of culverts and through-pass drains that are strategically placed along the route during construction. Sizing of the culverts and drains can be accurately calculated so as to establish a total flow cross-section that approximates the local conditions, including flood events.

2) Fill should be free of environmental pollutants which could be released by erosion and leaching. Special care should be exercised when dredge spoils from industrial and urban waterways are used. Consideration should be given to the planting of vegetation on the fill slopes to minimize erosion.

3) The technical team(s) responsible for planning, designing, and engineering capital-intensive coastal development projects should have specialists qualified not only in the relevant aspects of marine engineering, but also in coastal lowlands ecology. Professional adherence to the basic design requirements and performance standards can reduce the long-term economic cost and minimize the environmental damage that is usually attributable to inappropriate practices associated with road, railway, and bridge construction in the coastal lowlands.

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See Also: Mangrove Ecosystems (p. 23).

URBANIZATION

SHORE PROTECTION

Introduction

Erosion is a common phenomenon on many shorelines of the world (Figure 41). In fact, almost no coastal area of the world that has been developed by man is free of problems caused by beach erosion. The erosion and accretion of any coastline are ultimately controlled by the natural forces responsible for the motion of wind and water along the beach and in the nearshore zone. Under the action of nearshore currents, waves, and/or winds, sediments are moved on, off, and along the beaches. This mass transport of sand (the primary sediment type found on beaches) results in the net erosion or accretion of a particular segment of the coastline. Due to the development of beachfront property in many parts of the world, erosion and the problems it creates have become widespread.

Coastal geomorphologists have determined that man himself has created most of his own beach erosion problems through poor planning of construction along these beaches. This has created a variety of serious environmental impacts including the loss of life, property, and income. Since most of these problems are known to be self-imposed through poor planning, sound integrated planning approaches can prevent their future occurrence. Lessons learned from the mistakes of the past should be applied in the planning phases of every new development in the coastal zone. The costs involved in preventing coastal erosion are orders of magnitude less than those required to solve an erosion problem once the structures are in place.

Problems

There is a general opinion among coastal geomorphologists that, on a worldwide basis, erosional processes tend to dominate depositional processes and that, in the absence of any other mitigating factor, beach erosion is a major phenomenon. Activities which affect the source and transport of beach-building materials may accelerate the erosional balance (Figure 42). Among the more commonly cited factors promoting beach erosion are (1) river dams, barrages, and diversions that trap sedimentary materials, thus preventing their entry into the coastal zone, or that reduce the transport power of the river water; (2) coastal dredging projects that remove beach-building materials from the longshore transport processes, thus starving downstream

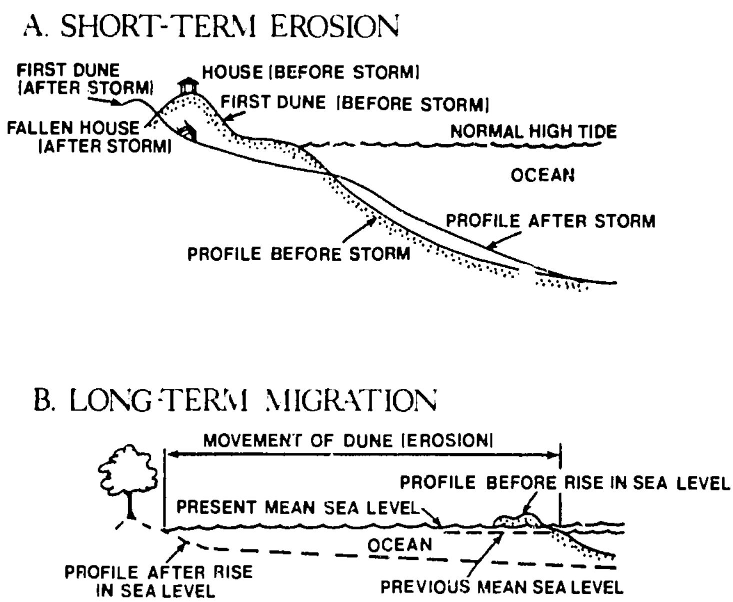

FIGURE 41. Beach and dune changes resulting in (A) short-term erosion from storms and (B) long-term migration resulting from the rise of sea level. (Source: Ref. 1.)

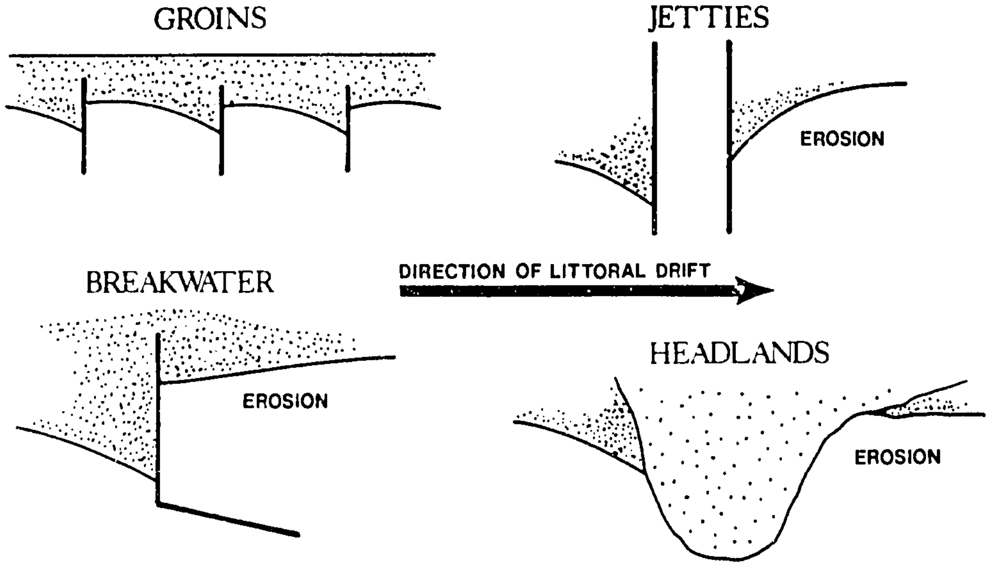

FIGURE 42. Shore-perpendicular features which block longshore transport.

beaches; and (3) poorly designed coastal engineering works that alter longshore currents or wave forces and lead to undesirable erosion and deposition patterns.

Maura Port provides a good example of the possible effects poorly planned dredging projects can have on coastal stability. The port represents the only deep-water port on the coast of Brunei. A natural harbor exists at Maura, but its exit into the South China sea is too shallow and too prone to siltation to make a good navigational channel. Consequently, an approach channel was cut directly across Pelompong Spit to the open ocean in 1969.[2] (Figure 43). This cut has resulted in several problems since that time, because it was built contrary to the prevailing natural wave approach and sand transport patterns. Specifically, this cut has led to severe land erosion, scour problems, jetty instability, shoaling, and siltation. Concern at present is for a complete breach of the now highly erosional spit, which would cause subsequent loss of all land and property there.

A second example describes the acute coastal erosion problems in Togo and Benin stemming from the construction of deep-water ports at Lome in 1966 and in Cotonou in 1963 (Figure 44). The jetties of these ports interrupt longshore sand transport which in this area, is among the strongest in the world, travelling from west to east.[1] No sand-bypass system was installed at either harbor entrance, so erosion has become a serious problem downdrift of either harbor. The jetties at Lome provide a classic example of man's impact of beaches. The shoreline updrift (west) of the jetties is building out at a rate in excess of 50 meters/year, whereas downdrift, the beaches are receding at rates up to 8 meters/year. Local outcrops of beachrock slow the erosion rate on the downdrift side. In the erosion zone, many fishing villages have been abandoned and a major tourist hotel is threatened.

The erosion/deposition patterns at Cotonou, Benin, mimic those described for Lome, Togo. West of the port, the beach has built out 700 meters since construction of the jetties. The area east of the jetties is complicated because of the presence of a dam and some groins, but a huge, erosional, crenulate bay has formed east of the last groin. A maximum of 250 meters of erosion has occurred in the middle of the bay, which is located approximately 1,000 meters east of the jetties. Many fishing villages have been moved, and an industrial zone is threatened in this area. The rest of the coast of Benin is stable. Other factors have been cited as contributing to this

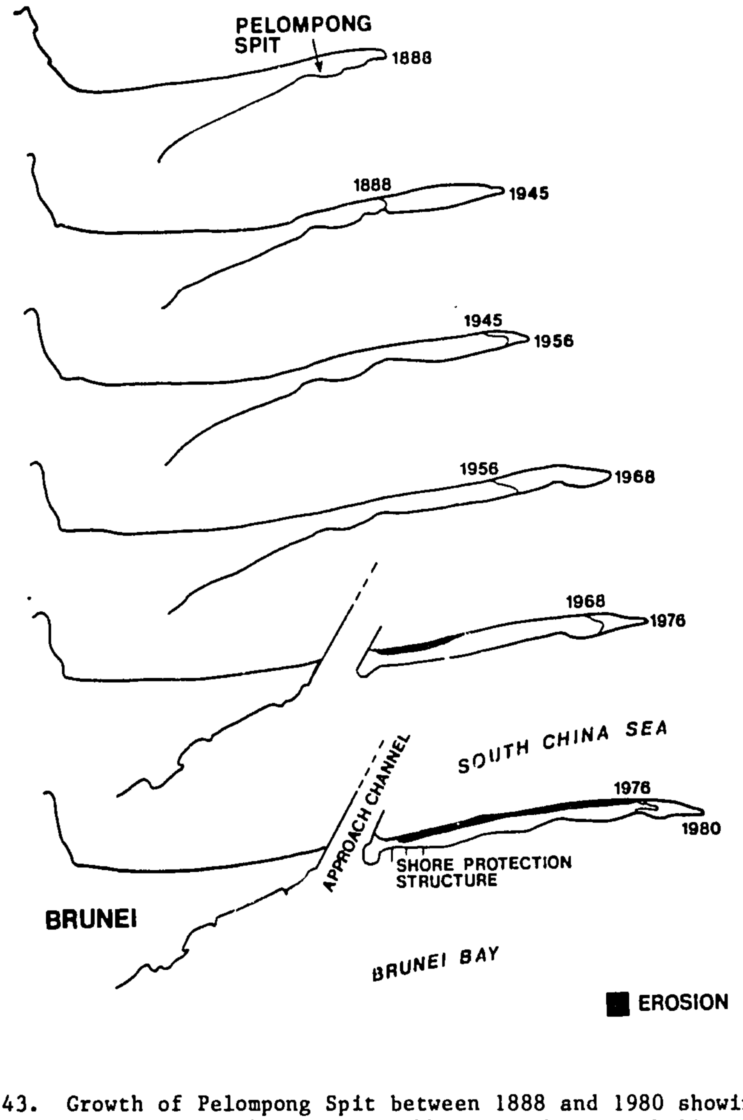

FIGURE 43. Growth of Pelompong Spit between 1888 and 1980 showing a channel cut in 1969 and its effect on shore stability. (Source: Ref. 2.)

