Handbook for Mangrove Area Management

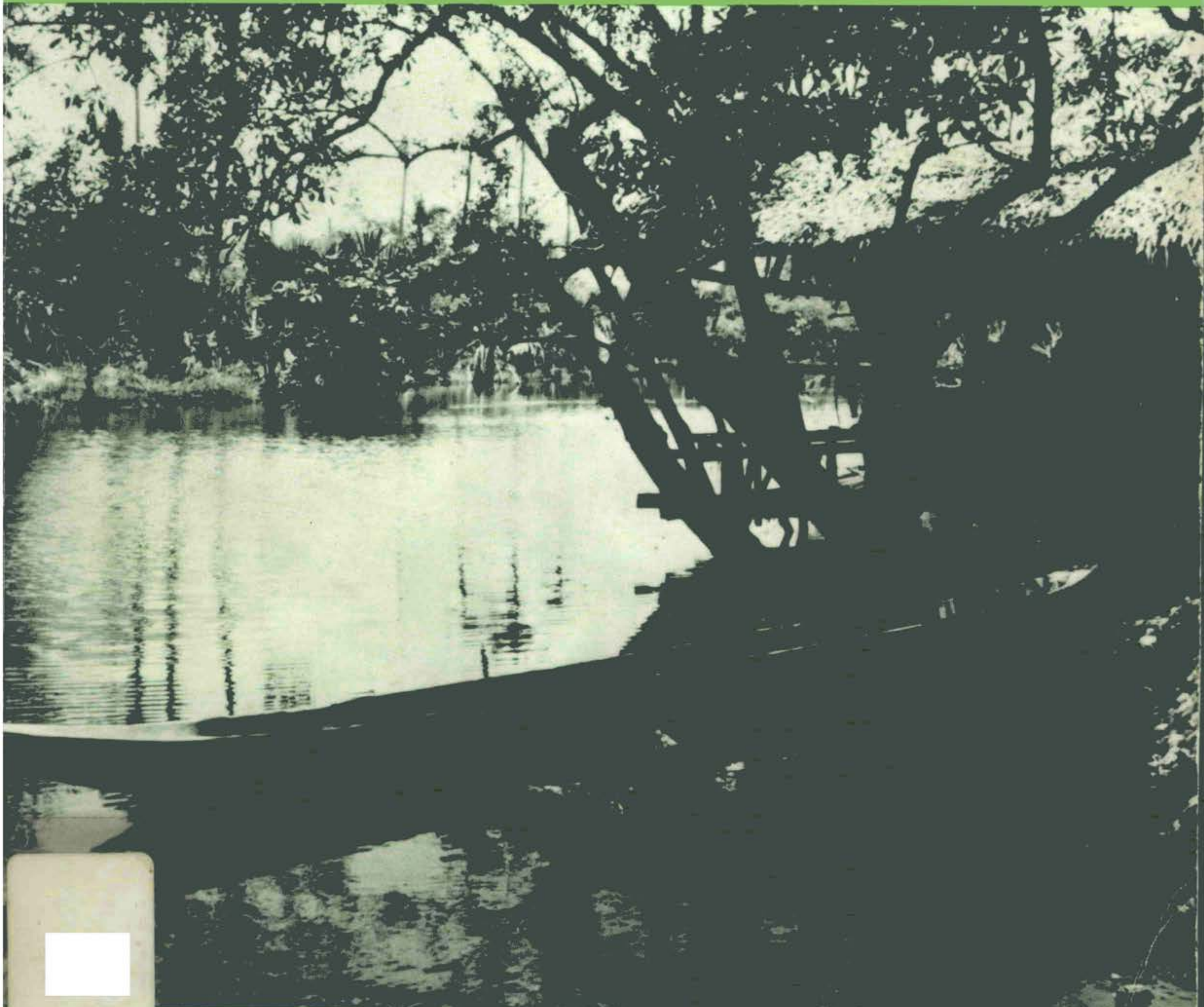
By a Writing Team of the

Environment and Policy Institute
East-West Center

International Union
for the Conservation of
Nature and Natural Resources

United Nations
Educational, Scientific
and Cultural Organization

with additional support from the
United Nations Environment Programme



Edited by Lawrence S. Hamilton and Samuel C. Snedaker

1984

EU ELREY. Faço ſaber aos que eſte Meu Alvará com força de Ley, virem, que por parte dos Erectores das Fabricas de Sola em Atanados nas Capitanias do Rio de Janeiro, e Pernambuco, me foi repreſentado que os Povos das vizinhanças das referidas Capitanias, e das de Santos, Paraiba, Rio Grande, e Seará, cortaõ, e arrazaõ as arvores chamadas Mangues, ſó a fim de as venderem para lenha, ſendo que a caſca das meſmas arvores he a unica no Braſil, com que ſe póde fazer o curtimento dos Couros para Atanados, e que pelo referido motivo, ſe achaõ já em exceſſivo preço as referidas caſcas, havendo juntamente o bem fundado receio de que dentro de poucos annos falte totalmente eſte ſimples, neceſſario, e indiſpenſavel para a continuaçaõ deſtas utiliſſimas Fabricas: E querendo Eu favorecer o Commercio, em commum beneficio dos meus Vaſſallos, eſpecialmente as manufacturas, e Fabricas, de que reſultaõ augmentos á Navegaçaõ, e ſe multiplicaõ as exportaçoens dos generos: Sou ſervido ordenar, que da publicaçaõ deſta em diante, ſe naõ cortem as arvores de Mangues, que naõ eſtiverem já deſcaſcadas, debaixo da pena de cincoenta mil reis, que ſerá paga da cadea, onde eſtaraõ os culpados por tempo de tres mezes, dobrando-ſe as condenaçoens, e o tempo da prizaõ pelas reincidencias; e para que mais facilmente ſe hajaõ de conhecer, e caſtigar as contravençoens, ſe aceitaráõ denuncias em ſegredo, e faraõ a favor dos Denunciantes as referidas condenaçoens, que no cazo de naõ os haver, ſe applicaráõ para as deſpezas da Camara: Pelo contrario ſou outro ſim ſervido que aſſim aos Fabricantes dos Atanados, e ſeus Feitores, ou Commiſſarios, como a todas, e quaeſquer Peſſoas, que levarem a vender as Caſcas de Mangues para eſtas Manufacturas, ſeja livremente permittido o deſcaſcarem as referidas arvores, ſem diſtinçaõ de lugar, ou Comarca, e ſem duvida nem contradiçaõ alguma; no cazo porém que ás referidas Peſſoas ſe faça algum embaraço poderáõ recorrer aos Intendentes das Meſas da Inſpecçaõ reſpectivas para que lhes façaõ executar, e cumprir eſta Minha Real Determinaçaõ; aſſim, e do meſmo modo que

nella

nella ſe contém, para o que ſou ſervido conceder-lhes toda a Juriſdicçaõ neceſſaria.

Pelo que: Mando á Meſa do Deſembargo do Paço; Regedor da Caſa da Supplicaçaõ, Conſelho de Minha Real Fazenda, e do Ultramar, Meſa da Conſciencia, e Ordens; Senado da Camara; Junta do Commercio deſtes Reinos, e ſeus Dominios; Vice-Rey do Eſtado do Braſil, Governadores, e Capitaens Generaes, Deſembargadores, Corregedores, Juizes, Juſtiças, e Peſſoas de Meus Reinos, e Senhorios, a quem o conhecimento deſte pertencer, que aſſim o cumpraõ, e guardem, e façaõ inteiramente cumprir, e guardar como nelle ſe contém, ſem embargo de quaeſquer Leys, ou coſtumes em contrario, que todos, e todas Hey por derogados, como ſe de cada huma, e cada hum delles fizeſſe expreſſa, e individual mençaõ valendo eſte Alvará como Carta paſſada pela Chancellaria, ainda que por ella naõ ha de paſſar, e que o ſeu effeito haja de durar mais de hum anno, ſem embargo das Ordenaçoens em contrario: Regiſtando-ſe em todos os lugares, onde ſe coſtumaõ regiſtar ſimilhantes Leys: E mandando-ſe o Original para a Torre do Tombo. Dado no Palacio de Noſſa Senhora da Ajuda, a nove de Julho de mil ſetecentos e ſeſſenta.

REY

Conde de Oeyras.

ALvará com força de Ley, por que Voſſa Mageſtade he ſervido prohibir, que nas Capitanias do Rio de Janeiro, Pernambuco, Santos, Paraiba, Rio Grande, e Seará, ſe naõ cortem as Arvores de Mangues, que naõ eſtiverem já deſcaſcadas, debaixo das penas nelle conteúdas: Tudo na fórma que aſſima ſe declara.

Para V. Mageſtade ver.

Regiſta-

Regiſtado neſta Secretaria de Eſtado dos Negocios do Reino no Livro da Junta do Commercio deſtes Reinos, e ſeus Dominios a fol. 19. Noſſa Senhora da Ajuda, a 10 de Julho de 1760.

Joaquim Joſeph Borralho.

Joaquim Joſeph Borralho o fez.

Alvará de 10 de julho de 1760. Del-Rey d. José pelo qual determina a proteção das árvores mangues do Brasil.

Edict enacted by D. José, King of Portugal, on the 10th of July of 1760, making unlawful the felling of mangrove trees for firewood without the utilization of the bark. The edict was a result of the widespread felling of trees for firewood in the Capitamas of Rio de Janeiro, Pernambuco, Santos, Paraiba, Rio Grande, and Cearz. Felling of trees just for firewood had caused an undue increase in the price of bark needed for the tanneries. Furthermore, according to the edict there was reasonable fear that within a few years bark could become totally scarce. The edict imposed a penalty of 50,000 reis and a jail term of three months for the felling of trees that had not been previously debarked.

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Foreword

The Environment and Policy Institute (EAPI) of the East-West Center conducts research and education programs through multinational collaboration on issues of central concern to the United States and nations of Asia and the Pacific. Established in 1977, EAPI programs address the critical issue of how countries individually and collectively manage and use the natural environment to assure its sustained productivity in meeting human and societal needs.

The EAPI focus on analysis of natural systems provides a perspective on policymaking and management that intersects with and complements more institutionalized approaches generally based on policies and activities of specific sectors, such as energy or agriculture. This combined approach assists in analyzing tradeoffs that may not be apparent in a sectoral-based analysis, and it also avoids a polarization of environmental versus sectoral goals.

This approach is consistent with that taken by the IUCN and Unesco, particularly in their work on mangrove ecosystems. Our three institutions have combined resources to produce this *Handbook for Mangrove Area Management*. It is our hope that this work will be of use to practitioners and policymakers responsible for the sustained functioning and productivity of mangrove ecosystems.

William H. Matthews
Director
Environment and Policy Institute

Preface and Acknowledgments

This *Handbook for Mangrove Area Management* is one of a collection of publications prepared under the auspices of the IUCN Commission on Ecology's Working Group on Mangrove Ecosystems, the Unesco/Major Interregional Project on Coastal Systems (COMAR), and, in this case, the East-West Environment and Policy Institute. The first publications in the collection were the *Bibliography on Mangrove Research 1600–1675* published by Unesco in 1981 and the *Global Status of Mangrove Ecosystems* released in 1981 by IUCN (and printed formally in 1983). This was followed in 1982 by an audiovisual program, "Understanding Mangrove Ecosystems," produced cooperatively by the East-West Center and IUCN/WWF. In press at the time of preparation of this handbook and to be released in spring, 1984, was a volume in the Unesco Monographs in Oceanographic Methodology entitled "Mangrove Ecosystem: Research Methods." It is the result of the Unesco/SCOR Working Group 60 on Mangrove Ecosystems, established in 1978. Those two completed volumes establish the value and status of the mangrove ecosystem, and present a general research methodology for investigators, respectively. This management manual fills another important gap: it provides a global perspective of alternative uses for economic development that are consistent with the long-term sustainable functioning of mangrove ecosystems. The final publication in this first phase of joint activities will be a biosphere inventory of mangrove forest lands with profiles of institutions managing mangroves and summaries of research initiatives. Prepared with the support of the United States Man and the Biosphere Program and the United States Forest Service, it is expected to be printed and released in late 1984. Other collaborative activities are being planned for the second phase, and these will focus on specific management and conservation problems and new knowledge of these important global ecosystems.

The twenty-two authors who cooperated in writing this handbook have been identified as a group. The editors, who were part of that group also, wish to gratefully acknowledge the outstanding work performed by these men and women during a writing workshop held at the East-West Center, 25 September to 4 October 1983. They worked literally day and night in a concentrated period, writing as individuals, in pairs, and in groups, reviewing and revising each other's material and interacting across disciplines and topics to discuss problems and obtain input. Some magical group "chemistry" manifested and gave the enterprise a real excitement and multiplied productivity.

Some of the writers were "lead" authors and brought rough draft material to the workshop or accepted primary responsibility for pushing the chapter or section along. They have not been singled out by name, but they are known to this group of scientists and to themselves, and they merit special thanks. Two persons, Eddie Hegerl and James Davie must be thanked especially, however, for staying on for several days and doing extensive rewriting and new writing in some particularly troublesome areas. Dr. Ong Jin Eong, Mr. R.G. Dixon, and Dr. S.M. Saifullah were not present at the workshop but contributed as authors.

We also acknowledge the assistance of Evan Mercer, a research intern at the East-West Center who increased the workshop productivity by attending to routine tasks and logistical support for each of the writers, and by subsequently assisting the editors. Samuel Pearsall III, while a research intern prior to the workshop, prepared valuable country background papers based on available literature. Karen Ashitomi worked unstintingly and cheerfully as typist under a demanding schedule, and she has our respect and applause. We also wish to acknowledge the contribution made by Dr. Abu Ahmed of the Department of Zoology, University of Dacca, Bangladesh, who joined the workshop as an unexpected but welcome "walk-in" for two days and provided his advice and comments on the material in preparation on mariculture and fisheries.

We acknowledge the very considerable help of a distinguished group of professionals who reviewed, commented on, and critiqued the various chapters. A considerable amount of rewriting resulted from their helpful input. These reviewers included P. Bacon (University of West Indies, Jamaica), G. Baines (Planning Office, Solomon Islands), J. Bardach (East-West Center, U.S.A.), R. Becking (Humboldt State University, U.S.A.), P. Berjak (University of Natal, South Africa), H. Gregersen (University of Minnesota, U.S.A.), J. Knetsch (Simon Fraser

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Introduction

Mangroves are salt-tolerant forest ecosystems of tropical and subtropical intertidal regions of the world. Like tropical forests of wholly terrestrial environments, mangroves have played an important part in the economies of tropical peoples for thousands of years and constitute a reservoir and refuge for many unusual plants and animals. In both developed and developing countries of the world, mangrove ecosystems support both commercial and recreational fisheries and provide many other direct and indirect services. Especially in the developed world, local people and tourists alike are turning increasingly to mangroves and their secluded waterways for recreation and nature study.

Like the tropical rainforests, mangroves are being degraded and destroyed globally on a large scale through overexploitation of their potentially renewable products and through conversion to single-use options such as agriculture. Large-scale conversions of mangrove lands to mariculture ponds and to salt-evaporation ponds is of further critical concern. Unlike tropical moist forests, however, much of the conversion of mangrove ecosystems is based upon the assumption (held by many regional, national, and international planners and administrators) that mangroves are "wastelands" that are of no value until they have been "developed" through conversion or some other direct method of exploitation for cash products.

This handbook, which was prepared by a group of leading mangrove researchers and managers, summarizes the most up-to-date information on the range of products, benefits, and services provided by the world's mangrove resources. Our objectives go further than this, however, and guidelines are provided throughout the handbook for sustainable, multiple-use management of mangrove ecosystems. Sustainable use is a theme of prime importance in approaches for better utilization of the mangrove resource. Failure to view the resource in this way has led to inefficient use and waste of mangroves and denied their many other values to the coastal people who depend on them for fundamental needs — food, fuel, shelter, and monetary earnings. Poor management decisions and practices have severe and direct social, economic, and ecological impacts.

The approach in this handbook is to discuss these problems in four sections. Section I is written particularly for administrators and planners operating at national or regional levels, and it is hoped that its contents will also be of interest to entrepreneurs and to administrators of international aid organizations. The objective of Section I is to foster increased understanding so that better decisions on land-use allocation might be made.

Section II is directed primarily to professional resource managers responsible at the operational level for the many products, services, and benefits that mangrove systems provide. The first chapter in this section includes a summary in matrix form of the uses that can be made of individual mangrove species. This is followed by a brief explanation of the critical processes essential for sustaining mangrove ecosystems that need to be understood in order to implement successful management practices. Subsequent chapters provide descriptions of problems, constraints, and management methods that apply to several major uses of mangrove ecosystems.

As far as has been possible, each chapter in Section II that deals with a particular use examines the scale, technique, and design guidelines necessary for establishing sustainable management practices. Attention also is given to potentially compatible uses for multi-use management that would not foreclose other options as do single-use developments.

It is recognized that treatment of the various uses and management options in Section II is uneven. For instance, considerable details are included in the chapter on wood production. This is occasioned by the fact that a considerable body of knowledge and experience has developed out of the professional field of forestry over half a century of attempting sustained-yield management of mangroves. In dramatic contrast, there has been little experience with wildlife management in mangroves, other than preserving the habitat, and therefore this chapter consists of several descriptive paragraphs and a table of species at risk. The chapter on fisheries does not deal with the management of the fisheries, since this does not affect the mangrove area; instead it concentrates on highlighting something of the relationship between the mangrove forest and the fishery. Some understanding of this relationship is important because it must influence the manipulations of and disturbances to mangroves from the other use options. On the other hand, some detail has been presented on mariculture management, for the kind of mariculture and its extent directly affects the mangrove resource and the alternative uses and services from it. Honey production and nipa palm utilization would seem to offer opportunities for increased exploitation, and information is presented in some detail on these rather unusual and interesting management activities.

From all available evidence we know that ecological, sociological, and long-term economic benefits can be optimized by promoting a policy of maximum — not minimum — retention of mangrove areas. The positive philosophy contained in Section III of this handbook provides the approach and some of the techniques for using available intertidal land to expand, restore, and establish new mangrove vegetation so that it can serve many local purposes.

Section IV deals in detail with the economic aspects of a sustainable multi-use approach to mangrove resource management. The information presented reinforces the view that positive advantages exist in sustained, multiple-use management of mangrove resources and that methods and approaches necessary to weigh the benefits and costs are available.

Section V discusses the development of national plans for the intergrated management of mangrove resources in individual countries. The options for utilization of mangroves will vary among countries depending upon the properties of the mangrove ecosystems that are found there and also upon historical, social, and economic factors. These need to be understood when a program is devised recognizing the values of conservation of the mangrove resource.

Since it is recognized that various users, managers, planners, or policymakers will find one or a few topics of direct interest and others of only marginal or no interest, the authors have attempted to make each chapter or section stand on its own. Thus, most chapters or sections are followed by a list of literature cited plus useful references for those wishing more information on a particular topic. This strategy has meant that there is a certain amount of repetition of underlying themes of "sustainability" and the processes tying together the various components of the mangrove ecosystem and its related environments.

SECTION I POLICY AND PLANNING

Mangroves and mangrove ecosystems are often regarded as wastelands of little or no value until they are "developed." All too often, this term means *conversion* of the mangrove ecosystem to some other form of use assumed to be of greater value. This approach to utilization is based on a failure to recognize the natural values of mangrove ecosystems that are expressed as a variety of products and services.

In our rapidly industrializing world, there is a tendency to presume that any services can be provided if funds are available to pay capital and maintenance costs. For example, it has become common practice to use engineering methods to provide basic services typically required by a coastal urban community such as storm protection, erosion control, wastewater cleanup, and a variety of educational and leisure activities. In coastal areas with mangrove ecosystems, such financial outlays are unnecessary, because the majority of those services required by society are in fact provided by mangroves.

Several examples illustrate this. Cyclones in the Bay of Bengal pose a major threat to human life and property in India and Bangladesh. It is noteworthy that the loss of life and property is consistently lower in the areas inland from the Ganges-Brahmaputra Delta (heavily forested in mangroves) than in similar areas to the east or west. In southern Florida, U.S.A., mangroves are purposely planted or protected under government mandate to minimize shoreline erosion and provide habitats for local sport and commercial fisheries. Engineering alternatives to mangrove planting are considered to be prohibitively expensive and fail to provide a natural habitat. Finally, in Trinidad, the creation of the Caroni Swamp as a popular recreational area has proved also to be an important tourist attraction for only the cost of providing relatively simple access for visitors. These examples illustrate the fact that scarce financial resources are frequently committed to providing services that otherwise could be obtained without the outlay of funds.

In addition to the multiple and sustained "free" services provided by mangrove ecosystems, a range of direct (Table 1) and indirect (Table 2) products from mangroves forms the basis for mangrove-dependent economic activities vital to many coastal peoples and their countries. Commercial and traditional products taken from the mangrove ecosystem range from construction materials to medicines and honey. Mangroves are used as an important and potentially sustainable source of wood and charcoal to meet the increasing needs of developing countries for domestic fuel. Interest has also arisen in species such as the *Nypa* palm, which produces alcohol that can be processed into transport fuel. In some areas, grazing occurs in mangrove areas, and mangrove trees may be the sole source of fodder during dry periods for domestic herds of cattle, camels, sheep, and goats. Other natural products harvested in mangrove areas include crustaceans, molluscs, and finfish.

These uses sustain many communities whose economies are based on harvesting the fish, shellfish, wood, and other products. Locally important industries, such as the Nipa shingle industry, are based on the mangrove resource and provide rural employment.

The value of the mangrove resource in terms of its marketed products can be expressed in economic terms. The "free" services provided by the mangroves are more difficult to measure and consequently are often ignored. These "free" services would require considerable energy, technology, and money if they were provided from other sources. Since this is seldom taken into account, the total value of the mangrove resource generally is significantly underestimated.

More important, however, are the economic and social well-being of coastal communities and the many economic regional and national activities that are dependent on the continued viability of mangrove ecosystems. This concept is the reverse of the common assumption that mangroves are worthless unless they are fully exploited for single-use activities or converted to some other use. Single-purpose exploitation effectively discounts the value of developing all other forms of mangrove goods and services and in the case of conversion forecloses alternative utilization options.

As mangrove management experience increases, planners and developers will recognize the potential for multipurpose use without sacrificing ecosystem integrity. This broader perception of the potential economic and social benefits that can be derived from compatible, multipurpose utilization can only be developed

Table 1. Direct Products from Mangrove Forests

Uses	*Products*
Fuel	Firewood for cooking, heating Firewood for smoking fish Firewood for smoking sheet rubber Firewood for burning bricks Charcoal Alcohol
Construction	Timber for scaffolds Timber for heavy construction (e.g., bridges) Railroad ties Mining pit props Deck pilings Beams and poles for buildings Flooring, panelling Boat building materials Fence posts Water pipes Chipboards Glues
Fishing	Poles for fish traps Fishing floats Fish poison Tannins for net preservation Fish attracting shelters
Agriculture	Fodder Green manure
Paper Production	Paper of various kinds
Foods, Drugs, and Beverages	Sugar Alcohol Cooking oil Vinegar Tea substitutes Fermented drinks Dessert topping Condiments from bark Sweetmeats from propagules Vegetables from propagules, fruits, or leaves Cigarette wrappers Medicines from bark, leaves, and fruits
Household Items	Furniture Glue Hairdressing oil Tool handles Rice mortar Toys Matchsticks Incense
Textile and Leather Production	Synthetic fibers Dye for cloth Tannins for leather preservation
Other	Packing boxes

Table 2. Indirect Products from Mangrove Forests

Source	*Product*
Finfish (many species)	Food Fertilizer
Crustaceans (prawns, shrimp, crabs)	Food
Molluscs (oysters, mussels, cockles)	Food
Bees	Honey Wax
Birds	Food Feathers Recreation (watching, hunting)
Mammals	Food Fur Recreation (watching, hunting)
Reptiles	Skins Food Recreation
Other Fauna (e.g., amphibians, insects)	Food Recreation

by an accounting of the benefits or costs from uses that are nonrenewable because of their impact on critical ecosystem processes.

Being a living resource (Figure 1), mangroves are self-maintaining and renewable. For example, as a coastal protection barrier, mangroves maintain themselves at no cost, and in the event of a severe tropical storm, the damage they sustain will be self-repaired without cost. Similarly, both the direct and indirect harvests of products from mangroves are renewable; for example, sustainable yields of timber or fish can be derived from the mangroves on a continuing basis. Yet the mangrove resource is renewable only if the ecological processes governing the system are maintained.

The "internal" ecological processes responsible for maintaining and renewing the mangrove ecosystem are regulated largely by "external" processes that rely on (1) an adequate amount and balance between fresh and salt water, (2) an adequate supply of nutrients, and (3) a stable substrate. Modification of one or more of these critical factors will severely impair or eliminate the renewability of the resource. For example, the freshwater supply and its nutrients may be altered by major upstream water storage areas or diversions.

Figure 1. A solitary mangrove tree on the Fiji coast.

Mangroves are threatened throughout the world by traditional users exceeding the sustainable-yield limit in the harvests of direct products and now also by large-scale commercial wood chip operations. More important, conversion activities such as agriculture, fish ponds, and residential development are increasing. With such conversion activities, the condition of the intertidal zone is irreversibly altered and the three critical factors are so modified that the renewability of the resource is lost.

Both overexploitation and conversion activities can result in severe socioeconomic consequences for coastal peoples and their regional economies. In addition, many plant and animal species are now threatened with extinction in mangrove areas, and this can be expected to increase steadily unless rational, multiple-use management for sustainable yield can be implemented.

Mangroves are too valuable to allow them to be lost to other forms of land use except when overriding national priorities are involved and no other alternative is economically or environmentally feasible. Overexploitation of mangroves by traditional users is closely linked to the general problems of rapidly expanding populations and associated decreases in economic standards. No easy short-term solution may be available, but education programs that inform people of the diversity of sustainable uses of the mangrove resource may be helpful.

Both sustainable use and preservation can be incorporated into an effective management policy if it has the following goals:

1. To prevent further destruction of mangroves by halting all unjustifiable conversion activities.
2. To provide for traditional and contemporary human needs while ensuring that the diversity of plant and animal life is adequately protected within reserves.
3. To manage mangroves as a renewable resource on a sustainable-use basis for direct and indirect products as well as the "free" environmental services they provide. Management on a sustainable-use basis often does not involve added costs, at least in the long term.
4. To view mangroves as an integral part of the coastal zone rather than as an ecosystem surviving in isolation. Decisions concerning the use of mangroves should be made in the context of their dependence on the adjacent water catchment land use

and on their important interrelationships with adjoining coastal waters and any associated tidal marshes, seagrass beds, and coral reefs.

5. To conduct impact assessments for projects in and adjacent to mangroves on the basis of the dynamic nature of this ecosystem with particular emphasis on the vital "external" processes related to the supply of both fresh and salt water, the supply of nutrients, and the stability of the substrate.

As a first step toward achieving these goals, a mangrove data base and a national plan for management and preservation of mangroves should be developed. A mangrove data base would be a comprehensive collection of information on such subjects as the areas and distribution of mangroves, their flora and fauna, present and potential yields from various uses, and the socioeconomic structure of human populations dependent on the resource. The national plan should define the total national mangrove resource by maps and inventories; assess people's needs in relation to sustainable uses of the resource; assess the international significance for waterfowl migration, genetic reservoirs, regional sedimentary stability, and marine species migration; and define the criteria that must be satisfied for nonsustainable uses of the resource prior to any allocation of mangrove areas to such an activity. It should include areas of complete preservation of special nationally significant areas.

SECTION II

CHAPTER 1. Overview

Known Uses for Mangroves

Globally, mangrove ecosystems are thought to contain about 60 species of trees and shrubs and more than 20 additional species frequently associated with the mangrove flora but not necessarily restricted to it (see Barth 1982). Although definitive lists are not available, it is thought that the mangrove environment also provides living space for a dependent biota of more than 2,000 species of fish, invertebrates, and epiphytic plants.

Policymakers and resource managers often ask about the potential uses of mangrove species with which they may be familiar. Each plant species has a variety of direct uses that may vary from region to region. Table 1 lists the known uses of many of the tree and shrub species found in mangroves, but there are likely many other uses that are localized and essentially unknown outside the immediate area. It is important for managers to know the specific uses for mangroves in their areas prior to making decisions that will deny those uses to the local people.

Although the mangrove ecosystem may be considered by some to be useless and suitable only for reclamation, Table 3 shows that the number and variety of known uses and products from the forest are substantial. Traditionally mangroves have been exploited as multiple-use systems, and because of the small scale at which this use has occurred, it was in most cases sustainable. Evidence of one such system in West Java has been outlined in Chapter 10 on Human Habitation, while the use of nipa discussed in Chapter 8 provides a further example. Nevertheless, this was not always the case and some evidence for this appears in Chapter 12 on salt production. In West Africa traditional salt extraction may have caused the irreversible conversion of large mangrove areas to less productive saline plains over the past several hundred years.

Under management regimes in many parts of the tropical world, it is likely that important mangrove resources, as in the West African example, will not be sustained. Changes in philosophy by policymakers must be complemented by expanded awareness and greater specific knowledge by professional managers operating at the resource level. Of critical importance is the need for managers to understand that implementation of national or regional development policies involving modern technology may produce environmental change of such magnitude that local effects will be devastating. Frequently these changes are concerned with conversion activities aimed at expanding agricultural or maricultural outputs, and little consideration is given to the natural resources that are of vital importance at the local level.

Ecological Perspective on Mangrove Ecosystems

The diversity of living species in mangrove ecosystems is paralleled by a variety in vegetation structure. Mangrove ecosystems are as structurally diverse as the general sweep of terrestrial vegetation. They encompass everything from the giant, closed forests of *Rhizophora mangle* and *Avicennia germinans* that reach 40–50 m in height in parts of Brazil, Colombia, Ecuador, and Venezuela to the more familiar closed forests of species of *Rhizophora*, *Avicennia*, *Bruguiera*, *Xylocarpus*, *Excoecaria*, and *Laguncularia* found in Asia and Oceania to the stunted shrubs less than 1 m tall, forming open communities on more arid coasts throughout the tropical world. In addition, growth habits show a wide variation from single-stemmed trees to multistemmed trees and shrubs, and they may be erect or sprawling.

Diversity in the structural formations of mangrove ecosystems can be witnessed along latitudinal gradients (as for *Avicennia* along the east coast of Australia), and probably also along longitudinal gradients that reflect climatic—especially rainfall—gradients. One example is from the Malay Peninsula east across Indonesia to Sulawesi, Nusa Tenggara, Irian Jaya, and the Philippines.

Across latitudinal gradients air temperature appears to be the most important factor in defining the growing season of plants. Across longitudinal gradients available water and soil fertility are factors that affect cell elongation and dynamics of shoot populations in survival or turnover of meristems. Such factors may also act on biogeographic patterns.

Table 3. Current Uses of Mangrove Species

Species	Uses
Acanthus sp.	
A. ebracteatus Vahl.	medicines
A. ilicifolius L.	medicines
Aegialitis rotundifolia Roxb.	honey
Aegiceras corniculatum (L.) Blanco	firewood, beams, poles (building), fish poison, paper (various kinds), honey
Avicennia sp.	fence posts, pipes, chipboards, glues, fodder, green manure, rice mortar
A. alba Blume	firewood, beams, poles (building), fence posts, pipes, chipboards, glues, wood for smoking fish, fish poison, paper (various kinds), fodder, green manure, sweetmeats/propagules, medicines
A. eucalyptifolia Zipp.	fence posts, pipes, chipboards, glues
A. germinans L.	firewood, charcoal, timber, scaffolds, railroad ties, boat building, dock pilings, beams, poles (building), flooring, panelling, fence posts, pipes, chipboards, glues, pallets, honey, medicines
A. mariana Vierh.	firewood, heavy construction, beams, poles (building), wood for smoking fish, paper (various kinds), fodder, green manure, vegetables, honey, soap
A. nitida Jacq.	firewood, charcoal, timber, scaffolds, heavy construction, railroad ties, boat building, dock pilings, beams, poles (building), flooring, panelling, fence posts, pipes, chipboards, glues, pallets, fodder, green manure, sweetmeats/propagules, honey, furniture
A. officinalis L.	firewood, wood for smoking fish, paper (various kinds), fodder, green manure, vegetables, rice mortar
A. schaueriana Staph and Leechman	firewood, tannins for leather, honey
Bruguiera sp.	synthetic fibers, dye for cloth
B. cylindrica (L.) Blume	firewood, charcoal, timber, scaffolds, mining pit props, beams, poles (building), poles for fish traps, tannis for leather, rituals
B. gymnorhiza (L.) Lam.	firewood, charcoal, timber, scaffolds, heavy construction, mining pit props, boat building, beams, poles (building), fence posts, pipes, chipboards, glues, wood for smoking fish, tannins/net preservatives, tannins for leather, condiments from bark, vegetables, medicines, furniture, tool handles
B. parviflora (Roxb.) Wight and Arn	firewood, charcoal, timber, scaffolds, mining pit props, beams, poles (building), tannins for leather, paper (various kinds)
B. sexangula (Lour.) Poiret	firewood, charcoal, timber, scaffolds, beams, poles (building), tannins for leather, condiments from bark, vegetables, medicines, chewing gum, incense
Camptostemnon sp.	
C. philippinensis Becc.	firewood, paper (various kinds)
C. schultzii Mast.	timber, scaffolds, paper (various kinds)

Table 3. (Continued)

Species	Uses
Ceriops sp.	charcoal, dye for cloth, fodder, green manure
C. decandra (Griff.) Ding Hou	firewood, boat building, beams, poles (building), tannins for leather, honey
C. tagal (Perrottet) Robinson	firewood, timber, scaffolds, mining pit props, boat building, beams, poles (building), tannins/net preservatives, dye for cloth, tannins for leather, paper (various kinds), tea substitutes, medicines
Conocarpus erectus L.	firewood, charcoal, timber, scaffolds, boat building, beams, poles (building), flooring, panelling, honey, furniture, tool handles
Cynometra ramiflora L.	firewood, heavy construction, flooring, panelling, honey
Excoecaria agallocha L.	timber, scaffolds, flooring, panelling, floats, fish poison, paper (various kinds), packing boxes, condiments from bark, honey, toys, matchsticks, incense
Heritiera sp.	
H. fomes Buch.-Ham.	timber, scaffolds, heavy construction, boat building, dock pilings, beams, poles (building), flooring, panelling, furniture, matchsticks
H. littoralis Aiton ex Dryander	firewood, timber, scaffolds, heavy construction, railroad ties, boat building, dock pilings, beams, poles (building), flooring, panelling, fence posts, pipes, chipboards, glues, tannins/net preservatives, furniture, tool handles, rice mortar
Kandelia candel (L.) Druce	firewood
Laguncularia racemosa Gaertn. f.	firewood, charcoal, beams, poles (building), fence posts, pipes, chipboards, glues, tannins for leather, tool handles
Lumnitzera sp.	medicines
L. littorea (Jack) Voigt	firewood, heavy construction, railroad ties, mining pit props, boat building, dock pilings, beams, poles (building), flooring, panelling, fence posts, pipes, chipboards, glues, poles for fish traps, wood for smoking fish, furniture, tool handles
L. racemosa Willd.	firewood, heavy construction, railroad ties, mining pit props, boat building, dock pilings, beams, poles (building), flooring, panelling, fence posts, pipes, chipboards, glues, poles for fish traps, wood for smoking fish
Nypa fructicans van Wurmb.	fuel alcohol, thatch, matting, poles for fish traps, floats, raincoats, umbrellas, hats, sugar, vinegar, fermented drinks, sweetmeats/propagules, cigarette wrappers, medicines, baskets
Phoenix paludosa Roxb.	fence posts, pipes, chipboards, glues
Rhizophora sp.	tannins/net preservatives, dye for cloth, tannins for leather, woodenware
R. apiculata Blume	firewood, charcoal, timber, scaffolds, heavy construction, railroad ties, mining pit props, dock pilings, beams, poles (building), fence posts, pipes, chipboards, glues, poles for fish traps, furniture, Christmas trees

Table 3. (Continued)

R. harrisonii Leechman	firewood, charcoal, timber, scaffolds, heavy construction, railroad ties, mining pit props, boat building, dock pilings, beams, poles (building), flooring, panelling, fence posts, pipes, chipboards, glues, pallets
R. mangle L.	firewood, charcoal, timber, scaffolds, heavy construction, railroad ties, mining pit props, boat building, dock pilings, beams, poles (building), flooring, panelling, fence posts, pipes, chipboards, glues, pallets, poles for fish traps, tannins/net preservatives, tannins for leather, fodder, green manure, tea substitutes, honey, tool handles
R. mucronata Lam.	firewood, charcoal, timber, scaffolds, heavy construction, railroad ties, mining pit props, dock pilings, beams, poles (building), fence posts, pipes, chipboards, glues, poles for fish traps, tannins for leather, paper (various kinds), fodder, green manure, fermented drinks, sweetmeats/propagules, honey, medicines, furniture, Christmas trees
R. racemosa G. Meyer	firewood, charcoal, timber, scaffolds, heavy construction, railroad ties, mining pit props, boat building, dock pilings, beams, poles (building), flooring, panelling, fence posts, pipes, chipboards, glues, pallets, poles for fish traps, tannins/net preservatives, tannins for leather, tool handles, woodenware
R. stylosa Griff.	firewood, charcoal
R. x selala (Salvoza) Tomlinson	firewood
Scyphiphora hydrophyllacea Gaertn.	firewood, fence posts, pipes, chipboards, glues, tool handles
Sonneratia sp.	hats
S. alba J. Smith	firewood, heavy construction, boat building, dock pilings, beams, poles (building), flooring, panelling, fence posts, pipes, chipboards, glues, poles for fish traps, floats, dye for cloth, fodder, green manure, vinegar, sweetmeats/propagules, vegetables, furniture
S. apetala Buch.-Ham.	firewood, timber, scaffolds, heavy construction, boat building, furniture
S. caeseolaris (L.) Engl.	firewood, timber, scaffolds, heavy construction, railroad ties, boat building, dock pilings, beams, poles (building), flooring, panelling, fence posts, pipes, chipboards, glues, pallets, floats, paper (various kinds), fodder, green manure, sweetmeats/propagules, furniture, cosmetics
Xylocarpus sp.	dye for cloth
X. gangeticus Parkison	unknown
X. granatum Koenig	firewood, timber, scaffolds, railroad ties, boat building, dock pilings, beams, poles (building), flooring, panelling, fence posts, pipes, chipboards, glues, dye for cloth, paper (various kinds), furniture, tool handles, toys, woodenware, carvings, pencils
X. moluccensis (Lam) Roem.	firewood, timber, scaffolds, railroad ties, boat building, dock pilings, beams, poles (building), flooring, panelling, fence posts, pipes, chipboards, glues, paper (various kinds), furniture, hairdressing oil, tool handles, woodenware, carvings

Similar scales of structural vegetation variation also occur at a single geographic location across the steep gradients that frequently characterize the intertidal environment (see Thom 1982). This structural diversity is best represented in seasonal climates, especially where moderate to high tidal ranges exist (e.g., > 2 m). On horizontally expansive prograding shores or deltas the communities of diminishing stature may extend sequentially. This phenomenon appears to be controlled largely by available water (Cintron 1979), which is a function of tidal inundation, rainfall, runon, and evapotranspiration (Pool et al. 1977).

All of these considerations are important in assessing the potential of forests for production of one or another resource and probably also to determine the ability of the species to regenerate. For example, where vegetation is cleared from high tidal sites that are seldom inundated by either tides or rain, evaporation will rapidly increase the water and salt stress on species being established. The new conditions may not permit replacement by plants and lifeforms that previously existed there, and this may necessitate the need to change management objectives to be in line with the new ecological status quo.

It is important for planners and managers to recognize that intertidal environments are extremely varied when considering strategies for coping with derelict land resulting from the abandonment of such enterprises as coastal fish ponds. This problem is evident in many parts of South Sulawesi and in northern Java and elsewhere in Southeast Asia where there are extensive flat, low, coastal plains. In Sulawesi, some examples of "old field" recolonization by mangrove species exist. Properly managed, such areas may be able to support local fuelwood industries or honey production.

As with all other vegetation, the structural and functional properties of mangrove ecosystems are determined by a complex of climatic and site conditions such as air and water temperatures, the availability of water and mineral nutrients (including high concentrations of salt), and light. In addition, intertidal landforms are subject to rapid change by erosion and sedimentation. These changes are mediated by the interaction of climatic, physiographic, and geomorphic processes so that intertidal areas are typically much less stable than the landforms that support hinterland forests.

The approach adopted here and in the global status report (Saenger et al. 1983) is to divide the physical and biological processes or factors that influence intertidal ecosystems into internal and external categories. Internal processes of energy fixation, accumulation of biomass, decomposition of dead organic material, and mineral cycling are most strongly influenced by a small number of external factors governing available water, the pool of available nutrients, and the stability of the habitat.

External factors, such as dam building, watershed erosion, oil pollution, or coastal engineering work, are beyond the control of the mangrove ecosystem. They may cause a change in the status of internal processes and must be considered by the professional mangrove manager. If external factors are maintained within prescribed limits, the ecosystem will persist. Perhaps the most important task for a managing agency should be the estimation of the limits of tolerance for ecosystems under examination, so that guidelines can be established limiting modification of watersheds and other neighboring ecosystems likely to impinge on the mangrove resource.

Conclusion

Analysis of the categories for which mangroves are utilized reveals a range of manipulative impacts involved in developing a particular mangrove product or service. The extent of manipulation will influence the compatibility of a specific use with all other values the mangrove may provide locally. The order of the following chapters generally reflects the increasing extent of environmental manipulation. The order does not indicate in any way the relative importance of any category.

To emphasize the concept that mangrove ecosystems, properly managed, can provide for multiple resource needs on a sustainable basis, a small section in each chapter discusses the compatibility of that use with other management options.

Managers must recognize the variation in the properties of different types of mangrove ecosystems. Different mangrove species may have the potential for quite different uses, and structural variation often will reflect functional properties important to the manager in assessing the range of uses that can be made of the vegetation.

Planning for resource development based on the guidelines provided in the following chapters should allow for a more balanced approach to sustained, multiple use of mangrove ecosystems.

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SECTION II

CHAPTER 2. Preservation

Introduction

Reserves have been established for the preservation of mangrove ecosystems or to enhance the survival of particular species within those ecosystems in at least eighteen countries in the world. Details about individual reserves have been listed in the global status report (Saenger et al. 1983). In most of these countries, the individual areas under preservation are less than 1,000 ha. However, protection is afforded to a total of over 11,000 ha in four reserves in Venezuela, and twenty-six reserves totaling more than 80,000 ha have been established in Australia. Everglades National Park in the United States, containing almost 100,000 ha of mangrove forest, is the world's largest mangrove preservation area.

The total area of mangrove forests presently under some degree of preservation status represents less than 1 percent of the total world mangrove resource, and few reserves are subject to an adequate level of management. In terrestrial ecosystems, the preservation of such a small sample of a particular ecosystem would be regarded as inadequate. The importance of mangrove ecosystems and the broad objectives of mangrove preservation make the declaration of many more reserves a matter of urgency in virtually every country with mangrove resources.

The Objectives of Preservation

Mangrove preservation areas can have many objectives in addition to ensuring that essential ecological processes and genetic diversity are maintained (Table 4). While the full list of preservation objectives is not applicable in every situation, it should indicate that preservation areas are valuable economic and social assets and prevent the extinction of species that may be of tangible economic value in the future. Mangrove preservation areas should be seen not as a luxury only suitable for developed nations but as essential and appropriate in every country with mangrove resources (see Figure 2). Preservation areas should be incorporated into management plans even where the resource has already been degraded but where a reasonable level of recovery in the future can be expected.

Table 5 shows the mangrove areas of various countries, along with population density and per capita GNP. Because of the economic and population characteristics, and because of their wide geographical coverage, Australia, Venezuela, and Gabon could be viewed as the three countries with the greatest prospects of achieving global significance as repositories of mangrove-related genetic material.

Planning Mangrove Protected Areas

There are good reasons for designating not only a totally protected core or sanctuary area but also a buffer zone of protected or controlled use that includes "linked habitats" such as adjacent seagrass beds, mud and sand-flat areas, reed beds, coral reefs, and such features as sand dunes, barrier islands, and beaches. In addition, the upstream watershed lands that provide the necessary fresh water, sediment, and nutrient inputs that maintain the system need to come under some control. If they do not, and serious alteration of these inputs occurs subsequent to establishing a mangrove preserve, then the core area could be totally and disastrously altered. Control of such distant, difficult-to-monitor activities clearly is very complex, but it is necessary.