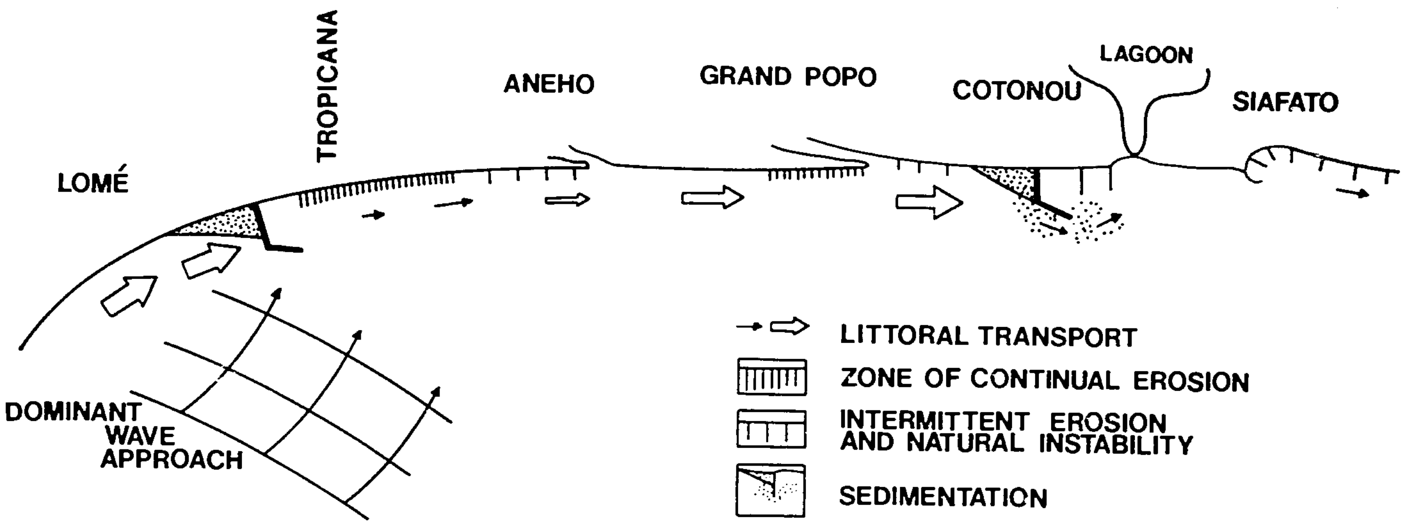

FIGURE 44. The effects of port construction on sediment transport and coastal stability on the coasts of Togo and Benin. (Source: Ref. 1.)

situation, including a gradual rise in sea level, periods of high wave activity, a decrease in sediment supply from rivers caused by a recent drying trend and by dams and rivers, and a sand-mining industry updrift from the erosional areas estimated to take over 200,000 cubic meters of sand from the beach per year.[1]

In the Togo and Benin erosion cases, it was suggested that a setback line be established and that isolated problems due to erosion be treated on a case-by-case basis. In certain key areas, it was suggested that a series of short groins be constructed to slow erosion locally and that in some areas quantities of sand be pumped onto the beaches (areas of maximum erosion, selected on an economic basis, since this option is expensive). Where trends in erosion are not clear, it becomes necessary to establish a monitoring program to establish rates of erosion and/or deposition, in order to plan actions.

Guidelines

Coastal erosion represents a long-term economic loss as well as a potential loss of life and property. The best time to deal with coastal erosion problems is in the planning phases for coastal development activities, not after unwise building of a coastal structure has caused the threat of erosion. The principles of coastal erosion protection are addressed as specific guidelines in the following section. These principles are based upon the seven golden rules of combating beach erosion which were developed and discussed by Hayes (Beach Erosion Case Study).[1]

1) Develop a setback line for coastal structures. This is the most important rule of all. However, a thorough knowledge of the historical evolution of the site is required for this kind of an evaluation.

2) When a major obstruction to longshore sediment is constructed (e.g., a harbor), allow for an adequate sand-bypassing system. Decisions to begin major developments such as harbors are usually based on weighty issues such as the economic well-being of a country. Beach erosion concerns pale when compared to such issues in the planning stages of a project. Unfortunately, ten years later, after it is too late to do anything about it, beach erosion may be so severe that it becomes the

overriding economic concern. Sand-bypassing systems cost only a small fraction of the costs of another major project, so they should be included in every master plan for a project which has the potential to interrupt the flow of nearshore sediment.

3) Wherever possible, use "soft-engineering" solutions (e.g., sand nourishment and diversion of channels) rather than "hard" solutions (e.g., revetments and seawalls) to solve beach-erosion problems. Soft solutions are always difficult to sell to developers and managers, who usually prefer to see a hard structure in place. The few applications of soft solutions carried out to date have been generally successful, so it is recommended that these techniques be quickly adopted by progressive coastal engineers.

4) Do not modify or destroy the foredunes (where present). Building on top of foredunes or flattening them for construction sites are both common practices in high population areas. Such practices do not allow space for the occurrence of natural erosional/depositional cycles on the beaches. The result is the undercutting of the buildings on the dunes, which necessitates the construction of seawalls. Dunes should be spared so sand can always move back and forth along the beach in an unimpeded natural cycle.

5) If the beach is desirable in a given location, do not mine the sand from dunes, beaches, or nearshore areas in that vicinity. The sand supply on beaches is not limitless. In fact, the longshore transport system is so delicately balanced that removing sand from it is the surest way to guarantee beach erosion.

6) Do not panic after a storm and drastically alter the beach. Let the normal beach cycle return the sand (if possible). Resist the urge to move sand around during the first few days after a storm. Beaches recover rapidly, and the first few hours and days are the periods of greatest change.

7) Try to understand the normal beach system before it is altered (e.g., direction and magnitude of longshore sediment transport). Site-specific studies may be required at many localities. The interface between the land and sea is a dynamic, changing natural system. Dealing with this

system requires careful study, which may be costly. But, these costs are minimal when compared to the loss of beaches and coastal structures which results from beach erosion following poor coastal erosion planning.

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See Also: Beach Systems (p. 39); Coastal and Marine Mining (p. 191); Ports, Channels, and Harbors (p. 141).

WASTE DISPOSAL AND DISEASE CONTROL

Introduction

Aquatic and marine water bodies have long been considered to be convenient receptacles for the disposal of domestic, urban, and industrial wastes because dilution and microbial activity can, up to a point commensurate with the assimilative capacity of the water body, eliminate or minimize the potential for adverse human-health or environmental impact. This practice is particularly common in coastal areas due in part to the fact that large bodies of water exist nearby and that alternative forms of waste treatment and disposal may not be conveniently available or cost-effective.

For some waste components, such as sewage, the nutrient components provide a stimulus for plant growth which is usually detrimental if volumes are high relative to the size of the water body and the ability of the system to assimilate the constituents. Such excess enrichment, termed "eutrophication," can result in a variety of adverse health, biological, and economic impacts. The occurrence of other components in discharge effluents, such as human pathogens and a variety of persistent toxic materials (e.g., heavy metals), argues strongly against disposal in nearshore marine waters under most circumstances, unless appropriate treatment occurs. Industrial liquid wastes are also often discharged as ocean outfalls, primarily because industrial waste treatment tends to be very expensive and alternative places for disposal are frequently unavailable. Industrial wastes vary considerably, however, and while certain effluents have only very limited, transitional and not necessarily adverse effects, others may cause dramatic impact at even very low levels. Some types of industry, such as factories that process palm oil, tannins, coconut oil, etc., have wastes that are not acutely toxic but which deplete the oxygen in the receiving water and can result in fish kills, persistent noxious odors, and other effects. Marine disposal of wastes is aggravated by the fact that various pestiferous insects (e.g., mosquitos and sand flies) common to the nearshore environment seem to be favored by disturbed conditions and can also act as disease vectors. In spite of an increasing public awareness and better public control in many areas concerning waste disposal in marine waters, the problem continues to exist and worsen. For example, in India (Porto Novo), cholera-causing bacteria have been reported surviving in coastal waters. This represents a concern because under most circumstances, these pathogens do not survive in saline environments.

Problems

Sewage discharged into coastal waters has the potential to pose a variety of problems. The nutrients in sewage wastewater frequently stimulate plant growth and have been documented to cause major changes in the composition and abundance of estuarine and marine species, including the loss of some particularly sensitive species. Ammonia in wastewater, for example, can stimulate the growth of algae and boring sponges, eventually causing the death of coral reefs. When the organic load is high, oxygen is depleted in the water, resulting in the death of most marine life around the point of discharge.