For delineating the core protected area, survey and assessment are necessary to determine such information as

- The type and location of valuable habitats for preservation and such characteristics as size, species diversity, degree of naturalness, uniqueness, representativeness, and the degree of dependence on them by any key wildlife species (critical habitat);
- The type, extent, and location of any existing human uses (recreational, commercial, or subsistence activities), their effects, the degree of dependence of local inhabitants on these uses, and the possibilities of shift-

Table 4. Objectives and Uses of Preservation Areas

Objective	*Use*
Preservation of essential ecological processes	Preservation areas can provide buffer areas to ensure that exploited areas remain productive
Natural restocking of adjacent exploited areas	Preservation areas can act as a vital "seed" source
Preservation of rare and endangered species and habitats and also the common "representative" species and habitats	Preservation areas can provide a source for manually restocking exploited areas where economically important species have been depleted; they also ensure the survival of species that might be of economic benefit in the future
Protection of commercial and recreational fisheries	Preservation areas ensure a supply of organic carbon for the benefit of inshore and offshore fisheries and can ensure that productive fry and nursery grounds are not alienated or overexploited
Establishment of reserves for scientific study	Preservation areas are important to management of exploited areas as they can provide reference sites for scientists to compare unexploited areas and species to the exploited areas and species
Establishment of reserves for educational study	Preservation areas may provide students with their only opportunity to study the natural environment and to better understand the need for sustainable management of exploited areas
Maximization of recreational opportunities and preservation of aesthetic qualities	Preservation areas offer far more for human enjoyment than degraded or altered areas and can be a tourist attraction
Protection of coastlines and riverbanks from erosion and storm damage	Properly sited preservation areas offer maximum protection to human life and property
Containment of floodwaters within natural floodplains	Preservation of estuarine floodplain mangrove ecosystems can also maximize protection to human life and property
Maintenance of navigation channels	Preservation of mangrove islands and coastal and estuarine vegetation can maintain the hydrological conditions necessary to prevent siltation in many navigational channels

ing any of these uses to other areas or resources if they degrade the habitat or deplete species stocks below sustainable levels; and

- Existing and potential threats to the area from activities outside the area.

Once these facts are gathered, one may begin designing the totally protected core and delineating the buffer zone.

Criteria and guidelines for the selection, design, and establishment of Biosphere Reserves under Unesco Man and the Biosphere Programme are helpful. In particular, MAB Report Series No. 22 of 1974, published in Paris by Unesco and a General Technical Report edited by Franklin and Krugman (1979) and produced as PNW-82 by the U.S. Forest Service may be obtained and consulted (see References). Available in 1984 from IUCN is Salm's book, *Managing Coastal and Marine Protected Areas: Principles and Guidelines for Managers of Natural Areas of the Seas.*

Additional Protection Measures

Areas designated for protection are also susceptible to declassification and allocation to other development uses. Such action has recently occurred in Sabah, where one of the largest mangrove reserves in the world has been degazetted to permit exploitation for wood chips. The additional protective layer of some kind of international designation may sometimes be effective in impeding such actions. Biosphere Reserve designation under the Unesco Man and the Biosphere Programme is one such possibility, since the program is attempting to include representation of all the world's biogeographi-

Table 5. Population Density and Economic Status of Countries with the World's Major Mangrove Areas

Country	*Area of Mangroves (ha)*	*Population Density (n/km^2)*	*Per Capita GNP ($US)*
Brazil	2,500,000	14.2	2,220
Indonesia	2,176,271[a]	77.9	530
Australia	1,161,700	1.9	11,080
Nigeria	973,000	94.8	870
Venezuela	673,600	16.9	4,220
Mexico	660,000	36.1	2,250
Malaysia	652,219	43.0	1,840
Burma	517,077	50.4	190
Senegal	500,000	30.1	430
Panama	486,000	24.7	1,910
Colombia	440,000	23.2	1,380
Bangladesh	417,013	629.9	140
Papua New Guinea	411,600	6.7	462
India	356,500	209.9	260
Malagasy	320,700	15.3	330
Vietnam	286,400	168.8	—
Gabon	250,000	2.8	2,420
Pakistan	249,489	105.1	350
Philippines	246,699	165.3	790
Ecuador	215,852	30.3	1,180
US	205,000	24.5	12,820
Cameroon	200,000	18.3	880

Sources: Area from Saenger et al. (1983); population density and real per capita, 1981 data from the 1983 World Development Report, World Bank, USA, Washington, D.C.
[a] Official Indonesian figures indicate 3.6 million ha.

Figure 2. "The tunnel" — a wild waterway in Caroni Mangrove Swamp Forest Reserve, Trinidad — proposed for total protection.

cal ecosystems. Countries may wish to have areas of outstanding international significance (including presence of endangered species) designated as World Heritage Sites. Even the relatively simple step of having the preserve area officially listed in the U.N. World List of National Parks and Equivalent Reserves may provide an extra measure of security.

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SECTION II

CHAPTER 3. Recreation

Introduction

Mangrove ecosystems, with their variety of subhabitats, offer a range of recreational opportunities (Table 6) in at least sixteen countries. In some areas, the mangrove forests are managed to widen the scope of recreational experiences or to permit more intensive usage. Developed nations have been most active in this regard, but some other nations that have not previously stressed outdoor recreation as a development objective are realizing the advantages of doing so. In addition to providing temporary escape from the pressures of urban living for local residents, mangrove forests may have features that will attract visitors from other areas and provide an additional economic asset to the local or regional economy.

Managing a mangrove forest for recreation can serve the needs of both residents and tourists and can be compatible with preservation or nondestructive commercial uses such as honey production or fishing. In Trinidad, the Caroni Swamp attracts many foreign and local visitors to view the large, resident scarlet ibis *(Eudocimus ruber)* population while allowing for compatible multiple uses of the proposed national park. In the Philippines, residents now value the recreational opportunities developed at the intensively managed Mangrove Forest Research Center at Pagbilao. Some nations have protected mangrove forests by establishing national parks over large areas, but recreational opportunities can also be developed in carefully chosen and managed mangrove stands of relatively modest size. The tourist industry has found that cruises and tours through mangrove areas can be profitable enterprises.

Table 6. Recreational Uses of Mangrove Areas

Power-boating
Canoeing
Fishing
Collecting molluscs and crustaceans
Hunting
Hiking
Picnicking
Swimming and snorkeling
Birdwatching
Wildlife observation
Photography
Nature education

Evaluating the Recreational Potential of a Site

In some areas it is easy to select a site for managed recreational use because local residents have already established distinct patterns of recreational use or because the site possesses an obvious natural endowment (such as a rookery site of an attractive bird species). If this is not the case, aerial photographic analysis and field surveys of potential sites will be necessary. The planner must also ensure that data are gathered on social and economic factors to determine if an area will fulfill human recreation needs.

It is important to know if the managed recreational resource will attract foreign tourists as well as domestic users and if one group of users will conflict with or reinforce the other's activities. It also may be necessary to ascertain whether local people are attracted by the same things as foreign tourists and if one particular user group is likely to make greater use of a specific feature of the site.

Some of the more important attributes of a viable recreation area are shown in Table 7. Ideally, a site will possess all of these characteristics, but often there is one favorable attribute that outweighs all others and negates any unfavorable features.

Recreational attributes may be qualitatively evaluated, or a proposed managed recreation area may be evaluated using one of the benefit-cost analysis techniques developed specifically for recreational land uses. Some recreational management projects may not provide significant economic benefits, particularly in the short term, but they can provide socially desirable benefits important to local people.

Managing a Mangrove Recreation Area

The first priority in developing any management scheme is to define the objectives of management. Objectives will vary greatly between a large mangrove wilderness park and a remnant

Table 7. Important Attributes of a Recreation Area

Type	*Attribute*
Biophysical	Presence of life forms prized by consumptive and/or nonconsumptive users
	Presence of rare or exotic species
	Variety in vegetation, fauna, and landscape
	Aesthetic appeal of the scenery
	Favorable climate
	Uniqueness at the regional or national level
Socioeconomic	Proximity to population centers
	Easy access to the area by land or water
	Existing or potential access routes within the area (trails and waterways)
	Awareness of the site among potential users
	Compatibility of recreation development with current or projected uses, including traditional use by local people

mangrove stand in an urban area. Nevertheless, the objectives must be consistent with the national mangrove plan and in harmony with coastal management plans.

The management objectives may give first priority to preservation of the entire ecosystem, a selected component of that ecosystem (such as habitat for an endangered bird), or to the provision of one or more compatible recreation opportunities. The area may be managed specifically for birdwatching, fishing, public education, or a wide spectrum of other uses. Attracting tourists might be an implicit management objective.

Examples of management objectives for a mangrove forest are those contained in the Caroni Swamp National Park Management and Development Plan (Trinidad Forestry Division, MALF 1979):

Protection:	to protect the mangrove ecosystem including water quality, floral and faunal habitat, in particular that of the scarlet ibis.
Education:	to provide opportunities for environmental education and interpretation centering on the ecosystem of the mangrove swamp.
Research:	to provide opportunities for and actively promote research related to the mangrove ecosystem and the management of the National Park.
Recreational:	to facilitate the sympathetic development of the recreational attributes of the area.
Traditional Production Uses:	to accommodate regulated commercial fishing insofar as it does not conflict with the other objectives.

Managing people is by far the most challenging part of recreation management. Comfortably accommodating visitors in mangrove areas is often more difficult than in a terrestrial ecosystem (see Figure 3). Soft substrate and tidal inundation generally limit most visitor access to navigable waterways or artificial walkways. Concentration of users can lead to site degradation and eventually to a decline in ecosystem integrity as well as conflicts among user groups. These problems can be alleviated in several ways:

- Limit the number of visitors in heavily used areas (this is done with a permit system at Everglades National Park in the United States), or rotate the use of sites.
- Limit boat traffic to nonmotorized canoes, to licensed concessionaires, or use time period quotas.
- Segregate incompatible uses through a zoning system (e.g., fishermen use one area and birdwatchers another). Ecologically fragile areas can be zoned to exclude visitors.
- Construct boardwalks or other infrastructure to protect the ecosystem in heavily used areas.
- Educate visitors through information and communication programs.

The method and intensity of visitor management is dictated by management objectives. Mangrove recreation areas can be managed on a continuum from nature preserves to highly developed parkland. As the objectives become

Figure 3. Bathing and camping activity in area adjacent to main mangrove section of Morrocoy National Park in Venezuela.

Figure 4. Visitor center at Mangrove Forest Research Center, Pagbilao, the Philippines.

more people oriented, more park managers are needed, as is a more thorough understanding of the environment. Good management plans are based on a detailed resource inventory and analysis and must indicate clearly how the objectives are to be achieved within the legal, fiscal, and ecological constraints that apply to the recreation area.

Visitor facilities serve the dual purpose of improving visitor comfort and protecting the resource (see Figure 4). Facilities that should be considered by mangrove managers include the following:

- *Boardwalks* to allow the greatest number of people to view and enjoy a mangrove ecosystem. Boardwalks have been successfully installed in the United States, Australia, New Zealand, and Trinidad. Boardwalks built of wood are likely to cause the least ecosystem damage during construction but need more maintenance than more durable materials (see Figure 5). Boardwalks with concrete posts, for example, require a greater capital investment and are likely to cause greater ecosystem damage on installation but require relatively low maintenance.
- *Hiking trails* to be at least intermittently routed over areas of dry land adjacent to or within the mangroves.
- *Canoe or boat trails* to lead visitors through winding mangrove waterways.
- *Docking facilities* for canoes and other craft used in park operations.
- *Campgrounds and picnic sites* established on naturally dry areas or on elevated wooden platforms accessible by boat.

Figure 5. Boardwalk in Trinidad's Caroni Swamp.

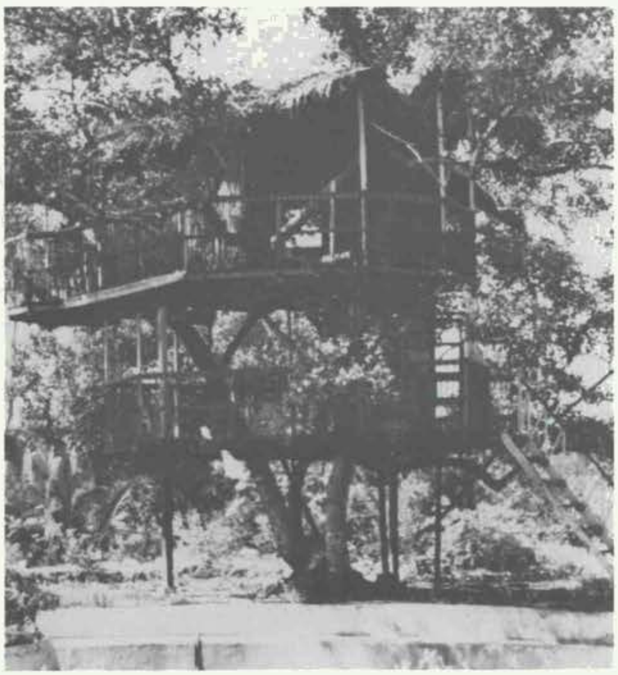

Figure 6. Tower and shelter for viewing mangrove area.

- *Toilets and litter receptacles* in areas of visitor concentration.
- *Viewing towers* to permit observation of nesting birds and other fauna and give an overview of the mangrove community (see Figure 6).

The level of active management required within a recreation area will vary according to the activities permitted and the intensity of usage. Some periodic ecosystem monitoring is important to ensure that the recreational resource is not being damaged. Regular maintenance work will include trimming vegetation where it obstructs waterways or trails and controlling exotic flora. Litter and garbage collection and disposal will probably be necessary. If fishing, hunting, or collecting of molluscs and crustaceans are permitted, it is necessary to monitor to ensure that such species are not collected beyond their sustainable yield. It may be necessary to impose a limitation on the numbers taken or on specific catch techniques. In some cases hazardous fauna such as crocodiles may need to be moved from areas near boat ramps or swimming areas to ensure visitor safety, or it may be sufficient to erect warning signs that hazardous fauna occasionally may be present. Crocodilians can be a major tourist attraction, especially at night, as long as they can be viewed from the safety of large boats or hides built on boardwalks or viewing platforms.

Insects are a controversial component of the mangrove ecosystem. While scientists recognize that insects form an important link in the food chain, visitors may be annoyed by mosquitoes, flies, and midges. Planners need to realize that tourists are often more sensitive to biting insects than local residents. Where and when insects are a problem, visitors should be advised to use insect repellents and wear appropriate clothing. Attempts to control insects are not recommended unless the insects cause serious health problems, and in such cases control should be attempted only with sound scientific advice. Spraying with insecticides is generally ineffective, harmful to nontarget organisms, and in the long term actually may promote an increase in problem from biting insects. Where new tourist developments intend to make recreational use of mangroves, planners should obtain professional advice to determine if biting insects will be a problem and if possible locate visitor center and overnight accommodation facilities beyond the habitats of the local species.

A detailed compilation of national park planning and management methods for tropical countries has been prepared by Miller (1978) entitled "Planning National Parks for Ecodevelopment."

Interpretive Programs

Forming a link between land and sea, mangrove ecosystems have a great deal of educational and research value. Terrestrial, intertidal, and shallow-water marine environments exist very close to one another. Life forms from the land and sea coexist, and some species are unique to the mangrove ecosystem. The unusual adaptations of the mangrove flora and the role of the mangrove ecosystem in the marine food chain are especially worthy of study and public education.

Self-guided tours on boardwalk trails with fixed signs and brochures are in use at Everglades National Park in Florida in the United States and Waitangi Reserve in New Zealand. Ranger-guided tours of these trails are usually far more useful than self-guided tours, however, and they are often much more popular.

Private tour boat operators also can play an educational role by having trained guides on the boats explain the natural history of the ecosystem. Special tours for birdwatching or snorkeling are also possible in some areas.

A visitors' center may serve as the central facility for slide shows, movies, or talks that interpret information about mangroves for the public. Displays should be illustrated by photography or realistic artwork. Experience in Everglades National Park has shown that "impressionist" interpretations of mangrove organisms may be difficult for park visitors to understand (Morehead 1983, pers. com.).

Case Studies

TRINIDAD

In 1936, the major part of the Caroni Mangrove Swamp was proclaimed a forest reserve. In 1953, an area of 135 ha was declared a wildlife sanctuary for protection of the scarlet ibis (*Eudocimus ruber*). Extensions to the sanctuary were made in 1954, 1959, 1960, and 1966 because of the birds shifting their roosting areas, and this brought the total area to 200 ha. In 1972, the swamp was proposed as a national park. Between 1978 and 1980 management, site, and education plans were prepared. Legislation to protect the resource is now being drafted.

Between 1950 and 1970, three boat houses and docking facilities were constructed at strategic points. During this same period, private tour guides developed a thriving tourist trade. In 1980–1981, a parking lot, a reception office, a rustic waiting shed, two small boardwalks, a picnic site with a shelter, and a bird viewing tower were constructed at an approximate cost of US $35,500.

The main tourist attraction is viewing the scarlet ibis coming to roost in the mangroves every evening. Oysters on the prop roots of *Rhizophora*, crabs scurrying on the muddy floor, herons, other birds and animals, and the scenic waterways are also major sources of interest to the visitors. A conservative estimate of the annual number of visitors to the swamp is 18,000 tourists and 12,000 residents.

The area is administered by the Forestry Division but there are activities such as fisheries and effluent discharges within and outside the area that are not controlled by the division. The area is currently patrolled by a staff of seven who are equipped with radio sets, powerboats, and a jeep. This number, however, is inadequate for proper and effective management.

The tour boat operators do not purchase permits or licenses for carrying on their trade in the area. However, visitors are charged between US$5 and US$10 per person depending on numbers, time, and interest. No self-guided tours are available.

At the rustic shed, there are drawings, posters, and notices explaining the ecosystem and that cooperation is sought from the public. An educational brochure has been prepared.

PHILIPPINES

In the Philippines, both children and adults make use of mangroves for recreational fishing,

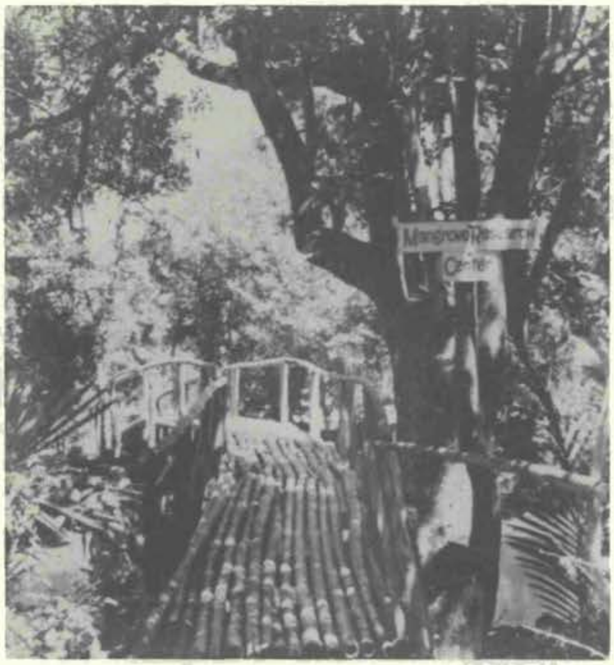

Figure 7. Entrance and bridge over channel to visitor facilities of Mangrove Forest Research Center, the Philippines.

crabbing, swimming, and canoeing. The Philippine government has established a special facility for research, recreation, and education at Pagbilao on Luzon Island. Facilities occupy about 0.5 ha in a mangrove reserve of 114 ha.

The Mangrove Mini Park and Nursery, of the Agroforestry and Mangrove Forest Research Center of the Forest Research Institute of the Philippines, was conceived in 1977 and was fully developed and operational by early 1978 (Figure 7).

Despite the range of facilities provided, the cost for the park's establishment was only about US$3,000 including the installation of water pipes for a potable water supply and an electrical system powered by a portable electric generator. The center is visited by approximately 500–600 people every year including some foreign visitors.

Facilities provided for recreational uses include treehouses with toilet facilities; picnic sheds and playgrounds; a children's swimming pool; cooking and dining sheds; canoes and motorized *banca* for boating on rivers and coastal waters; swimming and fishing areas; aquaculture projects from which immediate food needs of visitors are met on special occasions; a jungle trail; toilet, water, and electrical facilities; a maintained access road from the national highway and a foot bridge across a river leading to the center; and a natural lagoon seeded with brackish-water fish species.

The main visitor activities are boating, fishing, and relaxation and resting under trees, in treehouses, and in sheds. Some enjoy swimming and playing ball games on the playground.

The natural features that attract visitors are the river and riverine systems; a relatively undisturbed second-growth mangrove forest; the lagoon system within the park; the established "mangrovetum" that attracts scientists and researchers, especially those who work on mangroves; and the privacy and exclusiveness of the location.

The Agroforestry and Mangrove Forest Research Center manages the park and nursery and supervises the researchers and recreational users. There are five technical staff people at the center, and there are four support or maintenance personnel. The visitors are either guided into the area or are left to themselves to explore the site with some restrictions to prevent damage to vegetation and facilities.

There is no central interpretive facility, but technical personnel at appropriate occasions do lecture on the importance of mangroves, their role in contributing to local and national socioeconomic stability, and their role in maintaining a well-balanced ecosystem. To date, no leaflets on mangrove conservation have been produced for center visitors.

In December 29, 1981, Presidential Proclamation No. 2151 was issued declaring certain islands or parts of the country as "Wilderness Areas" for an aggregate area of about 4,326 ha. These areas are withdrawn from entry, sale, settlements, and exploitation, subject to any existing recognized and valid private rights.

These are potential areas for recreation in addition to their educational and scientific significance. Their protection and maintenance are essential, and development plans for their effective management need to be formulated to determine the various nondestructive, alternative uses that could be derived from them. They serve as mangrove parks, although they are not designated officially as "national parks."

VENEZUELA

Opportunities for recreational and educational use of Venezuelan mangrove forests are provided in the 4,580 ha of mangroves of the Parque Nacional de Morrocoy located in the Golfo Triste of the Venezuelan coast. In 1974 a Presidential Decree was issued to protect Venezuelan mangroves. After removing a large number of private structures and stopping a major resort development, the Morrocoy Park was established to provide for public recreation. The park has high scenic value and motor boating, swimming, water skiing, diving, and birdwatching are the major recreational activities. At present, there are only five National Park Service staff members to manage the 32,090-ha reserve. Consequently, it is not possible to provide guided tours, and self-guided tour routes have not been established. There are no facilities for visitors, not even toilets. Despite these limitations, the park has become so popular over the past nine years that there are now 250,000–500,000 visitors each year. This level of use is exceeding the park's capacity to accommodate it and threatens both the mangrove forests and the adjacent coral reefs and seagrass beds.

Future management of the park should be oriented toward sustainable use, which would include ecological monitoring and the application of specific management measures, restrictions on the number of boats and marinas, restrictions on access to areas of critical ecological importance (e.g., nesting sites, overcrowded fishing grounds), greater development of recreational activities with less severe impacts (encouraging swimming), and better interpretive efforts. The construction of an educational and research center is planned.

AUSTRALIA

Mangroves occupy 22 percent of the Australian coastline and occur in all states except Tasmania. The major use of mangrove ecosystems in Australia today is for recreation. Line fishing, generally from small boats anchored in mangrove channels, is the most popular recreational activity in the mangrove area. Power boating and canoeing in mangrove channels and collecting mud crabs (*Scylla serrata*), other portunid crabs, oysters, and bait are also popular activities. Rental of boats and fishing equipment provides significant employment and economic benefits in coastal communities.

Mangroves are used for birdwatching and increasingly for education. There is some use of mangrove waterways for swimming in subtropical and temperate areas, but this is not as common a practice in tropical Australia because of the potential year-round presence of saltwater crocodiles (*Crocodylus porosus*) and the seasonal presence of box jellyfish (*Chironex fleckeri*).

Crocodiles are, however, one of the major attractions drawing tourists to mangrove river cruises. In the South Alligator River in the Northern Territory and at several localities along the Queensland coastline, specially designed shallow-draft boats carry thousands of tourists annually on guided tours of mangrove ecosystems. Small boats also can be hired for fishing on many of Australia's mangrove estuaries and bays.

Mangroves are one of the recreational attractions in the Cooloola National Park in Queensland. There is an interpretive center with poster displays and models of wetland ecosystems, including mangroves, and a boardwalk to a mangrove area and bird hide provided for the observation and photography of waterfowl. Other boardwalks have been built on Hinchinbrook Island to serve research and tourist needs.

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SECTION II

CHAPTER 4. Wildlife

Figure 8. Egrets and ibises in mangrove forest.

The animal inhabitants of mangrove forests are both valuable products and interesting and valued amenities. They are "harvested" by capturing them for food or other animal products (e.g., hides, animal trade), and they are also "harvested" by viewing, studying, or photographing them in nonconsumptive ways. Those comprising a commercial or artisanal fishery are discussed in Chapter 5. In addition to shrimp, oysters, clams, and mussels, crabs in mangrove areas are often harvested as food — in some places as an important local enterprise. Saltwater crocodiles, long-tailed macaques, other primates, and a few other animal species are also harvested on a small scale in some places.

Most of the wildlife of the mangrove system, however, is valued primarily for its role as a recreational or scientific resource. The value may come from the sheer number or variety of wildlife (usually birds) or from the rarity of certain species (see Figure 8). In the former case, as is true with the bird life of Morrocoy National Park in Venezuela, the management of mangrove areas is oriented toward managing the human visitors, as discussed in Chapter 3, Recreation. In the latter case, as is true with the Bengal tiger or the proboscis monkey, the need is for habitat protection in a mangrove preserve, and this aspect was treated in Chapter 2, Preservation. Many species of fauna using mangroves exclusively or partially (e.g., for roosting but not for feeding) are rare or endangered. The *Global Status of Mangrove Ecosystems* presented a list of plants and animals "at risk," and the animal portion of that list is reproduced here as Table 8 (Saenger et al. 1983).

Protection of the habitat is the principal tool for wildlife management in mangrove areas (Figure 9). A new publication by Salm on *Managing Coastal and Marine Protected Areas: Principles and Guidelines for Managers of Natural Areas of the Seas* to be available in 1984 should be consulted. It is essential to include an area judged to be large enough to sustain a viable breeding population of key species. Considerations include the number of species or genera present in a given area, some idea of population sizes, the distance of the site from human settlements, the migratory patterns of key species, and the feeding patterns and ranges of key species. It is also important to include all of the vegetation zones or inundation classes of the mangrove complex and not merely the fringing forest or the basin mangroves or any other single type. "Overwash" islands, however, due to their importance as bird rookeries, may be protected as one type of mangrove forest community. In setting aside a protected area for wildlife, it is important also to recognize the need for a buffer zone that includes a large part of

Table 8. Animals at Risk in Mangrove Areas

Species	*Common name*	*Status*
Mollusca		
Strombus gigas	Botuto	Vulnerable — Venezuela
Terebralia palustris	Mangrove whelk	Vulnerable — South Africa
Reptiles		
Alligator mississippiensis	American alligator	Threatened — Florida, USA
Caiman crocodylus	Baba	Endangered — Venezuela
Crocodylus acutus	Gran caiman/American crocodile	Believed extinct — Venezuela Endangered — Florida, USA
Crocodylus porosus	Saltwater crocodile	Vulnerable; protected within reserves — India and Malaysia; collecting prohibited — Australia, India, and Sri Lanka
Drymarchon coarais couperi	Eastern indigo snake	Endangered subspecies — Florida, USA
Epicrates striatus fosteri	Bimini boa	Vulnerable — found only in Bahama Islands
Nerodia fasciata taeniata	Atlantic saltmarsh snake	Endangered subspecies — Florida, USA
Birds		
Agelaius xanthomus	Yellow-shouldered blackbird	Endangered — USA
Agelaius xanthomus xanthomus	Puerto Rico yellow-shouldered blackbird	Vulnerable — found only in Puerto Rico
Amazona arausiaca	Red-necked parrot/Jacquot	Endangered — found only in Dominica
Amazona vittata	Puerto Rican parrot	Endangered — found only in Puerto Rico; protected within a reserve
Anas acuta	Pin tail duck	Endangered — Puerto Rico
Anas bernieri	Madagascar teal	Vulnerable — found only in Madagascar
Anas clypeatra	Shoveler	Endangered — Puerto Rico
Anas crecca	Green wing teal	Endangered — Puerto Rico
Anas platyrhynchos	Mallard	Endangered — Puerto Rico
Ardea cinerea	Grey heron	Endangered — Malaysia
Ardea herodias	Great blue heron	Endangered — Puerto Rico
Ardea purpurea	Purple heron	Endangered — Malaysia
Ardea sumatrana	Dusky-grey heron/ Great-billed heron	Endangered — Malaysia
Aythya collaris	Ring neck duck	Endangered — Puerto Rico
Bebrornis sechellensis	Seychelles brush warbler	Vulnerable — found only in Seychelles; protected within a reserve; collecting prohibited
Botaurus lentiginosus	American bittern	Endangered — Puerto Rico
Casmerodius albus	Garza real/Royal heron	Vulnerable — Venezuela
Catoptrophorus semipalmatus	Willet	Endangered — Puerto Rico
Circus buffoni	Long-winged harrier	Vulnerable — Trinidad and Tobago
Coccyzus melacoryphus	Dark-headed cuckoo	Vulnerable — Trinidad and Tobago
Cochlearis cochlearis	Boat-billed heron	Vulnerable — Trinidad and Tobago
Columba leucocephala	White crown pigeon	Endangered — Puerto Rico
Dendrocygna arborea	West Indian tree duck	Endangered — Puerto Rico
Dendrocygna bicolor	Fuluus tree duck	Endangered — Puerto Rico
Dendroica petechia petechia	Barbados yellow warbler	Endangered subspecies — Florida, USA
Dichromanassa rufescens	Reddish egret	Endangered — Puerto Rico
Dryolimnas cuvieri aldabranus	Aldabra white-throated rail	Vulnerable — found only in Aldabra; protected within a reserve
Dupetor flavicollis	Black bittern	Endangered — Malaysia

Table 8. (Continued)

Species	*Common name*	*Status*
Egretta alba	Large egret/Great egret	Endangered – Malaysia and Puerto Rico
Egretta thula	Snowy egret	Endangered – Puerto Rico
Eudocimus ruber	Corcora/Scarlet ibis	Vulnerable – Venezuela, Trinidad and Tobago
Falco peregrinus	Peregrine falcon	Endangered – Florida, USA
Fulica caribaea	Caribbean coot	Endangered – Puerto Rico
Halcyon senegaloides	Mangrove kingfisher	Vulnerable – South Africa
Haliaeetus leucocephalus	Bald eagle	Endangered – Florida, USA
Ibis cinereus	Milky stork	Endangered – Malaysia
Ixobrychus cinnamomeus	Common bittern	Endangered – Malaysia
Ixobrychus involucris	Stripe-backed bittern	Vulnerable – Trinidad and Tobago
Laterallus jamaicensis jamaicensis	Black rail	Endangered – Puerto Rico
Leptoptilus javanicus	Lesser adjutant stork	Endangered – Malaysia
Limnodromus griseus	Short-billed dowitcher	Endangered – Puerto Rico
Limosa fedoa	Marbled godwit	Endangered – Puerto Rico
Limosa haemastica	Hudsonian godwit	Endangered – Puerto Rico
Mycteria cinerea	Milky stork	Vulnerable – protected within a reserve on Pulau Dua off western Java; collecting prohibited in Malaysia except by aborigines
Numenius phaeopus hodsonicus	Whimbrel	Endangered – Puerto Rico
Nycticorax nycticorax	Black-crown night heron	Endangered – Malaysia and Puerto Rico
Ortalis vetula deschavenseei	Utila chachalaca	Endangered – found only on Utila Island in Caribbean
Oxyura dominica	Masked duck	Vulnerable – Trinidad and Tobago
Oxyura jamaicensis	Ruddy duck	Endangered – Puerto Rico
Pandion haliaetus	Aquila pesadora/Osprey	Endangered – Puerto Rico Vulnerable – Venezuela
Paroaria gularis nigrogenis	Red-capped cardinal	Vulnerable – Trinidad and Tobago
Pelecanus occidentalis	Brown pelican	Endangered – USA
Phalacrocorax carbo	Common cormorant	Endangered – Malaysia
Plegadis falcinellus	Glossy ibis	Endangered – Puerto Rico
Pluvialis dominica	Golden plover	Endangered – Puerto Rico
Podiceps dominicus	Least grebe	Endangered – Puerto Rico
Porphyrula martinica	Purple gallinule	Endangered – Puerto Rico
Porzana carolina	Sora rail	Endangered – Puerto Rico
Porzana flaviventer	Yellow-breasted crake	Endangered – Puerto Rico
Pseudocolopteryx sclateri	Crested doradito	Vulnerable – Trinidad and Tobago
Sterna albifrons	Least tern	Endangered – Puerto Rico
Sterna hirundo	Common tern	Endangered – Puerto Rico
Sterna maxima	Royal tern	Endangered – Puerto Rico
Sterna sanvicensis	Sandwich tern	Endangered – Puerto Rico
Xiphorhynchus picus altirostris	Trinidad straight-billed woodcreeper	Vulnerable – found only in Trinidad; protected within a reserve
Mammals		
Canis rufus	Red wolf	Believed extinct – Florida, USA
Cyclopes didactylua	Silky anteater	Vulnerable – Trinidad and Tobago
Felis concolor coryi	Florida panther	Endangered subspecies – Florida, USA
Felis pardalis	Ocelot	Vulnerable – Texas to Argentina; collecting prohibited in most countries of its range
Macaca fascicularis	Long-tailed macaque	Protected within reserves – Malaysia
Nasalis larvatus	Proboscis monkey	Found only in Borneo; protected within reserves

Table 8. (Continued)

Species	*Common name*	*Status*
Odocoileus virginianus clavium	Key deer	Endangered subspecies — Florida, USA
Panthera onca	Jaguar	Vulnerable — South American countries; protected within reserves in Colombia, Peru, Bolivia, and Brazil; collecting prohibited within most of range
Panthera tigris sumatrae	Sumatran tiger	Vulnerable — found only in Sumatra; collecting prohibited
Panthera tigris tigris	Bengal tiger	Endangered — protected within reserves in India, Bangladesh, Bhutan, Burma, and Nepal
Presbytis cristata	Leaf monkey	Some geographic subspecies are vulnerable — Thailand
Procyon cancrivorus	Crab-eating racoon	Vulnerable — Trinidad and Tobago
Pteropus vampyrus	Malaysian flying fox	Protected within reserves — Malaysia
Sciurus niger avicennia	Mangrove fox squirrel	Found only in southern Florida where two breeding populations remain; protected under Florida legislation
Trichechus manatus latirostris	Manatee	Endangered — Venezuela and Florida, USA

Source: Saenger et al. (1983).

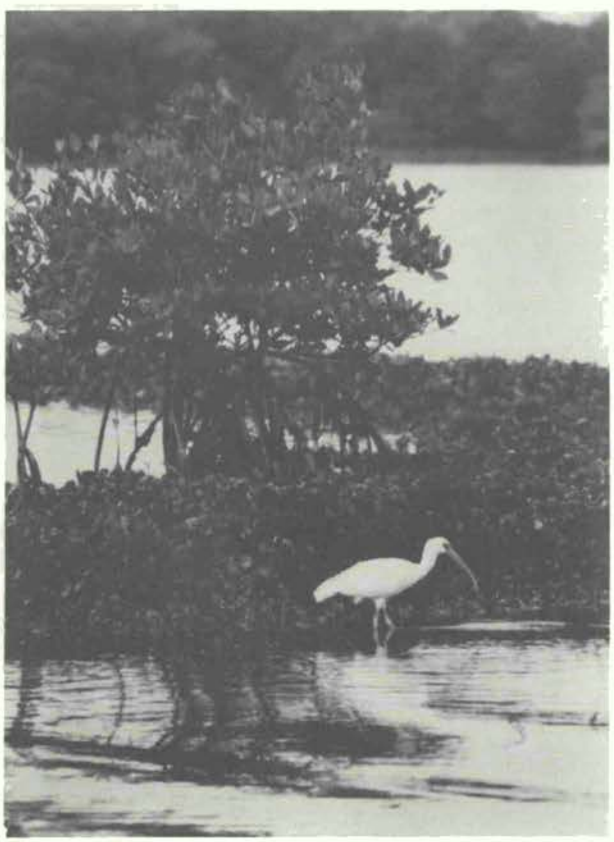

Figure 9. Mangrove forests provide all of the habitat requirements of many species of wildlife, and habitat preservation is the principal management activity.

the watershed that is the source for fresh water, nutrients, sediments, and pollutants.

Maintaining mangrove wildlife may involve law enforcement to prevent harvesting or to control harvesting at sustainable levels. Such actions may be brought to bear differentially within the same area. In Trinidad's Caroni Swamp, for instance, fishing and hunting of ibis are prohibited in the core wildlife sanctuary. The fishing prohibition is needed because of "fishermen" poaching the birds. Fishing and duck hunting are permitted outside the sanctuary but still within the Caroni Forest Reserve during daylight hours. Outside the sanctuary, there are bag limits on migratory game waterfowl, and there is a shortened hunting season to ensure that the arriving birds have "settled in" for at least a month before the season is declared open. Maintaining mangrove wildlife also involves continual monitoring to detect changes in populations.

Some modest habitat improvement is carried out for wading birds in the Caroni Swamp. Small, shallow feeding areas are regularly maintained, and new ones are established as the need arises. This involves controlling invasion by *Rhizophora* into these areas and removing fallen trees.

During the nesting season, areas normally open to visitors may have to be closed. In

Caroni Swamp, aircraft using Piarco International Airport nearby are required by law to fly 1,000 m above to minimize disturbance to the birds within the sanctuary.

A common problem with the welfare of wildlife in mangrove areas is the fragmented and sometimes uncertain responsibility for management. Separate departments or divisions of forestry, fauna, and fisheries may all be involved, and unless there is clear jurisdiction or well-integrated management, the forest, the wildlife, and the fishery may all or separately suffer by single-sector-management myopia.

Wildlife management in mangrove areas seems singularly plagued by a lack of basic research on the ecology of the mangrove fauna. Increased research is certainly needed to enhance the wildlife products and amenities and to slow the slide toward extinction of many important and interesting species.

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SECTION II

CHAPTER 5. Fisheries

Introduction

Fishery activities within or dependent upon mangrove systems rarely require any major modification of mangrove forests or associated creeks and lagoons (see Figure 10). Commercial, subsistence, or recreational fisheries generally are based upon the exploitation of one or more species of organisms in the mangrove ecosystem and merely harvest portions of the species populations. The success or failure of any fishery dependent upon the mangrove system as a basic food source is influenced, however, by the impact of numerous activities generally unrelated to fisheries (for instance in the catchment area) that may singly or collectively alter the nature and productivity of the mangrove system.

The important role played by mangroves in the maintenance of fishery operations in many tropical and subtropical areas of the world has only recently begun to be widely accepted. Fish such as mullet and milkfish, which constitute an important source of high-quality protein in many parts of the world, utilize mangrove estuaries as a habitat and source of food. Banana prawns, barramundi, and bream in Australia have been considered to be linked to mangrove systems. Similarly, marine shrimp, a valuable source of foreign exchange, are highly dependent upon mangrove estuarine areas during their postlarval and juvenile stages. Further, it has been estimated that 80 percent of all marine species of commercial or recreational value in Florida, U.S.A., are dependent upon mangrove estuarine areas for at least some critical stage of their life cycles. In Fiji, approximately 60 percent of the commercially important coastal fishes are either caught within the mangrove zone, or the species involved utilize this zone at some stage in their lives; in eastern Australia, 67 percent of the entire commercial catch is composed of species dependent upon mangrove estuarine areas.

The importance of general fishery activities as a source of income and protein cannot be overstated. It is estimated, for example, that five million people are directly employed in full-time fishing in Southeast Asia alone. This number is magnified several-fold when one considers those people engaged in support activities such as marketing, processing, vessel construction, gear manufacture, and repair activities.

Figure 10. Grouper have been caught by these fishermen from an estuarine mangrove area.

Fish harvesters capture the benefits provided by a natural system and exert little influence on the basic productivity of that system.* Various mechanisms have evolved to increase the catching efficiency with which a fishery operates, but the inherent abundance of important species is affected by the basic productivity of the system and other factors, such as pollution, over which the fishing industry has no control. Human-induced alterations from activities unrelated to fishing and the adverse effects of such changes are often manifested in the fishing industry.

The natural fishery benefits from mangrove estuaries may be and often are threatened by activities that destroy or significantly modify the system. In some instances, these activities have become large scale, as in the Philippines where almost 40 percent of an estimated 450,000 ha of mangrove coastline are reported

* There may be a few special cases of an *in-situ* fishery, such as the harvesting of oysters from proproots, where the mangroves are directly damaged or the food chain disturbed.

to have been converted to fishponds or otherwise modified between 1967 and 1978. It also should be recognized that although a specific loss of mangrove area may not appear to be significant on a national scale the repercussions on a local fishery could be considerable.

The Support Role Mechanisms

Mangrove systems are among the most productive natural systems on earth. The sources of this productivity are the mangrove trees themselves, algal colonies on the mangrove root surfaces and forest floor, and seagrass and phytoplankton communities in associated bays and lagoons. Productivity is usually enhanced by shallow waters, which are an important characteristic of natural estuarine systems, favoring the survival and growth of most organisms. A combination of high natural productivity and shallow brackish-water bodies combine to provide a varied and favorable habitat that supports a wide variety of animal life in various life cycle stages.

The primary food source for aquatic organisms in most mangrove-dominated estuaries occurs in the form of particulate organic material (detritus) derived from the decomposition of mangrove forest litter (i.e., leaves, twigs, flowers). Annual litterfall normally ranges from 10,000 to 14,000 kg dry weight per ha per year.

During decomposition, mangrove litter becomes progressively enriched in protein and serves as a food source for a wide variety of filter, particulate, and deposit feeders such as molluscs, crabs, and polychaete worms. These primary consumers, which include representatives of most phyla, in turn form the food of a secondary consumer population. The secondary consumer level is usually dominated by small forage fish species and by the juveniles of the larger predatory species that form the third consumer level. In addition, there are important fishery species, such as the shrimps, which occupy both primary and secondary consumer levels. They feed directly on particulate organic detritus and also feed to some extent upon primary consumers.

An additional source of nutrition for estuarine organisms is provided by dissolved organic compounds (e.g., amino acids), also largely of mangrove origin. Although relatively few species of invertebrates or vertebrates are known to be capable of utilizing such dissolved material directly, it would be expected that fungi and unicellular organisms such as bacteria are able to assimilate dissolved organic materials from the water column. These unicellular organisms then form a part of the food base for primary consumers.

Mangroves as Fish Habitats

The importance of mangrove areas as habitats for commercially important fishery species is becoming widely accepted, but it should be recognized that the *primary* habitats of these organisms are the shallow bays, inlets, and channels that are an integral part of the mangrove system. The intertidal mangrove forest contains few habitats used directly by species important to fisheries (a notable exception being the mangrove oyster). Rather, mangrove forests provide the nutritional inputs to adjacent shallow channel and bay systems that constitute the primary habitat of a large number of aquatic species of commercial, subsistence, or recreational importance. It follows, therefore, that system alterations or modifications that result in a decrease in the total area of shallow water estuarine systems or a decrease in their organic inputs may result in a concomitant decline in fishery benefits.

Most estuarine areas are characterized by turbid waters that have reduced light transmission and hence reduced aquatic primary productivity. Consequently, shallow waters within the mangrove systems become a paramount factor in overall levels of production. There appears to exist in most estuarine areas thus far studied a recognizable relationship between available shallow-water habitats and the life cycle patterns of commercially valuable species that live in these shallow-water areas.

Detailed examination of an estuarine system indicates that the percentage of shallow waters (less than 1 m depth at mean tide level) increases dramatically with increasing distance inland from the ocean coastline, with the result that greatly increased areas of favorable habitat become available. Quantitative sampling investigations at Rookery Bay, Florida, U.S.A., have demonstrated that the greatest number of individuals and highest species diversity occurs in estuarine areas at 0.3 –1.5 m depths.

It would appear that numerous species, including fish of direct commercial importance and those upon which the former group feed, benefit from the high natural productivity of mangrove-dominated estuarine systems and that these benefits are directly related to the shallow-water characteristics of such systems and the mangrove plants. Consequently, the juvenile stages of many commercially important fish species, guided by instinctive migratory mechanisms not yet fully understood and by availability of food, tend to congregate in shallow-water areas of high productive potential.