Although many human pathogens cannot survive in saline water, some find refuge in sediments and in marine organisms where they persist for relatively long periods. When present in marine animals that are consumed by man, they can also pose a distinct health hazard. Likewise, synthetic organic pollutants, such as the pthalates that leach from plastics, and heavy metals can accumulate in the environment and in marine life which man utilizes. The dramatic effects resulting from human uptake of some substances, exemplified by the Minimata, Japan, mercury-poisoning incident, underscore the advisability of considering the fate of effluent constituents prior to discharge.[1]

With respect to pathogens and chemicals, the estuarine/marine environment has a relatively low assimilation capacity. Wastewater treatment in its simplest form usually involves settling of solids, biological oxidation of organic matter, and chemical treatment of the effluent with chlorine. There is some concern, however, that the leftover chlorine and chlorine compounds that are formed (e.g., chloroamines) may create a secondary pollution problem in the coastal environment. In many cases, however, this can be corrected by insuring that excess chlorination does not occur. A recommended disposal technique is the forced discharge of the wastewater in deep offshore areas. Sometimes the effluent is released through diffusers for maximum dispersal in shallow water. Elsewhere, the effluent outlet is below the thermocline (temperature boundary in deep water) off continental shelves; the introduced wastewater, although buoyant, is retained and dispersed without rising to the surface.

Industrial wastewater is also a potential problem. Most industrial activities result in the creation of greater or lesser amounts of polluted water which, in the coastal zone, is usually disposed of in the nearby water. Certain types of polluted water can be of relatively minor significance.

Examples include wash-down water and storm runoff from a plant site, and minimally contaminated process water such as is produced by organic materials from abattoirs and fish-processing houses. At the other extreme are heavily contaminated or highly concentrated wastes that pose more serious problems. Within this category are process water from the chemical refining of ores, brines, and some types of oil-based drilling fluids from oil operations; chemical liquors from pulp and paper mills; and organically enriched wastewater from palm-oil and sugar refineries. Disease-control techniques themselves may have negative environmental effects.[2,3]

Guidelines

In regions where there are insufficient capital resources to install and maintain wastewater treatment plants, a convenient alternative is the construction and use of holding lagoons for settling, precipitation, and/or oxidation. For many kinds of wastewater, particularly those enriched in organic matter, their retention in lagoons results in the settling and oxidation of a sizable fraction of the load over a period of a few days. Slow disposal from the lagoon minimizes adverse effects in coastal waters. In some instances, local marshes and mangrove areas can be used as biological treatment areas for small amounts of wastewater which do not contain pathogens, heavy metals, or particularly toxic, synthetic, organic compounds. The use of natural systems for biological treatment has to be viewed with caution, but can also be one of the best and most viable options if properly designed and implemented.

1) Domestic sewage waste should be treated prior to discharge to minimize the overfertilization of marine waters, particularly in enclosed or restricted embayments and lagoons, and to control, to the extent possible, the introduction of human pathogens. Although the chlorination of sewage effluents poses its own unique environmental problems, it probably remains the best (i.e., effective and low-cost) alternative for the control of pathogens. When treatment facilities are unavailable or economically impractical, wastes can be introduced into an artificial lagoonal system for natural settling and decomposition prior to release into the marine environment.

2) Use of waste assimilation lagoons is a low-cost alternative for certain industrial liquid wastes. Although not totally effective in most circumstances, some wastewaters can be "detoxified" within a lagoonal system. The reduced pollutant-loading of marine waters usually justifies the practice.

3) Contamination of groundwater resources should be avoided, particularly with respect to holding lagoons, because of the potential for contamination of domestic water supplies. The problem can be avoided by siting lagoons in areas where percolation rates are low. When the use of lagoons is mandated in areas where groundwater contamination potential is high, lagoons should be lined with an impermeable material such as clays or heavy plastic.

4) Deep-well injection of certain types of wastes is a viable alternative only where adequate technology exists to insure that contaminant escape and secondary uptake does not occur.

5) The use of certain natural systems (e.g., some lagoons, marshes, and mangroves) for waste assimilation and treatment is also a viable alternative but should be carefully designed and viewed with caution. Although natural freshwater and marine ecosystems can effectively remove the nutrient components in wastewater and reduce the total suspended solids, some pathogen components, including viral organisms, can survive.

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See Also: Capture Fisheries (p. 95); Coral Reefs (p. 11); Estuaries and Lagoons (p. 49).

COASTAL RECREATION AND TOURISM

Introduction

With the exception of the period characterized by the oil disruption of 1973/74 and 1979/80, world tourism has sustained a continuous rate of growth over the last two decades. In 1980, this near-continuous growth reached an estimated 286 million total tourist arrivals accounting for some $92 billion in gross receipts.[1]

Since 1973, tourism in the developing countries has grown at a faster rate than the developed regions (6 percent versus 4 percent). East Asian and Caribbean regions, together with several countries in Africa, lead the others.[1] Developing nations represented 16 percent of world total arrivals in 1980, accounting for some $15 billion in revenue.[2]

While in many developing countries tourism contributes only a small share to total foreign-exchange earnings, in several other countries, tourism-generated revenues represent a significant percentage of total national product (tourism in the Bahamas, for example, contributes 55 percent of the country's GNP).[3]

Coastal developing countries where tourism earnings represented 10 percent or more of domestic exports in the period 1978/79 are listed in Table 2.

Countries with coastal environments characterized by beaches for swimming and leisure, mangrove estuaries for fishing and boating, and/or clear water and coral reefs for skin diving (to cite a few examples) are increasing their share of the market as these attractions are developed for use as recreational focal points for local residents and foreign tourists. With regard to foreign tourists, coastal recreational attractions also stimulate local economic development and represent a significant source of foreign earnings for a national economy.

In general, the minimal means required to develop a recreational area consists of site identification, development which includes land clearing, and provision of access, accommodation, recreational facilities, and services.[4]

Generally, the more sophisticated a recreational development the greater the need to increase (1) visitor accommodations; (2) provision of visitor amenities such as boats, guides, swim gear, etc.; and (3) the availability of other recreational pursuits such as shopping and nighttime activities. The successful development of a coastal recreational area which is specifically

TABLE 2. Domestic exports and tourism receipts (US$ million). Data are for 1978 except those with asterisks (**) which are for 1979. (Source: Ref. 2).

	DOMESTIC EXPORTS	TOURISM RECEIPTS	RATIO
LAC			
Bahamas**	131.5	442.3	336.3
Barbados**	151.2	200.5	132.6
Haiti	116.9	46.7	39.9
Jamaica	639.1	148.2	23.2
Dominican Republic	519.2	108.7	20.9
Mexico	5,975.7	1,121.0	18.7
EMENA			
Jordan	296.5	355.9	120.0
Tunisia	1,171.0	416.7	35.6
Cyprus**	466.0	145.3	31.2
Egypt	1,699.5	500.0	29.4
Morocco	1,613.6	434.0	26.9
Portugal	2,314.1	599.8	25.9
Turkey	2,196.7	230.4	10.5
AFRICA			
Seychelles	3.6	37.4	1,038.8
The Gambia	41.8	7.5	17.9
Kenya	1,069.6	157.9	14.8
Senegal**	627.2	78.9	12.6
Mauritius	336.8	35.0	10.3
ASIA AND PACIFIC			
Fiji	138.7	86.0	62.0
Philippines	3,321.1	355.3	10.7
Thailand	4,153.2	435.0	10.5
Sri Lanka**	981.3	79.0	8.1

aimed at the international tourist market generally requires an intensive advertising and promotional program at the international level. In many specific regions of the world, tourism is a major basis for local, coastal environment economics. Planned recreation and tourism also have a conservation benefit in that the owners or operators have an interest in preserving the natural landscape and habitats that create the basic attraction to the area.

Problems

The recent growth of tourism, together with the absence of sound planning and management in its development, has resulted in unexpected loss and degradation of the very coastal resources that attracted tourists.

Facility and location is a principal factor contributing to degradation and loss f coastal resources. Improper site selection can result in foreclosure of present and future development options, result in a number of impacts leading to declines in fragile ecosystems, and even lead to loss of physical infrastructure. Failure to account for natural processes characteristic of the coastal zone (e.g., natural hazards, beach erosion, saltwater intrusion) has been a common fault of land use planning. Many of these problems have been addressed elsewhere in the guidelines and should be reviewed accordingly.

The facilitation of access to a tourist attraction is a second source of concern. This can result in the loss of vegetation through trampling and disruption of wildlife not sensitized to human presence. In Spain, the construction of a tourist resort in the vicinity of a wetland marsh utilized by migratory birds during the winter months has contributed to the decline of the sanctuary and appears to have caused infertility in such rare species as the Spanish eagle.[5]

There has been a growing concern over the "appropriateness" of accommodations built to serve tourists. It has been said that often the design of these structures ignores the surrounding natural environment, exhibiting an insensitivity to the sociocultural context in exchange for the ease of constructing a functional standardized style of architecture.[5]

Failure to adequately account for services required to support tourist pressures and maintain environmental quality has led to deterioration of many of the same resources which the site depends. Unsightly pollution associated with human waste and solid waste disposal can quickly ruin an area's reputation as a tourist haven. One such area where pollution has become a major concern is Jamaica. Extensive tourism development along the country's northern coast has resulted in hotel waste disposal systems dumping raw or poorly treated sewage directly into coastal waters, thus threatening the coral reefs characteristic of that part of the island.[6] Similar concerns have been raised elsewhere in the Caribbean as well as the Mediterranean.[3,5]

In addition to the natural environment the successful development of a tourist facility must also take into account the sociocultural and economic environments. While beyond the scope of the present guidelines, important sociocultural considerations include the significance of certain artifacts and historical sites, the tenets of a local religion, interhuman relations between tourists and employees, and availability of high-quality employment opportunities.

Plans for the development of coastal recreational areas which are based on the international tourist market must take into account the cyclical market based on international, national, regional, and economic conditions. Overseas tourist areas, in general, experience economic problems which are related to economic recessions and distortions in currency values. For example, Mexico experienced a massive influx of tourist activity as the Mexican economy and the peso weakened. but can likewise expect a decline in tourism as the country's economy and peso strengthen.

A recent example of the successful development of a coastal area for local recreation and tourism is the Caroni Swamp Reserve which is located a few kilometers away from the capital, Port of Spain, Trinidad.[7] It encompasses a reserve area of some 5,000 hectares that has been proposed as a National Park in order to protect water quality and the local fauna and flora, with emphasis on the scarlet ibis. Once identified, it became an important focal point for recreation and tourism and is now proudly promoted by the Trinidadian government.

Guidelines

The development of coastal recreational and resort sites has a significant economic potential, but is also subject to a variety of problems. The following guidelines based on UNEP's Environmental Operational Guidelines for Tourism provide the means of correcting or minimizing many of the problems.[3]

1) Coastal tourism development should be conceived within the framework of national, regional, and local socioeconomic development plans which assure proper integration of environmental objectives in development strategies. In particular, coastal tourism development should be approached within a national strategy for coastal area development and management, which will identify the zones most suitable for tourism.

2) Coastal areas reserved for tourism development should be covered by zoning plans which take into account the natural geographic and socioeconomic condition of the area. To achieve optimal exploitation of tourist resources, an inventory should first be conducted in the region of the proposed site(s) to include the physical environment; the man-made environment; the sociocultural environment; and the existence of endemic or temporary communicable diseases.

3) The "carrying capacity" of the area should be defined for the purpose of determining the total population the tourist area can sustain without overburdening existing infrastructure and causing degradation of the natural resources.

4) Clearing, where required, should be controlled to insure minimal impact to the natural coastal ecosystems.

5) Means of access must be properly designed to take into account minimization of traffic congestion, noise, solid and liquid waste pollution, and other impacts on the surrounding areas.

6) The development of accommodation facilities should be concentrated, leaving as much of the natural resource in as undisturbed a state as possible. The scale, size, and type of infrastructure should be appropriate. Structures should be set back a good distance from the beach (e.g., 100 to 300 meters).

7) Allowances must be made for adequate waste disposal measures. Where possible, waste disposal should use existing municipal or regional collection and disposal systems. Liquid waste should not be discharged onto beaches, coral reefs, or other sensitive areas.

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See Also: Beach Systems (p. 39); Shore Protection (p. 157).

WATER RESOURCE DEVELOPMENT

Introduction

The worldwide demand for fresh water for agriculture, industry, and domestic uses continues to increase, although the basic supply remains relatively stable, albeit unevenly distributed in both space and time. Water resource development, therefore, has as one of its fundamental objectives the development of existing freshwater resources while insuring that the supply which is made available is equitably allocated among users. A corollary objective is that the economic and social benefits resulting from a project justify the water resource development activity. In general, water resource development and economic development cannot be treated separately, especially in areas where the demand exceeds the supply.

A conflict that frequently arises concerns "downstream effects"--alteration of the fresh water that flows in rivers to the sea (Figure 45). Some water resource development proponents view this water as wasted, in part because there is no obvious direct benefit to man. Seldom considered in this argument is the role of fresh water in the perpetuation of the coastal ecosystems that are the natural recipients of terrestrial runoff (e.g., freshwater's singular-basis role in maintaining the high fishery productivity of estuaries).[1,2] Likewise, mangrove forests require fresh water for maintaining the salinity of sediments within a range that permits their growth. The freshwater flow to the sea also performs a variety of other useful roles, including the delivery of terrestrial sediments for distribution along beaches, the maintenance of navigable waterways by the scouring of channel sediments, and the prevention of salinity intrusion into inland areas.

Problems

There are three major classes of problems that affect the coastal environment as a direct or indirect result from the way in which fresh water is manipulated and used: (1) collection and consumption, (2) diversion, and (3) groundwater drawdown. Each of these activities can have profound economic, social, political, and biological consequences (Figure 46).

Fresh water that is collected and consumed for a variety of purposes is released finally via evaporation or in a form that often precludes other uses. Such consumptive uses include agricultural irrigation, domestic consumption (resulting in sewage wastewater), and certain industrial processes

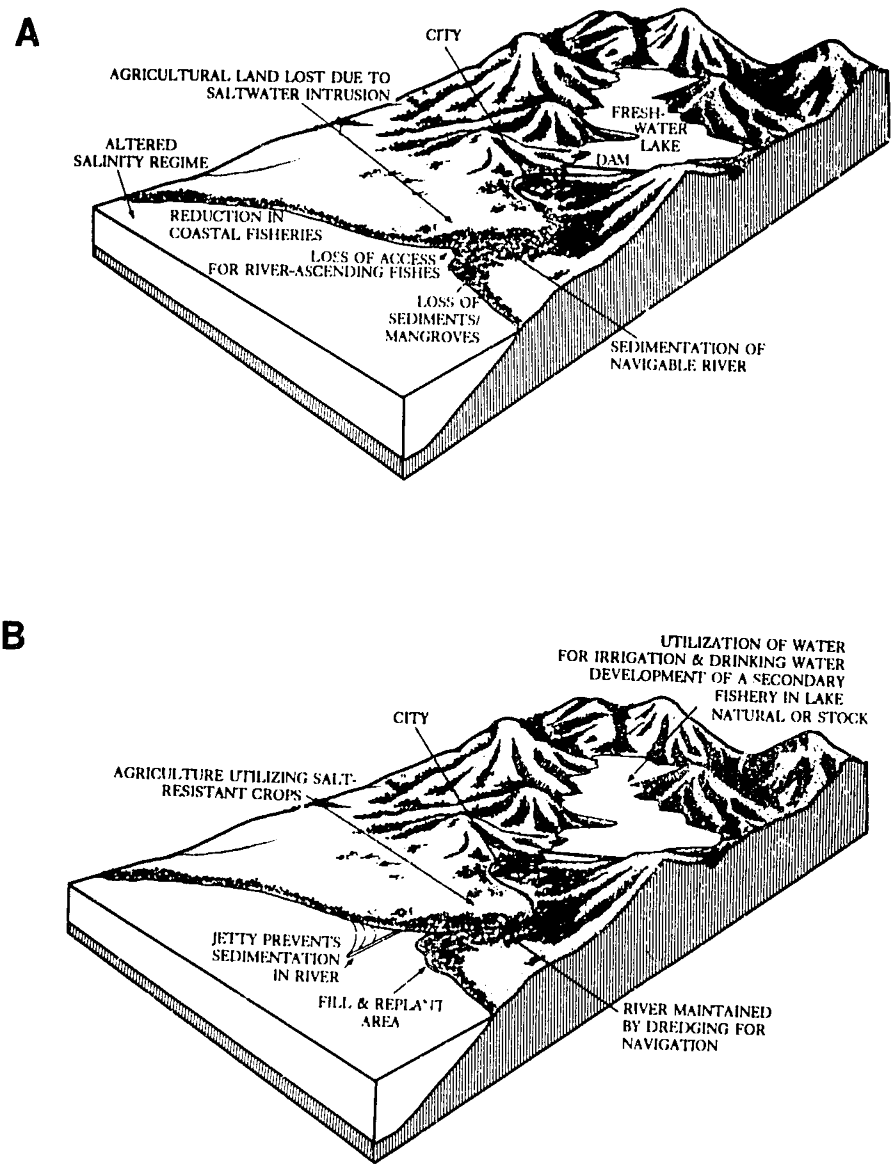

FIGURE 45. Coastal problems from (A) poor water management and (B) result of integrated planning.

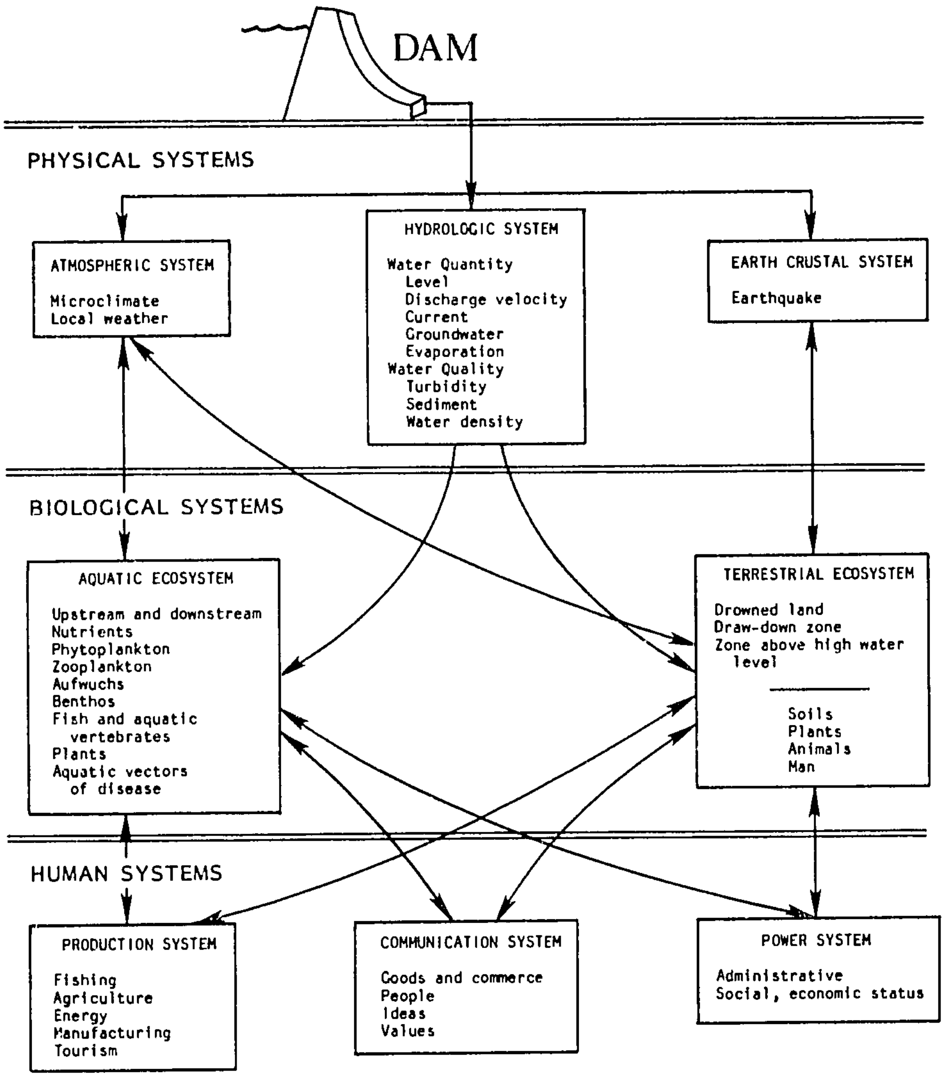

FIGURE 46. The relationship of physical, biological and human systems to dams. (Source: Ref. 3.)