The pink shrimp, *Penaeus duorarum*, in the Gulf of Mexico and many others of the *Penaeus* species worldwide display typical behavior patterns that take advantage of favorable shallow-water habitats at critical life cycle stages. After offshore spawning and drifting of the pelagic larval phases, at the postlarval stage *P. duorarum* enter estuarine areas on flood tides, usually at night. With the onset of each ebb tide, they seek substrates such as mangrove roots to which they can cling and maintain their position until the subsequent flood tide. Thus, on successive flood tides, they penetrate shallower portions of the estuarine system. Eventually, they assume a benthic existence for several months while they grow rapidly in a shallow highly productive habitat. Thus, the instinctive tendency to proceed into the estuary on successive tides increases the probability of encountering favorable habitats.

This example of behavioral patterns is not limited to *Penaeus* or to other crustacean genera. The red drum, *Sciaenops ocellata*, of western Atlantic waters can be taken as a further illustration of the migratory patterns of juveniles into estuarine areas. Red drum spawn in nearshore marine waters, and continuance of the life cycle is dependent at this stage upon tidal currents that convey the young fry into nearby coastal estuaries. Data from Florida indicate that young red drum that fail to reach and penetrate estuarine regions do not survive. The individuals that enter estuarine environments penetrate far inland, often to fresh or nearly freshwater regimes, apparently in search of shallow-water habitats. This species spends up to three years of its early life cycle in estuarine environments and moves progressively seaward during this time. At the end of this juvenile estuarine phase the individuals assume a more fully marine existence and are recruited to the commercial and recreational fishery industries.

Similar inshore migrations occur with important tropical fish species such as mullets, milkfish, sea perch, and rabbitfish, although according to Pauly (1983 pers. comm.) most tropical Indo-Pacific fish species in mangroves do not reach three years of age.

Fishery Considerations

The capability of estuarine mangrove areas to support major fishery industries is widely recognized. The fisheries may be inshore ones, which are generally artisanal or recreational in nature, or offshore fisheries, which can require a considerable capital input and relatively high technology. Inshore and offshore fisheries frequently harvest the same species but at differing stages of their life history, resulting in conflicting demands on availability of the resource.

Artisanal fisheries are usually in inshore or estuarine waters and are frequently of major importance as a protein source for the local people. The product of offshore fisheries is frequently a cash crop that is either exported, thus producing foreign exchange, or processed for distribution and marketing in inland areas. Both types of fishery, however, are ultimately dependent upon a common resource and upon the mangrove estuarine system that sustains that resource.

Recent investigations in Indonesia indicate a close correlation between mangrove estuarine area and annual yields of penaeid shrimp. It has been estimated further that commercial yields of penaeid shrimp in equatorial regions reflect the nearby existence of estuarine areas (Macnae 1974). Estimates suggest that an annual shrimp harvest of approximately 160 kg can be derived from 1 ha of tidal marsh. It should be noted, however, that these figures represent gross estimate correlations and do not necessarily reflect a true cause-effect relationship.

Fisheries, both inshore and offshore, appear to be dependent in many areas upon mangroves for continued exploitation of finfish stocks. Although the correlation between the magnitude of catches and existing estuarine areas is not well documented, a list of species that spawn offshore and then utilize estuarine mangrove areas as larvae, juveniles, or adults and are taken by fishermen either inshore or offshore is exhaustive. Such a list would include bream, mullets, milkfish, mojarras, snooks, barramundi, sea trouts, snappers, drums, croakers, seacats, groupers, and tarpon.

In addition to fisheries for such motile species, mangrove estuarine areas often support important harvesting operations of mollusc species that are largely sessile in nature and constitute an *in-situ* fishery. The bivalve molluscs such as oysters, mussels, and clams are generally the most important harvest crops. Collection and sale of these organisms frequently constitute a major fishery activity in estuarine areas, such as those in Trinidad, Brazil, Venezuela, and the Philippines, and involve a large labor force. Often, harvesting activities merely involve the collection of animals from naturally occurring surfaces. In many areas such as in Brazil, Venezuela, and Australia, however, the harvestable yields are augmented by the provision of artificial substrates in the form of rafts, simple stakes, or ropes placed in the shallow waters of mangrove estuaries for settlement and growth of bivalve molluscs. Harvesting of sessile organisms such as oysters requires minimal capital input but is highly dependent upon the suitable substrate and planktonic food source available in mangrove estuarine environments.

Reduction of Fishery Potential

Mangrove-associated fishery species are dependent upon the mangrove habitat and derive essential nutrition, either directly or indirectly, from the primary or secondary productivity of the mangrove ecosystem during at least a portion of their life cycles. The condition or well-being of mangrove-associated fisheries is dependent, therefore, upon the health and survival of the mangrove ecosystem. Unfortunately, mangrove ecosystems and mangrove-associated fisheries are being subjected to human activities in upstream catchment areas (watersheds). These activities include dredging channels, constructing roads, and draining lands for land reclamation projects, primarily for agricultural and industrial development. Other more subtle actions that may only alter the timing of water and sediment input may also be important. These activities are discussed in detail in the IUCN global status report on mangroves (Saenger et al. 1983).

Such activities can result in altered freshwater inputs to the mangrove system, increased sediment loads, altered salinity regimes, introduction of organic and chemical pollutants, or other things that can result in alteration of the mangrove ecosystem with consequent detriment to associated fisheries.

Development activities that alter the slope of the land, the natural vegetation, or the drainage patterns in catchment basins contributing to a coastal mangrove system can also alter the quantity and periodicity of freshwater inputs into a mangrove ecosystem. Depending on the specific work done, these activities may increase or decrease freshwater runoff into the tidal creeks and lagoons of the mangrove system, thus altering natural circulation and tidal flushing patterns and affecting natural salinities and sediment loads.

Mangroves may be damaged or killed by too much or too little freshwater input and subsequent low or high salinities. Losses from both extremes have been reported from Bangladesh, Fiji, and Australia. Such losses ultimately result in decreased plant litter in the mangrove ecosystem, which in turn reduces the base of the highly productive mangrove food chain upon which the fishery depends. Increasing or decreasing salinities also influence the species composition of the fishery catch and the suitability of areas as spawning or nursery grounds.

Dredging activities are another major cause of increased sediment load. The pattern of sedimentation is determined by the amount of freshwater runoff, by the extent and pattern of tidal flow, and by existing geophysical features of the estuary, with sedimentation rates being highest where water movement is lowest. Increased sedimentation rates can lead to long-term changes in water depth, and to changes in estuarine circulation and tidal flushing patterns, any of which will ultimately affect the inhabitants of the estuary. Although mangrove mortality from sediment deposition may not occur dramatically from increased sediment loads, increased sediment can severely reduce the net primary productivity of mangroves, upon which the fishery depends.

Summary and Recommendations

Fishery activities in many coastal regions of the tropics are highly dependent upon mangrove-dominated estuaries. It is widely believed that these estuaries constitute an important habitat or food source for many of the species sought by the fishing industry. The success or failure of many marine fisheries may be closely correlated with the viability of a productive mangrove system.

Management of a mangrove system for the benefit of inshore or offshore fisheries involves careful consideration of the effects of changes to the system. Such changes or disruptions generally are stimulated by modifications to the existing natural mangrove system or its upland watershed for purposes unrelated to fishery activities.

These changes include such obvious activities as conversion to mariculture ponds, conversion of mangrove lands for agricultural purposes, placement of solid fill for housing developments, clearcutting large blocks for wood chips, or dredging to create navigational channels or port facilities. Other modifications may be less obvious in nature but may be equally detrimental to the overall productivity of the estuarine system. These may include diversion of freshwater sources from the system, activities resulting in significantly increased sedimentation, the introduction of toxic chemicals or other pollutants, or alterations in tidal regimes resulting from dredging or spoil deposition. It is recommended that careful consideration be given to the impacts on fisheries of activities in catchment areas as well as those within the mangrove estuarine areas.

Mangrove-based fishing generally exploits a resource that is produced at little direct cost to society. The magnitude of these natural benefits, however, can be greatly reduced by ill-conceived alterations that result in a diminution of the mangrove estuarine resource base. Management for maximizing natural fishery products involves avoiding, whenever possible, acts that tend to reduce the natural productivity or habitat utility of the mangrove system. A methodology for analyzing the benefits and costs of alternative actions is described in the section on Economic Considerations in the Management of Mangroves.

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Section II

CHAPTER 6. Honey Production Techniques in Mangrove Environments

Introduction

Utilization of a honey resource by bee hunting occurs in many parts of the world and represents a traditional activity in certain regions of Africa and Asia. Bee hunting probably accounts for a major portion of the honey harvest in the world's mangroves. Mangrove forests, despite their potential for high honey production, however, are only lightly utilized for this purpose, and the bulk of this appears to result from casual or incidental bee hunting, which is the first and lowest stage in the bee-human relationship. While definitive data are not available on the world potential for mangrove honey production, assessments from the global status report on mangroves (Saenger et al. 1983) show that of ninety-two nations having mangrove resources, only five indicate the production of honey as a current use and of those only two (India and Bangladesh) identify honey production as being of some national importance. In India where some information on honey production is available, a 2000–km² tract of mixed mangrove species in the Sunderbans is reported to produce about 20 tonnes per year (Blasco 1975). The bulk of this honey is produced from pollen of the *Ceriops*, which is a dominant mangrove form, but the best quality honey is apparently produced from *Aegialitis rotundifolia* and *Cynometra ramiflora*. From April to June of 1971, approximately 2,000 people were employed in honey collection in the Indian Sunderbans. The average annual production in the Bangladesh Sunderbans was 177 tonnes of honey and 49 tonnes of beeswax during 1957–1977 (FAO 1982).

Beekeeping and honey harvesting are among the few uses of mangroves that have little or no negative impact on the basic functioning of the forest and the natural benefits and products that are produced there. On the contrary, because of pollination of the trees by foraging bees, beekeeping may exert a positive influence on the mangrove forest. This is particularly true for those mangrove species dependent upon insects for pollination. Thus, the basic resources taken from the forest are reproductive surpluses that through proper bee management may be collected profitably as a renewable seasonal benefit without affecting or foregoing other useful forest processes and products.

This review of honey production in mangrove forests provides basic information on how honey is produced in these specialized environments and the various techniques used in maintaining and managing populations of bees with emphasis on methods that utilize readily available natural materials and require little or only modest capital investment. This chapter focuses on methods and estimated honey production rates for the relatively sophisticated beekeeping operations in black mangrove (*Avicennia germinans*) forests in southwest Florida in the United States. Significant increases in the quantity of high-grade, high-value honey and associated by-products may be achieved if it is more widely understood that mangroves represent a high potential for seasonal honey production using a relatively low level of technology with only moderate labor demands.

Honey Production Methods

The utilization of bees has evolved through three basic stages: bee hunting, bee maintenance (or bee having), and beekeeping. In bee hunting, the colony is killed to harvest the honey combs and brood combs (combs containing young bees). In a raided wild nest, the surviving bees are left without honey or brood; thus, the wild colony is destroyed. The continuance of this source of honey harvest is solely dependent on the vigor of the wild bee populations and their capacity to create new colonies since the hunters make little or no effort to conserve these populations.

A variation on bee hunting is practiced in some parts of Africa where straw containers or clay pots are hung in trees to attract wild bees. After allowing sufficient time for the colony to accumulate a store of honey, the bees are killed and the honey harvested. This method eliminates the searching effort necessary to find wild colonies of bees.

Bee maintenance presents an improved relationship between humans and bees in which there is recognition that individual colonies may produce a continuing quantity of honey. Housing is provided for the bee colony that may take the form of hollow logs, clay pots, gourds, or containers fashioned from straw and mud. These are known as fixed-comb hives. Bees attach honey and brood combs to the insides of the containers, and there is little or no opportunity for inspection, manipulation, or management of the colony. In harvesting these hives, only honey combs are removed leaving brood combs undisturbed.

In bee maintenance the bee owner provides protection for the colony in return for periodic harvests of honey and wax. The significant advance in this technique is that the owner maintains the colony for future production instead of destroying it for a one-time harvest. While this is an important advance, it falls well short of the production possible from more sophisticated methods. The more advanced methods require considerable knowledge of the biology and behavior of the bee, however, thus the success of such methods is dependent upon the knowledge and accumulated experience of the owner.

Beekeeping is the third stage in the evolution of bee utilization and involves the manipulation of the bee colony for the enhancement of honey production. There is an intermediate and a high technology used in beekeeping. The intermediate level uses moveable-comb hives, which allow considerable manipulation of the colony compared with the fixed-comb hive. For small-scale beekeeping in relatively undeveloped areas, this technique has a number of advantages which will be discussed in the section on Simple and Intermediate Technology Beekeeping. The high technology method utilizes the moveable frame hive, which requires an advanced level of understanding of bee biology and behavior as well as carefully constructed hives and sophisticated equipment.

In addition to making use of a largely unrecognized and underutilized resource in mangrove areas, there are a number of additional advantages in initiating a beekeeping effort in these regions. It is an activity that fits well with the concept of small-scale agricultural development. It is a labor-intensive activity that integrates easily into agricultural or forestry projects. Bees are well known to be of considerable benefit in the pollination of commercial crops, forests, and mangroves and they also make use of the otherwise unused resources, nectar and pollen.

As an integrated small-scale activity, beekeeping in general and in mangrove areas in particular can provide a number of agricultural, social, and economic benefits. These benefits include:

- Supplying an additional nonperishable food for rural people;
- Providing cash crops of honey and wax;
- Providing gainful work when the farmer is not otherwise occupied with other crops;
- Providing gainful work for local craftsmen who make beekeeping equipment;and
- Increasing the production of other crops through improved cross pollination.

From a social and economic perspective, beekeeping is basically a family activity and has the following advantages over other types of agriculture:

- It requires a relatively small investment.
- It uses little land and quality of the land is not critical.
- It can be done by both sexes and by adults of any age.
- It does not compete for space of resources with other types of agriculture.
- It is an income-producing activity based on a forest resource, yet it is not destructive to that resource.

Types of Bees

There are many different bee species, including a large number of solitary species and the social bees that are used in beekeeping. All bees gather nectar and pollen but only a few of the social bees store the nectar as honey. Even fewer species store sufficient quantities of honey to make the harvesting worthwhile.

The genus *Apis* is the most important group and contains four species. Three species of *Apis* are native to Asia and one to Europe and Africa. All are similar in appearance with some variability in size and color, and all build vertical combs that are two cells thick.

The giant or rock honey bee (*A. dorsata*) and the little honey bee (*A. florea*) are found in Asia. Both of these species build a single-comb exposed nest, often seen hanging from tree branches. Because of the restricted size of the nest structure, the honey yield from these species is not high.

The remaining two species of *Apis* (*mellifera* and *cerana*) build multicomb nests in enclosed cavities. These species can be kept in hives and offer the greatest potential for beekeeping.

The western hive bee (*A. mellifera*) has been introduced into most parts of the world including the Americas, Australia, and Asia. Under favorable conditions, this species builds large colonies with yields under optimum conditions of 100–150 kg per colony per year.

It should be emphasized, however, that in initiating small-scale beekeeping effort such as might be appropriate in mangrove forests, the species existing in the local area should be used. Local species are adapted to the climate and are resistant to existing diseases. Importing of bees for small-scale projects has high capital costs and risks that are probably not justified.

Figure 11. Flower of *Avicennia germinans*, one of the principal honey source species of the mangrove forest in Florida, U.S.A.

Climate, Environment, and Honey Production

The relationship of climate to the activities and productivity of bees is associated with the availability of pollen, the nectar flow, and the honey flow.

For most plant species, adequate rainfall previous to blooming and relatively dry sunny conditions during the actual bloom promote pollen production and nectar flow (see Figure 11). Obviously, the timing and relative amounts of rain and sunshine vary from year to year, thus influencing the pollen and nectar production.

Pollen is a powdery substance produced by the male organs of the flower and contains the sperm cell. Pollen clinging to the fine hairs on the bees' bodies is distributed widely among the flowers as the bees visit the flowers in search of nectar, thus aiding in the pollination and ultimate fertilization of the blossom. Excess pollen is carried back to the hive by the bees in a specialized pollen basket on the hind legs. Within the hive, pollen (sometimes called "beebread") is used to feed young bees and is eaten in large quantities by workers (undeveloped female bees that dominate the colony population). It is nutritious food containing 26 percent protein and a broad spectrum of vitamins and minerals. Pollen is virtually the only source of protein in the bee diet, and therefore it is extremely important in the seasonal buildup of colony population.

The nectar flow is also a function of the plants and refers to both the quantity and quality (dissolved sugar content) of nectar secreted by the plant. In general, climate and soil factors (and in mangrove areas, hydrologic factors as well) determine the flora of the area and thus the *potential* nectar flow. Rainfall, temperature, and sunlight affect the plants directly and thus influence the *actual* nectar flow.

The honey flow is a function of the relationship between the colony and the plants and reflects the efficiency of the nectar-gathering activities as well as the refinement of nectar in the hive to honey. While the beekeeper can do little to influence the weather and the nectar flow, good colony management will maximize the honey flow for the particular conditions. Strong colonies built up just previous to the nectar flow are highly important to maximum honey production.

The optimum areas of the world in terms of beneficial climate and potential honey production are areas of deciduous forest in the tropics exhibiting a wet-dry seasonal pattern. Such areas have a long dry season that allows bee colonies to build to their maximum strengths.

Another factor that is somewhat climate dependent is the availability of fresh water. Fresh water is a necessity and is carried to the colony in the honey stomachs of the foraging bees. In the hive, water is mixed with honey before the bees eat it or feed it to the brood. During hot weather, water droplets are placed about the hive and air currents are created by bees that stand and fan their wings to produce evaporative cooling.

In late spring and early summer when mangrove nectar flows tend to be heaviest, these areas may also exhibit high temperatures and intervals of drought. In these circumstances, care should be taken to protect the hives from high temperature extremes by placing the hives in cleared areas with some shade and ventilation. It may also be advantageous during dry periods ɔ provide a source of fresh water near the hives. This will reduce or eliminate extensive foraging for water and allow more effort for honey production.

In mangroves areas, there may be some special climate and environmental conditions of which the mangrove area manager should be aware. In most parts of the world, farming and other trades amenable to beekeeping are rarely practiced close to mangrove forests where low land and frequent flooding along with salty soils can inhibit plant growth. Thus, small-scale beekeeping in mangrove areas may, by reason of distance from an individual's home, be difficult to maintain. This problem may in part account for the extremely low utilization of mangrove forests by beekeepers. Where a higher technology exists for small-scale beekeeping, hives can be moved on trucks to appropriate sites within or near the mangroves.

In selecting mangrove sites for beekeeping, care must be taken that the location is not fire or flood prone. High water tables and moist soils usually reduce the threat of fire in mangrove areas, but flooding from heavy rains or high tides may be a problem. Flooding that covers the entry opening of a bee hive will cause mortality or destruction of the hive. If danger of flooding exists, hives should be moved to higher ground or placed on platforms.

Because hive sites that are high enough and easily available may be rare, large areas (usually seaward areas) of extensive undeveloped mangrove forests may not be accessible to the beekeeper. Until techniques are developed for safely placing hives in these remote areas, honey from wild colonies collected by bee hunters may be the only means of producing honey there.

For the mangrove beekeeper, salt may be a problem to the health of the bee colonies. Salt is an everpresent mineral in most mangrove areas, and in a number of mangrove species it is excreted directly from the surface of the leaves and may build up visible deposits during dry spells. Foraging bees exposed to such accumulation may bring salt into the hive. Bees are susceptible to relatively low concentrations of salt in their food and consequently may be adversely affected by high salt accumulations on mangroves. Feeding studies have shown that salt concentrations as low as 0.125 percent in food produces mortality in bees (Dadant and Sons 1982). While the salt problem in mangroves is yet to be researched, beekeepers who put hives in mangrove areas in southwest Florida believe that in dry years salt may be a factor affecting the maintenance of strength in the hives. However, the salt problem appears to be intermittent and generally minor in its impact relative to the usually heavy flows of honey that can be produced in mangrove areas.

Diseases and Pests

The diseases and pests that affect bees and honey production are numerous, and a detailed discussion of their types and complexities are beyond the scope of this chapter. A summary of the principal diseases that afflict the honeybee, the causes, and the most obvious symptoms are presented in Table 9.

Pests that consume bees or disturb the inner workings of the hive are less serious than disease to the health of the colony. Pests are usually visible to the attentive beekeeper, their effects are direct and immediate, and the solution is generally more obvious. Notable pests include wax moths, beetles, birds, lizards, ants, toads, mice, and insect and honey-eating mammals. Additional information on these pests may be found in Gentry (1982). Among the mammal pests, Gentry mentions the honey badger of Asia and Africa, but no mention is made of bears. Root (1975) comments on bear damage in certain locations and advocates the use of electric fences to exclude such predators. In southwest Florida, bee yards (apiaries) are often extensively damaged by the Florida black bear seeking honey and possibly brood cells. This type of damage is prevalent in mangrove areas and as a result most mangrove bee yards in Florida are enclosed by a two-strand battery-charged electric fence.

In summary, pests (excluding predatory mammals) are generally of minor importance, having a serious impact only on colonies that have been allowed to decline in strength or are already affected by disease. Pests are usually controlled by removing them, preventing access to the hive, or excluding them from the area of the hives.

Simple and Intermediate Technology Beekeeping

To increase the utilization of mangrove forests for the production of honey and allied products

Table 9. Principal Diseases of the Honeybee, Causal Organisms, Affected Life Stage, Symptoms, and Treatment

Disease	*Causal Agent*	*Life Stage Affected*	*Visible Symptoms*	*Prevention or Treatment*
American foulbrood	Bacteria (*Bacillus larvae*)	Late larval, early pupal	Many brood cells empty Brood cells have foul odor Larvae are soft and ropy Broad cell caps are sunken with holes in them	Application of terramycin and tylosin[a]
European foulbrood	Bacteria (*Bacillus alvei*)	Early larval	Many brood cells empty Dead larvae have a foul odor Dead brood in uncapped cells Dead larvae appear soft, watery to pasty	Application of terramycin, erythromycin[a]
Sacbrood	Virus	Late larval	Dead larvae in tough skin Brown to dark brown in color in late stages Cells are mostly uncapped with larvae head upraised	Treatment methods are unknown
Chalkbrood	Fungus (*Ascosphaera apis*)	Early larval (unsealed; about four days old)	White, mummified larvae Usually found on outer fringes of brood comb	Removal of affected brood comb
Nosema	Protozoa (microsporidian; *Nosema apis*)	Adult	Disjointed wings, number of bees unable to fly Distended abdomens Absence of stinging reflex	Fumigation (acetic acid, ethylene oxide)[a] Sterilization of equipment[a] Application of fumagillin[a]
Varroa	Parasitic mite (*Varroa jacobsoni*)	Late larval, pupal, adult	Presence of visible mites on larvae and pupae Deformed wings Wingless adults	Treatment methods are unknown
Acarine	Microscopic mite (*Acarapis woodi*)	Adult	Similar to Nosema	Treatment methods are unknown

Source: Adapted from Gentry (1982).
[a]Additional information may be found in Gochnauer et al., 1982.

on a worldwide basis, special attention must be focused on beekeeping that employs practical technologies commensurate with the skills and materials available in relatively undeveloped areas. Mangrove forests are often associated with undeveloped or rural societies that have little knowledge of beekeeping and little capital to invest in such a venture. For these reasons, it is wise to start with small-scale projects using modest technology and requiring few purchases.

Small-scale beekeeping projects are sometimes started with the most advanced moveable-frame hives, but with no experienced beekeepers or readily available continuing technical assistance, such a project is unlikely to succeed. This results in a situation where a relatively high investment is made in equipment that allows for a high return, but the technical ability to operate the equipment and realize its potential is lacking. From an economic standpoint, a cheaper and simpler system such as a moveable-comb hive would be better (Gentry 1982).

The moveable-comb hive can be constructed of many materials, including straw, bamboo, mud-plastered baskets, metal, or wood. This type of hive has a series of wooden bars across the top that allow for the attachment of the comb. The bars are spaced to give the bees sufficient room to build a comb centered on each bar and to leave crawl space for the bees between the suspended combs.

Ideally, the sides of a moveable-comb hive should be sloped at 120 degrees to follow the natural curve of the suspended comb. This produces easier handling because the bees are less likely to attach the comb to the sides of the hive and thus break or complicate the removal of the comb.

Moveable-comb hives offer a logical intermediate step between the primitive fixed-comb hives and the high technology moveable-frame hives. Moveable-frame hives offer a beekeeping method that is within the training level and economic reach of bee hunters and bee maintainers who use fixed-comb hives.

The advantages of moveable-comb hives are:

- The combs are removable and can be replaced without destroying them. Thus, bee*keeping* is possible.
- They are simpler to construct because there are fewer critical dimensions.
- They are easily made of readily available materials.
- They offer a cheap and better alternative to more primitive methods such as fixed-comb hives.
- Beeswax production is relatively high.
- Honey can be conveniently and quickly harvested from new combs, thus producing a higher quality honey.
- The top bars can be constructed so they meet, leaving no opening along the top of the hive. This makes it easier to work with more defensive strains of bees.

The disadvantages of the moveable-comb hives are:

- The combs are attached only to the top bars; thus, it is difficult to move the hive without damaging or breaking the suspended combs.
- Since the combs are attached to the top part of the hive, the colony can only expand horizontally along the wooden bar. This somewhat limits the expansion of the brood comb since the natural tendency is for the bees to expand the brood nest upward. This is not considered a serious disadvantage.

Because of its simplicity, the moveable-comb hive does not allow sophisticated management options for the beekeeper. But in underdeveloped areas, these options are probably beyond the knowledge and experiences of the indigenous beekeepers. As local skills develop, more sophisticated methods and equipment become practical.

Intermediate technology beekeeping methods offer an inexpensive incentive for those still hunting bees or using less efficient fixed-comb hives to make the transition to real beekeeping. Intermediate methods provide a relatively simple beekeeping system that is more within the economic and technical reach of most small-scale projects while allowing the user to become familiar with and use the most current beekeeping knowledge. The system sacrifices some honey production for wax production, but wax is also a useful and valuable product.

The moveable-frame system, the ultimate in beekeeping development, will remain economically and technologically out of the reach of many people who need or want to improve their beekeeping capabilities. Until they acquire the necessary skills and capital to employ such a system, an intermediate system can serve their needs and for honey production in mangrove areas.

Mangrove Honey Production in Southwest Florida

Beekeeping in southwest Florida is mechanized and highly developed using only the advanced moveable-frame hives. It is inappropriate to compare these methods with the less sophisticated techniques described earlier and used extensively in other parts of the world. Fairly detailed information is available on techniques and honey production, however, and this provides some perspective on potential production.

Mangroves that are known sources of pollen and nectar in Florida are listed by Sanford (1983) and include black mangrove (*Avicennia germinans*), buttonbush (*Conocarpus erectus*), and white mangrove (*Laguncularia racemosa*), with the former two identified as major sources. While Sanford does not include red mangrove (*Rhizophora mangle*), local beekeepers regard this tree as also contributing to the nectar and honey flow.

The mangrove honey season extends from mid-May to early August with maximum flows in June and early July. This corresponds well with the cyclic buildup in bee populations, which in Florida peak in late April (Sanford 1983).

In practice, southwest Florida beekeepers move their hives from the orange groves in central Florida at the conclusion of the citrus honey flow in early May to mangrove locations in mid- to late May.

In 1982 and 1983, the records of a successful Florida beekeeper show that his hives were in place in the mangroves for approximately fifty-five days from early June to early August during both years. Production varied considerably in the two years. Using approximately 560 hives during both years, total production reached 17,700 kg in 1982 (approximately 32 kg per colony) and declined to 6,980 kg in 1983 (approximately 12 kg per colony). Both years were considered to be below the average, which is estimated to be 35–40 kg per colony per year. This average is well below the production for tropical forests, which is estimated at up to 150 kg per colony per year. Care must be taken in this comparison, however, because the tropical forests referred to were not identified and were probably not mangroves. Early records for honey yields in south Florida mangroves show extraordinary production (up to 180 kg per colony) before the severe winter of 1894. The unusual cold killed the mangroves to the ground. It is reported that in terms of honey production the forest required twenty-five years to recover and even then only produced small quantities of nectar. Comparative data for recent periods on yields per colony per year for mangrove areas could not be found in the available literature.

The existing information on southwest Florida mangrove honey production allows some preliminary estimates to be made on the potential yield per unit area and on the yield per unit effort for the beekeeper using advanced moveable-frame hives.

If it is assumed that bees can range in all directions up to 3 km from the hive, then these colonies have a maximum foraging area of approximately 2,800 ha. On this basis and assuming there are fifty colonies in the bee yard, the honey yield for black mangrove areas in southwest Florida can be estimated in 1982–1983 as ranging between 0.21 and 0.57 kg per ha.

For the southwest Florida beekeepers, the production of 6,980 kg of honey in 1983 required an estimated 435 worker-hours from the setting of the hives to the extraction of the honey. Thus, even in a low yield year, production averaged 16 kg of honey for each worker-hour of effort.

Summary

Despite their potential for high honey production, mangrove forests on a worldwide basis are only lightly utilized. In most mangrove areas, harvesting techniques are inefficient and primitive, often using methods that require the destruction of the colony at the time of harvesting. Beekeeping is among the few uses of mangrove forests that have little or no impact on basic functions of the forest or on the natural benefits that are produced there. Nectar and pollen are the basic resource harvested by the bees, and they represent reproductive surpluses within the forest which through proper bee management may be profitably collected as a renewable seasonal benefit. With relatively little capital investment and training, small-scale, low-technology beekeeping can be initiated with a number of economic, social, and food production advantages for underdeveloped areas. In southwest Florida, using advanced beekeeping methods, the honey yield from black mangrove forest in 1982–1983 ranged between an estimated 0.21 and 0.57 kg per ha. In 1983, when honey production was well below average, beekeepers in southwest Florida produced an average of 16 kg of honey for each worker-hour of labor.

Acknowledgments

The information presented in this chapter has drawn extensively on an excellent summary

produced by Gentry (1982) entitled *Small Scale Beekeeping* and from the basic beekeeping reference, *The Hive and the Honey Bee* (Dadant and Sons 1982). Special thanks are also extended to Mr. Henry Vaughn who generously gave his time and shared his knowledge of beekeeping in southwest Florida mangroves.

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SECTION II

CHAPTER 7. Utilization of Mangrove Foliage for Grazing, Stall Feeding, and as a Feed Supplement

According to one biosphere estimate, there are about 1.2 billion head of cattle, 1 billion sheep, about one third as many goats, 42 million horses and asses, 14 million camels, and 13 million water buffalo in the world (Janick et al. 1981). Although livestock, including domestic fowl, represent an important source of protein, the feed and forage requirement frequently exceeds the available rangeland and grain supply in many areas of the world. In densely populated regions of the world, the subsistence resource base may be inadequate to support both the basic nutritional needs of humans and the feed and forage requirements of large numbers of animals.

Even when a given country has a large area available for grazing, it may not support a large livestock population if the species of plants available are not suitable for livestock. Rangelands are ideal grazing areas but they can be degraded gradually by the selective eating habits of grazers that tend to eat the most palatable and nutritious species first, leaving behind the less desirable ones (Wahid 1968).

Another problem facing rangelands and pastures is that of waterlogging and salinity, which is serious in some countries. For example, 7 million ha of land in India are plagued with this problem (Kurian and Patolia 1980). In Pakistan, 4.2 million ha out of 16.6 million ha of irrigated land are affected by salinity (WAPDA 1980). Generally, these saline soils are not productive for either food or fodder crops. An alternative source of forage and fodder in arid, semiarid, and saline coastal areas are the plants known as halophytes (salt-tolerant plants). There are numerous examples of domestic animals feeding on mangrove foliage—camels in the Middle East; camels, cattle, and goats throughout Asia; and water buffalo in parts of Asia and Australia. In addition, endangered manatee and dugong are known to graze on mangrove foliage bordering waterways.

In Australia, for example, halophytes belonging to several species *Atriplex* are grown on saline soils for use as fodder. Species of *Atriplex* are also cultivated on a large scale on saline soils in Tunisia and tropical Africa for the same purpose (Kurian and Patolia 1980). These halophytes have been found to be very nutritious and comparable to the best types of nonhalophytic forages.

Among the halophytes, some mangrove species can provide an excellent alternate food for livestock. Their use for this purpose has prehistoric precedents (Kehar and Negi 1953), but their use as fodder is limited. Attempts are now being made to exploit mangroves on a larger scale.

Nutritive Value of Mangroves as Forage and Feed

Mangrove foliage can be used safely as fodder, feed, meal, concentrate, or roughage, since it contains significant quantities of all necessary minerals, vitamins, amino acids, proteins, fats, and crude fiber nècessary for the growth and nourishment of livestock. A comparison of the chemical analysis of mangroves with that of alfalfa reveals that mangrove foliage is even better in nutrition than alfalfa, the "queen of forages" (Janick et al. 1981).

Table 10 shows chemical composition of leaves of three local species of mangroves growing in Pakistan. *Avicennia marina* is the most abundant of the mangroves and dominates perhaps 99.9 percent of the total area of mangrove forest. *Rhizophora mucronata* and *Ceriops decandra (roxburghiana)* data are very rare and have been collected only from Miani Hor (Saifullah 1982). Table 10 does not include a complete chemical analysis of the plants, but the major ingredients have been measured. The results strongly indicate the potential for use of all three species, especially *A. marina*, as fodder and feed. *A. marina* is definitely more nutritive than the other two species and is comparable with the best types of fodders available in Pakistan, such as alfalfa, clover, barley, cabbage, beet root, and sunflower (Malik et al. 1966). The other two species, *R. mucronata* and *C. decandra*, though not so nutritive are still comparable with fodders of average quality such as millets, sorghum, oats, and sugarcane leaves.

Mangrove fodder appears to be superior to

Table 10. Composition Analyses of the Foliage of Three Mangrove Species from Pakistan

Species	*Moisture (% wet weight)*	*Na*	*K*	*Crude Fat*	*Crude Fiber*	*Crude Protein*	*Ash*	*Digestability (%)*
		(% dry matter)						
Avicennia marina	65.41	5.52	0.45	4.18	16.04[a]	10.8	16.30	62.60
Ceriops decandra (roxburghiana)	62.02	2.76	0.59	5.35	14.59	5.9	10.02	97.38
Rhizophora mucronata	68.90	3.45	0.62	2.68	11.30	4.7	14.00	77.10

[a]Crude Fiber value for *Avicennia* is taken from Kurian and Patolia (1980).

other types of fodders because it has significant quantities of common salt and iodine since it grows in the marine habitat. All other types of fodder contain little or no salt and animals feeding upon them must be given salt supplements. Grazing animals not given salt supplements often suffer from restlessness and must travel long distances in search of natural salt licks (Perry 1981). Iodine is also a necessary requirement for the nourishment and growth of livestock, and a deficiency causes "big neck" disease in young livestock and the young ones are either born dead or malformed (Perry 1981). Most nonhalophytic types of fodder are deficient in iodine.

Feeding trials with mangroves have shown them to be nutritious for livestock. Morton (1965) found that when milk cows were fed on *R. mangle*, milk yields increased. Feeding trials of sheep with *Avicennia* spp. meal in Madras have also proved to be promising (Kurian and Patolia 1980). Poultry feed made from dried mangrove leaves and twigs has been found nutritious and comparable to other high quality feed now in use (Allen 1981). When mangrove feed was used as a supplement to common poultry feed, the weight of the chicks increased (Sokoloff et al. 1950). Chemical analysis of mangrove meal made by Morton (1965) indicates its suitability for use as a poultry feed because it contains all of the required nutrients.

Grazing on Mangroves in Pakistan

Perhaps no other country can provide a better example of large-scale grazing of mangroves than Pakistan, where thousands of camels have been grazing regularly for years. Here the mangrove trees grow all along the extensive coastline of Sind Province bordering the Indus Delta. According to Saifullah (1982), they cover a total area of several hundred thousand hectares and are dominated by the single species *Avicennia marina*.

Grazing by camels in Pakistan may be broadly classified into two categories—ordinary grazing, and professional grazing. *Ordinary grazing* is restricted and local, involving the camels of fishermen living near the mangroves. The camels are few in number and swim across the narrow channels and gulleys to reach these areas. There are also sporadic instances of buffalo grazing. *Professional grazing*, on the other hand, is on a large scale. During the very hot and severe dry season, pastures and rangelands become barren, and the availability of forage in the area is drastically reduced. Thousands of camels residing in the interior of Sind face starvation as a result. In this situation, professional graziers belonging to the Jat community are hired by owners of the camels to herd them to the mangrove areas (Khan 1966). The camels reach there in June each year and remain there until October. They seem to have adapted very well to the typical muddy tidal habitat and the environment. At high tide, most islands are inundated, and even though the water level may reach the animals' thighs, they apparently are not disturbed. They are good swimmers and cross to the islands easily. Once they have reached the islands, only one or two watchmen look after the entire herd of thousands in this uninhabited area. Once each week the graziers bring in fresh water. At the beginning of the wet season the camels are herded back to their origin where they are an important part of the transportation system of the area.

Approximately 5,000 camels graze on mangrove islands situated mostly near the Indus Delta proper, about 200 km or so from Karachi. Keti Bunder defines the area where these camels graze most extensively on *A. marina*, and signs of overgrazing are readily visible. Many islands have become denuded, and others are partially defoliated.

Stall Feeding

Unlike grazing, which is observed on a large scale in a few countries, stall feeding using mangrove foliage is practiced in many countries. *Avicennia officinalis* is generally considered to be the preferred fodder. Leaves of *A. marina* are also used as fodder in United Arab Emirates and Iran (Miyake and Kogo 1982). In peninsular India mangrove foliage is fed to goats and cattle (Sundararaj 1954).

In Pakistan, stall feeding of mangroves is practiced only on a limited scale and is restricted to local coastal settlements like Korangi, Ibrahim Hyderi, Rehri, and Lelet (Khan 1966). The leaves of *A. marina* are either lopped or twigs cut off by local people and are loaded on a boat and carried to the mainland where they are distributed in the area on camel backs and donkey carts. This forage is then sold to local consumers for nominal prices. The animals that are stall fed include cattle, buffalo, donkeys, sheep, goats, and camels (especially those too young to swim to the islands). All of these species mentioned seem to relish this natural diet, and their owners speak highly of the quality of the forage.

Although Pakistan heads the list of the mangrove fodder consumers, scientific feeding trials of livestock with mangroves have not yet been carried out. Nevertheless, prolonged successful feeding of camels and livestock on these plants for so many years is itself evidence of the beneficial effects of mangrove forage. The owners of livestock fed on mangroves report that their animals seldom suffer from disease. The buffalo have adapted to the extent that they prefer mangroves to other fodders; the excess salts do not seem to have any purgative effect, and the quality and quantity of milk from cows, buffalo, and goats are either equally as good or better than when they were fed on other forages. Perhaps Pakistan is the only country where livestock consume mangrove leaves as a major fodder and not as a supplement or as an alternative diet.

Management and Conservation

It is a general rule that consumption of forest products should not exceed sustainable yields, and the same principle holds true for mangrove forests. The primary concern associated with the utilization of mangroves for forage and fodder is the ability to regulate the grazing and harvesting pressure to ensure a sustained yield. Because grazing animals frequently exploit the young, regenerated seedlings, management should be based on a rotation plan that ensures adequate regeneration. The rotation period will vary according to site conditions, but in general it should be long enough to permit the foliage of the developing plants to achieve its original density.

In Pakistan and northwestern India, where there is evidence of overgrazing of mangroves by camels, the most alarming fact is that even in areas where grazing is not so severe, one does not find any young plants or seedlings of *A. marina* because the camels eat them first. The mangrove forests of the Indus Delta were dense and luxurious some decades ago, but with the decrease in the discharge of fresh water from the Indus River as a result of barrages and dam construction and overgrazing by camels, the forests are slowly giving way to wastelands. If proper measures are not taken soon to manage and conserve them, the Indus Delta mangrove resource will be eliminated.

A number of measures have already been taken by the Department of Wildlife and Forests in Pakistan to control overgrazing by camels and to reforest the degraded areas. Revenues are charged for camel grazing for the whole season, but the amount is too small to discourage the graziers. Broadcast sowing of seeds and silviculture practices are carried out on the affected islands, but all efforts have been unsuccessful because the camels consume the seedlings.

Since stall feeding is practiced only on a limited scale in the area, harvest of mangrove foliage and twigs does not call for serious concern, yet minimal royalties are being charged per boat or camel load of leaves and timber.

Measures taken so far to conserve and manage mangrove forests in Pakistan are insignificant and futile. Overgrazing by camels continues, and the affected areas are deteriorating rapidly. Because camels play an important role in the transport sector of the country and in fact are the lifeline of transport in inaccessible rural areas, overgrazing can only lead to a self-defeating loss of the resources on which they depend.

In view of the importance of grazing and stall feeding of mangroves and considering at the same time the danger of their elimination due to their excessive exploitation, the following conservation and management procedures are recommended:

- Grazing areas should be rotated on a several-year basis to minimize the grazing pressure and permit recovery during the intervening period.
- Mangrove forests of Pakistan are categorized as protected forests. It is advised that at least certain areas that are seriously af-

fected should be treated as reserved for silviculture purposes. When these areas have recovered, they may again be opened for grazing.

- Exploitation of mangroves for any purpose in Pakistan should not exceed the annual sustainable yield of 14 m^3 per ha. Similar limits should be established for other countries prior to utilization.
- The growing tips of the trees should not be removed, older plants should be exploited, and only a part (less than one-third) of the canopy should be removed.

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SECTION II

CHAPTER 8. Management and Utilization of Nipa Palm

Introduction

One of the most common, widely distributed, and useful palms in the mangrove forests of the world is nipa (*Nypa fruticans* Wurmb) (Figure 12).*

The IUCN report on the *Global Status of Mangrove Ecosystems* (Saenger et al. 1983) showed that nipa occurs naturally in two (Asia and Oceania) of the six regions of the world and that it was introduced into West Africa in 1906. Written materials on nipa indicate its occurrence in a wide range of countries—Australia, Indonesia, Papua New Guinea, Philippines, Thailand, Malaysia, India, Sri Lanka, and Bangladesh. In addition, nipa is known to occur in Vietnam, Burma, the Carolines, and the Solomons, and it has been introduced into Nigeria.

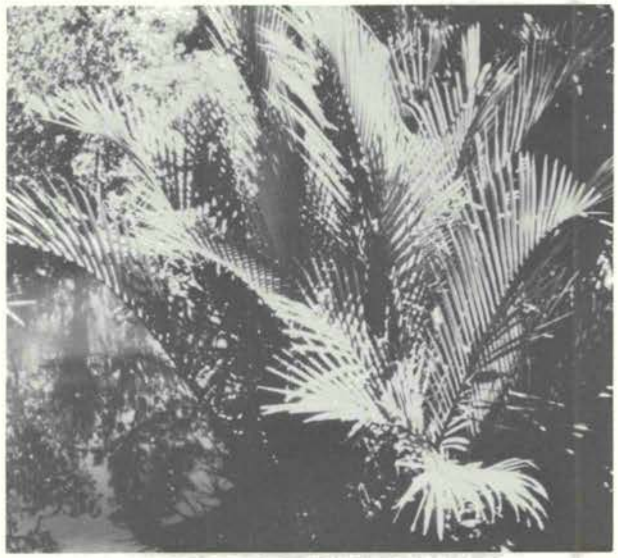

Figure 12. Nipa palm (*Nypa fruticans*).

Uses

This versatile palm historically has provided useful products to traditional peoples living near or in the coastal and estuarine mangrove forests. Products were obtained from the leaves, the juice or sap from the inflorescence stalk, and the fruit. These uses continue, and some have become the bases for cottage industries and commercial operations. Currently, some large-scale commercial interest has developed.

Nipa palm *leaves* have traditionally been harvested in all of the countries in which it occurs for roof thatching and for dwelling walls. The leaves are dried, the pinnas folded at two-thirds of their length over a rod of hardwood or bamboo, stitched in place with overlap, and sewn together in lengths of 1–2 m to make shingles for roofing or walls (Figure 13). These last three to five years or more, and a commercial market has developed. In fishing, nipa leaf petioles are used as floats for fish nets, the main axes for fish poles, and the leaflet midribs soaked and twisted as ropes. In the Philippines, dried petioles and stalks are being used for fuel in firewood-scarce areas. Young leaflets also are used as cigarette wrappers and older ones to weave hats, umbrellas, raincoats, baskets, mats, and bags. Leaves have also been tried in insulation boards, and it was found that the pith and leaf stalks were unacceptable but that the outer

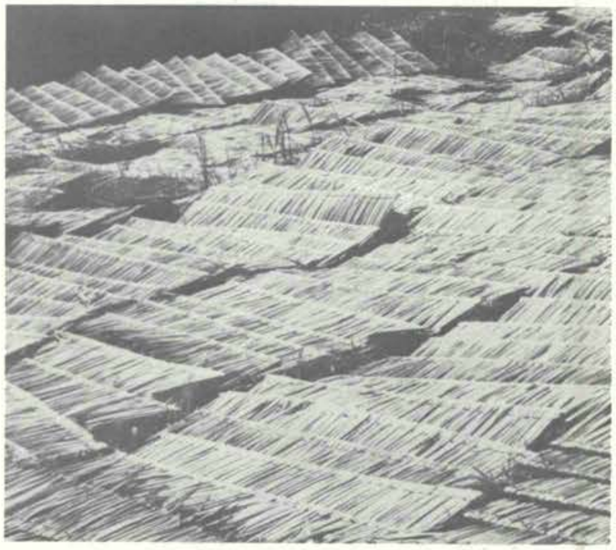

Figure 13. Nipa shingle panels being dried in the sun.