in which the output water is polluted. Although water used for consumptive purposes is often a necessity for economic and social well-being, there are serious downstream results of the water loss. For example, nearshore environments, including those occupied by man, may become progressively saline, and those species that are adapted to moderate salinities may experience a decline (e.g., the loss of Egypt's sardine fishery as a result of the Aswan Dam). Other major effects include the siltation of rivers, erosion along the sea front of delta areas and along downstream beaches, and the deterioration of coastal vegetation. A classic example in this regard is the Indus River, the sixth largest river in the world. Shortly after the year 2000, all of the Indus water will have been captured and diverted into the arid regions of Pakistan and northwest India, and the river will no longer flow. At that time, the development of the Indus River water resource will have been 100 percent completed. The impact on the Indus delta and the north Arabian Sea resulting from the absence of a freshwater input remains to be evaluated but will probably be serious.

Fresh water may also be diverted from one main flow channel into another for some purpose (e.g., the Santee-Cooper river diversion in the United States and the Ganges-Hooghly river diversion in India). By its very nature, diversion creates a shortage in the river system from which the water is withdrawn (as above) and freshwater excess in the environment around the new discharge point. Around this point, salinities are reduced which negatively affect habitats intolerant of moderate salinities. Also, the rate of sedimentation increases and local circulation patterns are changed. Dams have unusually complex effects on aquatic ecosystems, all the way to the ocean. This is true whether the dam's purpose is hydroelectricity, water supply, or flood control.

In areas that have a high water demand, but only a small resource of surface freshwater supply, groundwater resources may be developed when there is an adequate underground reservoir. In this situation, wells and pumps are used for groundwater withdrawal. Groundwater pumping creates what is known as a "cone of depression" that results in a drawdown of the local groundwater table in the affected area. Excessive pumping in coastal regions destroys the ability of the groundwater reservoir to prevent the intrusion of seawater; the rate of subsequent salinity intrusion is th proportional to the rate of pumping and groundwater drawdown. One of tne consequences of extensive salinity intrusion is that the fresh groundwater becomes contaminated with salt and is rendered unusable for most purposes. Sometimes the ground level falls (land subsidence) as the aquifer is pumped, causing flooding of coastal developments, as has happened around Bangkok.

In the majority of instances where water resource development creates major economic, political, or environmental problems, the cause can be attributed to insufficient planning beyond the engineering feasibility and design studies. In at least one example, that of Santee-Cooper Rivers in South Carolina (see U.S. Rivers Case Study), the coastal impacts associated with a river diversion project were so severe that present plans are to redivert the river to its former course. There are an increasing number of instances of the kind previously cited where project mistakes in water resource development and allocation are being corrected because of after-the-fact economic and environmental consequences. In general, it is much more expensive to correct mistakes than it is to do the kind of advance planning that would prevent the creation of problems.

Another pressure on often-limited sources of fresh water is the need of coastal industries for large volumes of fresh water and saltwater for industrial processes. Coastlines in most countries are frequently considered to be ideal locations for industrial siting because of convenient access to both oceanic shipping and land-based transportation systems. As a result, many different types of industries are located close to ports and harbors for logistical and economic reasons. A few specialized types of industrial activities also take place on coastlines, in part to take advantage of convenient transportation, but primarily to access clean seawater. For example, power-generation plants that require large quantities of water for cooling purposes are sited on coasts when possible (see "Coastal Power Generation" subsection). Also, in limited freshwater areas, desalinization plants are located on the coast to access the seawater that is to be processed into fresh water. Thus, coastal siting for industrial purposes has a number of definable economic advantages.

The siting of industries in the coastal environment poses a number of problems that, as a class, encompass the interactions between the specific industry and limited water supplies. The mechanism of the interaction invariably involves water directly as a vehicle for pollutant dispersal, but also indirectly through the manner in which the plant site may alter natural surface-water circulation and flow patterns (see "Industry Siting" subsection).

Many different kinds of industries use fresh water as "process water," for example, in the chemical or mechanical separation of metal ores from the parent matrix and the washing and cleaning of fresh seafood. In addition, most industrial activities utilize water for wash-down and industrial cleaning purposes. In the majority of instances, the water used is fresh water which, after having been used for whatever purpose is disposed of in the nearshore environment. The primary problem with industrial wastewater is the entrained contaminants that may have deleterious effects on coastal plant and animal communities (see "Waste Disposal and Disease Control" subsection). For example, metal wastes may be present in toxic (acute or chronic) concentrations or in forms that permit biological uptake and magnification; this is a potential hazard if the affected marine animals are consumed by man. Oils, greases, and other petroleum-residue wastes can be toxic to living organisms or deplete the life-sustaining oxygen in nearshore waters. In this latter regard, the heavy organic-matter concentrations usually associated with organic wastewater from fishery processing and oil-palm refining plants are particularly noted for the extreme oxygen depletion they cause in marine waters. Desalinization plants necessarily produce a heavy salt brine which results from the evaporation of seawater and the condensation of the steam to produce fresh water. In the coastal disposal area, the brine produces high salinities which, close to the point of disposal, are beyond the tolerance limits of most marine life.

Guidelines

Water-resource development objectives should take into account the natural roles of fresh water in maintaining coastal wetlands, estuaries, and lagoons, and their associated fisheries. To this end, the following guidelines should be considered in planning water resource development activities (Figure 45).

1) During the project planning phase of a water development project, when potential project impacts are being identified, special attention should be given to downstream effects in the coastal and nearshore marine environment. When it appears that water quality parameters may be altered by the project, studies should be undertaken to define modifying

actions. These actions should be defined as project performance standards.

2) Define the boundaries of the coastal and nearshore marine areas influenced by catchment processes. These boundaries should specifically include the zone influenced by fresh water, by riverborne pollutants and terrestrial sediment runoff, making ample allowances for prevailing current patterns, seasonality, and other physical factors which influence the extent of the zone.

3) Identify in order the critical coastal and marine resources in the affected area. This process should attempt to address the present and future socioeconomic importance of the resources, the degree to which they can sustain probable impacts attributable to inland sources and their present status.

4) Carry out baseline studies within this zone including resource surveys, status assessments, and descriptions of the physical environment and the processes which shape it. The studies should also assess the nature and quantity of inputs from inland water sources which enter and influence the zone.

5) Implement a monitoring program including systematic observations of "key" water inputs influencing the zone (such as freshwater flow, suspended sediments, selected nutrients, selected contaminants, dissolved oxygen). Periodic visits to vulnerable areas (such as reefs, beaches, and seagrass beds) should also be included to collect the data required for trend analysis. Where a monitoring program already exists within the catchment, coastal and marine components should be integrated into the existing work.

6) Once key inputs have been identified, establish the threshhold levels required to maintain the coastal/marine resources and processes identified above. This can be done through review of existing literature, visits to comparable sites where such inputs have already been altered, and establishing in-situ experimentation plots and testing programs.

7) Where harmful inputs entering the coastal area have been observed, identify their source and upstream location(s). Once this information is known, an evaluation of available corrective measures should be

completed and selection made accordingly. Complex, large-scale source problems such as deforestation may limit coastal area management responses to temporary remedial measures directed at the affected coastal area until the appropriate institutions and resources can be mobilized to address the underlying causes.

8) Where possible, consider in upstream water management the negative impacts of downstream sedimentation. Water storage cycles should be geared to restrain soil loss; water discharge from irrigation schemes should be timed to minimize sedimentation downstream; small holding dams should be considered to reduce sedimentation in the river bed itself.

9) Establish systematic procedures to evaluate coastal implications of proposed water development activities (or other intervention) in the catchment area.

10) Where key inputs may be altered by water development proposals and therefore pose a threat to threshold limits of coastal resources, make the appropriate modifications in development design.

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See Also: Upland Agriculture (p. 79).

INDUSTRY

INDUSTRIAL SITING

Introduction

Coastlines in most countries are frequently considered to be ideal locations for industrial siting based on convenient access to both oceanic shipping and land-based transportation systems. As a result, many different types of industries are located close to ports and harbors for logistical and economic reasons. A few specialized types of industrial activities also take place on coastlines, in part to take advantage of convenient transportation but primarily to access clean seawater. For example, industrial plants that require large quantities of water for cooling purposes are sited on coasts when possible. Also, in limited freshwater areas, desalinization plants are located on the coasts to access the seawater that is to be processed into fresh water. Thus, coastal siting for industrial purposes has a number of definable economic advantages. But there is also a great potential for disturbance of coastal ecosystems unless thorough consideration is given to site selection, design, and operational requirements.

Problems

The siting of industries in the coastal environment poses a number of problems that involve water not only directly as a vehicle for pollutant dispersal, but also indirectly through the manner in which the plant site may alter natural surface-water circulation and flow patterns. Many of the specific problems are discussed and guidelines given in other sections.