*Short synopses of botanical characteristics of nipa are provided in Corner's (1966) *The Natural History of Palms* and in Whitmore's (1973) *Palms of Malaya*. Aksornkoae (1976) has discussed the ecology of nipa in a mangrove forest in Thailand, and until more ecological studies are available over a wider geographic area, it is suggested that this work be consulted. For a concise account of a commercial plantation in Malaysia, a paper by Hinchy (1938) should be consulted.

layer of the leaf stalk yielded pulps suitable for making good quality boards of intermediate density (Razzaque 1969). Leaves have been found to be unsuitable for paper pulp (Hossain and Siddique 1969).

Young *seeds* (the gelatinous endosperm) are eaten raw or preserved in syrup, and in Malaysia they are used to flavor a commercial ice cream ("attap chi") and are added to local ice confections. The hardened endosperm of mature fruits is used as a vegetable ivory and for buttons.

Young shoots, decayed *wood*, and burned *roots* or *leaves* have been used medicinally in various parts of Southeast Asia for herpes, toothache, and headache (Burkill 1935). Herpes is treated both by drinking the juice from the young shoot mixed with coconut milk and by applying the pulp from which the juice is extracted to the affected area.

Nipa *sap* is a source of sugar, around 14 to 17 percent sucrose (Halos 1981). This is used to produce vinegar, alcohol, and in particular a widely used fermented beverage called "tuba" in the Philippines, "drak" in Indonesia, and "toddy" in Malaysia, India, and Bangladesh. Information about the sap characteristics and chemistry has been compiled by Murphy (1981) going back to early work beginning in 1911 in the Philippines and in the early 1920s in Malaysia. Most of this early study was due to an interest in fuel alcohol. Nipa sap also was considered promising for sugar production in the early decades of this century, again mainly in the Philippines and Malaysia. The high costs of fossil fuel and fertilizers have initiated a new look at its fuel alcohol and sugar potential.

There are currently two factories in Sarawak for the production of alcohol from nipa sugar (Chai and Lai, in press). Vinegar production from the sap is practiced in Papua New Guinea and the Philippines. A program to produce alcogas from nipa stands is under study in the Philippines, and interest in nipa as an energy source has been shown in several other quarters. For example, in Papua New Guinea, the Department of Primary Industry is planning an alcohol-from-nipa project (Fong, in press). Nipa alcohol may be blended with petroleum fuel up to a 1:4 ratio without the need to redesign or adapt the carburetors of gasoline engines (Government of Canada 1978).

Cultivation and Management

Much harvesting of nipa leaves, sap, and fruit is from wild stands where nipa may be a scattered member among mangrove or freshwater forest types, though it usually occurs in nearly pure stands. Salinity regimes in nipa stands vary during a single year as the dry season comes and goes. Tree density is often up to 2,500 palms per ha or more, but only 700–750 will be producing-palms for sap. Production apparently can be improved by wider spacing, anywhere from 500 per ha to 380 per ha. In thinning to the desired density, Gonzales (1979) in the Philippines recommends that the roots of the plants removed be cut up to prevent them from regenerating. Stands are planted in the Philippines at a spacing of 1.5–1.7 m, approximately 390 per ha. For planting, seedlings are grown in nurseries until a hand-span high and are then transplanted into pockets in the sides of planting drains (Gonzales 1979). In Bangladesh, the best nipa germination and survival in the nursery has been obtained in locations that are submerged at least 230 minutes per day.

Pollination of nipa is by drosophila flies and therefore if mangrove areas are to be used for nipa sap production, it is unwise for managers to use contact insecticides for such problems as mosquitoes.

The main pests of young seedlings are the grapsid crabs, which cut or girdle the plants. No reports of serious insect or disease problems in mature trees have come to light, but it has been reported that monkeys and pigs caused serious damage in North Borneo.

When leaves are removed for thatching, mature leaves may be cut off near the ground, as long as two or three are left (Melana 1980). Palms tapped for sap should not be cut for thatch since loss of mature leaves reduces yield. Old leaves must be cut out before they fall naturally, since a nipa's shape and unarmed petioles may direct the falling leaves from adjacent palms into its center where they may destroy the tapping stalks. Vegetation around the trees is cleared to allow free growth and access for tapping. In developing an old stand, careful thinning and clearing can bring many trees into bearing (Johnston 1975). In a new plantation, although trees may fruit as early as three years, fruit are full-sized only after five years. Tapping for sap would not ordinarily commence before the fifth year.

Tapping Nipa for Sap

Sap is collected from nipa's mature fruit stalk after the almost-full-grown fruit head has been cut. The stalks grow from ground level, so skilled climbers are not needed as in tapping for coconut sap. Mature trees average two tappable stalks at any one time. When tapping begins, the freshly cut stalk end is inserted into a hole in an earthenware pot or a bamboo container. Each time after collecting the juice, a thin end slice of about 2 mm is removed. Skillful tapping, so that the thinnest slice is cut each time, can greatly prolong tapping life. It is important to disinfect the cutter, since flow is reduced by microbial growth. Cutter design deserves research. Stalks are quite long, ranging from .6 to 1.0 m in the Philippines to 1.4 m in Sumatra, and tapping life depends on the length of the stalk.

Sap flow depends entirely on preparation of the stalk. Yield is low and lasts only a few days if this is not done. Traditional practice of kicking the tree sounds strange but has a sound logical basis. The base of the stalk is kicked about five times at weekly intervals, several kicks each time. It can also be beaten with a mallet. An early Malaysian description states: "The process is started when the fruit-head is fairly well grown but before any darkening of the seed takes place. It consists of gently oscillating the fruit once a day. As the fruit grows, the violence of the operation is increased until it becomes a good hard kick or violent shaking by hand" (Dennett 1927).

According to Melana (1980) in the Philippines, the schedule of kicking is as follows over a three-month, ten-day period:

Age of Stalks from Flowering	Frequency of Kicking
First month	Once each week
Second month	Twice each week
Third month	Once every two days
Fourth month	Daily for ten days

Evidently, this kicking or beating process—called "gonchanging"—is very important, and it deserves research. Presumably, it prevents or destroys the embolism that would normally block the vessels before fruit abscission. The stalk is also progressively bent for tapping convenience.

Sap flow is low for the first three weeks (about .5 liter per palm per day), rising to about 1 liter per palm per day throughout the life of the stalk (Johnston 1975). Yield is highest in cloudy weather, and it is claimed that transpiration competes with sap yield but is partly compensated by variation in sugar content (Hinchy 1938).

During the slow process of collecting, the sap begins to invert its sugar, ferment, and acidify. Although not a problem for alcohol production sap, this must be controlled if potential sugar yields are to be realized. Containers designed to exclude insects and allow continuous liming (to prevent fermentation) have been described by Dennett (1927). Enzyme inhibitors and disinfectants such as chlorine also are added, but collecting sap twice a day is recommended for the highest yields. Recoverable sugar means crystalizable sucrose, the most valuable market product, and for this, inversion must be minimized. The success of a commercial sugar plantation depends on attention to hygiene.

Economics

For the only nipa palm commercial plantation in the world before World War II (that in Kuala Selangor in Malaysia), figures for alcohol production were close to 15,600 liters per ha per year, based on tapping twice daily for 340 days per year (Dennett 1927). Annual yield in the Philippines is currently somewhat lower, with traditional practice yielding 6,480 to 10,224 liters per ha, though it is thought that under improved management this could be pushed to 18,165 liters (Halos 1981). For comparison, sugarcane is estimated to produce from 3,350 to 6,700 liters per ha per year; cassava, from 3,240 to 8,640; sweet potato, from 6,750 to 18,000; and coconut sap, 5,000 (Rosario in press).

For sugar production, the Malaysian data cited would be equivalent to 20.3 tons per ha per year recoverable sugar. For a Sumatra estate, Johnston (1975) used 22.4 tons as a conservative estimate, and assuming twice daily tapping, he proposed an estate labor force of thirty-eight per 10 ha plot (thirty on tapping/collecting, five on "gonchanging" and maintenance, two on syrup transport, and an overseer). With eight for a boiling station, and four extra for reserve, this corresponds to an average labor force of 5 per ha, which is much more labor intensive than sugarcane.

There are considerable advantages over sugarcane, however, at least for equatorial regions. Continuous productivity means no displaced labor, which is a major problem in sugarcane economics. Production is not interrupted by replanting and rotation. There is no bagasse (waste from the crushing mills) disposal problem, and the sugar factory itself is greatly simplified since there is no expensive crushing mill to maintain. Though bamboo is cheap and reusable, labor reductions by using PVC pipelines and disposable polyethylene bags are worth investigating to replace the traditional vessels, and this might reduce tapping to once a day. Unlike cane, nipa does not compete with other crops for agricultural land except where total reclamation is undertaken. The sugar yields cited compare very favorably with comparable values for the cane industry in Indonesia where about 8 tonnes per ha per year are taken as standard, making no allowance for replanting or rotation.

The shingle 'industry' is locally an important source of revenue. The shingle is usually 2 m long, though shorter lengths are also produced. In 1983, in some areas of the Philippines, prices for 2-m nipa shingles were US$7–10 per hundred. Production figures are difficult to obtain and are not always consistent, but the Philippine Bureau of Forest Development Statistics shows increasing shingle production from 1976 to 1980, with a 1980 figure of 2,978,000 pieces produced. One study of shingle production in Thailand reported a yield of 15,300 pieces per ha, with a value of US$230 per ha (FAO 1982).

The annual production of thatching from the Sundarban forest of Bangladesh has varied from 62,900 to 180,000 tonnes from 1957 to 1977, with an average of 81,600 tonnes (Khan and Karim 1982). The commercial value received from those in trade in 1976 was US$12,188.

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SECTION II

CHAPTER 9. Wood Production

Introduction

Forest management includes silviculture, a well-established practice having its origins in northern Europe several centuries ago and spreading to other continents primarily in the nineteenth century. Started as a horticultural art, forest management is now an established science based on a strong empirical knowledge base. The application of silvicultural methods to mangrove forests began in British-Colonial Asia in the mid-nineteenth century and to a much lesser extent in British Africa. In Asia, the British management plans developed for such countries as Bangladesh, India, and Malaysia formed the basis for the management plans that are presently being followed. In almost every instance, mangrove forests in these countries and Thailand also are managed on a sustained-yield basis; some forests are now in their fourth thirty-year rotation. Although silviculture research continues to lead to improvements in mangrove forest management, the most important aspect, that of management for sustained yield of the same major commercial species, remains the standard goal. Venezuela also is moving toward sustained-yield policies in some areas, using strip clearfelling and natural regeneration.

Whereas sustained-yield management is the main if not most important objective of forest management, there is an increasing occurrence of commercial quality mangrove forests being consigned to large-scale clearfelling. This is unsustainable because it does not require approximately equal annual coupes, based on a conservatively conceived silvicultural rotation offering similar annual yields in perpetuity. Such nonsustainable harvesting is presently underway in Indonesia, Sabah, and Sarawak and has been proposed in other countries such as Columbia and Gambia. Although the logged-over areas *may* regenerate into a mature closed-canopy mangrove forest, another harvest will not be possible for another twenty to forty years, and the total area consigned to harvesting will be cutover long before that. By definition this practice does not meet sustained-yield requirements. The chances of successful regeneration usually decrease as size of contiguous area cut increases, which adds to the problem of sustainability. Aggravating the problem is the fact that certain clearfelled mangrove forest habitats are being converted to other uses (e.g., human settlements, agriculture, aquaculture ponds), which effectively destroy the natural resource base that is capable of generating a variety of goods and services and wood and wood products.

This chapter outlines the basic management and harvesting principles applicable to mangrove forests that lead to and promote sustained-yield utilization. It is only through the acceptance and implementation of proper, non-exploitive silvicultural practices that mangrove resources, goods, and services can be perpetuated for the overall benefit of society.

Mangroves represent complex ecosystems. Though the number of plant species that can adapt to this unique environment is low compared with many other ecosystems, those species play an important role as a renewable resource of wood for a variety of uses, as well as the other uses and services described in Section II, Chapter 1. Thus, the long-term stability and productivity of coastal zones dominated by mangroves basically depend upon the stability and proper management of the plant communities. Even the productivity of many alternative uses (e.g., pond culture, apiculture, recreation, grazing) to which mangroves have increasingly been put depends to a great extent upon the stability of these plant communities. It is therefore imperative that a sound system be developed to manage the mangrove forests for wood production and other uses on a sustained-yield basis. Lately, there has been a growing trend toward the conservation of these forests and their more rational utilization through technical management plans that offer guarantees of a sustained and profitable yield. This chapter summarizes the present knowledge of techniques that have been applied to the management and harvesting of mangrove forests for wood production. The chapter concludes with a list of issues that need the serious attention of those entrusted with the management of the forest crops in this ecosystem.

In managing the mangrove ecosystem for wood production as well as other uses, the following are some of the important objectives:

- To produce and sustain maximum volume of wood for conversion to charcoal, fuelwood, poles, wood chips, posts, etc., for local populations, domestic and industrial use, and export purposes;
- To protect and preserve from physical damage and chemical pollution the likely breeding and feeding grounds for high-protein sea fauna and other wildlife by maintaining the ecosystem at productive levels;
- To regenerate naturally (or reforest failed and poorly stocked areas) with marketable indigenous species;
- To provide livelihood and employment to those dependent on the forest, especially the fishermen using the nearshore environment;
- To preserve sufficient areas for research and training in mangrove ecology and management; and
- To maintain the foreshore and river bank protective role in dampening the actions of wind, wave, and tidal currents.

Basic Mensuration Requirements

The rational management of any forest is based on an in-depth understanding of the forest and its environment that can be obtained through a series of observations and measurements relating to its composition, structure, and ecology. This permits a diagnosis of the present state of the forest and of the possibilities for future utilization and development.

Usually, the necessary information is collected by carrying out a forest survey that includes direct field observation and measurements and an analysis of aerial photographs of the area. This information consists primarily of the volume of the trees in a forest unit, its growth rate, the natural regeneration of the forest, the time required to reach maturity, the volume of products to be extracted, and the possible forms of management for its future development. The extent and frequency of flooding should be determined in order to classify the forest into inundation classes for management (usually five classes according to Watson [1928] with class 1 being most frequently inundated by all high tides and class 5 by only the abnormal or equinoctial tides).

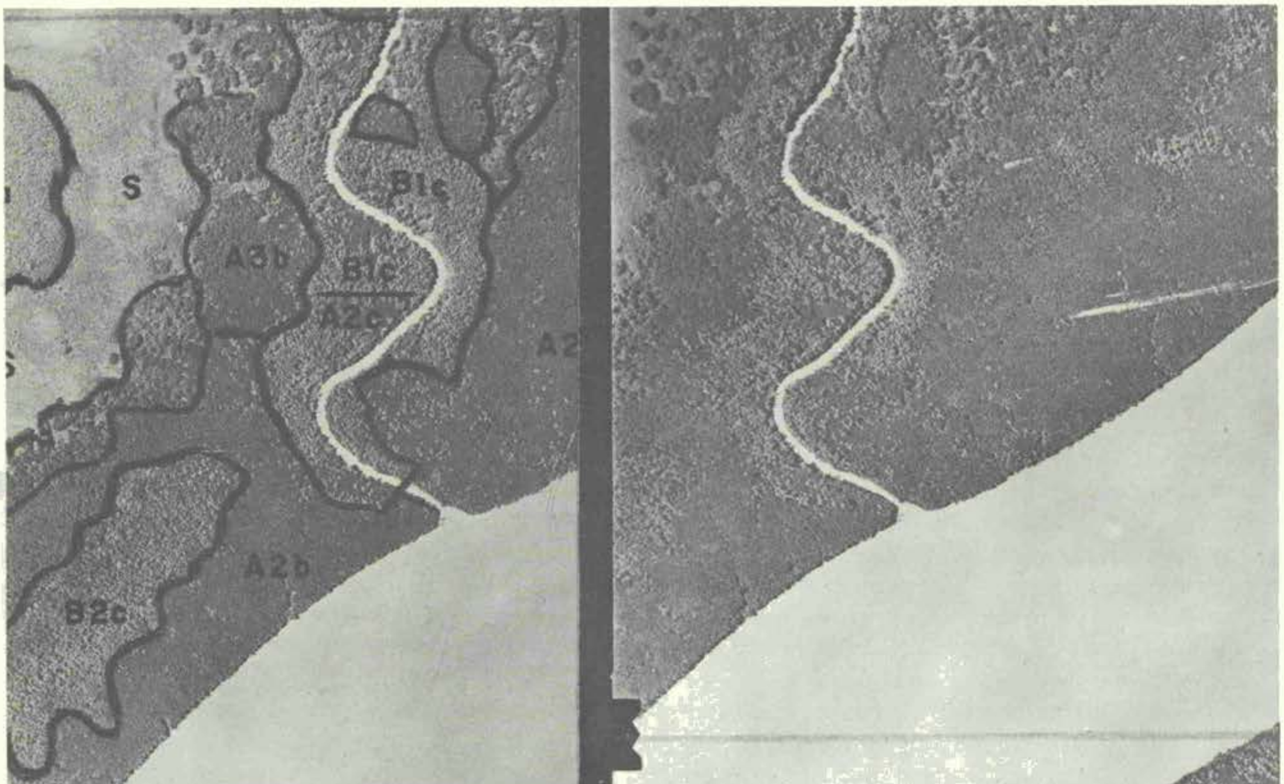

Figure 14. Type-mapping of Venezuelan mangrove forest on stereo airphotos (A—*Rhizophora*; B—*Avicennia*; S—marshland).

INVENTORY AND TYPE MAPS

In planning a forest inventory, it is useful to have a map of the area that contains the different forest types present. This permits greater efficiency in the work and a considerable reduction in costs.

The stratification of the forest is normally easily accomplished with the aid of aerial photographs or other remote sensing images, such as those derived from satellites or radar. The stratification criteria that are normally used are the landforms (physiography) and the appearance of the vegetation (physiognomy). With aerial photographs of a suitable scale and a modicum of field checking, it is possible to separate forest types on the basis of tree height or crown diameter, density of trees or degree of crown cover, color, pattern, or texture of the crowns; occasionally dominant species can be identified and related to age classes or volume per unit area (Figure 14).

In an inventory for a management plan of a mangrove forest area in Venezuela, it was possible to differentiate the three genera present (plus an unknown species) from black and white aerial photographs at a 1:25000 scale. The mangrove genera were easily recognized as follows by crown size and color and the relative heights of the trees:

Genus of Mangrove	*Crown Diameter*	*Crown Color*	*Tree Height*
Rhizophora	Small	Dark	Shorter
Laguncularia	Medium	Gray	Intermediate
Avicennia	Large	White	Taller

Moreover, it was possible to separate different types in each genus based on height and crown density, which were measured (under a mirror stereoscope) with a parallax bar and a transparent grid, respectively.

It should be noted that photo-interpretation at that scale permitted the establishment of the spatial distribution and degree of mixing of the three genera of mangrove but did not allow differentiation of the three species of *Rhizophora* (*R. mangle*, *R. racemosa*, and *R. harrisonii*) present in the area. Later, with a better understanding of the mangrove forest under study and especially the spatial distribution patterns of the three genera of which it is composed, it was also possible to differentiate these on smaller-scale aerial photographs (1:50000). It did not appear possible nor were attempts made, however, to differentiate the three species of the genus *Rhizophora* on larger-scale photos (1:10000, for example), nor did it seem necessary given the similar use of the three species.

Inventories are generally carried out at a very low sampling intensity of the survey area. This is especially true in the case of relatively homogeneous forests with species of moderate economic value such as mangroves. A 2-percent sampling may be adequate for general management purposes.

Since mangrove species usually exhibit zonation parallel to watercourses, sampling should be oriented perpendicular to the coast, estuarine shore, or river. Survey methods are well known to forest managers and will not be discussed further here.

The commercial wood products extracted from the mangrove forest are highly varied (see Table 1). All of these products are of different dimensions and often from different species. Thus, the differentiation of the various sizes and species of trees surveyed is a very important operation in forest inventories.

Generally, the classification of the forest stand is done during the compilation of the inventory results. The classes are established mainly as a function of products to be extracted. Normally, classes are established by species, form, and size. Sizes are established from the diameter and height of the stems; thus, the planning and execution of the inventory should consider them. This is valid even in the case of products like bark, charcoal, and firewood, whose yield in some way depends on the species, size, and form of the trees.

Diameter at breast height is usually measured 1.3 m above substrate level or 0.3 m above the uppermost prop root on large, prop-rooted species.

While classes normally are established by species, form, and size, it is ultimately most desirable to superimpose a site classification based on inundation classes. This latter classification work can begin during initial forest inventory work and then be improved upon as field indicators (such as presence of ferns and other weeds, build up of leaf litter, and hardness of soil surface) become more apparent.

ROTATION DETERMINATION

The rotation age in the management of a forest should be understood as the predicted age for the final harvesting of the trees. That is, the rotation length is the time required for the trees to reach the size, or the stand to reach the volume that corresponds to the financial maturity for the end use in mind. For any given minimum final product size or volume per hectare, the rotation will depend on the growth rate of the trees. This in turn depends on the site quality and on the managed density of stems (controlled by thinning). It also depends on how quickly regeneration can be obtained. Reforestation, rather than natural regeneration, has been used to shorten the rotation. In mangrove forests, products may be harvested over a wide range of ages. At ages of three to four years mangrove Christmas trees have been cut as thinning in the Philippines. It may require as long as forty years for construction timber and utility poles to grow in Fiji. A list of various ages for several end products in selected countries where data were known is shown in Table 11.

The determination of the rotation for the exploitation of a natural, tropical forest faces two fundamental difficulties. First, since the species composing the forest in a mixed forest grow at different rates, each species has its own rotation length. Second, prior information on the growth of trees is not immediately available (in contrast to temperate zone species), because tropical trees do not form annual growth rings, which facilitate this determination. Consequently, it is unfortunately necessary to make periodic (successive) measurements of the trees, which require a certain number of years, in order to make more or less valid predictions of the rotation length. Measurements are usually made of the diameter (dbh) and height of the trees, in order to estimate their increments and corresponding volumes.

Dixon (pers. com. 1983) recommends a method known as "aberrant increment" as a useful tool, and one that was applied to the Matang Mangrove Reserve more than fifty years ago with good predictive ability. He outlines the steps as follows:

1. For each important species select five to ten *free growing* trees within each 5-cm-diameter class up to the largest significant class present (possibly 40–45 cm).
2. Annually measure and record the diameters (and preferably the merchantable bole length and total height as a basis for basal area/form factor/volume relationship studies) of each sample tree. Recordings should be made for at least two years, and preferably five years or more, bearing in mind that the accuracy of forecasts based on the data will be considerably enhanced with the elapse of time covering the measurements.
3. Calculate the mean annual diameter increment for each species within each of the 5-cm-diameter classes covering the entire study period; use this figure to calculate the time necessary for each respective species to pass through the diameter classes, i.e.:

$$\text{Transit time in years} = \frac{5\text{ cm}}{\text{m.a.i. diameter cm.}}$$

Table 11. Intermediate Felling Age or Rotations (in years) for Various End Products

	End Products						
Country	*Firewood*	*Fence Posts, Corral Poles, Light Construction Wood*	*Charcoal Wood*	*Poles and Piling*	*Railroad Ties*	*Construction Timbers*	*Pulp Chips*
Fiji	15	20–25	40	40		40	
Thailand	30		30	30			
Peninsular Malaysia	30	15	30	15 and 20			
Sarawak	20		15–20				25
Sabah							20–25
Indonesia	20		35				20
Philippines	7	8	15				
Venezuela		15	30	30	30	30	
Puerto Rico							
Virgin Islands			25				
Gambia	30			30			30
Vietnam			20				

4. Sum the transit times for each diameter class to produce successively a diameter class-age relationship up to the largest class considered, and thus provide a basis for determining an acceptable rotation.
5. If merchantable bole lengths or total heights are also recorded, as well as diameter increments, and in addition a separate study made to determine form factors for various size classes, it is possible to proceed one step further and produce diameter-basal area-volume relationships that provide a useful tool in attempting to develop thinning regimes and make yield estimates.

When urgency demands, it is customary to assume a rotation based on knowledge from other similarly managed forests on apparently similar sites and to plan the exploitation on this basis until it is possible to obtain the specific data permitting adjustment of the plan. Local people may have had experience that can be used as a first approximation.

One should always bear in mind, however, that the most important consideration is not the growth and rotation of the existing trees, but rather the growth and rotation of trees that will be established after exploitation and that may have very different values from the present ones depending on the treatment applied to the forest stand.

CUTTING CYCLES

When the exploitation of a forest is not carried out through clear cuts, but by selective cuts of the largest trees over two or more stages or periods, the duration of these stages must be calculated. They are so-called cutting cycles that form part of the rotation and that like the rotation are established based on the growth of the trees and the types of products to be extracted in each stage.

In short, a cutting cycle is the time that elapses between two successive cuttings of a given plot or stand. It coincides with the rotation when clearcuts and no thinnings are applied, but it is only a part of it in the case of selective cuts, as when minimum diameter limits for cutting are used. In the particular case of mangroves, there is one particular rotation or cycle for fuelwood, another longer one for posts, and another one for saw-timber, for example, which are carried out successively and whose duration depends fundamentally on the species being used. Such intensive partial cuttings with several cutting cycles on one area require a high degree of supervision and control and are rare.

FRUITING AND SEEDLING BIOLOGY

Other basic information necessary for management planning of mangroves includes fruit production, fruiting periodicity, seedling viability, dispersal distance and method, and ease of establishment of tree species. All of these basic data have tremendous relevance to mangrove silviculture and management. For instance, knowledge of the timing of annual fruiting permits foresters to prepare for collection of mature propagules or seeds, while the dispersal efficiency and establishment behavior sheds light on the number and pattern of mother tree retentions for adequate and uniform natural regeneration.

Techniques developed to prolong the storage capability of propagules (Rabinowitz 1978) would allow planting activities to be carried out for a longer period and not confined to the fruiting season.

In addition, growth and early performance data for newly established seedlings are important for judging whether reforestation will be needed and have a bearing on planting spacing on a commercial scale.

Intermediate Cuttings

PROGRESS OF STAND

Very few systematic studies have been carried out to determine the progress of stands from the time of clearfelling until the end of the rotation cycle. Normally, visual evaluation is carried out after final felling (to determine the regeneration status of the area and whether it requires planting). In the Matang Forest Reserve of Malaysia, it is also conducted before first and second thinnings (to determine roughly the number of poles available for royalty purposes) and at the time of third thinning and at the final felling (to determine the volume or weight of the wood extracted). At the time of the preparation and revision of the working plan, the whole area is inventoried to determine the crops under various diameter and age classes and to finalize the working of the coupes. However, all these data, even if grouped together do not yield reliable information on the progress of the stand.

Recently, a few studies by Srivastava and coworkers and others have given a clearer picture

Table 12. Changes in Stand Characteristics Over Time

Age (years)	*Stems (per ha)*	*Mean Diameter (dbh) (cm)*	*Mean Height (m)*
6	8,371	3.2	6.34
9	4,661	5.5	10.96
12	4,181	6.9	12.62
15[a]	3,236	8.82	12.3–13.4
20[a]	2,107	9.65	16.9–17.1
25[a]	1,321	13.90	17.1–21.0
30	830	17.45	26.30

[a]After thinning
Sources: Tay and Srivastava (1982), Saw (1981).

of the progress of the stand (Table 12). The reliability of the data is limited, however, by the fact that the studies of the different age classes were not conducted on the same plot, though the sampled areas were typical sites and more or less in the same inundation classes.

The conclusion may be drawn that there is large-scale mortality between six and nine years. Moreover, forest managers believe that the number of trees for final felling is too low, hence the elimination of the third thinning at age twenty-five in current working plans.

WEEDING, CLEANING, AND CULLING

Normally, in areas either naturally regenerated or planted, no weeding, cleaning, or culling is carried out. Weeding is, however, recommended in an Indonesian directive from 1978, according to which the young plants have to be tended for two years (Burbridge and Koesoebiono, in press). The competing vegetation, especially *Acrostichum* fern, should be cleared from around the trees.

THINNINGS

Except in Matang, Malaysia, where intermediate thinnings form an important activity in the current clearfelling silvicultural system, nowhere else in the Southeast Asian region are thinnings practiced routinely. In Indonesia, one thinning is prescribed at fifteen years if approximately 1,100 trees with a diameter of 10 cm or more are present on a hectare. It is unknown whether it is currently being practiced. In Fiji, although three thinnings in fifteen-, twenty-, and twenty-five-year-old stands are prescribed at 1-, 1.5-, and 2.4-meter-stick distances, respectively, they are not always carried out.

The question of thinning has been discussed in Matang since Watson's classic work (1928). The main questions, which could never be answered with certainty even today, are timing of thinnings and intensity of thinning. There is no doubt that thinnings have a beneficial effect on diameter growth and on natural regeneration. Several Malaysian studies have clearly shown that the yield was better in plots that had undergone a thinning compared with unthinned plots.

Thinnings are prescribed at fifteen, twenty, and twenty-five years at Matang. In practice, however, thinnings are irregular, incomplete, and selective. This is because thinnings are commercial operations rather than silvicultural operations. The timings of the first two thinnings, when poles are extracted, are dependent upon the market demand. Thus, they may become overdue for a number of years in different coupes. Moreover, due to transportation problems, the interior portions of the coupe generally are not thinned properly; only the areas a few hundred meters along the channels are thinned. Thinnings are also commercially selective; often only trees of the diameter required by the market are extracted. In the current working plan the third thinning has been dropped, but the timings of the first two thinnings have been retained. Further research on timing and intensity of thinnings could lead to alterations in the prevailing practice.

Final Felling

This is the principal cut, made at the end of rotation, and may be performed as a total clearcut or by choosing trees of a certain size to be cut (selection cut). In the former case, unless there is a cover of advanced reproduction the whole forest floor is exposed to the elements (sun, rain, wind, etc.), which may affect it in an adverse way. In the second case, a certain amount of cover and soil protection is maintained as well as an onsite seed supply. Either system is acceptable and has been shown to work under appropriate circumstances.

HARVESTING SYSTEMS IN USE

The clearfelling system is being applied in Peninsular Malaysia. In Matang, a rotation of thirty years is followed, while Klang has a twenty-year rotation, and in Johore a twenty-five-year rotation is prescribed. There are two thinnings in Matang but no thinning in the other two areas.

In Sarawak a minimum-diameter system is followed with exploitation of all the trees down to 23 cm. Sarawak has a twenty-year final cutting cycle. In most of the areas, natural regeneration is poor, and intensive trials are underway to regenerate the exploited areas artificially.

In Sabah, traditional exploitation for charcoal was on a diameter limit of 20.5 cm, while firewood and fishing poles were cut to 10.2 cm. In the larger coupes of 2,000–4,000 ha for wood chipping, a diameter limit of 10.2 cm is used, providing that 100 seed trees per ha are left. In addition, an uncut strip 10 m wide is retained along coasts, estuaries, and waterways.

In Vietnam, charcoal production forests have a diameter limit of 4 cm on a twenty-year rotation with a minimum of thirty to forty seed trees per ha.

In Bangladesh's Sunderbans, minimum diameter limits are prescribed for all commercial species, varying between 11.8 cm and 56.3 cm in a selection system.

In many parts of Indonesia, the community government (Marga) controls mangrove use and prescribes kind and amount of felling. Good natural regeneration has been obtained when sixty-four seed trees per ha over 45 cm in girth were left. Current large concessions not controlled by Marga generally require felling of trees down to 7 cm in 50-m-wide strips interspaced with 20-m undisturbed strips on a proposed twenty-year rotation.

In Thailand and Venezuela, a strip clearfelling system has been found to allow adequate natural regeneration (see Figure 15). The strips, varying in width from 20–50 meters may be at right angles or at 45 degrees (in Thailand) to the waterways. Also in Thailand, some seed trees are left in the logged-over strips. Thailand is also instituting an uncut 10-m strip along the edge of waterways.

SIZE OF AREA FELLED AND REGENERATED

The size of the annual coupe varies in majority of the cases with the rotation age of the forest. Determination of rotation age has been discussed earlier in this chapter. In the theory, for

Figure 15. Clearfelling in strips 50 m wide and 300 m deep in the Guarapiche Forest Reserve, Venezuela.

sustainability, the annual coupe is 1/Rth of the area under management (where R = number of years in the rotation). In Matang, the size of the annual coupe for charcoal and firewood during 1977–1981 was around 1,010 ha, spread out in a mosaic of a few hectares in each patch. In Sarawak, in areas leased to a chipping company, approximately 607 ha are harvested annually with a block size of 200-by-300 m. The average annual cut in Sabah in areas leased to a wood chipping company is more than 3,000 ha in large clearcut blocks. Even with the most optimistic rotation age it is difficult to see how such large cuts can be sustained. Due to seasonal access difficulty, the annual coupe is split up and harvested at several localities simultaneously; there are thirty separate contractors with the company. In Klang, Malaysia, the annual coupe may vary from 250 to 500 ha. In Indonesia, in one area, a maximum of 1,000 ha is allotted to be harvested annually (but with seed trees left). In one of the projects in East Venezuela, the annual cut is 187 ha, which is split into alternate strip plots of 50-by-300 m perpendicular to the streams and channels.

As previously mentioned, in many cases irrespective of the size of the annual coupe and the silvicultural system, natural regeneration after the final cut is poor. No information is available from Indonesia, but the emphasis on "seed trees" and planting indicates that there are problems with natural regeneration.

The size of the annual coupe and the strict adherence to the prescriptions of the recommended silvicultural system in a particular area are strongly influenced by the products or end-uses of the mangrove wood. A few examples from Malaysia will illustrate the point.

1. It has been commonly observed in Matang that the thinnings, particularly the first thinning, are not carried out as silvicultural prescriptions due to the following reasons:
    - During thinning, no new canals are permitted, hence there are problems of transporting the poles from the inner areas that cannot be reached by boats. It has to be done manually, which becomes a costly and time-consuming operation. In practice, therefore, thinning is confined only to the narrow strips along the streams, and the still usable remnants of previous canals; the inner areas are allowed to remain overcrowded.
    - Poles in first thinning are chosen on the basis of market demand. When a stand is ready for thinning 1, the stems have a dbh range of 3–12 cm; however, due to small demand for lower diameter class, only poles above 8 cm dbh are extracted. This results in a larger proportion of trees of smaller diameter being left. Thus, thinning becomes a highly selective operation, resulting in either overthinning or underthinning (Tay and Srivastava 1982).
    - Generally, thinnings are staggered according to the market demand and may become overdue from a silvicultural standpoint (Srivastava and Singh, in press).
2. Even for the areas marked for harvesting to feed the charcoal kilns, logging is carried out at a slow pace according to the requirements of the kilns.
3. The most conspicuous influence of the product is visible in areas leased to chipping companies where in order to feed the factory continuously, harvesting is done on a large area and at a fast rate. This poses serious problems of regenerating the logged over forests adequately.

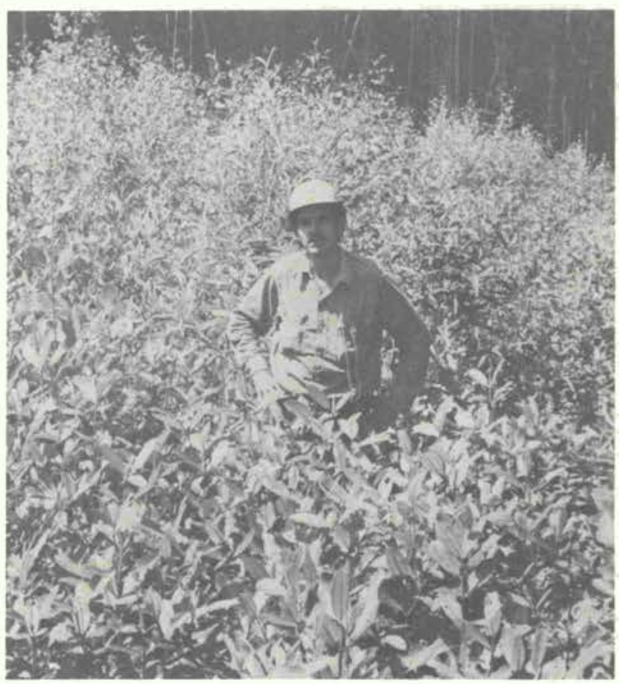

Figure 16. Prompt and adequate natural regeneration is a key component of low-cost, sustained-yield management for wood production.

Natural Regeneration

An important principle of sustained yield management of any forest type is ensuring that an adequate resource of advance growth natural regeneration survives harvesting operations at the end of a rotation so that an equally or even more productive successive rotation may develop (Figure 16).

Encouraging advanced reproduction by thinnings and then minimizing damage to it in final harvest is the surest way to regenerate the next crop at least cost. In its early ages, this regeneration is capable of recovering from damage by sprouting from dormant buds and by bending itself upward to form erect stems from those bent over or pinned down by an obstruction (Dixon 1959 and pers. com. 1983). Recruitment by casual waterborne propagules or seed may supplement this, but it is not usually the main source of regeneration. Dixon (pers. com. 1983) feels strongly that this is the case, and states further for *Rhizophora*:

> One needs little imagination, even after briefly studying the shape and deportment in the water of these propagules, to conclude that they most likely evolved on lines which allowed them to spear firmly into the mud and, for greater security, within the radial ambit of aerial root spread where they are protected from tidal current and buffeting flotsam. Indeed the otherwise chances of a floating propagule coming to undisturbed repose long enough to attain secure root anchorage on a blank, sun-baked space, before the expiry of its vigour are rather remote. However, where some submerged slash exists there is the chance that a floating propagule may be halted and lowered down within to establish a firm hold. One can find sporadic evidence of this phenomenon without too much effort. Another, but more remote, chance of survival occurs when a propagule is deposited at the extreme range of the tide during the regressive period of its lunar cycle and can thus lie undisturbed for an extended period—and provided of course that soil and moisture conditions are not too inhibiting.
>
> The above principles and conclusions stem largely from observation and experience covering several parts of the world and, regrettably, still await conclusive evidence based on formally conducted research. However, they are accepted in the meantime for want of better knowledge.

At least some supporting evidence comes from Malaysia's Matang Reserve where Srivastava and Daud (1978) reported that there was almost no addition to the natural regeneration in the form of new recruitment during the two years after felling. The crop of established seedlings, they found, was the one that had survived the effects of the final felling. Other recent works (Liew et al. 1975, Srivastava and Sani 1979, Srivastava et al. 1980) have shown an adequacy of advanced reproduction prior to logging and its decline after logging to levels often considered inadequate without artificial planting. Table 13 presents some results from various Malaysian studies on the average number of seedlings per hectare associated with various times of cutting.

Various silvicultural systems have been applied in different countries in the management of mangrove forests to obtain adequate natural regeneration. Malaysia's Matang Mangrove Reserve, with the longest history of systematic management of mangrove forests, provides a good example where many theories "have been proposed, adopted, amended and discarded, sometimes to be revived and again discarded" (Noakes 1952), mainly to obtain natural regeneration over larger parts of the annual coupe so that artificial planting does not become a routine practice. Dixon (pers. com. 1983) feels strongly that the lack of adequate regeneration results not from the specifications of the silvicultural system, but in administrative failure to control damage to the site and postharvest unauthorized reworking of the area. However, it is the general experience in all the mangrove growing areas in South Asia and Southeast Asia that regardless of the system applied, some planting is generally required (see Figure 17). Venezuela and perhaps some other areas of the world appear not to have this experience.

Species that are favored in management of mangrove areas of Southeast Asia are *Rhizophora apiculata* and *R. mucronata*. In other areas such as the Americas, *R. mangle*, *Heritiera*, and even *Avicennia* are utilized commercially. Nature assists in regeneration through such devices as profuse regular annual flowering, viviparous habit, and seed dispersal through water.

The problem of natural regeneration needs attention because of its failure in some areas. For instance, currently more than 50 percent of the annual coupe in Matang is replanted. In Sarawak, it was observed in 1974 that less than 10 percent of the Rejang Delta exploited area showed successful natural regeneration (Chai and Lai, in press). Inadequate natural regeneration has also been reported from Sabah, Indonesia, Burma, and Thailand. This is in part be-

Table 13. Average Number of Seedlings per Hectare Associated with Different Cutting Times

Site or crop condition	Rhizophora *(seedlings/ha)*	B. parviflora *(seedlings/ha)*	*Source*
Six months before final felling	18,563	8,215	Srivastava and Sani (1979). (Matang Mangrove Reserve)
Six months after final felling	8,579	1,205	Srivastava and Sani (1979). (Matang Mangrove Reserve)
Twelve months after final felling	9,145	3,164	Srivastava and Khamis (1978). (Matang Mangrove Reserve)
Twenty-four months after final felling	8,342	150	Srivastava and Khamis (1978). (Matang Mangrove Reserve)
After second thinning	26,510	4,226	Srivastava and Singh (in press). (Matang Mangrove Reserve)
After third thinning	18,977	1,110	Srivastava and Singh (in press). (Matang Mangrove Reserve)
After second and third thinning in *Acrostichum* infested area	6,066	2,630	Srivastava and Singh (in press). (Matang Mangrove Reserve)
Clearfelled *Acrostichum* infested area	1,777	222	Gan (1982). (Matang Mangrove Reserve)
Clear-felled *Acrostichum* infested area	444	0	Gan (1982). (Matang Mangrove Reserve)
One year after final felling	249	667	Roland (1980). (Rejang Mangrove Reserve, Sarawak)
Three years after final felling	333	447	Roland (1980). (Rejang Mangrove Reserve, Sarawak)
Six years after final felling	2,201	442	Roland (1980). (Rejang Mangrove Reserve, Sarawak)
Nine years after final felling	167	4,159	Roland (1980). (Rejang Mangrove Reserve, Sarawak)
Two months after logging in *Bruguiera* forest type	6,148		Liew et al. (1975). (Sabah)
Three months after logging in *Rhizophora* type	8,699		Liew et al. (1975). (Sabah)
Mature *R. apiculata*	*R. apiculata* seedlings only 25,327		Aaron (1983). (Rejang Mangrove Reserve, Sarawak)

Figure 17. Lack of advanced reproduction and failure of subsequent colonization following harvest mandate a planting effort to keep this area productive of wood. The light invasion of *Acrostichum* fern can be controlled at the time of planting.

cause of a desire for a high percentage of the two *Rhizophora* species in these countries.

In Venezuela, the Philippines, and Bangladesh, regeneration of seedlings of desired species is normally adequate in areas under management. This may be in part a reflection of a greater willingness to accept the species array that does naturally regenerate in the various zones, in part a limitation on the size of the coupe, or adequate control over the contractors (see Figure 18).

SITE CONDITIONS FOR REGENERATION

In mangrove environments, site conditions play an important role in determining the mix of species. The most important site conditions influencing the regeneration and the ecological succession gradient are the nature of substrate, age of swamp, inundation class, water salinity, and erosive and accressive action of the sea. To these might be added the presence or absence of canals, streams, and rivers. During the pioneer stages, some of these factors play a much larger part than others in determining the floristic composition and rate of succession.

Figure 18. A successful naturally regenerated stand following harvest by alternate strip clearcutting at right angles to channel.

Recent large-scale exploitation by logging and allied activities may further disturb or completely alter the site conditions. Under such conditions, it may take from three to seven years for the annual coupe to be regenerated naturally. It is in these situations that the problem of deficient natural regeneration (e.g., in Thailand) is now of great concern, particularly when it involves economically important species. Extraction methods must minimize damage to advanced reproduction. If adverse effects of these factors can minimized, natural regeneration probably can be obtained over large areas, and large-scale planting can be avoided.

Several site factors are of particular importance to the success of natural regeneration. There are harvesting debris (slash), damage to the site from wood extraction, invasion by *Acrostichum* fern, takeover by species of less or no commercial value, changes in the inundation regime due to lobster mounds, invasion by the strangling shrub *Derris uliginosa*, changes in frequency of tidal inundation, and damage to seedlings by crabs.

Slash. During harvesting in other parts of Southeast Asia typically only the large wood is removed; the branches, leaves, prop roots, and stumps are left on the site. In certain localities where on-site debarking of the billets occurs, bark is also left in the area to decompose. This harvesting debris is called slash. Even walking is difficult due to huge quantities of slash immediately after logging. According to Watson (1928), Landon (1933), Noakes (1951, 1952), and Phillipps (in press), thick deposits of slash act as a barrier to the dispersal of mangrove propagules and may be one of the most important causes of blanks in clearfelled areas. Moreover, undecomposed or partially decomposed slash may destroy seedlings by its movement in deep-flooding mangrove areas. There is very little progress in height growth or density of seedlings under the slash until the major part of the slash is decomposed, according to Srivastava and Daud (1978) (see Figure 19). However, Ong (pers. com. 1983) and Dixon (pers. com. 1983) both question the evidence that slash impedes or damages reproduction based on their experience in Malaysia. Research on the extent of slash damage is apparently needed.

Figure 19. Inadequate natural regeneration in logging slash requires that artificial planting be carried out.

In areas where there is a high local demand for fuelwood and homemade charcoal (as in many areas of the Philippines), there is no major slash problem. Even stumps and prop roots are used for fuel, while dead wood is utilized for driftwood crafts and as orchid stands.

Where the nature of the operations is such that managers feel that slash is a problem, the obvious answer is to reduce the quantity produced in the harvesting. In Matang Reserve in Malaysia one of the reasons given for reducing the rotation from forty to thirty years was the reduction in quantity of slash produced. Approximately thirty years apart, Noakes (1951) and Phillipps (in press) both called for closer supervision of contractors to ensure that they removed all useable wood from the coupe as a slash-reduction measure. Another alternative would be to have it finely cut (lopped) and scattered over the cleared area.

The disposal of slash must be decided on a site-specific basis because there is no general rule that covers all situations. The presence of slash left on site can, depending on the circumstances, promote or restrict subsequent regeneration. When relatively large blocks are felled in areas of no pre-existing regeneration, care must be taken to prevent the slash from becoming a barrier to the on-site dispersal of propagules brought in by tides and currents from distant seed sources. In contrast, slash dispersed over a barren site assists in the trapping of propagules and permits their establishment. When

Figure 20. Abundant natural regeneration in spite of fairly dense slash.

an adequate population of seedlings and saplings exists at the time of harvesting, the disposal of slash is an inconsequential issue (see Figure 20). In areas where the weed palm *Phoenix paludosa* is a management problem dried slash may be used as fuel to assist in burning and eradicating the palm.

Figure 21. Heavy *Acrostichum* fern infestation in Malaysian mangrove area.

Wood Extraction Site Damage. In some places, artificial canals are dug so that boats may enter to remove the wood. These are usually dug at right angles to the natural waterway and are often about 200 m apart. Earth is thrown up to form banks that may impede both water movement over the surface and the entry of waterborne propagules and seeds into the felled area. These banks must be broached frequently or else made so that the earth is piled in short distances alternately on each bank. Paths may be cleared and even planked so that products may be hand carried or moved in wheeled carts to the water. If serious compaction occurs here, subsequent regeneration may be inhibited. Where stems are winched out to a barge site, continual ground dragging on one track can gouge a deep channel that does not easily regenerate. On the other hand, dragging material over the entire area (instead of a few channels) can damage much advanced regeneration.

Acrostichum *species invasion.* Another conspicuous feature of felled areas that has important bearing on natural regeneration of economic species is the invasion by the *Acrostichum* fern. This fern occurs throughout the whole range of *Rhizophora* forests of Southeast Asia, particularly in drier areas (higher inundation classes) and on prawn heaps and lobster mounds. It also occurs in South America but does not seem to be as severe a problem. It has two species, *A. speciosum* and *A. aureum*. The fern may occur as a small and tufted groundcover under the canopy. With the opening of the canopy, it forms tall (4 m), dense, and continuous thickets, with each plant developing into a large clump. This makes it almost impossible for waterborne seeds to enter the area. Large areas have been rendered unproductive due to invasion of *Acrostichum* in a former *Rhizophora* zone.

Recent studies in Malaysia by Srivastava and Sani (1979), Srivastava and Singh (in press), and Roland (1980) have confirmed the poor regeneration status in *Acrostichum*-dominated areas (see Figure 21). Gan (1982) concluded that (1) irrespective of the *Acrostichum* species, whenever the infestation is over 60 percent of area, regeneration of economic species is invariably inadequate; (2) the most important factor influencing the occurrence and distribution of *Acrostichum* is the frequency of inundation, followed by the logging method (especially drainage effects) and the presence of crabs and prawns; (3) the main sources of natural regeneration in a clearfelled, *Acrostichum*-infested area, in order of importance, are the seedlings from standards, recovery of partially damaged seedlings due to coppicing, and waterborne propagules; and (4) the best method of obtaining natural regeneration in areas prone to *Acrostichum* invasion is to retain standards. One effect of the third thinning in the Matang forests was the stimulation of seedling regeneration, thus giving them a head start on the fern after final clearfelling.

Noakes (1951) suggested immediate planting of areas prone to invasion after logging, although this appears to be impractical because of slash. Srivastava (1980) suggested that studies were needed on site conditions that favor growth of *Acrostichum*, dispersal of seeds and progress of regeneration of seeds in infested areas after logging, minimum number of seedbearers to be retained on such sites, and economically viable effective control measures.

Currently in Matang such areas with poor or no regeneration are being planted with *Rhizophora apiculata* after eradication of *Acrostichum*. Two methods of control are being tried, namely: (1) manually uprooting the fern using a 1.5-m-long wedge iron bar, costing about M$482–1,568 per hectare (20 worker-days) depending upon the intensity of *Acrostichum*, and (2) spraying with the weedicide Velpar 90, costing around M$494 to 988 per hectare. The second method is still in the experimental stage, and the cumulative effects of the weedicide are not yet known. The extent of the fern problem seems to be closely linked to the inundation class. Managers should consider the fact that changed drainage and sedimentation are gradually altering both water-salinity relations and relief. Natural succession may be changing the composition on a site to where it becomes increasingly difficult to maintain a given commercial species. Managers may face reduced amounts of advanced-growth *Rhizophora* and well-established fern understory on such sites, and it is a difficult problem to secure *Rhizophora* regeneration. Dixon (pers. com. 1983) suggests that at some point it becomes unfeasible to attempt standard management for wood, and that such sites might be classified by inundation criteria and be preserved as a seed supply and nature reserve.

Takeover by Uneconomic Tree Species. Another factor inhibiting natural regeneration of more valuable *Rhizophora* spp. is the preponderance of less desirable tree species in logged-over areas. Large areas of potential *Rhizophora* stands in Matang have been classified as unproductive because of the dominance of *Bruguiera parviflora* (Dixon 1959, Mahmud 1969), a species not preferred by contractors for conversion to charcoal. The main reason for the increase of this species is the ease in dispersal of its comparatively smaller seeds by water currents even in semidecomposed litter—similar to *Laguncularia* in Venezuelan mangroves. Under clearfelled conditions when a site is exposed to full light, *B. parviflora* flowers, fruits, and colonizes rapidly. The only control measure is to instruct the contractors to destroy the seed trees of this species during thinnings and at the time of final felling. Even then it is common to see dense patches of this species in the young crops of *Rhizophora*, particularly along the canals. In case the spread of this species cannot be controlled, its use on a large scale for wood chips may be considered. This is being done in Sabah and Sarawak.

In many mangrove forests in Southeast Asia, *B. gymnorhiza* represents the last stage on the successional gradient. It can tolerate more shade than *Rhizophora* spp., and whenever this species finds a foothold in *Rhizophora* stands, it effectively inhibits natural regeneration of the more valuable genus.

It must be recognized that different ecological zones tend to be dominated by different species and that one option is to develop uses and markets for the so-called "less desirable species." For example, *Excoecaria* and *Heretiera* are used in Bangladesh as commercial woods.

Lobster Mounds. According to Chai and Lai (in press) mounds built up by the lobster *Thalassina anomala* in felled areas in Sarawak changed the inundation regime. This resulted in poor regeneration of *Rhizophora*. These mounds on silty clay soils were 0.3 to 1.5 m high. A survey in Rejang Mangrove in Sarawak found an average of 442 mounds in a 100-m² area. Other mangrove tree species do grow on these mound-dominated areas, however (Ong, pers. com. 1983).

Derris uliginosa. This strangling shrub, wherever it is dominant, causes much harm to the advanced regeneration and even to poles through its smothering action (Saw 1981). If it is a serious problem *Derris* should be controlled in the weeding process.

Frequency of Tidal Inundation. Tidal inundation is important not only in maintaining a constantly soft and favorable substrate for seedling establishment, but it is also an effective way to disperse seeds and propagules. Dixon (1959) has questioned the part played by waterborne propagules in regenerating the felled areas in Malaysia. According to him, few would survive, particularly those stranded on relatively exposed sites where in addition to other disadvantages, their horizontal position would render them more susceptible to dehydration by heat. In fact, sudden climatic exposure sometimes results in high mortality (Liew et al. 1975). No quantitative study has been reported on the role of water in regenerating the felled areas. Aksornkoae (1981) recently showed in Thailand that regeneration of *Rhizophora, Bruguiera,* and *Avicennia* was most abundant at the edge of the estuary and decreased inland, whereas the reverse was true for *Xylocarpus, Ceriops,* and *Lumnitzera*, reflecting the normal zonation of these species.

Crabs. In Malaysia, Thailand, and Indonesia, crabs have destroyed *Rhizophora* seedlings, particularly of planted ones, by eating the bark above the collar. It is estimated in Klang, Malaysia, that almost 25 percent of the planted seedlings are destroyed by crabs (Soo 1979), though Ong (pers. com. 1983) has pointed out that these mangroves are highly disturbed by humans and thus not typical. Crab damage may be fostered by a shortage of normal food supply.

SEEDS AND PROPAGULES: THEIR INFLUENCE ON TIMING OF HARVEST

In the unfelled areas, the main sources of seeds and propagules are the standing trees. The reproductive ability of *Rhizophora* and many other species is high. Annual fruiting begins at about four years of age, but the amount of seed varies considerably from year to year. Trees along the canals and streams fruit more heavily than those farther inland. In Southeast Asia, there are no attempts to coincide the felling with fruiting season. In Venezuela, it is recommended to coincide the felling operations with fruiting season of important *Rhizophora* spp. Logging in mangrove areas, particularly final felling, is controlled by demands of the market. Where advanced growth is present, coinciding the felling with fruiting season is not necessary. In logged areas, new (not advanced) regeneration occurs three ways, from tidal currents bringing in seeds or propagules from adjacent uncut areas, from seeds or propagules from standards, and from coppicing of stumps (in some species) or broken seedlings on the cutover area. The respective roles of these three regeneration methods has been discussed by Noakes (1951), Dixon (1959), Srivastava (1980), and Gan (1982). A listing of some mangrove species and their ability to coppice is given in the section on Restoration and Establishment.

A quantitative basis for the part played by these three sources for regenerative materials under a variety of situations has not yet been established. The consensus gaining ground, however, is that under most of the situations where no adequate advanced growth is present, standards are most effective in regenerating the logged area. The questions related to the standards (e.g., number, age, pattern of distribution for varying situations) have yet to be worked out. In practice, a wide variation is seen in number and pattern of standards in different mangrove areas. For instance, in Sarawak, twelve trees per hectare are left. The latest regulations in Indonesia recommended forty trees per hectare. In Sabah, fifteen trees per hectare are retained. In Matang, Malaysia, in areas prone to *Acrostichum aureum* invasion, seven trees per hectare are retained as a group in a corner or center of each coupe. In the Philippines, eighteen to twenty seed trees per hectare are left to regenerate the area.

In some areas (Sarawak, Thailand, Indonesia, Venezuela) an alternating strip clearfelling system is being tried to encourage natural regeneration, with the strips approximately 40–50 m wide, and as much as 300 m in depth.

Natural Regeneration vs Planting

Seed production of mangroves is generally abundant, and normally there should be no problems with the natural regeneration of exploited areas provided that sufficient numbers of existing seedlings or new ones survive the consequences of harvesting. Some of the problems have been discussed previously. Special situations exist in which one cannot totally rely on natural regeneration, either because it does not occur or because the regeneration occurring is insufficient or unsatisfactory for the desired result. These include cases in which species of lower value dominate the composition of the regenerated area, or when regeneration is not sufficiently abundant. Planting in an area occupied earlier by the natural forest is a confession of a failure to lead nature to regenerate the area free of cost.

In Malaysian mangrove forests in the past

Table 14. Planting Data for Malaysia's Matang Reserve

Year	*Area Planted (including refilling in ha)*	*Cost of Planting (Malaysian $)*	*Percent Planting of Total Area*
1977	495	22,116	48
1978	757	54,407	74
1979	784	28,753	76
1980	840	24,414	82
1981	822	67,617	80

Source: Perak State Forestry Department (Hassan 1981).
Note: Annual coupe of charcoal and fuelwood = approx. 1,010 ha.

when the area of the annual coupe was not large, regeneration was not the problem. It was generally observed that 75 percent of the coupe was regenerated naturally within three to seven years after felling (Noakes 1952). The situation has changed in some areas because the area of exploitation has increased for the supply of fuel wood, wood chips, poles, and charcoal. Large wood chip concessions in particular have resulted in clearcutting on an unsustainable basis in such places as Sarawak, Sabah, and Indonesia. This has resulted in an increased need for planting the understocked and deficient areas. All commercially exploited areas have strong planting programs due to failure of natural regeneration, though this has not solved the problem of overcutting the growth capacity. The preferred species for planting are *R. apiculata* and *R. mucronata*, depending on the inundation class appropriate to the respective species. In some areas *B. parviflora* has also been used. In Burma *B. gymnorhiza*, in addition to *R. mucronata*, has been tried.

During 1977–1981, more than 75 percent of the annual coupe in Malaysia's Matang Reserve needed planting. Table 14 indicates the current magnitude of planting in this well-known area of mangrove management.

Planting of inadequately regenerated areas in Southeast Asia is carried out from June to December, which coincides with the fruiting of *Rhizophora* species. After the area has been inspected by the field staff (normally one to two years after felling), small blanks are marked for refilling while the larger inadequately regenerated areas are marked for planting.

Planting

AVAILABILITY AND COLLECTION OF SEEDS AND PLANTS

There is rarely a problem obtaining seeds or propagules in most mangrove forests. They can be found on the soil and in the water, and this does not appear to seriously affect their viability and capacity to germinate. Nevertheless, there exist indications for *R. mangle* that viability is variable and that the floating angle of the *Rhizophora* propagules can be used as an indication of seeded viability (Banus and Kolehmainen 1975). *Rhizophora* propagules are large and visible and thus easily collected; they can be collected from the trees using boats, selecting only those propagules easily detached from the tree. Animals do not appear to cause serious damage (to seeds) in mangrove forests.

Rhizophora starts flowering early (at four years) and continues to flower regularly. The trees along streams and channels produce more heavily than others. In recent years, however, in Matang, Malaysia, there has been some problem getting adequate amounts of good quality seed. Consequently, a seed stand of *R. apiculata* has been developed to ensure supply. Propagules are procured by contracting with the local people who collect them from the streams or shake them from trees along the stream.

In recent years, due to an irregular supply of seeds, attempts have been made in some localities in the Philippines to raise nursery stock. Propagule planting success may range from 10 to 70 percent. *Rhizophora* seedlings have been grown in pots and transplanted with survival rates of 80 percent. Propagules have been stored in dry rooms for up to two months without loss of viability.

Propagules of other species may also be collected and used to produce plants for reforestation. Because of their ease of handling, species of *Bruguiera, Ceriops,* and *Kandelia* lend themselves to this.

SITE PREPARATION

Normally nothing is done to prepare the site for planting, which is carried out two years after felling when most of the slash has decomposed. If logging has left excessive slash, however, it may be advisable to eliminate or reduce it first to create space for the new plants and to facilitate access for later operations. In recent years, some attempts have been made to lop and heap the slash in rows perpendicular to the waterways to encourage access of waterborne seedlings from farther inland. The inflow and outflow of tidal water also create the salinity and substrate conditions for proper growth of planted seedlings. In Indonesia, directives are given for clearing the site before planting. Areas invaded by *Acrostichum aureum, A. speciosum*, or *B. parviflora* are cleared of these species before planting with *Rhizophora*.

PLANTING METHOD

The planting operation is simple and can be carried out by even untrained laborers with brief instructions. The soft, moist soil facilitates the propagule placement and plantlet rooting. A crew, each with a small sack of propagules (or occasionally seedlings) on his or her hip, starts in a predetermined line. As they walk, they stick one propagule after another into the soft mud at their feet, at a specified distance (Figure 22). The operation is easy and rapid. The areas are inspected generally a year after planting to assess the need for refilling (see Figure 23).

SPACING ARRANGEMENTS: PURE VS MIXED

Wherever planting must be done in Southeast Asia, a pure plantation of *Rhizophora* spp. is established. Mixed plantations in mangroves are rare or nonexistent. *R. mucronata* is planted along the channels in the softer mud while the rest of the area behind a few rows of *R. mucronata* is covered with *R. apiculata*, the former at a spacing of 1.8-by-1.8 m and the latter at 1.2-by-1.2 m. In Sarawak both the species have been planted at 1.5-by-1.5 m. In Thailand a common spacing is 1-by-1 m. In the Philippines spacing of 1-by-1 m and 2-by-2 m are used.

SUBSEQUENT CARE

Once planted, mangrove seedlings need little or no tending. Even the postplanting weeding of *Acrostichum* is rarely needed, especially if its eradication has been thorough before planting. Mangrove environments are so exacting that very few species can compete with planted *Rhizophora* seedlings if they have been planted in suitable sites. It may be worthwhile, however, to weed out undesirable tree species and *Acrostichum* during the first two years after planting in any refilled areas. It is interesting to note that weeding has been recommended in the Indonesian directive on mangrove management (Burbridge and Koesoebiono, in press).

SUCCESS OF PLANTING

In Peninsular Malaysia *Rhizophora* planting is successful over most of the area. Only 20–25 percent mortality has been reported, and dead trees are replaced after a year or two or the area

Figure 22. Planting operation in area lacking natural regeneration.

Figure 23. Inspection of planted area to assess need for refilling or replanting.

is left to nature to fill in. This produces a uniform crop for the next cut. Crabs cause damage, which is sometimes serious (Soo 1979). However, Phillipps (in press) in Sabah reported on much less successful experimental plantings. He suggested that crabs might account for 40 percent of the mortality but that dessication and floating slash injury were also involved. *Ceriops tagal* had only a 5-percent survival, *R. apiculata* had a 12-percent rate, and *R. mucronata* had a 17-percent rate. Crab damage and moth larvae attacking lateral and terminal shoots account for injury to 10–20 percent of plantations in the Philippines.

Mortality in *R. apiculata*, *R. mucronata*, and *B. gymorhiza* planted at 1-by-1 m under forest canopy in Thailand from the edge of the estuary to inland during the first year was reported by Aksornkoae (1981) as 81, 18, and 80 percent, respectively. Planting in the open, however, gave respective mortalities of 5, 4, and 9 percent. It is clear that planting under a canopy is not rewarding with possible exception of *R. mucronata*.

Harvesting and Extraction

NEED FOR RATIONAL EXPLOITATION OF MANGROVE FORESTS

There is a strong need to develop proper and efficient logging practices to maximize production and meet the increasing demand for mangrove wood without sacrificing the other functions or services that mangrove ecosystems provide. It is all the more compelling in the particular case of mangrove forests because of their invaluable protective function as a barrier against strong sea winds and tidal currents and their vital food link for marine fauna.

Because of the fragile nature of the ecosystem, the plastic nature of the soil, and the difficulties and irregularities imposed on working disciplines by tidal forces, mangroves do not easily lend themselves to large-scale, capital-intensive harvesting operations. On the other hand, they provide a unique opportunity for local community development and responsibility. Mangrove forests are often fringed by small communities of people who derive a modest existence from the area in the form of food, building materials, and cash exchange items such as fish or wood. Some of these communities have been in place for centuries, and their populations are well accustomed to the unique conditions in mangroves and understand the natural processes that occur there. It would be practically and economically prudent, as well as socially just, to have mangrove management objectives that give high priority to local community involvement in working in, further developing, supervising, and policing the resource and the activities entailed. In many cases, there is wisdom in the suggestion of union between government authorities, industries, and local communities through the establishment of a common "board of control" that can draw technical advice and services from the government professionals when needed.

Damage to the Site from Extraction of Wood

The extraction of products always causes some negative effect on the forest soil unless it is done by special techniques using aerial cables (which is not common today in the logging of mangroves except in Venezuela).

Dragging trees and logs results in damage to advanced growth, removal of surface soil, and compaction of the upper horizons. The skid trails may become deep-flooding areas in which regeneration is delayed. The making and widening of canals may again, as stated earlier, pose the problem of natural regeneration by altering tidal patterns and micro-relief.

No studies have been reported on the physical and chemical changes in mangrove soils due to logging, however, particularly in areas invaded or occupied for shorter or longer durations by nonmangrove species, e.g., *Acrostichum*.

INFLUENCES ON EXPLOITATION AND EXTRACTION METHODS

The mangrove environment places many constraints on harvesting methods and practices. Use of modern equipment for logging and transport is not practical. Though the terrain is flat, it is inaccessible to most conventional means of transport. Small barges often traverse hand-dug canals to extract poles or billets from mangrove areas (Figure 24). Alternatively, light trolleys on wooden rails or small-wheeled carts pushed on wooden planking are used (Figure 25). These primary systems of transport are augmented by shoulder carrying of billets or poles or use of wheelbarrows on planks. These operations are labor intensive and provide substantial permanent local employment when the mangrove management is such that the use is sustainable. In some large-scale operations,

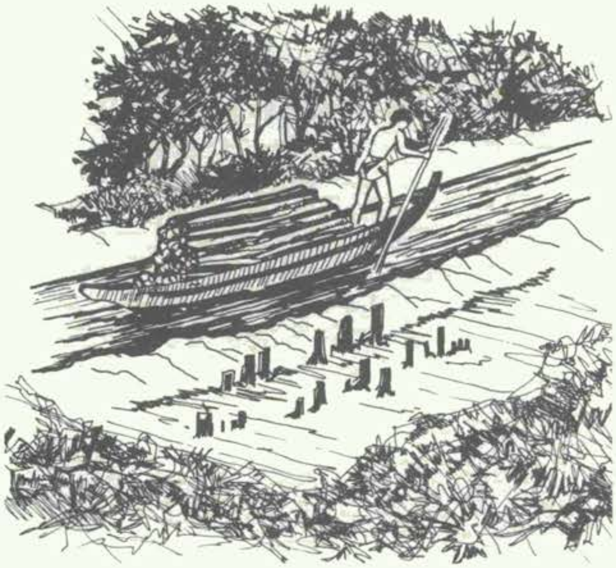

Figure 24. Hand-dug canals are sometimes created to accommodate small boats that transport the wood from the cutting area to the main channel.

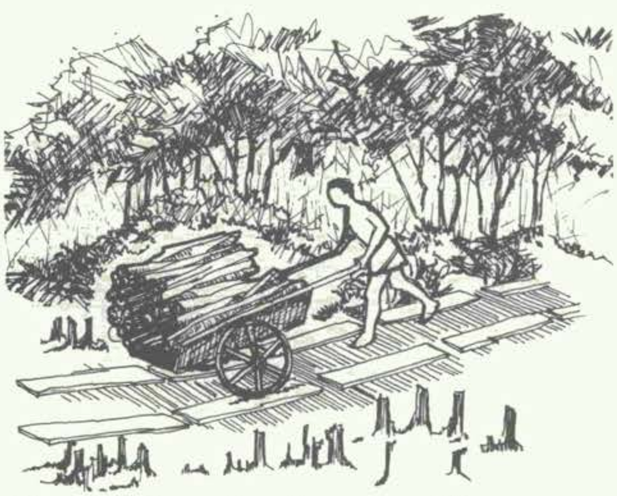

Figure 25. Extraction of mangrove billets on a cart pushed along plank tracks.

barge-mounted winches moored in the stream or river are used to skid stems from the stump to the barge. The potentials for damage to advanced reproduction and for erosion to begin at the barge site are high, and the skidding and loading sites must be selected carefully.

The wood products of most mangrove species are not buoyant and therefore most transportation from the cutting location to the utilization site must be done using barges. In Bangladesh, however, one of the important commercial species, *Excoecaria agallocha*, has naturally buoyant wood, and poles and logs can be rafted long distances.

It is not possible to maintain regular working hours in mangrove operations. Daily working routines are subject to the tidal pattern, which includes diurnal changes, lunar monthly changes, and annual changes. This pattern of tidal peak times and heights restricts daily performance at best, and precludes it entirely for periods of several days at a time during monthly and annual extreme lows.

The marine air and saltwater also cause serious problems of corrosion of equipment and tools that considerably reduce their useful life, with obvious economic consequences.

METHODS OF EXPLOITATION AND EXTRACTION

Felling (Figure 26). The logging operation is usually carried out by a team of four to five workers with a leader who is responsible for ensuring efficient timber extraction in the working area. Tree felling is done systematically and usually starts from the river bank and proceeds inland. For smaller trees, heavy-bladed machetes or axes are used while larger trees are usually felled with chain saws. Trees are normally cut 15 cm above the prop roots and are felled singly or in groups of two or four. Large prop-rooted trees must have their props cut in the felling operation. Group felling is done whenever trees are clustered together.

Bucking. The mangrove timber is cut into the required lengths for its end use. Mangroves for poles are cut roughly into lengths of 6 m, while stems for charcoal or firewood normally are cut

Figure 26. Felling in Guarapiche Forest Reserve, Venezuela.

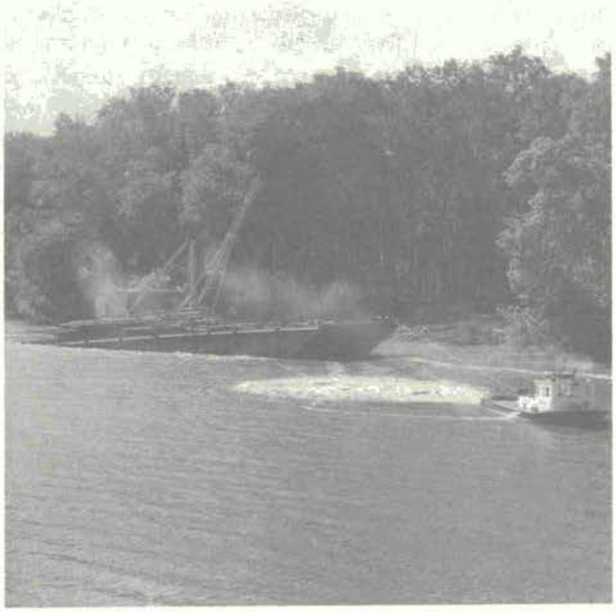

Figure 27. In Venezuela's major commercial mangrove operation a high-lead system using a boom on a floating barge brings stems to the edge of the channel where they are then loaded onto a transportation barge towed by a small tugboat.

into billets of 180 cm length. Length sometimes depends on whether manual or mechanical extraction is used. No bucking occurs when dragline winching is used.

Transportation. Mangrove poles and billets are often carried manually from the felling site to the river bank where they are stacked for transportation. This is tedious and laborious and becomes more taxing as the logging operation progresses farther inland. In Malaysia mangrove billets for charcoal or firewood are transported to the loading site beside the canal, stream, or trolley way using wheelbarrows pushed on plank tracks (see Figure 25). This technique is more efficient than manual transportation because of the weight of the billets.

Canals may be created deep and wide enough to permit passage of a small, shallow draught boat, which is then loaded with wood for transport out to the main channel (see Figure 24).

In Venezuela's San Juan-Guarapiche area, stems and poles are hauled to the stacking site by the river bank by using a high-lead system mounted on a floating barge with two barge settings in each 50-m-wide clearcut strip (see Figure 27). The poles and billets are transferred onto barges and transported to the jetty. Occasionally, small boats are used to transport the timber to the barges, especially when stacking sites are on the banks of shallow creeks. A barge can carry a load of 400 to 450 pieces of poles or 18,000 – 24,000 kg of billets for charcoal or firewood. In Venezuela, long-distance transport to the factory is carried out by floating platforms hauled by tugboats. In Bangladesh, the natural buoyancy of one of their commercial mangrove species permits long-distance rafting of logs.

Improving Mangrove Management for Wood Production

Sustained wood production in mangrove areas may be improved if managers take the following actions:

- Place emphasis on sustained yield, holding the area harvested each year to 1/Rth of the area under a management plan or concession. This is especially important in the large areas currently being allocated for clearfelling for wood chips.
- Carry out thinning on a silvicultural schedule rather than strictly on an end-use demand schedule.
- Retain sufficient numbers of seed trees to reduce reliance on artificial reforestation.
- Design extraction methods to minimize damage to seed trees and to advance regeneration. One example of an attempt at this comes from Venezuela's Orinoco Delta where two barge settings instead of one can be used in each 50-m clearfelled strip.
- Adjust strip width in clearfelling to ensure supplementary adequate regeneration from adjacent uncut areas.
- Retain buffer strips along rivers and waterways to stabilize the banks and protect the natural processes of the inland forests.
- Minimize disturbance of the sediments in logging.
- Attempt to reduce slash size and volume. A large amount of logging slash represents not only an underutilized wood resource, but a damaging agent to regeneration until it has decomposed.
- Conduct further study of *Acrostichum* control because of its severe infestation in some areas.
- Study socioeconomic conflict between local traditional (and sustainable) uses of mangroves and new large-scale commercial operations (particularly for export) in a comprehensive economic analysis frame-work that includes all benefits and costs — direct, indirect, and intangible.

- Give major consideration to the role and involvement of local communities in improving their livelihood and ensuring successful management.
- Give due consideration to the practical ability to actually enforce management prescriptions. So important are these forests that there is wisdom in appointing "Boards of Trustees" comprising all interested parties to ensure that these prescriptions are being adhered to.
- Make necessary arrangements for staff to receive special training in mangrove management and silviculture.
- Make provision either in management plans or separately for program of mangrove and mangrove products research. Such should cover such items as growth and yield of wood, marine fauna production, plant and animal ecology, plant regeneration requirements, timber extraction methods and associated site damage, timber utilization, and seasoning and preservation.
- Governments should take steps to bring all available mangrove resources under protective and/or productive management plans as soon as possible and thus avoid the ever-present danger of ad hoc decisions covering their use. Refer to Section V on National Mangrove Plans.
- Devise management objectives to cover the total ecosystem with the subsequent preparation of composite or integrated plans applicable to prudent management of the total terrestrial and marine resources.

The economic potential of mangrove forests stems from three main sources: forest products, marine products, and tourism. In addition, to one extent or another, mangroves fulfill a foreshore protective role in dampening the action of extremes in wind, wave, and tidal current activity. All of these aspects need to be given due consideration and prominence in prescribing the "objects of management" of any rationally based management plan. Otherwise, grave environmental and economic damage will certainly result. Mangroves must not be summarily regarded as solely forest estate nor their management the peerless jurisdiction of foresters. Fishery interests need to be covered adequately as well by marine biologists and ecologists not only to satisfy the prudence of total resource management but also to help defuse ever-likely dangers of ad hoc political decisions being made in cases where technical background information and management prescriptions are deficient or incomplete.

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SECTION II

CHAPTER 10. Human Habitation

Introduction

Human habitation in mangrove areas ranges from traditional human settlements to large, industrialized cities. The latter often include harbors, airports, recreation centers, power plants, and residential developments. Few studies have focused on this subject, and there is a lack of integrated research that could lead to better planning.

Traditional mangrove dwellers in Malaysia, Indonesia, and Venezuela have been studied by anthropologists. They constitute an essential historical aspect of the sociocultural importance of mangrove ecosystems.

Since the beginning of the twentieth century, all over the world and for countless reasons, great urban centers have attracted manufacturing firms, which in turn entice rural populations to urban areas. Satellite areas near the urban centers are generated by this process, and they commonly increase in size due to central depopulation and, in developing countries, by a high demographic growth that results in excessive unemployment. Although tropical developing countries are mainly agricultural, the uncontrolled growth of their metropolitan centers poses a continuing problem to governments.

Major cities (such as Bombay, Calcutta, Saigon, Jakarta, Manila, and Guayaquil) with extremely high population densities are often located in sheltered coastal areas that offer ease of access, permanent supplies of fresh water, and rich fertile sediments. These also often happen to be the best habitats for mangrove development. In Indonesia, 75 percent of the major cities having more than 100,000 inhabitants are located in coastal areas. Even in small nations such as Fiji, major urban development has taken place along coastal areas—usually mangrove reclaimed areas. To some extent, mangrove swamps are considered as useless barriers, inhibiting the growth of urban centers. The example of mangrove areas of Florida, a region that has undergone great population growth, illustrates most aspects of the diversity of modern impacts of urban development on these ecosystems.

Traditional Aspects of Human Habitation in Mangroves

Traditionally, mangrove ecosystems have played an important role for rural coastal populations in Asia, West Africa, Australia, Pacific and Caribbean islands, and South America. Ethnic groups in these countries live within the mangrove environments, particularly at river mouths, and derive their livelihood from harvesting products, mainly through fishing. In Malaysia, Thailand, and Indonesia the main form of human habitation is in permanent fishing villages varying in size from a few houses built on a platform raised on stilts to several hundred families and houses constructed on stilts made of mangrove poles (*Bruguiera* and *Rhizophora* spp.) (Figure 28). Spectacular instances of these traditional mangrove dwellers are found in south Sumatra at the mouth of the Musi River and in Port Klang, Malaysia.

In tropical Asia, three major categories of permanently settled mangrove fishermen can be identified:

1. Those using small rowing boats catching little with a wide range of rather primitive techniques, mainly passive gears. A substantial source of income is provided by mud crabs *(Scylla serrata)* and by cockles *(Anadara granosa)*.
2. Those using medium-sized boats equipped with seine, drift-gill, or cast nets. This group operates inside mangrove channels as well as in coastal waters near mangrove areas.
3. Those using large trawlers with drag nets operating in deep waters several kilometers off the mangrove shores. They catch large amounts of prawns and fish, which often originate from mangrove communities.

During the rainy season when fishing is often curtailed, the fishermen derive additional income by cutting and extracting timber from the forest either for firewood, charcoal wood, or for poles, which can bring fairly high market prices (Figure 29). Besides the fishermen, there are

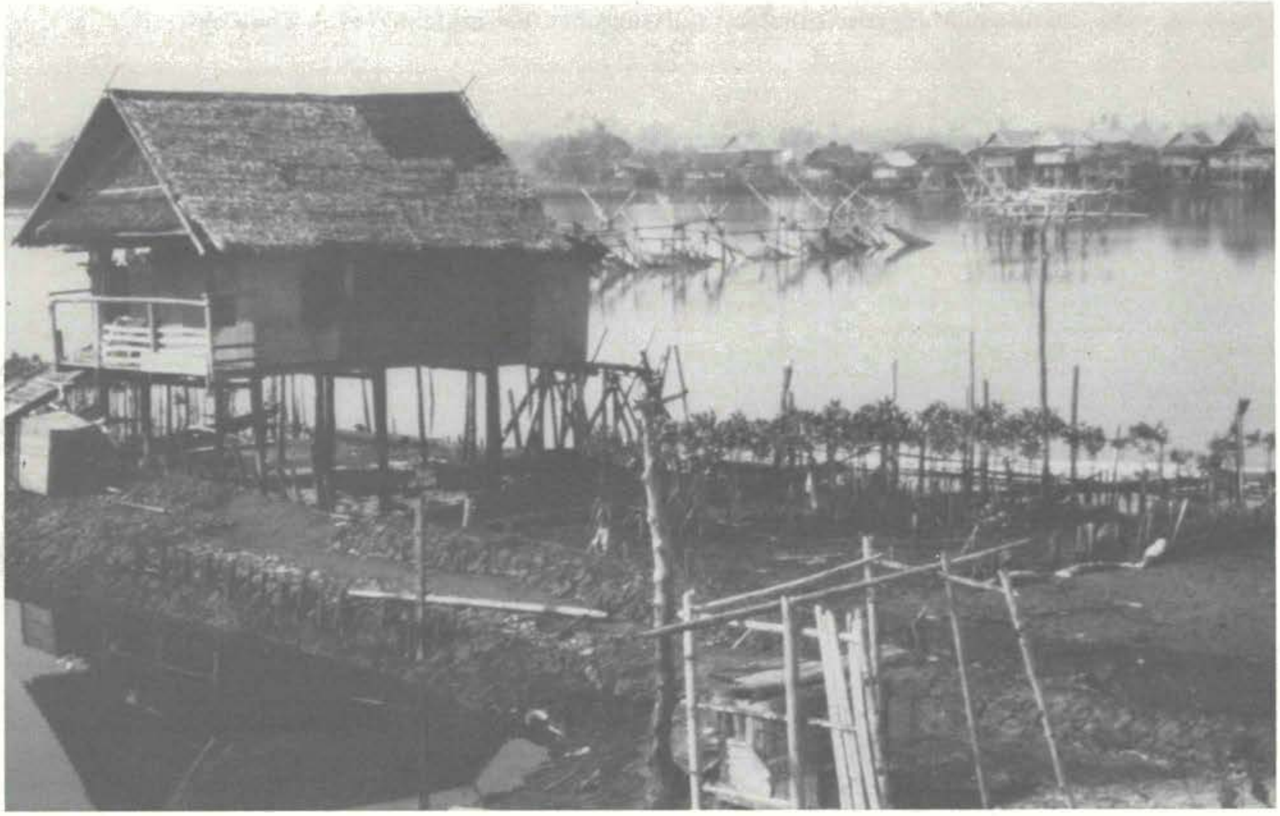

Figure 28. Many small fishing communities are in or in close association with mangrove areas and utilize the many products and services provided by mangroves. Note that one resident has even planted some *Rhizophora* as a "garden."

Figure 29. Charcoal wood cut by local fishermen awaiting pickup for the kilns.

Table 15. Occupation of Mangrove Inhabitants in the Chanthaburi Mangroves, Thailand

Main Income	*Additional Income*	*No. of Households*
Fishing		27
Fishing	Wood Cutting (illicit)	5
Wood cutting	Fishing	4
Wood transport		1
Merchant		1
Merchant	Fishing	2
Merchant	Pond Culture	1
Worker	Wood cutting, fishing	2
Total		43

Source: FAO (1982).

people in tropical Asia whose livelihood depends almost solely on harvesting mangrove forest products such as fuelwood, charcoal wood, fishing stakes, poles, nipa for thatching, and honey. Malaysia and Bangladesh are good examples. An example of a Thai community deriving employment and income from mangroves is given in Table 15.

Many coastal communities are highly dependent on the mangrove environment, and their habitation has minimal detrimental effects on the forest ecosystem. This fishery-forestry utilization is consequently in almost total harmony with the ecological requirements of the mangrove ecosystem.

In some cases, such as Java, the traditional use of mangrove ecosystems takes the form of *multipurpose conversion* as shown in Figure 30. Here, human habitation in mangrove areas has entirely transformed the landscape and the resource, but basic ecological conditions (e.g., free water circulation, sedimentation patterns, coastal protection, nutrient cycling) have been maintained.

Examples of semipermanent mangrove dwellers are found in Australia (especially on the Northern Coast of Arnhem Land and on Cape York Peninsula), Senegal (Sine Saloum Mangroves), Fiji, and Venezuela. In Venezuela, the Guaraunos community has become adapted to mangrove conditions over several thousands of years. Settled in the Orinoco Delta, their most specific behavior is that their villages are located at inner borders of mangrove areas so that they can easily migrate from mangrove swamps to temporarily flooded savannas to meet their nutritional needs during the season of low catches in mangrove areas. In this specific case the Guaraunos (or Guaraos) are depending upon two adjacent ecosystems — mangroves and savannas.

These few examples of traditional human habitation in mangrove areas show the existence of mangrove cultures based mainly on food and fresh water availability. Their survival depends on the sustainability of the ecosystem.

These examples also illustrate the fact that humans can live in a mangrove-dominated coastal environment without destroying the habitat. In developing and developed countries, supposedly sophisticated and educated people destroy and convert the mangrove habitat prior to occupying the coastal area. Possibly, the primary difference resides in the fact that "modern" humans are no longer so closely dependent on the resource base they destroy.

Direct Detrimental Effects of Modern Urban Development

The most spectacular decline of mangroves due to the land scarcity and increased population is provided by Singapore where the ecosystem has decreased in 150 years from 12 percent (73 km^2) of the total land area (616 km^2) to 3 percent in 1978 and an estimated 1 percent in 1980 (FAO/UNEP 1980).

A comparable situation has been recorded in Hong Kong where mangroves are facing rapid destruction; the genera *Rhizophora* and *Avicennia* are already extinct in the territory (Hu 1974).

Bombay, India, is an interesting example because at the beginning of the nineteenth century, before becoming a large industrial center, the town was located on a rather small island (65 km^2) with a population of about 250,000. As the island population began to grow (the population rose to about 4 million in 1961; to about 8 million in 1982), a Greater Bombay Plan was published (in 1948) but a decade elapsed before it was legally enforced, by which time speculative and uncontrolled development had largely exceeded its provisions. As a result, probably more than 1,000 ha of mangrove areas were eliminated to provide space for dormitory sub-

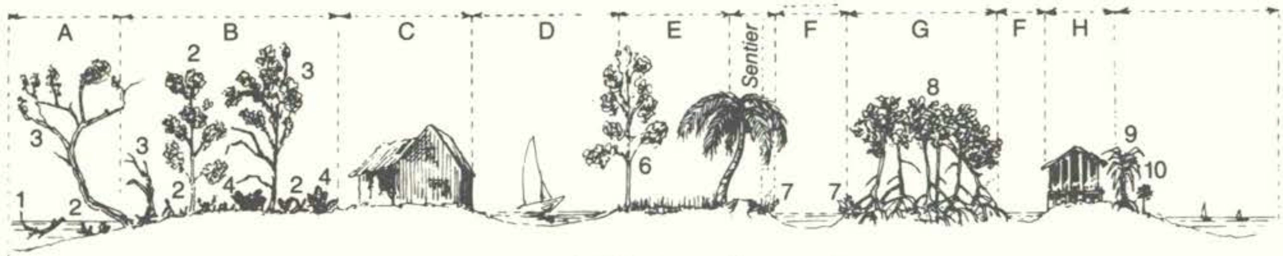

Figure 30. Human interactions with mangroves in Tji Tarum Estuary, Java.

A—Sea of Java, estuarine fisheries, shallow waters, high sedimentation rate. Permanent fishing activity using *bagangs*. This compartment receives inputs from the sea and organic matter from B.

B—Degraded mangrove, firewood, woodwork activity. *Avicennia* are dominant (2) with some *Sonneratia* (3) = *S. alba*?). This formation includes many more species (*Acrostichum aureum* [4]; *Excoecaria agallocha, Acanthus ilicifolius*), retaining alluvial sediments.

C—Village.

D—Principal waterway (brackish water).

E—Agriculture. Rice plantation with cane-sugar and coconut palms. 6 *Sonneratia* (*S. caseolaris* ?).

F—Aquaculture. Drain with banks stabilized by Cyperaceae (7) receiving organic matter produced by G and containing shrimps and fish.

G—Reforestation. *Rhizophora plantation* (8).

H—Sheep rearing, in cages (goats). Mangrove byproducts are utilized as fodder, notably various graminaceae, *Avicennia* (90 = Pandanus, (10) = *Hibiscus tiliaceus*, riverbank species: fresh water or holigohaline water.

urbs, vast worker tenements, and factories (textile, metal industries, chemicals, and pharmaceuticals). In northern Bombay, residences are now appearing on dry areas that bear stunted, overgrazed *Avicennia*. Even Thana and Ghodbunder, which are located about 35 km from the main city, are now congested satellites of Bombay, and beautiful stands of *Sonneratia apetala* are slowly disappearing.

The case of Banjul, Gambia, is entirely different because industries and marinas are almost unknown and population pressure has not yet reached a disproportionate level (about 600,000 for the entire country living on either side of the Gambia River). Nevertheless, the construction of a bund road 3 km long along the southern and the western sides of the town has "trapped" and destroyed more than 200 ha of mangrove forests composed of *Avicennia africana, Rhizophora mangle,* and *Laguncularia*. Being surrounded only by water and by mangroves, the ecosystem is intensively "tapped" for firewood (about 100,000 m^3 in 1980, mainly *Rhizophora*) and oysters and receives all kinds of urban and domestic wastes including solid wastes.