Many different kinds of industries use fresh water as "process water," for example, in the chemical or mechanical separation of metal ores from the parent matrix and the washing and cleaning of fresh seafood. In addition, most industrial activities utilize water for wash-down and industrial cleaning purposes. The water, after having been used for whatever purpose, is disposed of in the nearshore environment. The primary problem with industrial wastewater is the entrained contaminants that may have deleterious effects on coastal plant and animal communities.[1] For example, metal wastes may be present in toxic (acute or chronic) concentrations or in forms that permit biological uptake and magnification; this is a potential hazard if the affected marine animals are consumed by man. Oils, greases, and other petroleum-residue wastes can be toxic to living organisms or deplete the life-sustaining oxygen in nearshore waters.[2] In this latter regard, the heavy organic-matter concentrations usually associated with organic wastewater from fishery processing and oil-palm refining plants are particularly noted for the extreme oxygen depletion they cause in marine waters. Desalinization plants necessarily produce a heavy salt brine which results from the evaporation of seawater and the condensation of the steam to produce fresh water. In the coastal area of disposal, the brine produces high salinities which, closest to the point of disposal, are usually beyond the tolerance limits of most marine life.

Large-scale consumers of cooling water are a special case. The intake for seawater may cause problems by entrapping animals on the filter screens or by entraining plankton, including larval organisms, in the intake water. Large volumes of heated discharge water frequently alter the biological structure of the receiving marine system. It is a particularly severe problem in warm tropical waters where even a small increase in water temperature may exceed the tolerance limits for many organisms. Also, when sodium hypochlorite is used as an antifouling agent in industrial cooling systems, its subsequent disposal as reactive chlorine may pose problems for marine life. (See "Coastal Power Generation" section for details).

With respect to the location of a coastal industry or industrial complex, the development site and its linking network of roads, railways, etc., may interfere with the natural pattern of terrestrial runoff and/or pattern of estuarine tidal flushing. The partial or complete filling or impoundment of nearshore estuarine habitats may lead, respectively, to dysfunction or total disappearance. Similarly, inopportune selection of a shoreland site may lead to obliteration of critical terrestrial sites.

Guidelines

In general, there are few potential alternatives associated with the actual site selection for industrial development, since this decision is usually made and justified on the basis of economics. However, when several more-or-less equivalent choices are available, the selection process can include consideration of potentially significant environmental impacts. Following the final site selection, there is a broad range of design alternatives that should be implemented to minimize the total impact on the surrounding natural systems. In weighing these alternatives, the following guidelines should be taken into consideration:

1) In the actual selection of a site from several alternative choices, the chosen site should be the one containing the fewest sensitive or valuable habitats or living resources--where reliable information on existing living resources cannot be obtained locally, it will be necessary to engage an expert to make a survey. Plants with irremediably high pollution discharges should not be located at the coast.

2) Coastal heavy industry should be concentrated in particular areas rather than spread along the coast. In this way, less of the coast need be physically disturbed; also, cooperative action among industries and with government can solve water pollution problems. This solution requires effective combinations of land use and economic planning.

3) The site plan for an industrial plant should provide for a wide buffer of natural land along the shoreline, except where water access requires piers and roads.

4) In the design phase, prior to construction, attention should be given to the natural patterns of surface-water flow and tidal inundation. The design should include provisions that minimize the disruption of these flows. Storm water should be collected, settled, and treated.

5) Industries producing quantities of waste should be cognizant of the variety of low-cost, but effective, ways of controlling nearshore pollution that are available. A commonly used technique calls for the holding of liquid wastes in artificial lagoons for settling, precipitation, and/or oxidation. More expensive, but also more effective, are advanced waste-treatment processes, some of which permit the economically effective recovery of process water or of chemical components used in the specific industrial process.

6) The production of heated water by some industries is inevitable, but its ultimate fate can be engineered to reduce the environmental impact and/or to realize economic gain. For example, canals or holding reservoirs for cooling prior to disposal can be created at lower costs than industrial cooling towers. In some situations, it may be possible to

utilize the heat in other industrial processes requiring marginally heated process water. In temperate regions, heated water can sometimes be used in mariculture operations to extend growing seasons through winter periods.

7) Industries that are prone to accidental spillage of toxic materials, including petroleum, should have realistic contingency plans, pollution abatement equipment, and trained personnel for spill containment and cleanup.

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See Also: Roads, Rails, and Bridges (p. 149); Water Resource Development (p. 177); Urbanization (p. 155); Waste Disposal and Disease Control (p. 167); Coastal Power Generation (p. 133).

COASTAL AND MARINE MINING

Introduction

The coastal and nearshore marine environment is a source for a variety of minerals of geological and biological origin that have been extracted and utilized by man for centuries. Among the more common minerals are building materials and construction aggregate (rock, coral, shell and sand), lime (derived from coral and calcareous marls and sands), fill materials (sands and aggregates), fertilizer components (lime and phosphates), bauxite (ore from which aluminum is refined), jewelry (semiprecious coral and shells), and placer deposits of metals (e.g., tin, chromium, manganese, and titanium). Other marine minerals of major importance are oil and gas. In general, the marine minerals used for building and construction purposes are utilized locally, whereas those products that have a world market, such as jewelry and the industrial metals, may be largely exported in one form or another. In general, there appears to be an increasing demand throughout the world for construction materials and for the marine minerals of economic importance. The mining or extraction of these minerals, however, tends to be spontaneous, unmanaged, and detrimental to the environment from which it takes the minerals. Although the damage and environmental impact may not be obvious to the casual above-water observer, they can be severe and long lasting.

Methods

On a volume or quantity basis, the construction and building minerals are the most frequently sought-after and utilized of the marine minerals.[1] This category includes (1) rock, gravel, sand, aggregate, and shell which are used, for example, in the preparation of building and road foundations and in the formulation of construction concrete; (2) limestone from coral and carbonate deposits which are used, for example, as industrial lime in steel manufacturing and as the basic ingredient in cement; and (3) bulk fill, which is used for a variety of purposes that are usually associated with development or construction sites. Due to the large volume of material required for these purposes, the preferred sources are located close to shore in relatively shallow water and are close to the point of use. These materials are typically mined by using mechanical or hydraulic dredges, although in the case of the exploitation of coral reefs, the reef may be dynamited prior to the extraction of the fragments (e.g., Sri Lanka). Each type of dredge (Figure 47) offers different advantages and disadvantages relative to both the economics of the operation and the subsequent environmental impact. When the required material (e.g., sand or shell) is present onshore, beach and dune materials may be removed by using land-based bulldozers, scrapers, and loaders.

The mining of coastal placer deposits employs dredging techniques similar to those used for aggregate extraction, both to remove the overburden and to extract the ore. The major difference is that the ore of interest is separated mechanically or chemically from the matrix which then becomes a mine "tailing" waste requiring disposal, usually on land or on the shore (e.g., tin mining in Malaysia and Thailand). Also, when chemical separation procedures are used, liquid wastes which result from the process present a significant pollution problem.

Semiprecious corals, such as the black and pink corals, grow at deep depths that approach several hundred meters. As a result, harvesting is difficult. Common methods include scuba diving and trawling. A diver can be selective in the choice of mature corals, but because of underwater time limitations, the diver is unable to cover a very large area in search of corals; submersibles can solve this problem, but in general, they are expensive to operate. Deep trawling is nonselective, taking both immature and mature corals as well as nontarget organisms, but is efficient in traversing and harvesting a large underwater area. Unfortunately, current practices may be removing more mature individuals than the population is capable of regenerating prior to the next harvest. The problem is compounded when entire coral reefs are removed, because hundreds of years may be required for the recovery of the reef system.

Problems

The major problems associated with mechanical dredging are the turbidity resulting from the disturbance of the bottom sediments and the leakage of the silty water that is lost from the buckets prior to dumping (Figure 48). In contrast, hydraulic dredges tend to create less turbidity at the site of dredging, although the drainage water from the settling/holding tanks or ponds can create turbidity problems both on-site if a barge is used for transport and/or at a distant offloading location. Excess turbidity has a

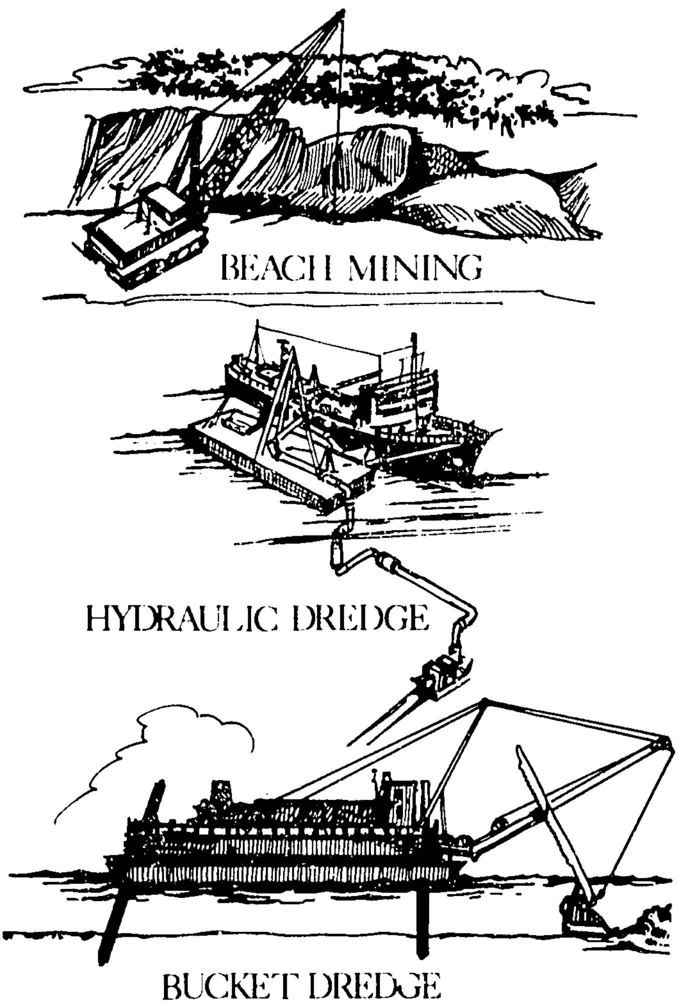

FIGURE 47. Various methods of coastal and marine mining. (Source: Ref. 1.)