In Fiji, in the Suva Peninsula, more than 80 percent of the mangroves have been reclaimed for urban development.

In many countries harbors are now being constructed or enlarged in mangrove areas. Nizampatnam is a fishing harbor in the Krishna estuary in India; Cotonou in Benin and Chalna in the Sunderbans (Bangladesh) are mainly commercial harbors; and Palembang in Sumatra, Bontang in Kalimantan, Miri in Sarawak, Port Dickson in Peninsular Malaysia, and Maracaibo (Venezuela) have either oil terminals, refineries, or gas plants in mangrove areas. The increasing demand for petroleum products is such that the capacity of most existing plants has to be enlarged. As far as is known, no impact assessments by mangrove specialists have been carried out in these areas.

The widening and deepening of navigation channels up to 15 m deep considerably affect turbidity as well as sedimentation patterns. Dredged fines are spread freely throughout the neighboring ecosystem. No documentation is available on the coastal land loss or the biological consequences of such disturbances. In the Sunderbans Chalna Port, which is now under construction by a Yugoslav firm, has been delayed because of unexpected heavy sedimentation that will create navigation problems in the Passur River. The river links the port to the Bay of Bengal through about 60 km of mangroves bearing the best developed stands of *Heritiera fomes* in the world, and for as yet unknown reasons many trees of this valuable species died in 1982.

In some countries the largest mangrove areas have become the most important ports and terminals for international commerce. In Brazil for instance, such important ports as Santos, Rio de Janeiro, Salvador, Sao Luis, and Parangua are sited within present or former mangrove areas. Urban growth and industrial development are constantly encroaching upon the remaining mangrove areas. In Suape in the state of Pernambuco a large industrial and commercial terminal is being built on a former mangrove area; 1,200 ha of mangroves are contained within the development scheme.

In Malaysia, particularly in the state of Selangor, mangroves have been extensively excised in land reclamation for industries, agriculture, and harbor extension. At Port Klang, about 1,500 ha of mangroves have been reclaimed for harbor extension and industrial projects since 1974.

Indirect Detrimental Effects of Urban Expansion

A comprehensive account of the consequences of coastal development in mangrove areas has been published by the IUCN (Saenger et al. 1983). These causes, linked to urbanization and industrialization, include solid and liquid waste disposal and oil and other hazardous chemical pollution.

Channelization and drainage activities that short-circuit the freshwater input and tidal flushing patterns have both direct and indirect effects (e.g., alteration of local hydroperiodicity, increased salinity). Much of the estuarine habitats of southeastern Queensland, south Florida, and Singapore has been affected by these alterations.

Although few in number, some new data are now emerging regarding thermal pollution. In Asia, this is becoming an important form of indirect impact on mangrove ecosystems because of the construction of power stations in mangrove areas. Most power stations use sea water for cooling. On Trombay Island, in front of Bombay Harbor, are India's first two nuclear reactors. In the Strait of Johore, the Seneko Power Station recycles water that has a temperature of about 35–40°C at the condenser outfall. In the Philippines, a nuclear 620-MW power plant could be constructed at Morong in Bataan.

In Indonesia, electric power production is likely to increase from about 5,000 MW presently to 64,000 MW in the year 2000. According to Soegiarto (1980), "by the year 2000, the annual volume of hot water being discharged from Indonesian nuclear power plants alone will be about $1,000 \times 10^6$ m^3. Almost all of this hot water is expected to be discharged into coastal waters." It has been suggested that as tropical marine organisms live at environmental temperatures close to their thermal limits, the impact of thermal discharges into tropical waters may be greater than in cooler temperate countries. While relevant data are largely lacking, it is clear that site-specific factors are involved. For instance, studies in Florida (Thorhaug et al. 1973) support this assumption, while in Australia this does not appear to be the case (Saenger et al. 1982). Nevertheless, the potential for major disturbances to mangroves and related ecosystems from thermal and other associated impacts from power stations (e.g., scouring, chlorination, screen impingement) is high and requires detailed investigations at each likely power station site.

Several other forms of indirect impacts on mangrove fauna and flora occur, but they are not yet properly assessed. These include wastewater effluents produced by factories, direct dumping of municipal wastes into rivers, pesticide runoff from neighboring agricultural areas, and heavy metals accumulation. In the past few years, there has been a noteworthy increase in public concern, accompanied by a fast-growing scientific interest regarding these problems, particularly along the coasts of the Gulf of Thailand, of the Strait of Malacca, and of the Java Sea.

Unavoidably, oil pollution is increasing in mangrove areas from shipyards, offshore oil wells, collisions involving oil tankers, and washing of tanks in coastal waters. In the Strait of Singapore, fourteen shipping casualties were recorded from January 1975 to November 1976. Little is known about their biological and physical effects, or that of subsequent cleaning operations using dispersants, on mangrove plants and soils, although some data are now available for tropical and subtropical America (Lewis 1983, Jernelov and Linden 1983, Baker 1983).

Conclusions and Guidelines

The increasing land reclamation in mangrove areas for urban purposes has led to a need for specific management systems that include the following elementary guidelines to minimize detrimental effects.

- Every decision taken by coastal developers of housing, by port and harbor authorities, and by sanitation officials must be submitted to trained scientists at the first phase of the project.

- The effects of any interference with the water flow (e.g., roads, construction, fresh water diversion) and with the water properties (e.g., salinity, turbidity, temperature) must be taken into consideration and carefully analyzed at the planning phase of urbanization projects. All necessary steps must be taken in order to maintain a free water and sediments circulation.
- In order to avoid intensive bank erosion as well as in order to partly reconstitute the initial coastal protection against cyclonic storms and surges, the planting of selected mangrove trees could be advised mainly on embankment margins and on most exposed coastlines.
- When residential developments are proposed, priority should be given to those designs that provide for houses on stilts within the forest and that do not require dredging, filling, bulkheading, and the construction of deadend canals.
- Shallow water and the gently sloping littoral zones contribute to high basic productivity, a variety of viable habitats, and a nursery area for the young of gamefish and commercial species. Management should be oriented to protect shallow conditions and the natural slope of the littoral zone if high productivity and fishery resources are to be sustained.
- Mangrove areas seem to invite both individuals and local governments to use them for solid waste disposal. Many otherwise attractive mangrove forests close to the centers of important cities have been rendered unsightly by their use as garbage dumps. A prime requirement is to prevent solid waste disposal in mangroves by regulations and enforcement of such regulations.

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SECTION II

CHAPTER 11. Mariculture

Introduction

Mariculture activities creating artificial pond systems for rearing specific marine or brackish-water organisms are long-established practices of animal husbandry and are practiced on a relatively small scale in many parts of the world. The use of mangroves for mariculture dates back some 500 years to the rearing of milkfish (*Chanos chanos*) in Indonesia (Ling 1977).

In most instances few species have been involved, and the cumulative impact on the natural environment probably has been minimal. In the past decade, however, mariculture activities have intensified dramatically, particularly for high-value crops such as the penaeid shrimp species. The potential and actual economic gains involved indicate that even greater expansion is to be expected, particularly in penaeid shrimp operations. These are generally large-scale projects involving hundreds of hectares of ponds in any single locality, so the environmental effects on the mangrove ecosystem could be significant. The state of the art of shrimp culture is essentially in its infancy and although it is potentially a lucrative venture, this potential has essentially not always been realized as can be seen from the many failures. Although it has been estimated that yields of *Penaeus monodon* can be as much as 4,000 kg per ha per yr (Gedney et al. 1982), actual yields are often up to an order of magnitude lower, and even in controlled stocking in coastal ponds in Taiwan (where the state of the art of aquaculture is generally accepted as being extremely advanced), Chen (1976) reported an average yield of 1,400 kg per ha per yr (also see Macintosh 1982). Thus, although the principles addressed here may be applicable to many aspects of mariculture operations, primary emphasis will be on the culture of marine shrimps of the Penaeidae family.

The requirements for successful culture operation almost inevitably result in the location of ponds in tropical intertidal areas, many of which are characterized by mangrove communities. Several costly experiences indicate that mangrove environments are not necessarily the optimum locations for mariculture ponds. The requirements for such operations are site-specific, but important general requirements and management practices are outlined in this chapter.

Site selection is the single most critical factor since it closely governs cost factors such as land clearing, pond construction, water exchange, harvesting efficiency, and water quality. Analysis of cost factors, pond management efficiency, and annual production levels has indicated to many large-scale commercial mariculture ventures that the disadvantages of siting ponds in areas forested by mangroves may outweigh the advantages. As a consequence, sites for mariculture ponds are sought landward of the mangrove zones whenever possible. As Ong (1982) has pointed out,

> The mangrove is nature's own aquaculture system, with a number of advantages: an artificial system enjoys relatively easier harvest and selection of particular species, but the natural system is vastly more stable and less susceptible to disease and epidemics. Unless the artificial ponds can very significantly surpass the natural ecosystem, the establishment of aquaculture ponds may be a case of robbing Peter to pay Paul—with the possible added cost of having to compensate Peter later.

Experiences in the Philippines and Bangladesh, however, indicate that the economic and social benefits may, in specific instances, outweigh any management problems incurred. Furthermore, national and local government agencies sometimes actively encourage the conversion of mangrove forest areas to mariculture ponds since mangrove soils are widely considered to be of little agricultural value and thus are regarded as "wastelands." Much of the information on which corporate or government policy decisions are based is generally proprietary, but the consensus appears to be that siting ponds in mangrove areas can be a costly mistake and should be resorted to only in the absence of other options.

In spite of this, mangrove areas are being converted into shrimp or fish ponds at a considerable rate. For instance, it is estimated that roughly one-third of the approximately 30,000 ha of shrimp ponds in Ecuador are constructed in former mangrove forest areas. Many pond systems sited in mangrove areas seem to be owned by marginal operators who practice little or no effective pond management and whose yields per hectare are correspondingly low and variable. Operations such as these often are sited in mangrove areas because more suitable land is either unavailable or unaffordable. Land tenure situations in some instances also result in the construction of mariculture ponds in areas that would otherwise have been avoided.

On the other hand, mangrove areas are sometimes actively sought as sites for shrimp and fish ponds, and apparently successful operations evolve. It is estimated, for example, that approximately 172,000 ha of mangroves in the Philippines have been converted to culture ponds for shrimp and milkfish. These operations are mainly controlled by affluent landowners who can afford to employ trained personnel and a large labor force to ensure effective pond management. Many of these ponds, however, have been sited on acid sulphate mangrove soils, and unless adequate supplies of fresh or brackish water can be introduced into the ponds to control pond acidity, the harvests steadily dwindle and the ponds eventually are abandoned.

The ultimate aim of the mangrove ecosystem manager is to develop or adapt successful aquaculture methods that have minimal impact on the ecosystem through compatible use strategies.

Mangrove Mariculture Practices

A variety of mariculture methods are practiced in mangrove areas. These may be put under two broad categories: (1) methods using mangrove estuarine waterways, and (2) methods using mangrove land areas.

METHODS USING MANGROVE ESTUARINE WATERWAYS

This category can be subdivided into methods using the substrate beneath the water, or bottom culture, and those that rely on the water column itself.

Bottom Culture. A good example of bottom culture is the culture of the cockle, *Anadara granosa.* This species is most extensively and intensively cultured on the west coast of Peninsular Malaysia but is also cultured in Thailand, Kampuchea, and Vietnam. *Anadara* occur naturally in some mangrove mudflats and thus are often simply harvested rather than cultured. In areas where there is no natural spatfall, however, seeds (young cockles 6–12 mm in diameter) are collected from spatfall areas and sown (4.5 to 5.5 thousand liters per hectare) in sheltered mangrove mudflats. The cockles are ready for harvest when they reach a size of about 3 cm (8–12 months from sowing). Thinning has to be carried out after about 3 months to a density of between 400 and 600 per m^2. In areas where natural spatfalls do not occur, new seedings are done after each harvest. Yield of cockles is between 20 and 24 tonnes per ha per year (Sribhidhad 1973). Malaysia, the largest producer and exporter of both cockle seeds and adults, produced some 56,000 tonnes valued at US$10 million in 1978 (Fisheries Div. 1979).

This form of mariculture has minimal adverse ecological effects on the mangrove ecosystem and is thus highly recommended. The main problem is the availability of seeds, which are decreasing in supply. This is aggravated by the destruction and deterioration of natural spatfall areas as a result of industrial pollution, overcollection, and illegal trawling activities in shallow water (Rabanal et al. 1977, Saraya in press).

Open Water Culture. This utilizes floating cages or rafts and enclosures for the culture of fish, molluscs, and crabs (Figure 31). Fish (the grouper *Epinephelus tauvina* and the sea bass, *Lates calcarifer* are the two most cultured fish) are grown in floating cages (approximately 4–5-by-5–6 m and about 2.5 m deep) while molluscs (the mussel *Mytilus viridis*) and several species of oysters are grown on ropes hanging from floating rafts (Figure 32). Sribhidhad (1973) has reported that the yield of mussels was 180 tonnes per ha per year in Thailand. Enclosures

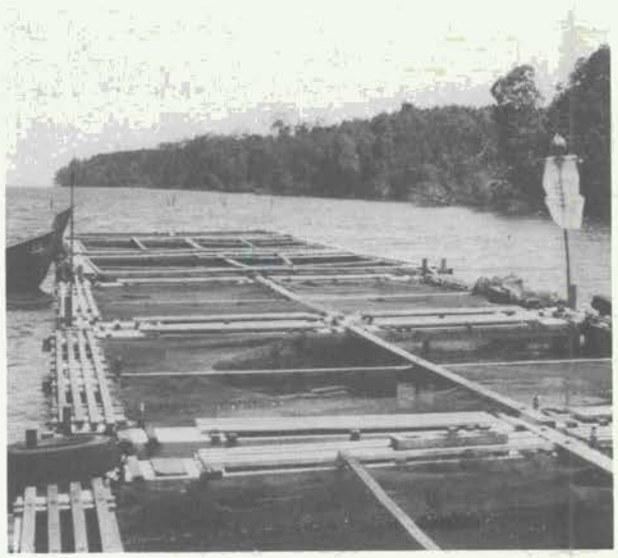

Figure 31. Open-water culture using cages.

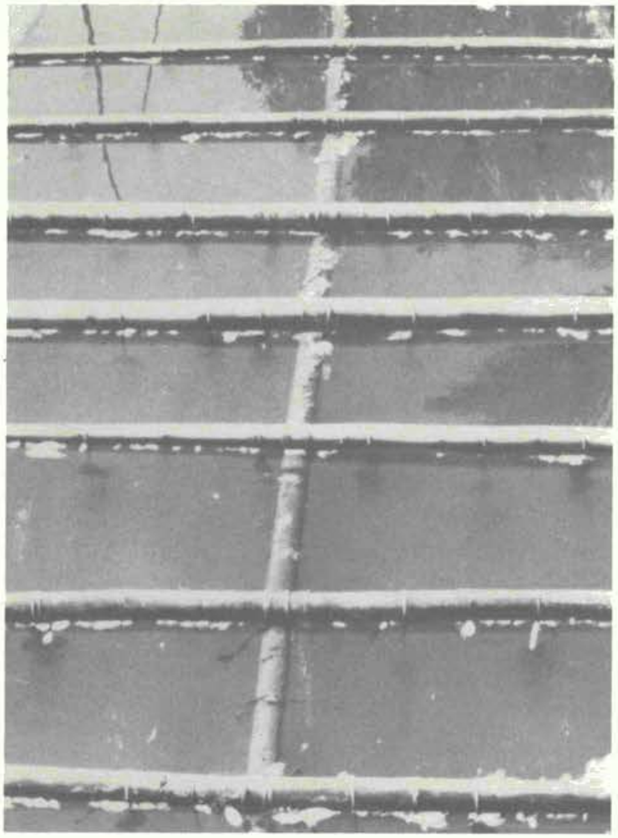

Figure 32. Oyster culture using rafts near Pagbilao, the Philippines.

of synthetic net or bamboo screens measuring from 0.25 to 5 ha are seen in the Philippines, largely for milkfish (*Chanos chanos*) culture. Yields of up to 4 tonnes per ha per year can be obtained with minimal supplementary feeding (Delmendo and Gedney 1974).

METHODS USING MANGROVE LAND AREAS

As with the methods utilizing mangrove estuarine waterways, there are various forms of mariculture utilization of the mangrove land area itself.

Small Fish Ponds. These ponds, which retain mangroves as part of the system, are used mainly for milkfish, but shrimp are also farmed. The ponds vary in size from about 0.5 to 10 ha, and the mangrove trees often are not cleared but are retained on dikes between the ponds. The mangrove leaf litter provides nutrients for the ponds. Most of these ponds produce at a subsistence level utilizing the inherent productivity of the mangrove system.

Trapping and Holding. Ponds of 1 to 25 ha (up to 900 ha in Bangladesh) are constructed by building mud bunds or levees. Sluice gates are open at flood tides to allow water and larval shrimp in. The gates are then closed and the shrimp are trapped and held. They are harvested by placing nets on exit gates during receding tides. In Singapore where this form of mariculture dates back to the turn of this century (leMare 1950), shrimp are harvested up to 20 days per month. In most other parts of Southeast Asia harvest takes place during the spring tides (at night when the mature shrimp tend to migrate seaward) (Cook and Rabanal 1978). In Thailand, Phumiphol et al. (1970) gave the mean yield as 184 kg per ha per year in Chantaburi Province, while the national average was 108 kg per ha per year (Fisheries Dept. 1973). Yields with this method may be generally low and unreliable. Due to their high value when operated on a larger scale in Bangladesh and India, however, such ponds are not a subsistence operation but are commercially harvested for the export market.

Large-Scale Commercial Ponds. Although fish also can be cultured, these are more often than not used entirely for shrimp culture because of the better economic returns. In the Indo-Pacific region the major species is *Penaeus monodon* although *P. merguienis* and *P. indicus* are also cultured. In the eastern Pacific *P. stylyrostris*, *P. vannamei*, and *P. occidentalis* are the common mangrove species, and in the Atlantic region *P. aztecus*, *P. setiferus*, and *P. duorarum* are common.

POND CONSTRUCTION AND OPERATION

In most schemes the mangrove trees are removed, and sometimes the "top soil" is also removed to increase the depth of the ponds (Figure 33). The engineering aspects of pond construction of this type are described by Jamadre and Rabanal (1975) who contend that mangrove areas with a tidal range of 1–3 m are suitable for pond construction since tidal exchange alone is enough for water circulation. This concept of tidal exchange will be discussed in greater depth later.

Culture operation involves draining the pond at low tide until only about 10 cm of water is left. A piscicide is then added to kill off predators. Rotenone (final concentration of about 4 ppm) is often used and so is tea seed cake (saponin being the active component). A day after piscicide treatment the pond is drained completely and left to dry for about a week (in ponds with potential acid sulphate soils, this practice of

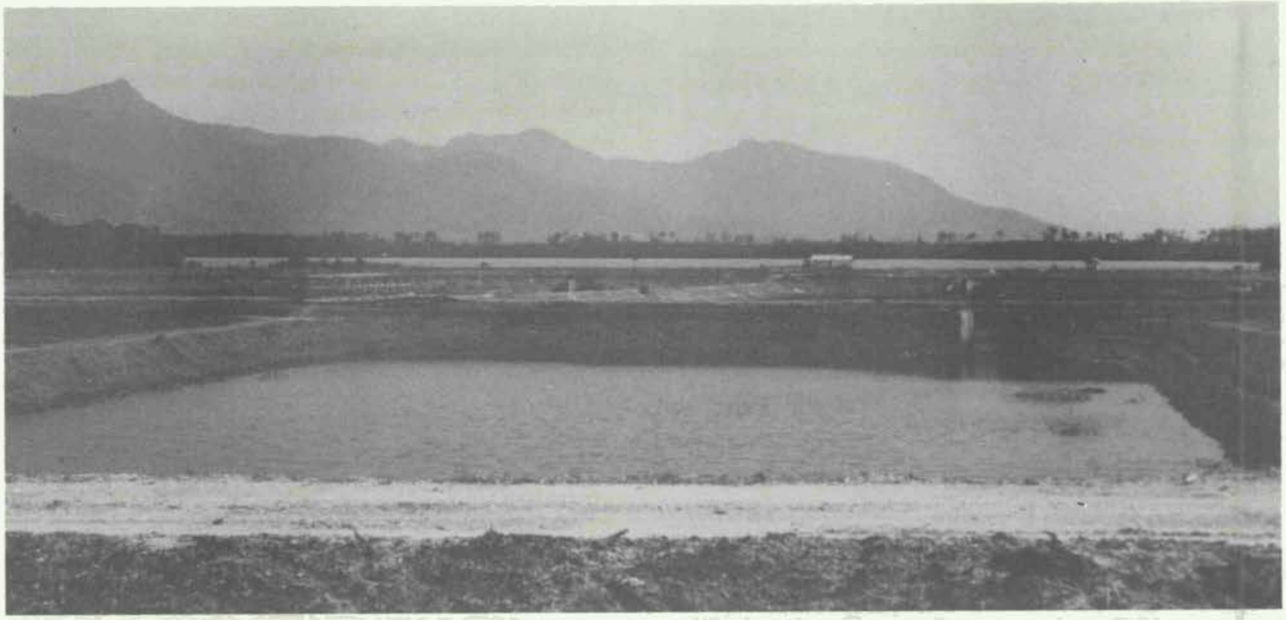

Figure 33. Ponds created among mangroves.

drying the pond is not recommended since oxidation will cause acid formation). Liming of ponds, if they are susceptible to low pH, is done at this stage. Some .5–2.5 tonnes of lime per ha is broadcast in the ponds as well as on the bunds. Boyd (1976) gives an account on how to calculate the amount of lime necessary.

Water is then slowly allowed in (passing through screens on the inlet gates to exclude predators) until the ponds are filled to a depth of 1–1.5 m. In some operations, nylon mesh (2 mm) enclosures are used as nursery pens, but in others there is no separation into nursery and rearing ponds. For *Penaeus monodon,* stocking rate is 2.5–3 million postlarvae per ha where nursery pens are used (Gedney et al. 1982). This is reduced to 30,000–50,000 per ha in rearing ponds when the fry reach a size of 2–3 cm (after about one month). In systems where no nursery pens are used, the stocking rate is about 50,000 per ha, depending on the cost and availability of seeds. For *Lates calcarifer* the stocking rate in rearing ponds is between 30,000 and 50,000 per ha.

For *P. monodon,* feed is usually chopped-up trash fish (although pelletized feed also is now used). In the first month, feeding occurs once a day (usually in the evening) at 50–100 percent shrimp body weight. After one month, feeding rate is reduced to about 10 to 30 percent of the shrimp body weight. *L. calcarifer* are fed until they are satiated.

Productivity is dependent on good water quality (pH 6.5 to 8.5, dissolved oxygen greater than 3 ppm, and salinity varying by age and species, but roughly between 10 and 25 percent). Pond water needs to be partially renewed each day, and a reticulation system should allow changing of bottom water. Most systems that depend entirely on water exchange from tides cannot meet this optimal requirement.

Depending on market requirements, prawn are harvested after three to six months (20–40 prawns per kg). Harvesting is best done on moonless nights during spring tides (when mature prawns tend to move up and migrate to sea) by draining the ponds and collecting the prawns in bag nets placed at the outlet gates. Fish *(L. calcarifer)* are harvested after about one year when they attain a weight of about 1 kg each.

Advantages of Siting Ponds in Mangrove Areas

LAND COSTS

The advantages of a mariculture operation using mangrove areas are often limited to cost or ease of land acquisition. In many countries, the coastal mangrove zone is under government ownership and can be leased at nominal cost.

Many governments actively encourage development of ponds in mangrove areas, preferring to have more landward areas utilized for terrestrial crops or human settlements. Thus the exploitation of "marginal" lands with saline soils is frequently regarded as a progressive policy. In other instances, private landowners are often willing to sell their mangrove holdings at low prices or to enter into joint-venture operations in which they provide the land and thereby acquire equity.

WATER EXCHANGE

Locating ponds in tidal mangrove areas often facilitates daily exchange of a percentage of pond waters, desirable in maintenance of a high-standing crop and rapid growth rates. This practice is only viable, however, if incoming waters are screened carefully to prohibit entry of potential predators and competitors. In situations where tidal ranges of 1 – 3 m exist, tidal exchange often proves to be satisfactory. When tidal ranges are less than 1 m, very few ponds can benefit materially. For intensive pond operations and optimal conditions, pumping may be economically feasible; thus, the advantage of natural tidal exchange is lost and siting in mangroves becomes less desirable.

SEED SOURCE

Stocking of ponds with fish fry or postlarval shrimp (seed) can sometimes be facilitated if the ponds are located in mangrove areas, particularly in the vicinity of a tidal creek. The still-widespread practice of simply opening gates, screened or unscreened, to allow an influx of postlarvae or fry is often counterproductive since predator and competitor organisms have similar unrestricted access. Proximity to the seed source does, however, reduce transportation time and hence stress and mortality between site of capture and the pond to be stocked.

Recent advances in hatchery production of young stages of many species reduce these problems, but with few notable exceptions the techniques of maturation, spawning, and larval rearing have thus far failed to produce large-scale and reliable sources of animals for stocking ponds.

It must be borne in mind that large-scale elimination of mangroves could result in disruption of the ecosystem to such an extent that the source of seeds could be drastically reduced or eliminated. It is fortunate that shrimps and the milkfish are extremely fecund species.

Disadvantages of Siting Ponds in Mangrove Areas

Several severe limitations to profitability may be imposed on mariculture ponds sited in mangrove areas. A successful operation depends upon (1) low construction costs, (2) rapid growth rates and low mortality rates, and (3) efficient pond management and harvest. Ponds located in mangrove environments often may not fulfill these requirements as effectively as more upland sites.

LAND CLEARING AND CONSTRUCTION

Land clearing, particularly areas characterized by *Rhizophora* spp., is difficult because of poor accessibility and the danger involved in felling large trees. Mechanized clearing is rarely possible because of the nature of the soils. Consequently, clearing operations are time consuming even though they frequently generate income for a local labor force.

Most mangrove soils have a low bearing capacity, so heavy earth-moving machines can rarely be used. Although the costs of moving and shaping earth into useable ponds vary widely and are site-specific, the lightweight machinery that can be used or hand labor are inefficient and result in an extended and expensive buildup period and sometimes unacceptably high construction costs. Satisfactory shaping and compaction of pond walls or levees are also difficult to achieve. Soft peats and peaty muds cannot be efficiently or effectively compacted by hand or by small bulldozers, with the result that slumping later occurs, the levees become impassable to wheeled vehicles, excessive seepage can occur, and water control structures become deformed and no longer function effectively. Surface stabilization by use of grasses and procumbent herbs often results in rapid erosion and deterioration of levees. Maintenance is a virtually constant and costly requirement. In the case of a high-value cash crop such as shrimp, these costs may be acceptable, but this is not often the case in relatively high-volume, low-value finfish culture operations.

POND CONDITIONS

Maintaining water quality and perpetuating general pond conditions conducive to rapid growth and low mortality are of paramount importance. In this respect, mangrove soils frequently pose severe limitations.

The most severe limitation results from the development of high acidity in pond waters. This is a direct consequence of constructing the ponds in the potential acid sulfate soils that characterize many mangrove areas. The pH of pond waters frequently falls below 5 and may in some cases fall below 4. Shrimp growth is slow in even slightly acid waters; growth ceases below pH 5 and mortalities occur at approximately pH 4.

Acidity can interfere with animal growth in many ways. Enzymatic reactions are highly sensitive to pH. Thus, in addition to direct effects on the organism, acidity also inhibits the growth of microorganisms, including bacteria, fungi, and the protozoans, that form a considerable portion of the animal's diet. Acidity also affects the ability of microflora and microfauna to assimilate metabolites. Important chemical processes are also sensitive to changes in pH. When pH is lowered, the equilibrium point shifts in the carbonate system and specific toxic heavy metals are released, whereas phosphate ions necessary for algal growth are immobilized.

Highly acid waters have been observed frequently in mariculture ponds, such as in shrimp culture ponds in Costa Rica and Ecuador. In all known instances, the ponds were constructed in mangrove soils of high organic content, which contributes to acid sulfate conditions. Most mangrove soils are potentially acid sulfate soils; that is, they become acid sulfate soils with low pH values when dried or otherwise oxidized.

During the steady process of mangrove soil formation under anaerobic conditions, pyrite (FeS_2) forms in the soils as a result of continual deposition of minerals and sulfates from seawater or from the decay of organic matter in the mangrove soils. Upon disturbance, which results in partial drying, the pyrite is oxidized by chemical and biological processes to produce sulfuric acid (Moormann and Pons 1975).

The acidity of pond waters results from two distinct sources: (1) soils incorporated in the soil levees become dried, the pyrite contained therein becomes oxidized, and runoff waters introduce the resultant acids into the ponds; or (2) soils forming the pond bottoms become oxidized by the overlying waters, and the generation of acid from pyrite begins.

In summary, the effects of acid conditions on mariculture ponds are that growth is drastically reduced or halted, mortalities occur if the problem becomes severe, and greatly increased quantities of phosphate fertilizer (Watts 1969) or artificial feed inputs are required to stimulate and maintain algal blooms.

Several strategies have been suggested to prevent acid conditions. All are expensive, and only one is generally successful. The common practice of avoiding the acidity problem by leaving mangrove stumps in place with no grading or leveling of the pond bottom has been followed for centuries in fish culture ponds in Asia. Unfortunately, this strategy is less than optimal in shrimp culture operations since it frequently results in a protracted harvesting period and low yields of a marketable product.

Exposure of potential acid sulfate soils can be avoided by using inert materials such as concrete, cement-asbestos board, or butyl rubber to build levees; or nonacid soils can be transported to the site to line the pond bottoms and use in levee building. Cost estimates are not readily available, but even if suitable materials were to be available near the site, these measures would probably be too costly. Furthermore, use of artificial substrates may result in lower primary productivity, which must be compensated by increased feeding or fertilizing rates.

An alternative strategy involves neutralization of the acidity by applying agricultural lime or a similar chemical base. The efficacy of such treatment is currently unknown, but estimates are that up to 20 tons of lime per ha administered 2–3 times per year for up to five years may be necessary to condition the pond sediments. Given the relative scarcity of carbonate products near most shrimp culture sites, this is probably not economically feasible in many mariculture operations.

Even if the potential for acid generation is removed during construction or its effects can be neutralized adding lime, the normal operation of saltwater ponds can regenerate potential acid conditions. It follows, then, that a dilution strategy involving continuous and abundant flushing of the ponds with seawater, or with fresh water as is practiced in the Philippines, is the only effective and economic method. This, however, takes a long time if pond operators rely on natural flushing by rain and freshwater runoff. Water exchange rates of 25 percent volume per day have proved adequate in Costa Rica, but either large volume pumps must be installed, or the design and location of the ponds must permit tidal exchange of water every day. The former case involves the use of electrical energy or hydrocarbon fuels, both of which are prohibitively expensive in most parts of the world, and a pump mechanism, which requires constant maintenance and is subject to failure. Tidal exchange strategies involve the construction of high levees, large conveyance canals, careful screening of incoming and outgoing waters, and, perhaps most important, the loss of flexibility in determining time and duration of harvest.

Strategies for reducing the problems of acid sulfate soils are obviously site-specific and in some locations have been employed successfully. In the Philippines, for instance, a large percentage of shrimp and fish ponds are located near major river estuaries that provide an abundant supply of fresh water. The adopted practice in the Philippine operations is to manage freshwater inflows carefully to flush and replenish pond waters. By such strategies, Philippine pond operators seem to have thus far avoided most of the problems of acid pond waters. It should be noted, however, that a dilution strategy using substantial volumes of fresh or slightly brackish water is not universally applicable and can probably only be employed seasonally, if at all, in many coastal areas.

POND MANAGEMENT

Although maintaining favorable water quality is a function of pond management, here it refers primarily to the ability to manipulate harvest date and duration. In the opinion of many large-scale commercial operators, the siting of ponds in fully intertidal areas to achieve a modicum of tidal exchange — to offset acid conditions or for other reasons — imposes unacceptable restrictions on harvesting strategies. If the ponds are so situated as to receive daily tidal inputs, they cannot in some instances be drained completely at harvest. Consequently, a large proportion of the crop remains in the ponds and must be retrieved by hand-operated seines or cast nets. These procedures take several days in a large (10 ha or more) pond and harvest an inferior product. More important, valuable growout time is subtracted from the subsequent crop, and profits are reduced accordingly.

Where large tidal amplitudes exist and an adequate labor force is available, such constraints are considerably lessened. Inability or unwillingness to devote time to draining the ponds completely, however, results in the perpetuation of populations of competitors and predators inadvertently introduced to the ponds during filling or water exchange operations.

Related Concerns

REDUCTION OF RESOURCE BASE

Mangrove systems are generally recognized as an important, sometimes vital, support element in maintaining fisheries resources and fishing industries locally or regionally. In many locations, the fishery industries appear to be based in part upon the availability of intertidal areas as nursery habitats for desirable species. Additionally, many mangrove systems export organic material with relatively high protein content that is easily available to primary consumers and that ultimately would maintain or supplement the resource base of desirable commercial fisheries, including shrimp fisheries. For instance, approximately 90 percent of the diet of *Penaeus merguiensis* in estuarine regions of northern Australia. appears to be derived from mangrove sources.

REDUCTION OF POTENTIAL SOURCES FOR STOCKING PONDS

Of more immediate importance to the shrimp culture operation is the potential for reduction of postlarval seed sources for stocking growout ponds. The techniques of hatchery production of postlarvae have advanced to the point at which the stocking of a shrimp farm of 500 ha or more presents few difficulties. Such techniques are capital-intensive, however, and are largely unavailable to small operators. The latter are dependent upon a wild source of postlarvae for pond stocking.

Supplies of wild postlarvae are notoriously undependable, but thus far the vagaries of supply cannot be correlated with destruction of mangrove communities for shrimp culture or any other purpose. Postlarvae of the eastern Pacific species *Penaeus stylyrostris, P. vannamei,* and *P. occidentalis;* the Indo-Pacific species *P. monodon, P. indicus,* and *P. merguiensis*; and the Atlantic species *P. aztecus, P. setiferus*, and *P. duorarum* tend to utilize tidal creeks within the mangrove zone and rarely penetrate the mangrove forest per se. Thus, supplies of postlarvae depend upon locating the right creek at the right time, an exercise that requires considerable fortitude.

The same potential problems exist in fishpond operations, many of which are highly dependent upon wild sources of fry or fingerlings. As in the case of shrimp postlarvae, fry and fingerlings of most commercially desirable finfish culture species occur most commonly in tidal creeks and are caught in these creeks prior to pond stocking activities.

Even the siting of mariculture ponds on the landward side of mangrove forest areas may affect the natural resource base of the system by diverting the surface flow patterns of freshwater runon. Such diversion can result in a reduction in net productivity of the mangrove forest, with consequent negative effects on harvestable yields of other valuable products such as timber and estuarine fishery species.

Summary and Recommendations

Mariculture using mangrove estuarine waterways (on-bottom mollusc culture, floating-cage fish culture, and floating-raft mollusc culture) has minimal effects on the environment. These culture methods are, however, only suitable in mangrove estuaries where the salinity does not fluctuate too widely. This type of mariculture should be encouraged in preference to pond culture utilizing mangrove land areas.

There are basically two categories of pond mariculture using mangrove land areas; they may be termed extensive and intensive. The extensive category relies essentially on the natural productivity of the system. Production is often low and is essentially a subsistence or artisanal type of operation. The tambaks of Java and the milkfish ponds of Philippines are examples of this type of mariculture. The intensive category is by-and-large a relatively recent development. The cultural organisms (mainly shrimp) do not rely on the natural productivity (fertility) of the system. An external source of feed is provided so that the natural productivity acts only as a supplement. Even the seeds may be from hatchery production.

The effects of both the extensive and intensive systems of pond mariculture on the mangrove environment are obvious: mangroves are replaced where ponds and infrastructural facilities are located, and the surrounding mangrove may also be disrupted.

Experience in Thailand, Ecuador, and Panama has shown that salt flats and other lands on the landward side of mangrove forests are suitable for pond prawn culture. Such areas have the advantage of being closer to such infrastructural facilities as roads, electricity, and potable water as well as avoiding the acid sulphate problem so prevalent in mangrove areas.

In places like Ecuador and Panama, however, many of those landward fringes of mangroves have been used so that there is now pressure to move into the mangrove areas. The best solution for mangrove conservation is to encourage a semi-intensive or intensive use of areas that have been converted to ponds. This is already the official policy in the Philippines where many of the accessible mangrove areas have been converted to nonintensive fish culture ponds. By practicing intensive farming it is possible to increase the yield per unit area by up to an order of magnitude. This will satisfy the need for increased fish production so often sought by many of the countries with mangroves and at the same time take the pressure off what is left of the existing mangrove areas.

Experience has shown that locating mariculture ponds in areas of mangrove forest communities is in some instances counterproductive. The availability and low cost of land in such areas may be far outweighed by the incumbent costs associated with land clearing, pond construction, highly acid waters, and the inflexibility of harvesting strategies. Consequently, large-scale operators, particularly in Central and South America, have tended to avoid mangrove areas in recent years and have concentrated upon more suitable landward sites. In Southeast Asia, on the other hand, many operators of mariculture ponds have proved willing to accept the incumbent costs of operations. As the market price of shrimp, for instance, continues to rise sharply an increasing number of operators will be prepared to accept the costs and difficulties of mariculture operations are established in mangrove areas.

Recommendations for managers of mangrove areas in which mariculture operations are established include the following:

- Note that floating-cage and raft cultures or on-bottom culture using mangrove estuarine waterways have minimal ecological impact on the mangrove ecosystem.
- Avoid siting shrimp ponds in mangrove areas whenever possible. Lands with more suitable soils should be sought even if land costs are higher.
- If more suitable land is not available, carefully assess the mangrove soils to determine their degree of potential acidity. If the acid sulfate potential proves high, the site should be avoided.
- If siting of ponds in acid sulfate soils is unavoidable, incorporate into pond design the ability to exchange approximately 25 percent of pond volume daily, either by tidal exchange or by pumping.
- If adequate water exchange cannot be achieved, nonacid soils should be transported to the site to line ponds and build levees, or heavy applications of lime must be used to neutralize acids.
- If pressures to convert more mangrove land area into mariculture ponds is great, consider increasing the efficiency of existing ponds by moving into semi-intensive or intensive methods rather than opening up new areas.

- For efficient harvesting, do not locate ponds much below the mean high tide level. Most ponds located below this level cannot be drained at will in areas in which tidal amplitude is less than 1 m.
- Do not site ponds that will obliterate natural tidal creeks, since these seem to be the primary habitat of the postlarvae required for pond stocking. Such creeks also promote the flushing and water exchange in the adjacent mangrove areas.
- Be fully aware at the outset that such an action often involves high construction costs, inefficient pond management, and low yields.
- Do not design or locate ponds in such a manner as to divert freshwater runoff from entering any mangrove forest seaward of the ponds. Any runoff waters diverted around the ponds should be redirected and dispersed to the mangrove areas by means of shallow lateral channels along the seaward margins of the ponds.
- Keep a careful tally of the total hectares of mangrove converted to ponds in any specific geographic area. While it is virtually impossible to determine the levels of conversion concomitant with safeguarding the postlarvae source and other local fishery activities, it might be recommended that no more than 20 percent of the mangroves in any discrete system be converted to pond culture operations. Conversion should be on a small scale with careful ecological monitoring for impacts.
- If mariculture ponds are abandoned for any reason, breach the berms and bunds at several locations to facilitate natural reforestation by mangroves and utilization of the former pond areas by estuarine organisms.
- On tropical arid coastlines largely devoid of mangrove systems consider the possibilities of mariculture ponds in conjunction with mangrove planting programs. In such situations it may be possible to utilize solar or wind energy to provide fresh water or tidal exchange waters to mitigate the hypersaline conditions that preclude rapid growth of both mangroves and aquatic organisms.

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SECTION II

CHAPTER 12. Salt Production

Introduction

Salt is fundamental to life and a staple commodity in the diets and in the economies of peoples throughout the world. Especially in the tropical developing world, salt serves not only directly in the human diet but also, and perhaps more important, in the preservation of foods (notably fish and red meat) and in the maintenance of stock animals.

Although modern, capital-intensive mining operations for rock salt may be cheaper where such a resource exists, the most common source of salt is still sea water, and the universal technique for extraction is solar evaporation. In India, 75 percent of the annual salt production comes from sea brine.

Mangroves, as the most common littoral ecosystems along tropical and subtropical coastlines, together with their economic resources, frequently are lost due to land-use conflicts stemming from the need to establish solar salt operations in the coastal zone. It often is difficult to resolve this conflict because of several specific conditions associated with salt extraction processes.

First, salt production in mangrove areas requires habitat conversion, and in almost all known cases the conversion process has been irreversible. Second, climatic constraints on solar salt production require that such operations be implemented in arid to semiarid coastal environments where the mangrove resource is already climatically restricted and probably under exploitation for other resources not compatible with conversion. Third, the operation of salt processing in marginal climatic zones often requires the further utilization of limited mangrove timber resources for fuel wood to accelerate brine evaporation. Fourth, the establishment of industrial-scale operations, as in western India, involves such infrastructural and human demographic changes that any remaining mangroves are subjected to increased exploitation pressures for alternative resources.

This chapter focuses on solar salt extractive practices in relation to mangrove ecosystem conservation. It offers suggestions for the placement and design of these activities to assist in sustaining both local salt industries, where they are required, and the adjacent mangrove vegetation.

The Products of Salt Extraction

Salts of chloride, sodium, magnesium, sulphur, calcium, and potassium comprise 99 percent of the chemical composition of sea water. In addition, holgens such as bromine and iodine are in sufficient concentrations to be economically extractable. Many of these mineral compounds have important economic uses.

Sodium chloride is the most common product and is used as noniodized or iodized table salts, in the preservation of foods (particularly red meats and fish), and as a supplement in the diet of stock animals (e.g., as in salt licks).

Other salts have high commercial importance. In India, magnesium is used in the steel industry, and high-purity magnesium salts from sea water are employed in rubber and pharmaceutical industries (e.g., as magnesium hydroxide, magnesium trisilicate, and magnesium carbonate). Potash, or potassium chloride, is an essential source of potassium fertilizer, while bromine and bromo-compounds have numerous applications in dyes, pharmaceuticals, and photography.

On a national scale, these products have significance within the Indian economy, and in Thailand 30 percent of the 406,990 metric tons produced is exported to neighboring countries. In relatively poor areas in Southeast Asia and in West Africa, the production of salt may be the basis of local village or regional economies.

The Global Distribution and Scale of Salt Production

A global assessment of the current significance of salt production on mangrove areas is difficult to obtain. Table 16 represents the most up-to-date qualitative assessments available but fails to convey the dynamic and opportunistic nature of this ancient industry. In the regions of Chaukoria Sunderbans and Cox's Bazaar in southeastern Bangladesh, for example, a recent

Table 16: Distribution and Significance of Solar Salt Operation by Country

Country	*Significance*
Australia	Intensive operations of localized areas of the northeast coast
Fiji	Localized minor use
India	Highly intensive industrial operations on northwest coast
Bangladesh	Widespread, major, and expanding use
Thailand	Moderate intensity in localized regions of the country
Malaysia	Localized minor use
Philippines	Widespread moderate use
Indonesia	Localized moderate use in eastern part of country
Senegal	Highly intensive but regionally localized industrial operations
Benin	Highly intensive and widespread
Mozambique	Intensive localized operations
Tanzania	Known to occur but no available data
Bahamas	Extensive operations on some islands, e.g., Andros
Turks and Caicos	Nominal to minor operations
El Salvador	Widespread and major use
Honduras	Localized minor use
Costa Rica	Localized moderate use
Brazil	Widespread moderate use in north and northeast states
Venezuela	Localized moderate use; large projects under investigation
Colombia	Widespread moderate use
Ecuador	Localized minor use

extended wet season and falling prices for salt are resulting in the expansion of an associated shrimp culture industry and the further conversion of salt evaporation ponds to mariculture. Subsequent dry years or better prices for salt may be expected to swing operations back to salt at a later date. In areas where a seasonally wet climate limits the production time for salt, ponds may be alternately used for shrimp or fish production. This is the case in Thailand, the Philippines, and Indonesia, and the implication of this strategy is a flexible multi-use management regime for intertidal lands that have already been converted.

Elsewhere in the world, large-scale industrial solar salt production is still being viewed as a favorable economic enterprise. In Venezuela new, large-scale evaporation pond operations are under investigation. The project concerns coastal areas adjacent to mangrove forests in the Bahia El Tablazo in the region of Lake Maracaibo and in Golfete de Coro. At this time, no accurate ecological investigations have been carried out in these areas, and the risks to adjacent ecosystems remain undefined.

The Production Process

The production of salt through solar evaporation is an ancient process that has been applied with local variations throughout the world (See Figure 34). Artisanal salt extraction techniques have been described from various countries in West Africa, Central America and the Caribbean, in South Asia, on some Pacific Islands, and in parts of eastern Indonesia and the Philippines. In the Gulf of Kutch near the Indo-Pakistani border, a huge solar-salt industry has been established (Figure 35) and large industrial operations are under way in many other countries where climatic conditions are appropriate.

While the rudiments of the production process are common to all these operations, important differences in resource management do occur and will be elaborated here. They can best be understood by first considering the environmental constraints to successful solar salt production.

Environmental Constraints

CLIMATIC FACTORS

The major environmental constraint to effective solar salt production is the amount and distribution of rainfall. In general, it has been found that most successful salt operations are in climates where average annual rainfall is less than 1,000 mm with at least eight dry months. These conditions occur in the huge sea-salt industrial com-

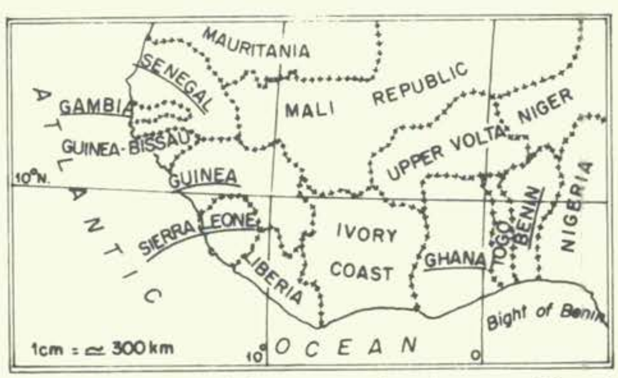

Figure 34. West African countries where traditional salt extraction could have been carried out in mangroves.

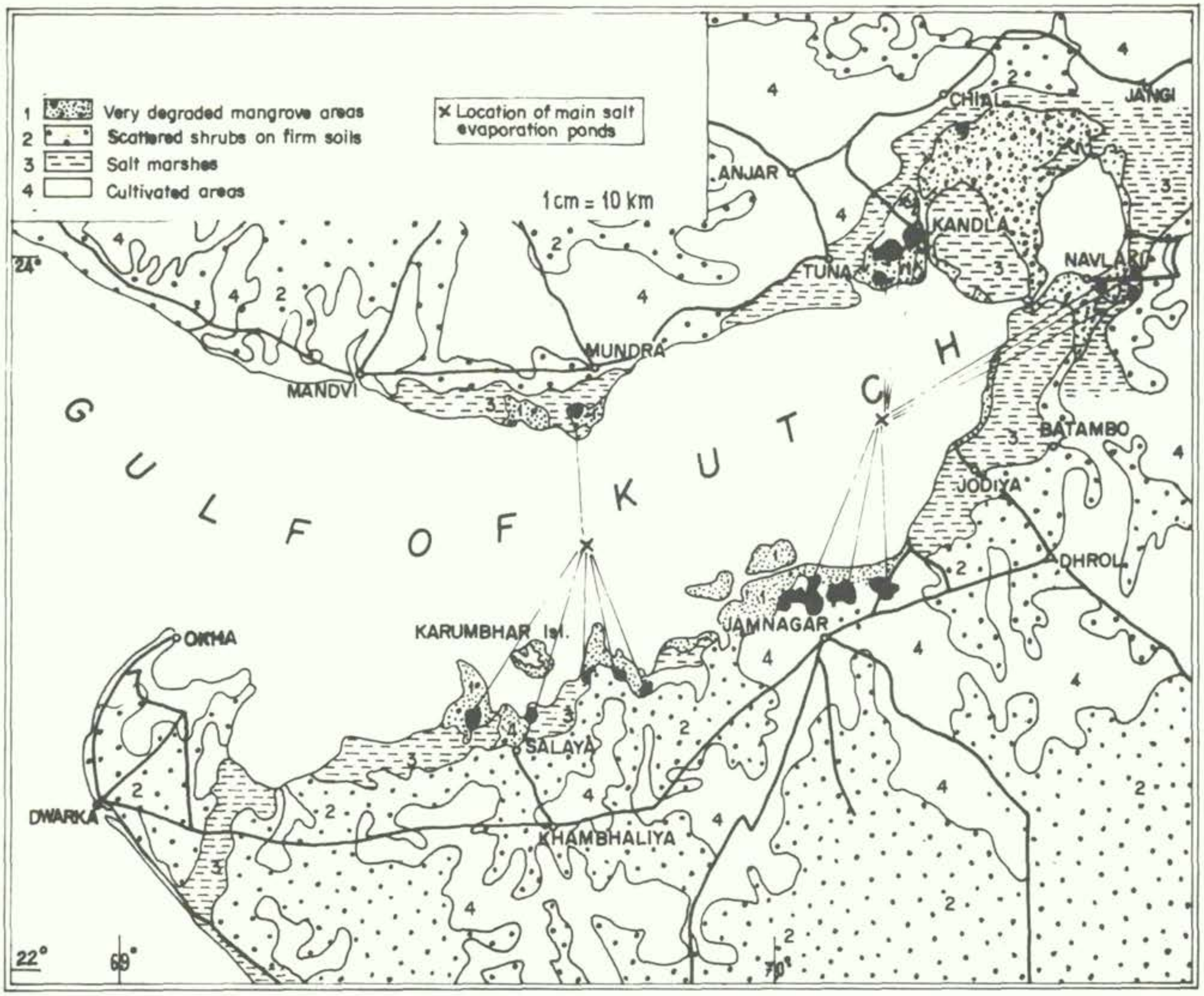

Figure 35. Salt industry in the Gulf of Kutch (India).

plex in the Gulf of Kutch in northwest India and in the region of Kaolack in Senegal where salt extraction has been carried out on an industrial scale since 1914.

Where the coastal "aridity index" (expressed as R/ETP where R is rainfall and ETP is evapotranspiration) is greater than 0.75, solar salt production may need to be augmented by additional boiling of the brine solution.

This is a practice widely followed in several African countries south of the fourteenth parallel. The process they have adopted and its implications will be discussed later in this chapter. One method of locating climatically suitable sites for solar production is the comparison of ombrothermic diagrams of regional climatic conditions. This has been done for six localities in West Africa, and the results are shown in Figure 36. Kaolack is the only one of these sites suitable for solar salt production without additional energy inputs.

SEA WATER QUALITY

Salinities of nearshore marine and estuarine water in the tropics can vary significantly from place to place and between the wet and dry seasons. This is primarily a function of total rainfall and subsequent freshwater runoff from the land, but coastal land formations also may have a significant influence. For example, where large freshwater swamps occur adjacent to beaches, freshwater seepage may be regulated.

High seawater salinities (up to 40 ppt in the Gulf of Kutch) increase the efficiency of solar evaporation pond operations as, for example, in northwest India and in the Koalack region in Senegal. Where seawater salinities are low during the dry season, it has sometimes been necessary to develop other procedures. This appears to be the basis for the operations in West African countries such as Benin and Gambia where mangrove sediments are turned and processed

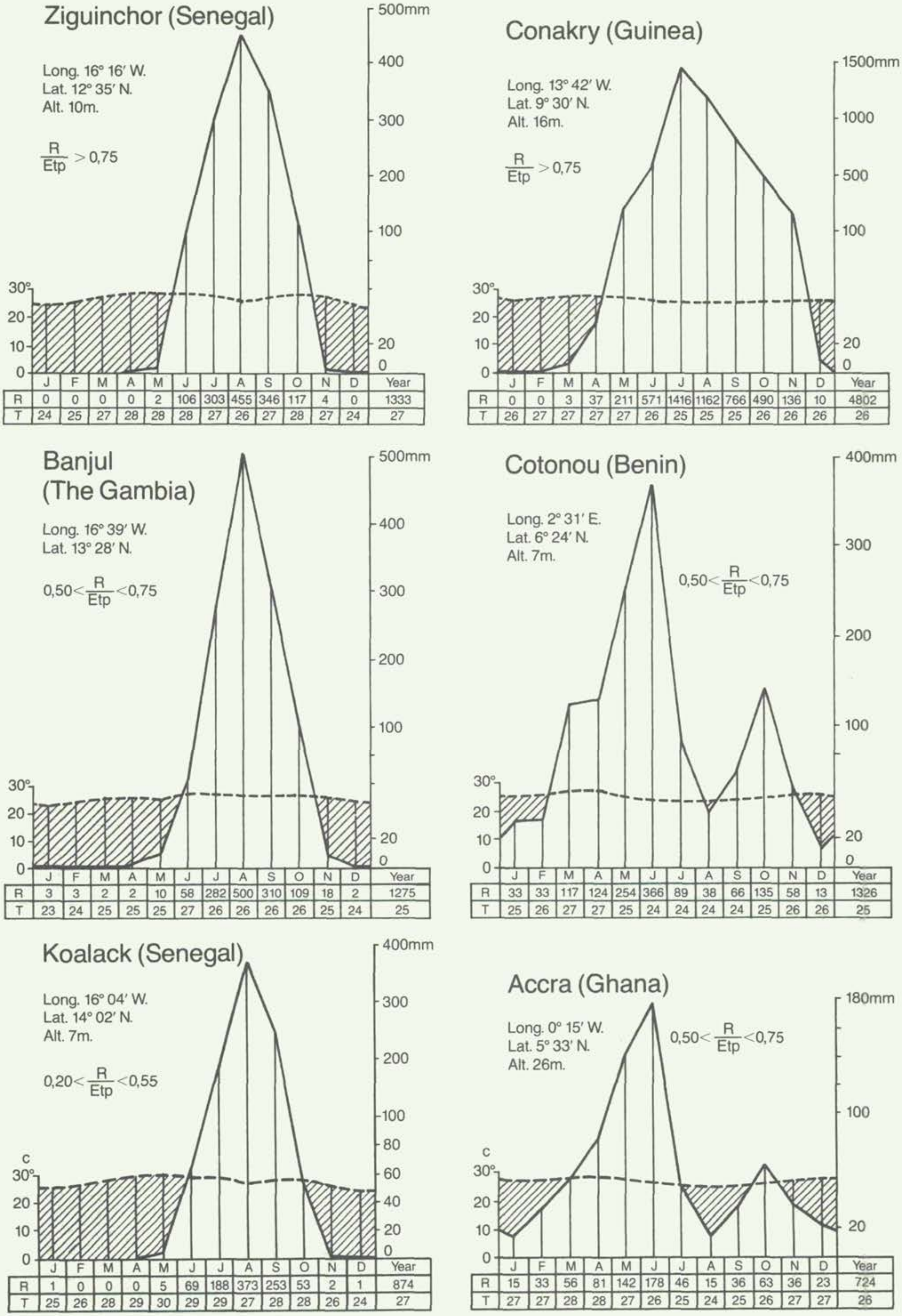

Figure 36. West African coastal climatic conditions.

to extract the salt from the more saline interstitial waters. This practice is potentially more energy-demanding with more serious environmental consequences than seawater evaporation.

Salt Extraction Procedures

EVAPORATION PONDS IN UNVEGETATED ZONES

For reasons related to local geomorphological, tidal, and climatic processes, saline plains are found at slightly higher elevations than the zone of the woody mangrove vegetation. These plains may be bare of vegetation or, in less environmentally extreme cases, colonized by a selection of low, shrubby, herbaceous, or graminoid halophytes. The extent of cover by these plants is variable from dense meadows to scattered individual plants, depending largely on local rainfall and evaporation. The vertical extent of these habitats appears to vary from place to place but in general lies from somewhere above mean high water spring tides to below the level of the highest equinoctial tides.

Depending on the nature of the physical processes that formed these habitats, these areas can be very extensive. On the wide marine plains of northern Australia, they can be up to 30 km or more in width, and similar sorts of habitats are found in north and west Africa where they are referred to as "tannes" and in South America where they are variously known as pampas, salitrales, salinas, or apicum. In the Gulf of Kutch in India, it has been estimated that they cover an area of at least 15,000 ha.

This part of the intertidal zone is used successfully for commercial solar salt production in northeastern and northwestern Australia where there are high tides of monthly or longer periodicity. It is in a similar set of environments that the large-scale salt production operations in West Africa have also been developed (e.g., "Les Salins de Saloum" at Kaolack in Senegal).

Solar salt production operations of these types in these environments are the least potentially damaging, and, depending on the scale of operation, coastal land-use conflicts will not be serious.

EVAPORATION PONDS UNDER NONOPTIMAL ENVIRONMENTAL CONDITIONS

Unfortunately, salt production has become a highly significant economic activity in regions where optimal conditions do not exist. Departure from the optimum involves the three separate but interacting factors: (1) an insufficiently arid climate; (2) insufficiently saline coastal or estuarine flooding water; and (3) an absence of available, naturally unvegetated, high tidal saline plain. Depending upon the regional combination of these factors, the following types of operations have developed.

Figure 37. Salt production from evaporation ponds in Indonesia.

In Thailand, eastern Indonesia, and India moderate to very large-scale operations occur where physical environmental conditions are adequate to optimum but where conflict for the use of land in the upper tidal and adjacent supratidal environments has forced the development of evaporation ponds within the mangrove (see figure 37). In South Sulawesi in the Jeneponto region, salt extraction is on a sufficiently large scale to be a major export commodity, and salt is supplied to areas throughout eastern Indonesia from this source. In Thailand more than 10,000 ha of evaporating ponds have been established within the mangroves, and nearly 410,000 metric tons of salt are produced annually for both domestic and export markets (FAO/UNEP 1980). In India, production of salt from ponds in the Gulf of Kutch is so large that hills of salt can be detected from LANDSAT imagery at a scale of 1:1,000,000.

Operations of this kind represent a land resource conversion activity that may be of significance to the sustainability of local, regional, or even national mangrove resources. In Thailand successful reestablishment of mangrove plantations on abandoned salt pond areas has been reported, but the conditions of management that have allowed this to occur require further study. This is not the case in the Indian example where the large, centralized industrial developments in the region have attracted high densities of people who find work as a result of this activity. Under these circumstances the mangroves already represent relict communities that are under several physiological stress and are subjected to further human exploitation. This exploitation often takes the form of grazing by domestic stock and fuelwood extraction for domestic use. Out of the 52,000 ha of mangroves officially recorded in that part of the country, at least 30,000 ha already have disappeared and the remaining 20,000 are mainly composed of shrubby, discontinuous formations. The demand for salt despite suboptimal environmental conditions for salt production creates severe impacts by salt pond conversion on the mangroves of the coasts of Benin, Senegal, Gambia, Sierra Leone, Ghana, and Guinea (Tomlinson 1957). In these areas, extensive conversion of mangrove lands to salt ponds has taken place, and it has been suggested that this activity has historically resulted in the expansion of the saline plains *(tannes)* in this region (Paradis and Adjanohoun 1974; Pales 1960; Paradis 1980; Rollet 1975).

In contrast to the operations discussed previously, climatic conditions in much of West Africa require that solar evaporation be enhanced by boiling the brine. This is a decisive additional process that places severe pressure on unconverted mangroves as a source of fuel wood. Because of the use of interstitial soil water that has a higher salt concentration than the surrounding coastal water, the substrate is disturbed during extraction. This further mitigates against successful reestablishment of vegetation after abandonment. Typically, the extraction procedure in this region is exemplified by the practice in Benin. The main steps involved are summarized in Table 17.

The impact of this practice in West Africa is alarming. In Benin, most of the 30 km² of mangroves that remain are composed only of shrubby or herbaceous halophytic communities. Scattered *Avicennia* (to 3 m high) appear in immense stretches of a graminoid or herbaceous cover composed mainly of *Paspalum vaginatum*. In Senegal, *tannes* now cover 25,000–30,000 ha compared with a total mangrove cover of 56,000 ha.

Table 17. Procedure for Salt Extraction from Mangrove Soils in Benin, West Africa

Step	*Action*
1	A selected mangrove area ranging from half an hectare to 10 hectares is clearfelled at the beginning of the dry season (December). This step concerns mainly the *Avicennia africana* zone, which is the driest and the saltiest. The topsoil, often rich in organic matter and containing vegetational detritus, is removed.
2	The denuded mangrove subsoil is turned up 10 cm in depth to soften the soil, to facilitate the ascension of salt water by capillary action. After a few days during the dry season the sodium chloride and other compounds concentrate near the surface.
3	As soon as the salt content of the soil is considered sufficiently high, the loosened salt-enriched soil is raked and arranged in many small heaps and later into a few larger heaps.
4	The heaped-up soil is leached either *in situ* or in nearby villages. This means that its salt has to be dissolved in water. This water often taken from the water table is heated or boiled. For centuries and until very recently, the water was collected in large baskets (120 cm in diameter, 90 cm in height) weaved from *Rhizophora* prop roots and waterproofed by coating the inner part with a layer of clay about 15 cm.

Source: Paradis and Adjanohoun (1974)

Environmental Problems in Salt Production: A Summary

In the majority of cases where it is practiced, salt production is associated with the conversion of mangrove forests in a way that often is irreversible. Because of the climatic requirements for economically efficient salt production, the sites for such activities coincide with coastal environments where mangrove plants already are subjected to difficult ecological conditions. In these circumstances, allocation of land for salt pond construction, combined with associated factors such as grazing, fuelwood extraction, and freshwater diversion, creates conditions in which mangrove ecosystems and all their benefits cannot be easily sustained.

There is evidence that salt-extracting activities have been a highly significant factor in the loss of woody coastal vegetation in arid and subarid regions of the tropics. A West African example of typical consequences of a salt extraction operation include the following:

- Complete eradication of *Avicennia* trees and shrubs and the local diking of the land.

- Selective destruction of some or all available *Rhizophora* for the construction of baskets with silt-roots and subsequently for heating or boiling of concentrated brine.
- Repeated soil raking and increased compactness by continuous trampling, creating local, barren, poorly drained depressions flooded only during the rainy season.
- Local mangrove woody species are replaced by herbaceous salt-tolerant pioneer plants usually common in the *tannes* such as the fleshy *Sesuvium portulacastrum* L. (Aizoaceae), *Philoxerus verminalis* (L). BEAUV. (Amaranthaceae), and some almost pantropical halophytic grasses such as *Paspalum vaginatum* Sw., *Aeluropus lagopoides* (L.) TRIN., and *Elaeocharis sp.*

The significance of this process is related to the scale of the operation. Negative effective are most severe today where large-scale intensive salt extractive industries are developing with their supporting social infrastructure.

More research is necessary to describe the potential scale of the problem globally, and attention must be given to the development of design guidelines that suit the physical, biological, social, and economic conditions under which human demand for sea salt is being met.

Guidelines for Salt Production in Mangrove Areas

Although specific social, economic, and ecological factors will vary from place to place, it is possible to offer a series of management guidelines here that will contribute both to the efficiency of the salt production activity and to the sustainability of both this industry and the many other uses that may be made of the mangroves in the same region. The following points need to be considered:

- Analysis of climatic conditions should precede the allocation of coastal lands for salt production. Experience indicates that the most efficient economic operations are maintained where ETP>R for a minimum of about eight months, or where R<1,000 mm annually.
- Climatic conditions conducive to evaporative salt production are generally also conducive to the formation of saline plains at the higher tidal levels. Aerial photography or other suitable remote techniques will be useful in determining the distribution of those areas that can best support such an industry. Optimal land-use practice would suggest that salt ponds should be located in these areas of saline plains with little or no halophytic vegetative cover. Although such a decision may be difficult in regions of high coastal population densities, it needs to be recognized that if more seaward mangrove communities are allowed to remain, other sustainable products, services, and benefits also will be sustained.
- Where such a land-use allocation is not possible, mangrove planting should be undertaken to seaward of the bund walls which surround the evaporation ponds. Planting will provide protection against erosion of the bunds and also will increase the potential of remaining mangroves to be sustained as multipurpose resources. Opportunities for tidal and freshwater exchange should be maintained, or where necessary, created to allow for the maximum expansion of the mangrove plantations.
- Where possible, buffer strips of natural vegetation, reinforced where necessary by plantings, should separate the evaporation ponds from the coastline.
- Planning for solar salt extraction industries should remain mindful of the value of multi-use management regimes with compatible uses. Many of these have been referred to in the preceeding text. Other examples include the culture of the unicellular alga *Dunaliella* for carotene extraction (e.g., in Australia) or the cultivation of *Artemia* brine shrimp as fish food.
- Where ponds in mangroves are abandoned, the walls should be breached to allow for seawater flushing and the possible subsequent recolonization of the area by local mangrove species.

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SECTION II

CHAPTER 13. Agriculture

Introduction

At best, mangrove soils can be considered a marginal resource for the sustained development of agriculture in the tropics. Examples of "good" rice lands or other agricultural uses of soils successfully reclaimed from mangrove are rare. In any case, yields of paddy on former mangrove lands remain well below those on favorable inland soils.

Mangrove soils often are characterized by properties that limit their agricultural value, including potential acid sulphate clays, salinity, and shrinkage or subsidence when the soils are worked.

The development of salt-tolerant plant varieties may help to improve potential agricultural yields from former mangrove areas but such areas will continue to be subject to coastal storm hazards, periodic flooding from exceptionally high tides, or poor watershed practices. The combination of these factors reduces the potential agricultural suitability of mangrove areas.

Historical and Traditional Practices

In Africa and Madagascar, mangrove ecosystems were almost untouched until the introduction of rice cultivation as a major food crop during the course of the nineteeth century, first in Guinea and Sierra Leone (1855) and later in Madagascar (1935).

In Asia, the decline of mangroves is concomitant with the progressive increase in rice cultivation. The case of Gangetic Delta provides a clear example. Rice became a major food crop in the twelfth century (or earlier), and since the fifteenth century, half of the mangroves in the delta have been reclaimed (about 6,000 km^2). The process accelerated during the twentieth century due to the local exponential population growth. As a result of this rapid growth, the northern limits of the gangetic mangroves cannot be delineated clearly because of the total land reclamation for agriculture (rice, coconut, *Casuarina*). According to Banerjee (1964), the total regression of mangrove ecosystems in the Indian Sunderbans during the last 100 years is of about 1,500 km^2.

The production of rice is not the only objective of the conversion of mangrove soils by local people. In the third or fourth year after the reclamation, coconuts (*cocs nucifera*) can be planted on slightly saline soils. In Chao Phya Delta in Thailand, on the northern coast of Sri Lanka, in Cambodia, in Vietnam, in India, in the Gulf of Papua, and in other locations coconut groves have replaced mangrove areas, but specific figures about areas involved are not available. In other locations like Trinidad, Martinique Island, Fiji, and Puerto Rico, considerable areas of mangroves have been reclaimed for sugar cane production (Bacon 1975, Baines 1977, Vivas 1974, Kermarrec 1977), whereas oil palm (*Elaeis quinensis*) is also grown on reclaimed mangrove soils on the west coast of Peninsular Malaysia (Wong 1979) and in Senegal.

The traditional conversion of mangrove soils to food crops is also often associated with the development of grazing lands. This is noteworthy in the Godavari Delta in India, and it has been recorded in Colombia (Las Barces, San Antonio) (Winograd 1982). A few spontaneously colonizing grasses (*Aeluropus, Dactyloctenium,* and *Porteresia*) and sedges (*Scirpus, Fimbristylis*) are able to grow on saline soils.

The Quality of Mangrove Soils for Agriculture

Mangrove soils may appear to have great potential for agricultural use. Factors such as flat topography, the potential use of tidal forces for drainage and irrigation, moderate to high nutrient levels, organic materials, or accessibility make them attractive. Closer examination, however, shows that mangrove soils can be difficult to manage due to problems of flooding, salinity, and the formation of acid sulphate soils.

FLOODING REGIME AND SALINITY PROBLEMS

Cultivation on mangrove soils requires major modifications in tidal-flood regions. These include building dikes or bunds to stop saltwater from flowing into field areas and constructing drainage and irrigation channels. Dikes or bunds need to be high enough to prevent extreme high tides from inundating the crops.

However, these dikes or bunds are often constructed in the cheapest way and are often so small and so unstable that fields are periodically inundated with salt water, which severely damages crops. In Senegal as well as in islands like Mindanao in the southern Philippines or on Java, Kalimantan, and Sumatra in Indonesia, such "tidal lands" used for rice production are commonly penetrated by saline water. In India and Bangladesh, tall embankments are used to protect areas of rice cultivation that occupy large stretches of mangrove, some of which are below the mean sea level. These embankments are often destroyed by cyclonic disturbances and it is also extremely difficult under these conditions to prevent seawater intrusion by seepage. Moreover, since embankments are usually constructed from mangrove soils, which are rich in organic matter, crustacean burrowing activities lead to seawater seepage.

In dry climatic regions (e.g. Mekong Delta, West Bengal in India, coastal areas in Thailand) strong seasonal salt accumulation is common. In humid regions where artificial drainage networks and empoldering works have been constructed (Musi River in Sumatra, Barito Delta in Dalimantan, Red River Delta in North Vietnam) the salinity has progressively decreased. Thousands of hectares of "mangrove rice lands" of India and Bangladesh have very low yields during the rainy season (about 1.5 tons per ha), and they are unproductive during the dry season due to the formation of a saline crust on the soil surface (Blasco 1975).

Although the sensitivity of rice to salinity varies considerably among varieties and according to the age of the plant, it appears that "soil solutions high in sodium chloride with electrical conductivity values of 5–10 millimohs per cm at 25° C are associated with 50 percent decrease in yield" (Moormann and Van Breemen 1978).

Alteration of the hydrologic regime to suit the requirements of agriculture in mangrove areas can deprive other coastal lands of their normal supply of fresh water. The reduction of fresh water supplies can create serious problems of increased salinity in other coastal lands and can reduce the productivity of other production systems, such as pond mariculture.

Maintenance of the hydrologic regime is an important factor in sustaining development in coastal areas. The construction of the Farraka Barrage on the Ganges in 1975 has created a major impact upon downstream land uses and sparked a major dispute between India and Bangladesh (Abbas 1982).

ACID SULPHATE SOILS

A further factor that can limit the viability of agriculture in mangrove areas is the presence of soils that develop an acid sulphate condition when tilled and exposed to air. Countless failures to grow rice successfully on these soils are reported from West African countries as well as from Southeast Asia. The pedological processes of acid sulphate soils formations, though extremely complex and diversified, are well known. Under anaerobic conditions, sulphates from the sea are usually reduced to iron sulphide or pyrite (FeS and FeS_2) by sulphate-reducing bacteria belonging to at least two genera (*Desulfovivrio* and *Desulfatomaculum*). Natural or artificial drainage and aeration of these pyritic sediments leads to their oxidization and to formation of sulfuric acid, which is abundantly released in the absence of calcium carbonates ($CaC0_3$) (Pons and Zonneveld 1965, Vieillefon 1974, Marius 1977).

When mangrove soils are in contact with the air, oxidation takes place in several stages which have been summed up by Beye (1973). Two of these stages are show below:

$$FeS_2 + H_20 + 3\frac{1}{2}\,0_2 = FeS0_4 + H_2S0_4$$
$$Fe_2(S0_4)_3 = 6H_20 = 2Fe(0H)_3 + H_2S0_4$$

Some acid sulphate soils in Senegal in the Tobor area have a pH of about 2.5. In the Plain of Reeds in South Vietnam pH values as low as 3.5 have been recorded. Toxicities seem to be due also to a high level of dissolved aluminium released from aluminium silicate at low pH and which is toxic when it exceeds 2 mg per liter. In Vietnam low pH values are accompanied by aluminium concentrations of about 10–50 mg per liter.

Many cases of major failures of conversion of mangrove lands to rice fields have been recorded in much of the tropical world (except Australia). Examples can be found even in the Americas, where little agricultural land is reclaimed from mangrove soils. Bacon (1975) has reported an attempt to reclaim about 400 ha of mangroves in Trinidad in 1921 where the aim was to provide more land for rice and sugar cane cultivation. The scheme ran into difficulties and was abandoned mainly because of low agricultural yields and sulphate soil formation. In Asia, major failures have occurred in Bangladesh in the Chittagong area and in Indonesia where low yielding *sawahs* (less than 1,000 kg per ha) have been abandoned near Banjarmasin on Borneo and Palembang on Sumatra.

These abandoned fields have a typical appearance because they are invaded by tall sedges (*Fimbristylis*) and sometimes also by *Melaleuca*. With the exception of Pakistan and the Philippines, it seems that the majority of Asian deltaic regions are dominated by extensive areas of acid sulphate soils. According to Ponnamperuma and Bandyopadhya (1980), they affect more than 5 million ha in the region; 2 million affected ha have been recorded in Indonesia, and 1 million ha are affected in Viet Nam.

In Africa, there are several examples of spectacular human-induced acid soils formation (in Guinea, Wellington and Kokupr areas in Sierra Leone). One of the most striking economic and ecological mistakes in mangrove areas is probably that of Tobor, near Ziguinchor in Lower Casamance (Senegal). About 200 ha of reclaimed mangrove soils have been significantly acidified (pH of 2.5), desertified and then abandoned (nothing else could have been done) after a private company had tried in 1970 to drain the area and to convert it to rice land. Thirteen years later, the mud remained barren (Blasco 1983a).

The reclamation of mangrove areas for rice has generally produced disappointing results, and the best yields from these soils remain below 3 metric tons per ha. During the early years of the reclamation process, the farmers are compelled to plant the rice on small ridges to facilitate the leaching of acids and salts and to avoid periodic inundation (see Figures 38, 39, and 40). At this stage, in West African countries, the yields are often below 1 ton per ha. In Malaysia, in the Merbok area, yields on recently reclaimed soils do not exceed 1.5 tons per ha and remain about 2 tons per ha even after liming and use of fertilizers (Diemont and van Wijngaarden 1975).

One specific disturbance that now exists in a mangrove area of the Orinoco Delta in Venezuela was caused by the closing of the Cano Manamo, one of the main branches of the Orinoco, with a dam primarily to increase the arable land. However, it has resulted in a remarkable, unanticipated change in vegetation patterns and soil conditions in the affected region. Contrary to expectations, the area around the northern extent of the dam remained flooded because of persistent hydraulic conditions created by a network of secondary watercourses in that area.

A drainage system was subsequently built to relieve the flooding and lower the water level to achieve what the dam had failed to do. That attempt brought further complications because it created acid sulphate soils that negatively impacted the distribution of natural vegetation besides restricting the agricultural capacity of the area. The interception of sediments by both the dam and the drainage works has affected the local strips of riparian mangroves in the lower course of Cano Manamo and other neighboring creeks (Pannier 1979).

Control Measures Needed for Agricultural Development in Mangrove Areas

If mangrove areas are to be developed for agriculture, drainage and water control measures will have four basic functions: (1) flood control, (2) saline water intrusion control, (3) water table control, and (4) water pollution control. These control measures generally require sophisticated and costly structures.

Drainage is required to remove excess water and to promote aerobic conditions. The depth of drainage required will depend upon the intended crop and its rooting characteristics. The structure of the soil, its water retention characteristics, and the distribution of rainfall over the growing season all have to be considered in the control of water levels. For areas directly influenced by tides, long-term cyclic variations in tidal range, daily and seasonal tidal flows, and the pattern and depth of field drainage will have to be balanced carefully.

Tidal range is a key factor in determining the suitability of mangrove areas for agriculture. The construction of water-control structures is related to the low water level of the average tidal range and the peak flood level of extreme high tides. A base level is used to determine gradients of slope for drainage channels to allow a sufficient gravity-induced flow of water from the cultivated area during a falling tide.

The elevation of the agricultural area should allow free drainage of the soil. If the elevation is too low, pumping will be required to ensure continuous leaching of acids or salts and to maintain proper water levels for crops.

The elevation of the agricultural sites will also have a bearing upon the gravity flow of fresh water for irrigation or for flushing acids and salts from the reclaimed soils. A balance between peak flooding levels and extreme high tides and the elevation of the proposed agricultural areas is required to allow free flows of fresh water and to avoid contamination from salt water. The seasonality of water flows and levels will also have a bearing on the determination of gradients for irrigation channels.

To provide adequate protection for reclaimed

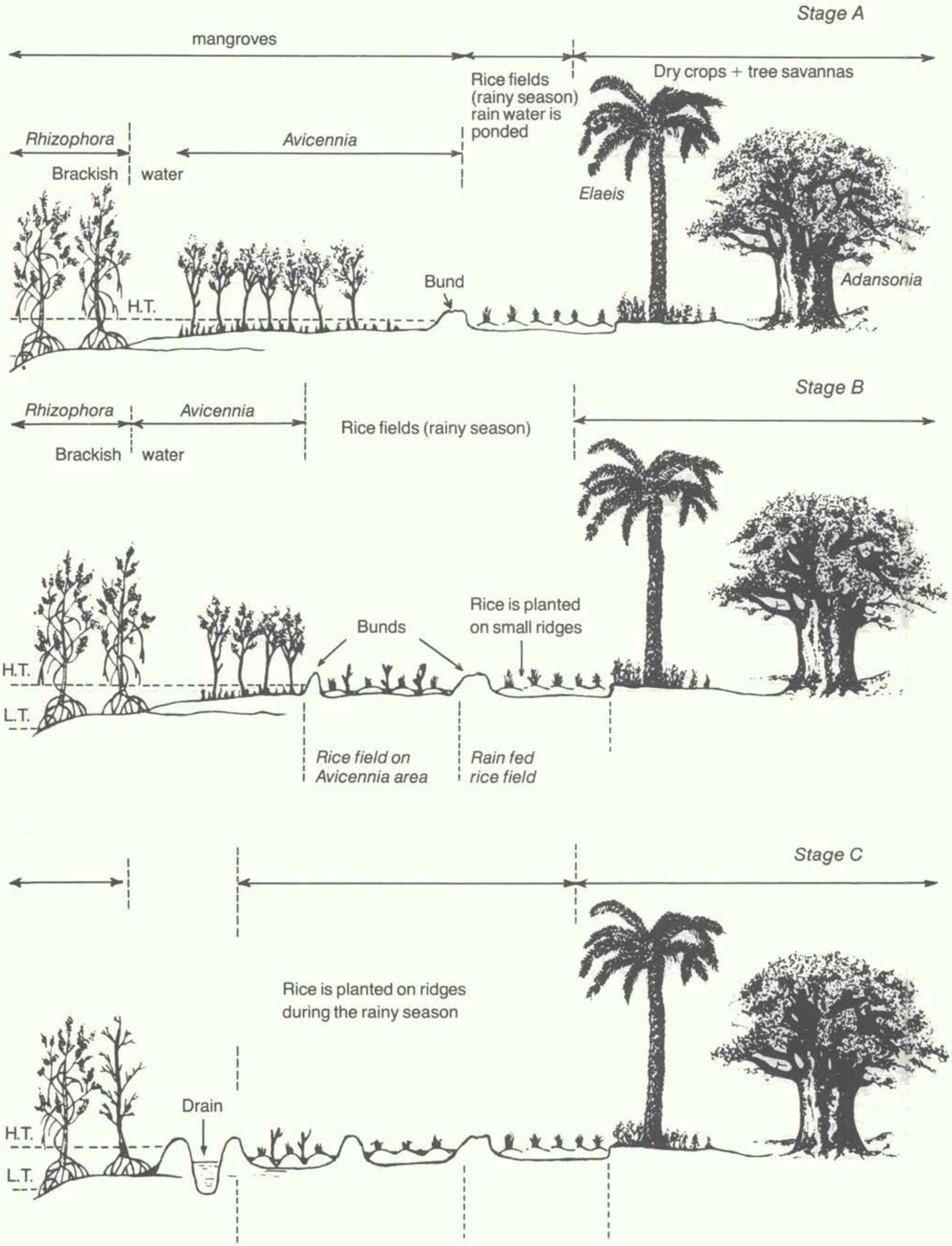

Figure 38. Conversion of mangrove soils to agriculture in Casamance (Senegal).

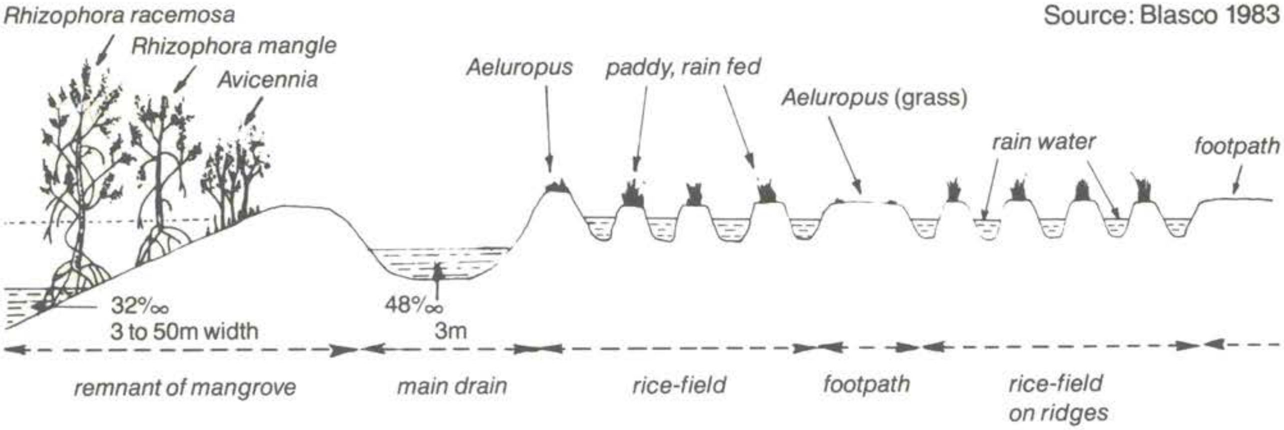

Figure 39. Artificial landscape at Ourong (Casamance, Senegal)—rice fields in a reclaimed area.

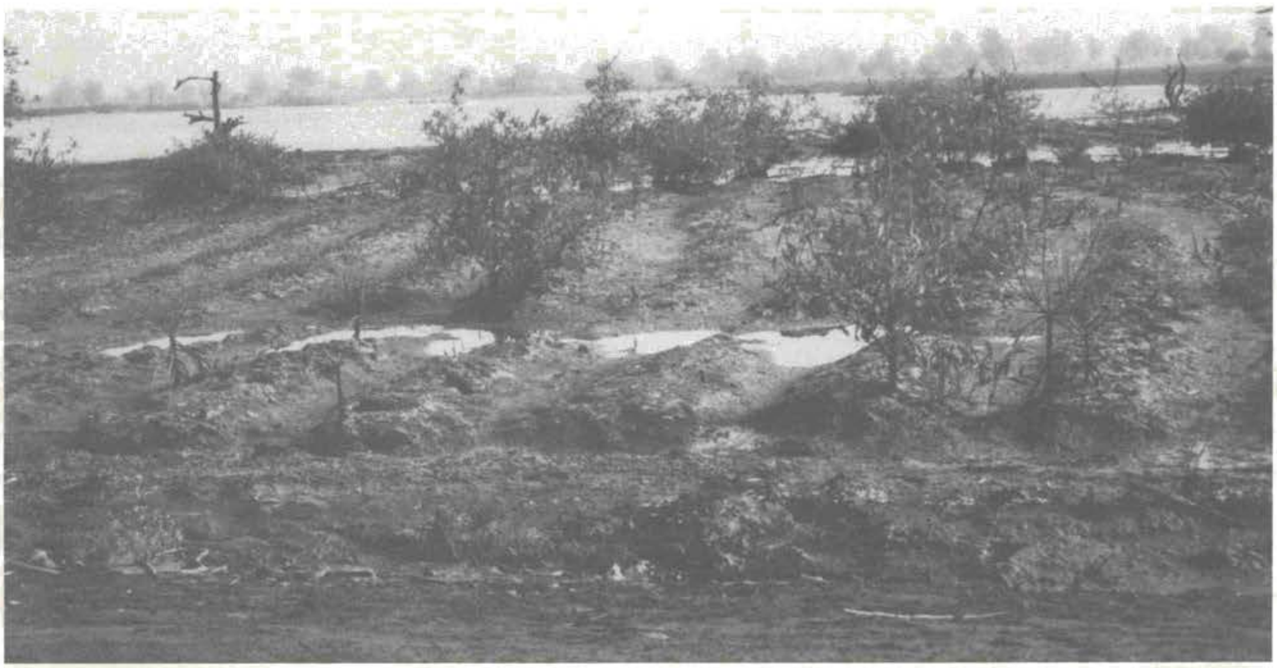

Figure 40. Mangrove area temporarily reclaimed for rice production on ridges. Acid sulfate soils have caused much land abandonment in adjacent areas.

lands, dikes or bunds need to be constructed that are sufficiently strong to withstand storm damage. The elevation for these structures is determined by the water levels attained during cyclic tidal crests or flood periods.

All of the characteristics of reclaimed agricultural areas will be subject to the effects of upstream activities such as land clearance and agricultural, industrial, or urban development. Each of these disturbances will have a bearing upon the quantity and quality of water available for flushing and irrigating the reclaimed mangrove soils. Data on these factors are often scarce and advice should be sought from hydrological and meteorological agencies.

Government-Sponsored Reclamation Schemes Affecting Mangroves

In most of Asia, population growth is concentrated in coastal areas. On the northern coast of Java, in East Sumatra, South Kalimantan, Selangor in Malaysia, the mouth of the Ganges, and other locations, population densities have increased between 3 and 4 percent yearly. Until recently, the reclamation of coastal lands occurred mainly on freshwater swamp lands external to the mangroves. This is no longer the case. Reclamation schemes are extending rapidly into tidal forests and mangrove areas. The case of El Salvador, with a national average population density of about 200 persons per km^2 and an annual population growth of about 3 percent, is interesting because this country is the most densely populated of the Americas. Daugherty (1975) assumes that El Salvador's mangroves and adjacent forests have been reduced by nearly one-half in recent years; this means that at least 300 km^2 of mangroves have been reclaimed primarily for cotton and coconut plantations. A similar situation exists on the island of Martinique where hundreds of hectares of "La Riviere Salee" have already been drained by a private society for sugar cane cultivation (Kermarrec 1977).

Population growth and plans to redistribute people to less populated areas are stimulating two of the world's major environmental transformations of mangrove lands. In Indonesia, a major problem facing the government is the uneven distribution of population where about 65 percent of its total population (about 160 million) live on about 7 percent of its territory, mainly in Madura, Bali and Java. An ambitious "transmigration programme" has been undertaken in order to resettle several million Javanese peasants in Sumatra, in Kalimantan on Borneo, and in Irian Jaya. Large-scale, highly mechanized, and capital intensive investments in dredging, opening of new waterways, and deepening of canals have been undertaken in these coastal areas of Riau, Jambi, and Palembang provinces in Sumatra, as well as in west, south, and central Kalimantan to prepare the swamp lands for agricultural settlement. The focus of these development efforts is the freshwater tidal swamps lying landward of the mangrove area. The mangrove forest is being left intact, but it is not yet clear how it will be affected by alterations in the freshwater flow, acid drainage from the cultivated peat soils, or pesticides and herbicides. As a result of the First Five-Year Development Plan (1969–1974) almost 200,000 ha of tidal forests have been converted into agricultural lands. In the Second Five-Year Development Plan (1974–1979), an additional 15 million ha were converted into rice fields, fishponds, and other production purposes (Soegiarto 1980).

Yields of rice remain low (1–3 tonnes per ha), but the government as well as local people (Bandjarese and Buginese immigrants in Kalimantan) continue to open more and more coastal forests for government-sponsored and spontaneous transmigration projects based on rice production. There are serious doubts concerning the long-term viability of converting many of these coastal peat swamp soils for agriculture. Subsidence within the soil profile, acid sulphate conditions, seasonal salinity, and problems of water control pose management challenges that few developing countries have either the financial resources or personnel to deal with effectively.

In Indonesia there is no basic scarcity of land, and the development of the tidal swamp lands has associated opportunity costs formed by the loss of the returns from the sustained-yield mangrove forestry. This form of opportunity cost can be considerable and seriously diminishes the potential net returns from agriculture. Coupled with the questions of the sustainable nature of the agricultural development of tidal swamp lands, this makes other alternative agricultural development options more favorable (Burbridge et al. 1981). Any damage to the mangrove system resulting from the reclamation of the peat swamp forests should also be included as a cost to be set against the potential agricultural returns.

In Senegal, the "new innovation" is the construction of *antisalt barrages*. The aim is not irrigation, flood control or power station construction. The main objective is protection of upstream lands from brackish-water intrusions. Four barrages of this kind have been planned in the lower Casamance where the average water salinity during the dry season varies from 32 ppt near the mouth of the river to about 60 ppt upstream at about 70 km from the sea. One of these dams (barrage de Guidel, near Ziguinchor) was constructed in 1982. All mangrove trees have been killed upstream in less than six months, and the general evolution of soils downstream is unfavorable because of the increasing salinity. Until now, nobody knew to what extent the biology of plants and animals would be affected by this kind of human interference on the downstream mangroves.