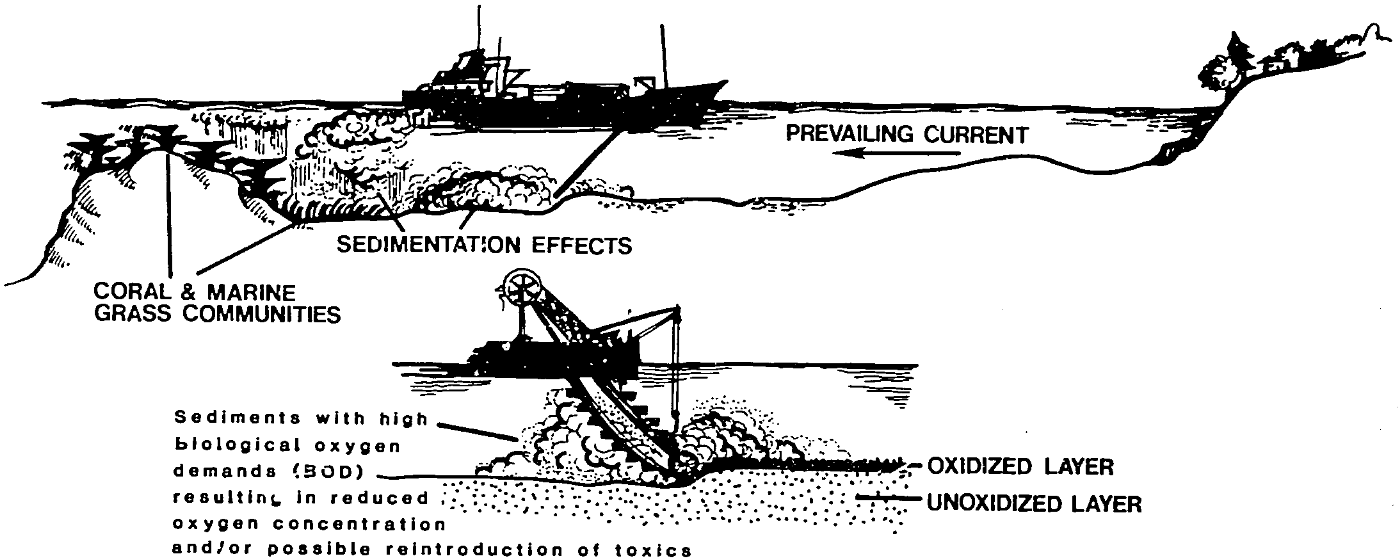

FIGURE 48. Environmental effects associated with marine sand mining. (Source: Ref. 2.)

particularly deleterious effect on such filter-feeding organisms as oysters, clams, and corals. The shading caused by the silt load in the water column also affects the primary plant producers, both phytoplankton and rooted plants, by reducing the light levels required for maximum photosynthesis.

Excavated holes or depressions that remain after dredging are a problem resulting from infilling with soft sediments which over time, become a source of turbidity as a result of chronic resuspension of sediments caused, for example, by storm events (Figure 49).[3] The soft nature of the sediments also precludes the reestablishment of seagrasses, marine algae, and corals, and their associated fauna. Because the walls of a deep hole eventually collapse, any structure close by, such as a coral reef, can become undermined and break off into the hole or depression.

Overexploitation of the renewable mineral resources creates certain specific problems resulting in foreclosure of the resources' future use options. For example, overexploitation of a sand deposit in a sand transport cell (see Beach Erosion and Marine Mining Case Studies) can lead to severe erosion in downstream areas normally fed by the extracted sand deposit.

Guidelines

With the exception of placer ore deposits which have a geological origin, most of the marine minerals are, in fact, renewable resources although differing significantly in their renewal or regeneration times. For example, most coastal sand deposits are constantly gaining and losing material in association with longshore currents. The semiprecious corals grow very slowly, but in fact are capable of regeneration. Based on the fact that these resources are renewable within some time period, it is necessary that levels of extraction and harvesting be established to achieve the maximum sustained yield for the target mineral. By setting standards that are based on plans for maximum sustained yield, overexploitation is prevented, thus perpetuating the availability of the resource base (Figure 50). The following guidelines are extracted from the summary of DuBois and Towle:[4]

1) Mining of living coral reefs should be restricted and, in some cases, prohibited. Corals are slow-growing organisms; since effective management strategies have yet to be discovered, living reefs do not appear to be able to sustain extractive pressures. Their importance as productive

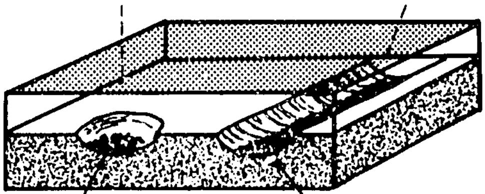

FIGURE 49. Patterns of physical alteration of bottom configuration from hydraulic dredging. (Source: Ref. 4.)

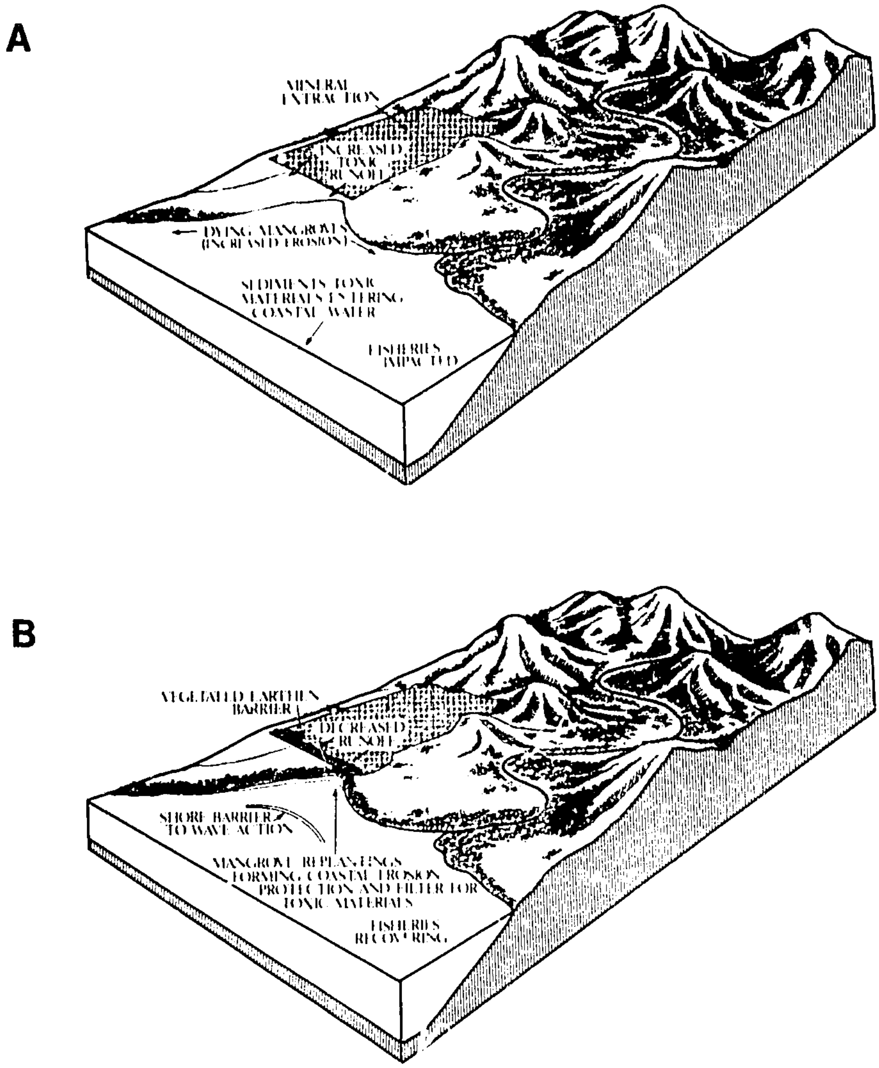

FIGURE 50. Comparison between (A) uncontrolled coastal mining and (B) mining done according to an integrated plan for resource management.

marine systems, fishing sites, recreational attractions, and offshore breakwaters seems to far outweigh their direct exploitation for construction material and aggregate. Alternatives to the living reef for meeting these needs are the rubble areas behind the reef crest. However, caution is also advised against heavy mining as this zone too serves as an energy barrier.

2) The mining of beach sands should generally be discouraged. Where scarcity of alternative resources dictates the need for beach and dune mining, extraction should be carefully regulated, using such management tools as periodic rotation of sites, licensing, and quantity quotas as needed. Preferred sites include growing beaches or other stable reservoir areas known to be the terminus of sand-circulation cells.

3) Submarine mining should be at sites of sufficiently deep water and distance from shore to prevent coastal impacts. Waters should be sufficiently open to currents to speed the leveling of dredge sites through natural bottom-sediment movement upon completion of operations. Activities should be adapted to existing conditions so that the extent and direction of sediment transport are limited, thus reducing risk to sensitive biological systems. Preferred sand deposits are stable reserves at the ends of the submarine sand-circulation pattern, such as near the heads of submarine canyons where sands are known to be drifting deeper and are no longer a part of the local, circulating sand budget.

4) All coastal and nearshore marine mining activities need to be preceded by the development of a comprehensive management plan. Mining activities must be planned within the context of the larger environment, an environment characterized by geophysical, chemical, and biological components interlinked through many pathways and processes. Failure to account for these linkages--and human uses--could result in negative environmental and economic consequences.

5) Mining activities should be preceded by a sand inventory. The elements should include:

   a. Identification of existing sand "reservoirs."
   b. Characterization of the deposits (depth, sediment sizes and proportions, and extent of coverage).

c. Characterization of the local environment of each site to include identification of the existing sources and sinks of the particular sand deposit, relevant processes linking the two (current regime and sand transport units), marine communities potentially affected by mining activities, and potential for reintroduction of toxic substances.

d. Economic and environmental assessments of exploiting alternatives to coastal/marine sources (e.g., pumice and granite).

6) Site selection should be based on an analysis of the information generated and relevant economic data. Final selection should consider issues such as the biological productivity, alternative present and future uses, the "sphere of influence" associated with mining activities, and existing current directions and velocity.

7) Once site selection has been completed, mining activities should be preceded by a baseline study of the locale. The physicochemical characteristics of a site and environmental quality tolerances of major biotic communities are required if monitoring activities are to be effective.

8) A monitoring program should be developed adhering to predetermined environmental quality standards. Selection of monitoring parameters should be based on the following criteria: which environmental factors are most likely to be affected by mining activities; what are the ranges of tolerance to environmental disruptions in the potentially affected biotic communities. Once the parameters are identified, standards should be set using the baseline and other preexisting information. Standards, if exceeded during operations, would warrant a modification or temporary cessation of activities. An assessment of available extraction and control options should be completed to determine the most appropriate system for site conditions. If possible, full mining operations should be preceded by a pilot mining phase to better assess project feasibility.

9) One or more (if warranted) environmental assessments should be completed after final cessation of mining operations. Follow-up assessments are required to gauge the degree of site recovery after activities cease. These assessments also represent a means of filling a critical data gap in the knowledge of mining activities in tropical waters.

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See Also: Beach Systems (p. 39); Shore Protection (p. 157).

SALT MANUFACTURE

Introduction

Salt (sodium chloride) is a required component in man's diet and has a variety of other applications including its use as a preservative (of red meat and fish) and as a supplement in the feeding of domestic animals. Although salt can be produced at a relatively low cost from rock-salt mines, most of the world's salt is produced from seawater evaporation in coastal zone, solar evaporation ponds. For this purpose, large interconnected ponds close to a source of seawater are required which, in many instances, involves the conversion of large areas of mangrove forests. In Thailand, for example, over 10,000 hectares of mangrove forests have been converted to evaporation ponds that annually produce some 410,000 tons of salt. In general, salt production is most efficient in arid and semiarid regions where the annual precipitation is less than 1000 millimeters/year with an eight-month dry season and where the local seawater is full-strength or higher (hypersaline). In the arid Gulf of Kutch area, for example, there are some 15,000 hectares of ponds utilizing seawater with a salinity approaching 40 parts per thousand (the common salinity of seawater is 34). With the exception of a few large industrial enterprises (e.g., in the Bahama Islands and Australia), yields from most saltworks are relatively low and could be significantly increased. This would lead to greater profitability without the costly requirements associated with large pond conversions.

Contrary to popular opinion, salt is not obtained by simply causing a volume of seawater to evaporate, leaving the sea salt as residue. In addition to sodium chloride, seawater normally contains a mixture of sediments, organic matter, and other salts which must be removed. In general, pure salt is extracted from seawater in a basic three-step sequence: settling, precipitation, and crystallization (Figure 51). In the first step, sediments and other large particles are removed through settling during the initial evaporation. Once settled, the relatively pure brine undergoes a longer period of evaporation during which time other seawater constituents, such as carbonates, are removed from the water through precipitation. In the final step, the continued evaporation results in the crystallization of salt which, upon drying, becomes pure salt. In practice, these steps may be partially combined or other steps may be included to increase the production efficiency and yield of salt.

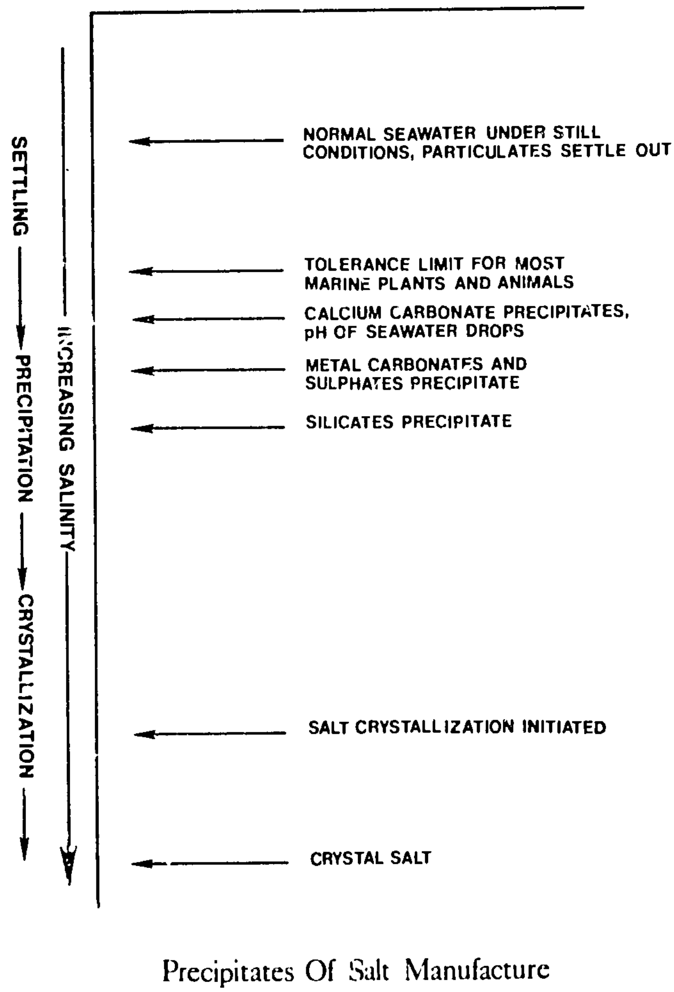

FIGURE 51. Precipitation process in salt manufacture.

Methods

Traditional, or small-scale, salt production involves the same procedural steps, although significantly modified. For example, in parts of west Africa (e.g., Benin), salt is extracted from highly saline mangrove sediments. At the beginning of the dry season, up to several hectares of mangrove forest are cleared and the organic-rich topsoil is removed. The deeper, more saline soil is overturned and allowed to dry, resulting in the salt concentration's being located near the surface. The salt-enriched sediments are then gathered and leached in water which is usually obtained from the water table. Due to the wet climatic conditions, the resulting brine must be boiled over a fire for crystallization with mangrove wood used as the fuel. Prior to the inter-introduction of metal pots, the boiling pots were constructed by using woven mangrove prop roots that were waterproofed with an inside layer of clay. Prop-root clay pots are still used in some areas.

Commercial-scale salt production uses large interconnected ponds for the sequential settling, precipitation through solar radiation, and final crystallization of salt. The more efficient operations also utilize marine microorganisms to literally drain the water so as to increase the solar-heat capture and thus increase the rate of evaporation. To control blooms of phytoplankton and remove other forms of organic matter from the water, small brine shrimp are commonly utilized.[1] Of course, considerable skill is required to promote the growth of large populations of these beneficial scavengers.[2] In some areas, such as India, the process is modified so that other minerals and salts are produced along with common salt. Among the by-products are sulfur, calcium, iodine, magnesium carbonates, silicates, and hydroxides (used in rubber and pharmaceutical industries), potassium chloride (used as a source of potassium fertilizer), and a variety of bromine compounds (used in dyes, pharmaceuticals, and photographic chemicals).

Multiple-use variations are employed during salt production in evaporation ponds, all of which tend to increase the economic viability of the entire operation. The first category includes the production of by-product chemicals and the harvesting and utilization of the brine shrimp and other organisms that are raised in the ponds. Brine shrimp have a commercial value as a fish food and as a human food item. In Australia, an algae is cultured in ponds for the purpose of extracting carotene, a pigment and vitamin. The second category includes alternating uses of a pond system. For example, in southeastern Bangladesh, evaporation ponds are used as shrimp growout ponds during wet years and for salt production during dry years. In some seasonally wet areas, such as Thailand, the Philippines, and Indonesia, pond uses alternate seasonally for salt production and for fish and shrimp production.

Problems

The most significant problem associated with salt production is the irreversible conversion of coastal habitats, mainly mangrove-dominated environments, into pond systems.[3,4] Fortunately, salt production is best in arid environments where coastal forests are not common, and, is a marginal enterprise in the wetter climates which also favor mangrove forest development. Elsewhere, salt-pond owners/operators are not encouraged to develop by-products of commercial value or to evaluate alternative uses where feasible. In terms of pond siting, consideration is seldom given to the natural functions and values of the supporting ecological system so conversions have an unduly large impact. (See "Mangrove Ecosystems" and "Mangrove Forest Harvesting" subsections). World demand is expected to increase, and in response, new saltworks are being planned in various countries (e.g., Venezuela).

Guidelines

The manufacture of salt represents a significant use of coastal lands in many near-tropical and tropical countries of the world. With an increasing knowledge of compatible alternative uses of these areas, salt ponds can be developed into highly successful ventures. However, the potential for causing the loss of highly productive coastal habitat resulting from poor site planning and design mismanagement justifies the need for the following guidelines:

1) New salt-production ponds and the expansion of existing ponds should be planned to minimize the overall impact on coastal habitats, mainly from interfering with natural surface-water flow patterns. Buffer strips of natural vegetation (i.e., mangroves) should separate the ponds from the shoreline. Stabilization of the pond dikes to minimize maintenance costs could also be promoted by planting mangroves along the perimeters.

2) When ponds are abandoned, the dik~s should be breeched to permit the eventual recovery of the former ponded area. Without repeated tidal and rain flushing, the loss of abandoned ponds is irreversible. Alternatively, new uses of abandoned ponds, for instance, as fish ponds, should be evaluated.

3) National plans and protocols should be developed to encourage proper siting and efficient production techniques. Not only would such regulations minimize the impact of pond operations, but they would also serve to reduce the economic risk. Pon operators should also be made aware of existing economic opportunities to produce chemical by-products and/or alternatives for multiple use of the pond systems.

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See Also: Mangrove Ecosystems (p. 23); Coastal Aquaculture (p. 87).