Altogether, the scheme that includes the construction of barrages in the Baila, Kamobeul, and Soungrougrou areas concerns 100,000 ha of saline areas for which the government hopes to gain water control and to gradually replace saline soils with good agricultural land. Needless to say, it is impossible to predict the future of the mangroves in lower Casamance or the future of the 2,000 fishermen whose catch averages 1,500 tonnes of shrimps annually in the delta. At this stage, little is known about the long-term impacts of such large-scale conversions on the ecology of the remaining tidal forests and the surrounding areas, particularly the linked marine ecosystem.

Conclusion

Even if conversions of mangrove ecosystems into agricultural land are poorly documented, the examples described here show clearly that ecological, cultural, and demographic factors encourage this type of substitution throughout much of the tropical world. The cost of reclamation practices in mangrove areas is high, often exceeding the benefits because of problems related to flood regimes, to salinity, and to acid-sulphate soil formation. Drainage and water control measures must deal with flood control, saline water intrusion control, water table control, and water pollution control. These functions require a considerable expertise as well as sophisticated and costly structures. Good agricultural lands reclaimed from mangrove areas are rare. In spite of spectacular and numerous failures, major reclamation schemes are being conducted in African and Asian mangrove areas leading to major environmental transformations that may have significant negative influences on coastal fisheries.

Basic Guidelines and Site Selection Criteria

The reclamation of mangrove areas for agriculture should only be attempted once all other alternative agricultural development options, such as intensification or expansion into upland areas, have been exhausted. If, after careful examination of the alternatives, it is decided to develop mangrove lands for agriculture, the following guidelines may help to improve the sustainability of agricultural use and to reduce the impacts upon the mangrove system and associated estuaries:

- Do not develop acid sulphate soils, but leave them undisturbed with mangrove vegetation.
- Restrict the control of tidal inundation and provision of improved freshwater supplies to the areas where fields or paddy will be developed. In all other areas where mangroves are to be left, the hydrologic regime should remain undisturbed.
- Consider only soils above the mean sea level for agricultural use to avoid salinity problems.
- Construct bunds, embankments, and polders to an elevation which will protect the agricultural uses from tidal inundation during the major storms. Use meteorological data and tidal records to determine the frequency and maximum flood levels to be expected in areas considered for agricultural use; storm surge levels, especially during cyclones need to be taken into account.
- Construct all drainage channels to facilitate the leaching of acids and salts from the agricultural fields and prevent formation of stagnant water or the intrusion of salt water. These drainage channels should flow into the larger rivers and not directly into surrounding mangrove areas.
- Be sure dry season freshwater flows are capable of sustaining the agricultural crops and preventing the seepage of saline waters into the agricultural soils.
- Assure that the area under agriculture and the cropping patterns will not place demands on the freshwater flows to rivers and increase saltwater penetration inland. Minimum freshwater flows must be maintained to prevent intrusion into groundwater supplies, agricultural soils, and irrigation waters.

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SECTION III RESTORATION AND ESTABLISHMENT*

Introduction

The restoration or establishment of mangroves is a management option that can be applied to stabilize unvegetated areas (such as river banks, shorelines, canals, or spoil heaps) or to enhance or regulate natural regeneration.

In general, planting of large tracts for non-silvicultural objectives is best left to nature because of the expense involved. It is possible, however to prepare the terrain and accelerate the recovery of an area by planting in naturally "bald" spots or thinning dense clumps of arrivals to avoid "stagnation." If an area is subjected to stress (e.g., chemical pollution), then for restoration to be successful the source of stress must be largely removed and only tolerable amounts left.

Planting Propagules or Seedlings

Rhizophora is one of the easiest and most economical genera to use for planting. Propagules may be collected and stored for more than twenty days in a moist container before use, and they can be allowed to develop primary roots without impairing their vigor. Propagules also have been stored in dry rooms for up to two months in the Philippines at the Mangrove Research Center. Mortality of these seedlings is site-specific and may range from 10 to 70 percent. Although recently collected mature hypocotyls are usually used for planting, in some circumstances there is a better survival rate and more rapid growth if they are grown in a nursery before planting. This allows the seedlings to develop a healthy root system before implantation. The higher nursery costs and increased difficulty of planting, however, may offset this advantage.

Seeds of other species (e.g., *Avicennia, Heritiera, Laguncularia, Cynometra*) may be sown by hand. They should be left on the surface and not buried, although gentle pressure may be used to push them into the soft sediments. They must be seeded at a time when the area is not expected to be flooded for at least a week so that the seeds are not dispersed before they become established. It is to be expected that less than 50 percent of the seedlings will become established so it is important to ensure that distribution of seed to the site is repeated as necessary. Use of nursery grown seedlings might be considered for these species.

Transplanting Trees

Small trees of *Rhizophora mangle, Aegiceras corniculatum, Avicennia germinans, A. marina, and Laguncularia racemosa* (five or more years old, 0.5–1.5 m high) have been successfully replanted. Planting trees of this size may be desirable where seedlings may be uprooted and washed away. The larger size of the trees and their more extensive root systems offer a promise of greater and faster shore protection than can be achieved using seedlings. This technique also may be used to salvage individual trees in areas to be used for other purposes, and the trees can serve as a source for restoration purposes in other areas.

Small trees of other species (e.g., *Avicennia marina, Aegiceras corniculatum* and *Rhizophora stylosa*) also can be transplanted. For plants less than 1 m high, success rates of approximately 80 percent have been achieved for the *Avicennia* and *Aegiceras* in mixed plantings of more than 50,000 plants.

The survival of larger trees following transplanting appears to be poor. For example, in Puerto Rico, the transplantation of thirteen *Avicennia germinans* and *Laguncularia racemosa* mangrove trees 5–13 cm in diameter and up to 6 m high resulted in the death of all trees within six months. These trees had been root pruned five to six months before transplantation and were top pruned to 1/4 to 1/3 of their height at the time of transplanting. Moving the trees rather than pruning caused the mortality.

When root-ball and soil-free transplanting techniques for planting small trees are compared, the root-ball method yields higher survival rates (85 percent vs 65 percent after three months) when the trees are planted at natural depths with leaves intact. Leaf stripping resulted in an initial high rate of leaf production but after four months the normal (unstripped)

*Much of the material in this section is based on work carried out by one of the authors in a study sponsored by the U.S. Coastal Zone Management Program (NOAA) and the Department of Natural Resources of Puerto Rico.

trees had more leaves. Leaf stripping did not seem to affect survival.

Twig and branch pruning before replanting apparently enhances recovery; pruned trees grow better and suffer less defoliation than unpruned ones. Reduced foliage also decreases water loss during the adaptation period following transplantation. Trees or bushes to be replanted should be pruned to two-thirds of their original height.

Unpruned and some pruned individuals of *R. mangle* and *L. racemosa* have exhibited defoliation following transplantation. In *L. racemosa* and *R. mangle* defoliation has occurred within thirty-six days after replanting but in *A. germinans* this occurred some eighty-four days after replanting. *R. mangle* suffers little defoliation even if unpruned, and pruning resulted in a 23-percent decrease in growth after transplanting. Pruned and unpruned *L. racemosa* have had difficulty in becoming established, but pruning does increase growth rates of this species following transplanting. Pruned and unpruned *Avicennia* respond well to transplantation although some trees will show partial defoliation.

Care must be taken in pruning *Rhizophora*. If branches greater than 2.0 in diameter are pruned back there will be no sprouting, and the branch will continue to die back. In contrast, *Avicennia* and *Laguncularia* are extremely tolerant of pruning, and this can include major branches as well.

Where individuals are being pruned for transplantation the root ball diameter should be as large as possible, no less than one-half the original (unpruned) tree height. The root ball must be dug from a depth of at least 20–25 cm to reduce damage to the root system, and the root ball should remain intact. In the case of *Rhizophora*, prop roots should be included in the root ball, but if severed they should be left on the tree for possible regrowth.

Replanting should be made at approximately the same tidal level as the original habitat. The root ball should be placed in the prepared hole, watered, and stamped on while replacing soil to seal the space between the root ball and the sides of the hole. During this stage, care must be taken not to bury or damage prop roots or pneumatophores. Slow-release fertilizers maybe placed in the hole before planting to aid in the recovery process, although no data are available to demonstrate the value of this practice.

Spacing

The determination of proper spacing intervals should be based on the distance that will minimize early competition. Thinning will occur naturally without human intervention; however, a stand can be managed to avoid periods of slow growth due to competition. By selecting an appropriate spacing, artificial thinning is postponed to later stages of development of the stand.

A planting distance of .4–.6 m has been used in plantations of *Rhizophora mucronata* in the Philippines. For mixed stands of *R. apiculata* and *R. mucronata* a spacing of 1.8-by-1.8 m has been recommended. For mixed stands of *Avicennia marina* and *Aegiceras corniculatum* a spacing of 1.5 m has been used in Australia. In general, at a mean tree spacing of more than 1 m, self-pruning does not start until the seventh year.

Habitat Selection

Each species should be planted within its tidal and flooding tolerance range and in suitably sheltered locations. In most cases it will be possible to ascertain these site characteristics by observing the growth of mangroves nearby. If this is not possible, a manager must ascertain the elevation of the site above the tidal datum and predict flooding depths. Species tolerant of submersion should be planted at the seaward edge (e.g., *Rhizophora mangle*, *R. stylosa*, *Avicennia marina*, *Sonneratia* spp.).

Ideally, planting should be behind a protective mangrove fringe or a protective barrier of transplanted small mangrove trees or a native nurse plant species to provide initial wave and current protection (i.e. *Spartina*).

At the landward margins, species tolerant of drier conditions should be used (e.g., *Lumnitzera racemosa*, *Ceriops* spp., *Excoecaria agallocha*, *Laguncularia racemosa*).

Air Layering

Air layering has been suggested as a promising technique to provide stock plants for transplanting without removing mangroves from a source area. It is a commonly used horticultural technique in which short segments of bark and phloem are stripped to the cambium and the exposed area is wrapped with sphagnum moss and aluminium foil or plastic to retain moisture. This promotes root development at the girdled area and allows the branch (the layer) to be removed from the parent plant and planted. It has been suggested that this technique should be attempted at the beginning of the wet season to assure exposure to moisture (and in Florida to warm weather). Moisture appears to be a crucial factor determining its success. Drying impairs root formation, whereas too much water may promote fungal and bacterial infections and cause death of the branch above the wound. No branches greater than 2.5 cm in *Rhizophora mangle* have been used in experiments since there appears to be no regrowth on branches greater than that size.

In summary, these investigations found that the girdling was more easily done in *Laguncularia racemosa*, followed by *Rhizophora mangle* and *Avicennia germinans*. However, the technique was most successful with *R. mangle* (rooting success 39 percent) followed by *L. racemosa* (35 percent) and *A. germinans* (6 percent). *R. mangle* produced the longest roots. These roots were firm, had good color, and often had short secondary roots. *L. racemosa* and *A. germinans* produced smaller roots. *A. germinans* often produced roots off the stem above the layer site. Callus formation occurred in 45 percent of the *R. mangle* airlayers, 20 percent of the *A. germinans*, and 15 percent of the *L. racemosa* that had not produced roots.

Additional work is needed to ascertain the practicability of this technique. Among the variables that still need further experimentation are type of wrapping material (aluminium foil, plastic, or other), effect of application of rooting hormones, and whether the plants can be planted directly or need to be stored under mist conditions for some time.

Costs

The cost of restoration of mangrove areas is highly variable depending on such factors as the local labor costs, the characteristics of a site (its accessibility), its proximity to propagule sources, and whether propagules or more mature stock (transplanting) is used.

In Malaysia, for example, at Port Klang, Selangor, contractors were paid M$99 per ha, while at Matang, Perak, the Forestry Department staff undertook planting at M$74–$198 per ha over a four-year period (1977–1981).

For red mangrove (*R. mangle*) planting in the United States, restoration has cost US$10,175 per ha for a spacing of 30 cm, US$2,470 per ha for 61 cm, and US$1,140 per ha for 91 cm. The costs of similar projects using black (*Avicennia germinans*) or white (*Laguncularia racemosa*) mangrove were about twice these: US$22,400 per ha for 30 cm distances, US$5,400 per ha for 61 cm, and US$2,510 per ha for 91 cm spacing. The cost of planting three-year-old trees at 123 cm spacing has been estimated at US$216,130 per ha based on nursery-grown stock at a price of US$35 per unit. These costs were extrapolated from small-scale experimental plantings and exclude profits and overhead. Other expenses that can increase these costs considerably are the need for preplanting surveys (biological and topographic), site preparation, and administrative requirements (e.g., permit transmittal).

Actual costs for a red mangrove (*R. mangle*) planting project at a 91 cm spacing was US $12,500 per ha, more than ten times the cost of small-scale experimental plantings. This was based on the actual costs incurred until 1979 for a large-scale mangrove restoration project on St. Croix (U.S. Virgin Islands).

At the new Brisbane International Airport in Australia, 51,000 seedlings were planted at a total cost of A$228,271 at A$4.50 per plant (Australia Department of Housing and Construction 1983, personal communication). The work involved collection of seedlings within the airport site of *Avicennia marina* and *Aegiceras corniculatum*, transportation, planting, and maintenance on a 10-m-wide bench for a length of 6.2 km on each side of a floodway. Plant density was 41 per 100 m² (1.5-m spacing). On the other hand, in the same project, a nursery supplied approximately 9,500 plants at a cost of A$1.33 each.

Success of Restoration Efforts

The success of planting efforts may be difficult to assess. The degree of exposure to wind and wave action is a crucial factor, and efforts to plant on rapidly eroding shorelines, exposed locations, or in areas of heavy boat washes have little success. When nature does the planting, the propagules disseminate over broad areas and only those that reach the proper locations develop into mature trees. This is achieved through massive plantings in space and through time so that opportunistic plantings can take place during unusual periods when conditions may briefly become conducive to establishment. Once established, these plants may fare better and have a greater chance of becoming mature trees than plants purposely planted.

Often, humans attempt to plant trees in areas where none are found. This invariably results in a waste of effort since the same forces that eliminated nature's plantings may adversely affect human efforts.

In 1938 John Henry Davis planted 4,100 *R. mangle* seedlings at Long Key, Tortugas, Florida. These were planted on calcareous sands and muds and on coral ballast where mangroves were forming a pioneer community. The plantings were made to see if a thicker stand of *R. mangle* could be developed to hasten the natural process of establishment of the swamp. By July 1939 about 3,300 (80 percent) had survived. Thirty-two years later none of these planted trees could be found.

At a high-energy site in the St. Lucie River (Florida), of 178 seedlings planted, all were lost within seven months. At a moderate-energy site where seedlings had been planted in jute mesh, survival was less than 10 percent after one year. At a low-energy site on the U.S. East Coast (isolated from public access) 90 percent of the plants survived after four years. At Charlotte Harbor (Florida) in a low-energy site 85–90 percent of 60,000 propagules survived after one year, and the majority were alive after the end of the second year.

On the south coast of St. Croix (U.S. Virgin Islands), of 86,000 red mangrove seedlings planted, 75 percent survived after one year and 40 percent survived for two years. Success with *A. germinans* (sown by hand) was low (1–2 percent) and only successful where wave and current energy levels were minimal. In some areas, growth of the black mangroves has been rapid, with some trees attaining 1 m in height in twenty months. Flower and seed production was seen at the end of this period in this species.

Planting in a dredge spoil island in Florida resulted in survival of 15.7 percent of the 2,477 trees planted 0.9-m apart with root balls 20–38 cm in diameter. Some of the transplanted trees had been treated upon planting with 100 g of a slow-release fertilizer. Three years after the initial planting there were only 389 survivors. The main factor impairing survival was attributed to the settling of the island, resulting in some submergence of the planted trees (possibly stressing the plants) and greater erosion.

Planting in high-energy environments yields poor results; for instance, 920 seedlings of the three major mangrove species (red, black, and white) were planted at the Big Bend Power Plant, in Tampa Bay, Florida, U.S.A., and although some of the seedlings were provided with artificial protection (such as stakes and rubber tires), the success rates were low. Only 11 percent of the *R. mangle*, 16 percent of the *Avicennia marina*, and 10 percent of the *L. racemosa* survived. The survival of planted *R. mangle* propagules was even poorer—only 2 percent. These low success rates were due to erosion caused by storm-induced waves and tides during winter.

Experimental plantings in an exposed area of North Biscayne Bay (Florida) resulted in a survival of only 7 of the 370 plants (red, white, and black mangroves) after ten months, and none survived after twenty-four months. In a low-energy canal site, survival after six months of 57 red mangrove trees (0.6–2.7 m tall), 13 black mangroves (1.2–2.5 m), and 18 white mangroves (.3–3.6 m) was 100 percent.

Planting of more than 48,000 seedlings of *A. marina* and *Aegiceras corniculatum* to stabilize a relocated mangrove creek in Brisbane, Australia, showed survival rates in excess of 80 percent after four years, with most plants flowering and fruiting in the fourth year (Australia Department of Housing and Construction 1984, personal communication).

In Vietnam large areas of former mangrove that had been severely affected by herbicide application during the war are currently being rehabilitated. One of the large-scale planting projects was at Rungsat near Ho Chi Minh City, where crews of up to 1,000 persons were each able to plant 0.2–0.3 ha with propagules of *R. apiculata* every three hours while the tide exposed the area (Zinke 1983, personal communication). The success rate in these low-energy, diurnally flushed areas has been over 90 percent at densities of 4,000, 6,000, and 8,000 per ha, and by 1983 some of the three-year-old trees were more than 3 m high.

Experiments have shown that uprooting by waves and erosion is a crucial factor impairing the success of many artificial restoration projects because planners attempt to plant trees along fringes where the rate of attrition is high and where restoration necessitates a continued planting effort with no guarantee of success. Planting efforts are most successful in riverine environments characterized by lower energy levels, low salinities, and high nutrient levels (See Figure 41). Even in these environments, planting is most successful when clearcutting has left a mature fringe of trees along the river banks to protect the inner areas from scouring and erosion. Mangroves often are planted in exposed locations on marginal to poor substrates. Since the trees grow poorly and slowly in these environments, they are vulnerable to uprooting

Figure 41. Plantation of four-year-old *Bruguiera gymnorhiza* in Bangladesh.

for a longer time period while subjected to greater exposure.

Planting on spoil islands has the risk that settling will increase exposure and erosion and lead to loss of the planted trees. If it is to be planted with mangroves, the island must be provided with an overburden so that when stabilized it will have the proper elevation in relation to the tides. Since in most instances the trees grow from propagule sources, created and naturally stabilized spoil islands tend to become colonized by mangroves. Such naturally colonized islands are common in dredged channels in Florida, Puerto Rico, and Venezuela (Lago Maracaibo). Vegetation becomes adapted to the characteristics of the islands. For example, in Venezuela the outer fringe was dominated by *Laguncularia racemosa* while the inner part of the island was colonized by *Avicennia germinans*. In Puerto Rico and Florida, many sandy dredge spoil islands have outer fringes of *Rhizophora mangle* whereas the inner higher portion of the island is populated by the Australian pine (*Casuarina*).

Aesthetic Enhancement of Mangrove Trees and Forests

If restoration has been done near residences, there are many situations in which horticultural practices can be employed to enhance the aesthetic appearance of mangroves and create a panoramic view from inland sites. The practices can be divided into two types based on the ultimate objective. First, individual trees or groups of trees can be pruned, trimmed, or shaped for aesthetic purposes in residential and waterfront settings in urban areas. In general, standard horticultural techniques can be employed without any modification or concern about the foliar response of the trees. The only qualification is that some species of mangroves have regenerative limitations which must be taken into account during the pruning or trimming. The regenerative capabilities and limitations of selected species are presented in Table 18.

In the second type of horticultural management, the objective is to reduce the height of a forested area for a panoramic view of adjacent areas. In general, this objective is met through the topping or removal of selected trees to stimulate coppice regrowth or rapid growth and development of seedlings and small saplings. When the coppice and new sprout growth form a full but lower-level foliage, the remaining trees can be topped or removed. Annual pruning and trimming of the new growth maintains the vegetation at a desired height. Based on the regeneration characteristics of the species, different strategies are employed to achieve the final result. For example, *Rhizophora* cannot survive a complete removal of branches and foliage (Table 18). However, when an abundant propagule source is available, total removal of selected trees (approximately 50 percent of population on site) is recommended to stimulate seedling or sapling growth. In the event of an inadequate propagule source (unlikely in most areas) or where there is a high probability of competitive domination by other mangrove species, the *Rhizophora* should be pruned or cut back in stages over several years.

An advantage afforded by the ability of mangroves to be managed using standard horticultural practices is that certain objectives, albeit limited, can be attained without the destruction or total removal of the mangrove forest. The practice has been clearly demonstrated and may be considered an alternative to the complete removal of mangrove forests for competing aesthetic reasons.

Suggestions for Mangrove Restoration

Before attempting to restore a particular area, a manager should consider the following:

- Select target sites carefully. If the area has contained mangroves before, determine the cause of loss and make sure the stressor has been removed. Naturally blank areas may be hypersaline or too elevated for successful establishment. Natural succession and ac-

Table 18. Regenerative Capabilities and Limitations of Mangrove Species

Genus, Species	*Roots*	*Stump*	*Trunk*	*Branches*	*Loss of Foliage*	*Remarks*
Avicennia						
alba		yes	yes	yes	yes	
germinans		yes	yes	yes	yes	
marina		yes	yes	yes	yes	
officinalis	yes	yes	yes	yes	yes	
eucalyptifolia		yes	yes	yes	yes	
Acanthus						
ilicifolius		yes	yes	yes		
Bruguiera						
gymnorhiza		yes	yes	yes		
Excoecaria						
agallocha		yes		yes	yes	deciduous
Conocarpus						
erectus	yes	yes	yes	yes		
Sonneratia						
alba		yes	yes	yes	yes	
casiolaris		yes	yes	yes	yes	
apetala		yes	yes	yes	yes	
Lumnitzera						
racemosa		yes	yes	yes	yes	
Xylocarpus						
australasicus		yes	yes	yes	?	deciduous
Laguncularia						
racemosa		yes	yes	yes	yes	
Rhizophora						
mangle	no	no	no	yes	yes	2 cm diameter limit for branch regeneration
stylosa	no	no	no	yes	yes	
Camptostemon						
schultzii	no	no	no	yes	yes	
Aegialitis						
annulata				yes	yes	
Aegiceras						
corniculatum				yes	yes	
Hibiscus						
tiliaceus				yes	yes	
Ceriops						
tagal	no	no	no	no	no	

Note: Blank spaces indicate that data were not available; a question mark indicates conflicting data.

cretion may have rendered the site unsuitable for the previous mangrove species.

- Select the species to plant on the basis of the dominant species at nearby locations having similar elevations, frequency of inundation, and exposure. Because of their ease of handling and planting, species of the Rhizophoraceae (*Rhizophora, Bruguiera, Ceriops,* and *Kandelia*) are the most suitable species for restoration projects, but they may not always be appropriate.
- Be sure soil elevation is low enough so the area is flooded frequently by tidal water and there is adequate circulation. Stagnant areas tend to overheat.
- Measure interstitial (soil) salinities. Interstitial salinities will determine the most suitable species. For example, areas above 55 percent are not suitable for *Rhizophora mangle*. Salinity tolerances for some mangrove species may be found in Snedaker and Brown (1981).
- Shelter areas from wave action and current scouring.
- Remove dead standing wood and clean up the area. Floating or falling debris will up-

root and damage planted seedlings.

- Control the spacing of seedlings. Dense plantings result in slower growth due to competition. For *Rhizophora* spp. the recommended spacing for seedlings is 0.6 –1.2 m, and for mixed *Avicennia marina* and *Aegiceras corniculatum* the spacing recommended is 1.5 m.
- Collect recently fallen propagules from nearby mangrove areas or from trees. Use only ripe propagules. For red mangrove (*R. mangle*), use those propagules in which the abscission layer has developed. (These are easily detached from the parent tree.) Select healthy propagules and discard malformed or damaged ones. Maintain the collected material wet and avoid exposing it to overheating during transportation and before planting. Propagules can be carried in a foam icebox or a wet burlap (hessian) sack.
- Do not insert propagules too deeply into the substrate. For example, *Rhizophora* should be planted only deep enough that it will not fall over. For a 20 –30-cm seedling the planting depth should be 4 –7 cm.
- Use natural primary and secondary succession processes to improve planting success (e.g., use of "nurse plant" cover).

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SECTION IV ECONOMIC CONSIDERATIONS IN MANGROVE MANAGEMENT

Introduction

There are basically three options for the management or development of mangroves. The first option is *preservation* of the ecosystem in its natural state. The second option is *utilization* of the system to extract various goods and services on a sustainable basis. The last option is the *conversion* (or destruction) of the natural ecosystem, usually for a single replacement use. Since these three management options are mutually exclusive, a framework is needed for evaluating the alternatives; economic analysis has a role to play in this process.

In practice, ecological and economic considerations cannot be separated in evaluating management alternatives for mangroves. This statement reflects the growing appreciation of the social and economic importance of mangrove ecosystems and reverses the once-common view that mangroves were worthless unless developed for major single purpose activities or converted to alternative uses. To measure the value of mangroves accurately, the value of the goods and services produced by these systems needs to be considered and incorporated into the assessment of the relative merits of development alternatives.

This section explores the economic characteristics of mangrove resource systems and discusses the use of economic analysis in weighing the costs and benefits of alternative forms of mangrove development. Although it may not be possible to put a monetary value on all relevant factors, they must be explicitly recognized and be incorporated into an economic valuation method to the extent possible. If planners and managers are aware of the uses and limitations of economic assessments of complex biophysical resource systems, they can help improve the expression of the social and economic significance of these systems to society. In the actual decision-making process the results of the economic analysis are normally evaluated and weighted along with political, social, cultural, environmental, and bureaucratic factors.

Mangrove ecosystems are difficult to value adequately using conventional economic analysis techniques. The difficulties arise because of two separate phenomena: first, many of the goods and services produced by a mangrove ecosystem are not easily monetized, and second, many of these goods and services occur off-site, that is, they are external to the physical system and thus become economic externalities. This concept is illustrated in Figure 42. As shown, the goods and services produced by a mangrove ecosystem can be divided into four categories based either on their location (within or outside of the ecosystem) and the extent to which they are priced and marketed. The division of the goods and services among the four categories is not unique; some goods or services will appear in one quadrant in one location and in a different one in another place. This is no cause for concern. If the economic analysis is done carefully and the flows of inputs and outputs identified, all relative factors will be incorporated. The goal of an economic analysis of mangrove ecosystems, therefore, is to include explicitly all of the benefits, as well as the costs of changes or loss of benefits from these changes, and thereby better evaluate alternatives.

If the full range of goods and services produced by mangrove ecosystems are included in an economic analysis of various management alternatives, quite different decisions may be made about how best to manage these unique ecosystems. The first task is to identify the important parameters involved and then discuss how they can be explicitly incorporated into an economic analysis.

The Analytical Framework

Economics, the science of the allocation of scarce resources, relies heavily on observed market prices to place values on various goods and services. This has been the conventional way that agricultural or natural resource development questions are analyzed. The values of inputs required and the resulting goods and services produced are compared to determine if a proposed activity is "profitable." When several options exist for use of the same basic resource (a field, a forest, a mangrove swamp) the net benefits of the various options are compared to determine the most profitable way to use the resource.

There are several problems with this approach when mangroves are the resource under

Valuation of Goods and Services		Location of Goods and Services: On-site	Location of Goods and Services: Off-site
	Marketed	**1** Usually included in an economic analysis (e.g., poles, charcoal, woodchips, mangrove crabs)	**2** May be included (e.g., fish or shellfish caught in adjacent waters)
	Nonmarketed	**3** Seldom included (e.g., medicinal uses of mangrove, domestic fuelwood, food in times of famine, nursery area for juvenile fish, feeding ground for estuarine fish and shrimp, viewing and studying wildlife)	**4** Usually ignored (e.g., nutrient flows to estuaries, buffer to storm damage)

Figure 42. Relation between location and type of mangrove goods and services and traditional economic analysis.

consideration. The first, and a point that will be the focus of this section, is that only a few of the goods and services produced by the ecosystem are usually included in the analysis. For example, a decision on whether to fill in a mangrove area for housing development that is based only on the value of lost charcoal production may be very different than if the value of fish caught in adjacent waters but dependent on the mangrove for part of their food chain is included. Excluding the fish or shellfish in the analysis will understate the true cost of destroying the mangrove area.

Another major aspect of this problem is that an analysis done from a *private* point of view (a *financial* analysis) may well give different results from similar analyses conducted from *society*'s perspective (*social* or *economic* analysis). Since the wide range of goods and services produced by mangroves should be included in an analysis of development alternatives, the social or economic analysis is often the appropriate framework.

In some cases, mangroves are privately owned. Private owners are usually concerned only with the commercial profitability of the use of the mangroves they control. As such, in assessing the relative merits of different forms of mangrove development, they are primarily concerned with the financial aspects of the funds, material, and labor required and the resulting goods produced and the prices these goods receive. This narrow *financial analysis* ignores many of the off-site or nonmarketed goods and services of a mangrove ecosystem such as those in quadrants 2, 3, and 4 in Figure 42.

Public bodies are also concerned with the financial aspects of development projects; however, their perspective on the relative costs and benefits of alternative projects is more broadly related to the economic impact upon society as a whole. Society generally seeks to allocate its resources in a manner that makes the greatest possible contribution toward satisfying its needs and wants for goods and services. Therefore, factors that often are excluded from financial analyses by private owners — such as the off-site environmental effects of the pollution they may create — should be considered by public bodies in an *economic analysis* as described in this section.

There are, of course, direct parallels between financial analyses and economic analyses, but there are significant differences in the manner in which costs (inputs) and benefits (outputs) are identified and incorporated into the respective analyses. There also may be differences in the way the costs or benefits are valued. In financial analyses, inputs (costs) are measured in monetary terms expressed as the price of goods and services purchased in a market. The outputs are also valued in terms of market prices. An economic analysis uses consumer willingness to pay as a measure of value; in reality such an analysis frequently uses market prices of inputs and outputs. However, additional concern is given to weighing what society gives up and what society receives in return from a specific form of resource development. This concern may be reflected by the use of "shadow prices" (adjustments to market prices to correct for distortions caused by government intervention or regulations) or by quantifying public opportunity costs.

The relationship between the steps in a financial and an economic analysis are illustrated in Table 19. Although developed for economic analysis of forestry projects (Gregersen and Contreras 1979), this comparison is valid for the analysis of mangroves or other natural systems.

Although this section concentrates on the construction of a broadly based economic appraisal, it is important not to lose sight of financial considerations that may govern the decisions of private owners. A mangrove development program that is considered economically efficient from a national viewpoint may not be attractive from a private viewpoint. Or, more likely, a development that is seen as attractive and profitable from a private perspective may have major negative externalities and therefore be undesirable from a social point of view. In this case, controls, taxes, or subsidies would be required to achieve the socially efficient and desirable outcome.

This section presents a framework for an economic analysis of a mangrove ecosystem. The details of how shadow prices are derived or the technicalities of what to include or exclude in an economic analysis are not covered here. A trained economist should be able to carry out such an exercise, and various texts on project evaluation and natural resource economics provide detailed information on doing an economic analysis (for example, see Gittinger 1982, Hufschmidt et al. 1983, Squire and van der Tak 1975, or Randall 1981).

Table 19. Relationship Between Steps in a Financial and an Economic Analysis

Financial Analysis	*Economic Analysis*
Develop Physical Flow Tables (inputs and outputs)	
Direct inputs provided by the financial entity and outputs for which the entity is paid are included.	In addition to direct inputs and outputs, indirect effects are included, i.e., effects not included in the financial analysis since they are not directly traded in a market. These are effects on others in society.
Develop Unit Value Tables	
Market prices are used. For inputs and outputs that occur in the future, future market prices are estimated.	Consumer willingness to pay (w.t.p.) is used as the basic measure of value. In cases where market prices adequately reflect w.t.p., such prices are used. In other cases, "shadow prices" are estimated to provide the best measure of w.t.p.
Develop Cash Flow/Economic Value Flow Tables	
Inputs and outputs are multiplied by market prices to arrive at total costs and returns, which are then entered in the cash flow table. Transfer payments (such as taxes, subsidies, or loan transactions) are added to the cash flow table.	Inputs and outputs are multiplied by unit economic values to arrive at total economic costs and benefits, which are then entered in a total value flow table. Transfer payments are not treated separately but are included only as part of the economic costs or benefits as appropriate.
Calculate Measures of Project Worth	
Using cash flow table, calculate chosen measures of project value or commercial profitability. Test results for uncertainty by varying values of key parameters in a sensitivity analysis.	Calculate chosen measure of economic efficiency or economic value using the information in the total value flow table. Test results for uncertainty by varying values of key relationships/parameters in a sensitivity analysis.

Source: Gregersen and Contreras (1979).

Economic Analysis of a Natural System

Mangroves are just one of many natural systems that are utilized or exploited for the benefit of society. As they would for any of these natural systems, the decision makers want to know what will be gained and what will be lost as the result of any decision. Because of the unique nature of natural systems (when compared with a factory, for example), new approaches have been developed to value the benefits and costs properly. Much of the recent work in environmental and resource economics has been directed to these problems.

An approach to valuing a natural system has been developed that consists of several steps:*

1. Identify the project to be analyzed as clearly as possible. For discrete projects, such as a port or pond development, this is fairly straightforward. For more extensive projects, such as wood harvesting or fishing in a mangrove area, this requires more thought.
2. After the project has been identified clearly, the physical boundaries of analysis need to be defined. The analysis should include major externalities generated by the project, and the boundaries should therefore be broad enough to incorporate most of the major effects. For example, a mangrove conversion project would have analytical boundaries broad enough to include the expected benefits and costs that occur off-site; examples of such benefits or costs are changes in coastal fish catch from conversion or destruction of mangrove-based food chains or changes in saltwater intrusion, drainage, or storm surges following conversion.
3. The next step is to identify all of the physical inputs and outputs of the system. This includes all possible factors that are important, given the broad boundaries of analysis referred to in the previous step. Many of these factors may be hard to measure, but an attempt should be made nonetheless. Social surveys are frequently a useful way to obtain information on how mangrove resources are utilized. These surveys should include local uses that may not otherwise be recorded and help trace the flow of mangrove products beyond the mangrove ecosystem itself. For example, mangrove timber may be cut and then used for a variety of uses such as fuel, boards for furniture, poles for fish traps, or chipped and then used for the extraction of chemicals, the production of pulp, or particle board. Surveys can be helpful in identifying and quantifying these flows.
4. The various factors are then quantified in physical terms to the extent possible. Changes in wood or charcoal production, changes in coastal fish catches, or any other factors identified previously are now quantified.
5. The placing of monetary values on the physical quantities measured or alternative costs or benefits is frequently the hardest step. Again, when monetary values cannot be determined, even when using many of the newly developed valuation techniques, the data on physical flows can still be used in the decision-making process. It should be noted that the goal is to include explicitly to the extent possible all benefits and costs in the analysis. When direct measurements are not possible, various surrogate measures or alternative cost or benefit estimates may be used (e.g., opportunity cost).
6. The final step is that of economic evaluation of the proposed project or projects. The techniques for economic evaluation are quite straightforward and well defined. They rely on the measurements made earlier, especially in the third and fifth steps. Among the most commonly used approaches are forms of benefit-cost analysis including net present value, internal rate of return, and benefit-cost ratio. Other approaches, such as cost-effectiveness analysis, also are used.

These steps can be applied to most economic analyses. The discipline of conducting such an analysis forces the analyst to state explicitly his or her assumptions and to identify clearly those factors that are included in (or are excluded from) the analysis. A final point is important—economic analysis does not provide "the answer" to a question. Rather, it should be seen as an aid to decision making and a means to provide more information, information that can be weighted with social, cultural, political, or other considerations in reaching a final decision.

The social dimension has not been included up to now. This is not to play down the very important role of social aspects. To the extent that social phenomena are quantifiable, they will be included (such as changes in income levels of mangrove area populations); those social phenomena that are not quantifiable (e.g., disruption of traditional lifestyle of mangrove-dwelling people) should be noted and included in the final package of factors that the decision maker will consider. Social considerations frequently can be very important and may have a decisive role in the final judgment.

The Mangrove as a Natural System

As stated previously, mangroves are a unique type of ecosystem—the combination of land, water, trees, animals, and humans results in the multiple goods and services that the mangroves

* See Hufschmidt et al. 1983; Hufschmidt and Hyman 1982; and Dixon et al. 1983.

provide. They are also fragile ecosystems, and the change of one part of the system may have profound effects on other parts. This interdependence of uses and production traditionally has been hard to communicate to policymakers and others who see the mangroves as a low-value resource to be exploited. It is precisely this multiplicity of uses and interdependencies that a complete economic analysis strives to include — the benefits as well as the costs.

This quandary was illustrated in Figure 42. In this two-by-two matrix, the goods and services of a mangrove ecosystem were divided into those that occur on-site or within the ecosystem, and those that occur off-site or external to what is traditionally defined as the boundary of a mangrove ecosystem. These goods and services can further be divided into those that are marketed and therefore have observable prices and those that are either nonmarketed (because they are felt to have little or no value) or are difficult to quantify. The first category of goods and services often is referred to as *pecuniary* goods, that is, they can be exchanged and valued using existing market prices. The second category may be called *environmental* materials or resources. These would include the biological production of food that supports mangrove-dependent plant and animal species and the role of mangroves as spawning or nursery areas for finfish and shellfish. Although these goods and services frequently are not priced, they still are valuable. A major task is the economic valuation of these environmental resources.

The matrix in Figure 42 therefore breaks down into four units. Those in the first quadrant (on-site, marketed) usually are included in an economic analysis. The other three quadrants usually are not included in an analysis. The second quadrant (off-site, marketed) contains goods and services that could be included in the analysis if the boundaries of analysis are drawn sufficiently broadly. Quadrants 3 or 4 (on-site, nonmarketed and off-site, nonmarketed) are either seldom included (quadrant 3) or are usually ignored entirely (quadrant 4) (see Figure 43).

Tables 1 and 2 list many of the products of a mangrove ecosystem. Many of these products have been discussed in earlier chapters. What is striking is that almost all of the products listed in Table 1 (mangrove forest products) fall in quadrant 1 in Figure 42, that is, these products are produced on-site and can be valued using market prices. In Table 2 is a list of other natural products. Some occur both on- and off-site (for example fish, honey, wax, birds), and some can be valued easily while others cannot. These products fall largely in quadrants 2 and 3 — off-site and marketed, and on-site and nonmarketed goods.

Figure 43. A nonmarketed resource, seldom included in traditional economic analysis.

One major set of goods and services is not included in Tables 1 and 2. These are those in quadrant 4, the benefits or costs that occur off-site and are largely nonmarketed. Examples of these goods and services include the value of mangroves as a storm barrier by reducing coastal storm damage, the contribution to nutrient flows in estuarine food webs, entrapment of pollutants in sediments, and nursery areas for juveniles of valuable fishing species.

Economic Valuation of Mangrove System Products

The process of economic valuation of the various mangrove goods and services presents many interesting challenges. For a wide range of products, the calculation is quite simple — a physical quantity of crabs or wood chips or charcoal is multiplied by the appropriate price, either a market price or a shadow price. Much of the previous discussion has been concerned with the explicit identification and quantification of various goods and services produced by a mangrove system. These goods and services may occur on-site or off-site, but once identified, they are often readily amenable to quantification and valuation.

For example, a plan to fill in an isolated mangrove community to develop an industrial or housing area could be evaluated within the proposed framework. The benefits of the development are known (the net benefit from the industries developed or housing built). In addition, some of the costs of the development also can be quantified and in most cases valued. These costs should include the lost annual production of various mangrove products listed in Tables 1 and 2, the value of lost or decreased fish production in the surrounding waters, and other resource costs. Appropriately discounted, the present value of these lost "benefits" can be calculated. If physical quantities cannot be measured directly or values assigned, the values of surrogate (or alternate) goods and services can be used in the analysis. For example, if a mangrove provides a storm barrier and with the mangrove removed a seawall must be built, the cost of this seawall serves as a proxy for the "lost" natural mangrove service.

While it is true that there are theoretical and measurement problems with quantifying some of these goods and services (such as lost fish production following mangrove conversion), some attempts have been made, and more research will lead to better estimates (FAO 1982). Valuation problems become particularly acute when intangible, difficult-to-quantify phenomena are concerned. Examples of these are the value of mangroves to estuarine and coastal food webs or as habitat for an endangered species.

In a case study of a mangrove system in Thailand (FAO 1982) an effort was made to identify and value both existing mangrove system products and the benefits from conversion. The values per ha per year ranged from US$30 to US$400 from charcoal (depending on intensity of development), US$30 to US$100 for on-site and off-site fisheries, and to as much as US$2,000 from intensive shrimp farming. Rice farming produced a relatively modest US$165 per year.

The environmental and resource economics literature illustrates a number of techniques that have been used to place values on difficult-to-measure effects. For example, the value of mangroves in preventing storm damage also can be calculated from an analysis of damage with and without the presence of mangroves. The value of damage prevented by retaining the mangrove barrier is an implicit valuation of one of the benefits of mangroves. This value is of course closely linked to the presence of structures such as houses, roads, and factories, and herein lies a dilemma. Without such structures, the value of storm damage prevented may be quite small. With development, however, the value of the *land* may increase so much that the opportunity cost of preserving mangroves becomes too high—the land is more valuable if it is built upon even if there is a need for a protective seawall or redress of periodic storm damage.

One way to evaluate the wide range of goods and services produced by mangroves in their natural functioning state is the "with" and "without" concept. The "without" case describes what would happen if a proposed project did not take place, while the "with" case describes the results of fully implementing a proposal. Here, the "without" state should be used to denote a healthy, fully functioning mangrove ecosystem and the goods and services produced by that system.

Any analysis of alternatives for converting mangroves (the "with" case) should begin from a perspective that clearly reflects the range of goods and services that would be lost with development. Many of these goods and services have a common property or open access nature. For example, fish species that utilize a mangrove for part of their life cycle normally are free to enter, use, and then leave the mangrove. They in effect cannot be owned by the mangrove owner and are considered common property resources, because once they leave the mangrove they are free to be captured by anyone. In the same way, everyone can enjoy the benefit of reduced wind and wave damage to coastal lands due to the buffer activities provided by a mangrove forest without either owning the mangrove or paying for the benefit.

Proposed development projects need to be evaluated critically in terms of what will be gained versus what may be lost by altering the natural properties of the mangrove. For example, in Bangladesh the withdrawal of fresh water upstream by the Farakha barrage affected the productivity of mangroves in the delta. Also, the construction of coastal embankments has greatly decreased the availability of shrimp and other saltwater fish that used the mangrove ecosystem for part of their life cycle (Khan and Karim 1982). In all analyses, it should be remembered that conversion of mangroves or their utilization can result in sizeable economic benefits. These benefits have to be included in the calculations, just as the external costs caused by this conversion also should be included. There is a symmetry between benefits and costs; just as a benefit lost can be counted as a cost, a cost prevented can be counted as a benefit.

It is when more intangible benefits of existing

Table 20. Examples of Economic Values Placed on Mangrove Systems and Mangrove Ecosystem Products

Type of Resource or Product	*Location*	*Date*	*Value Placed on Resource (US$ per ha per year)*
Complete mangrove ecosystem	Trinidad	1974	500
	Fiji	1976	950–1,250
	Puerto Rico	1973	1,550
Forestry Products	Trinidad	1974	70
	Indonesia	1978	10–20 (charcoal and wood chips)
	Malaysia	1980	25
	Thailand	1982	30–400
Fishery products	Trinidad	1974	125
	Indonesia	1978	50
	Fiji	1976	640
	Queensland	1976	1,975
	Thailand	1982	30–100 (fish); 200–2,000 (shrimp)
Recreation, tourism	Trinidad	1974	200

Sources: Fiji—calculated from information present in Baines (1979) and Lal (1983).
Indonesia—Peter R. Burbridge (Pers. Comm. 1983).
Malaysia—Tang et al. (1980).
Puerto Rico—Baines (1979).
Queensland—Baines (1979).
Thailand—FAO (1982).
Trinidad—Ramdial (1975) and Trinidad Div. of Forestry (1979).
Note: All of these estimates are approximate and are presented to give a range of values placed on mangroves and mangrove ecosystem products. The values in each locale will vary.

mangrove systems are considered that valuation becomes more difficult. Recreational values or genetic diversity and gene pool type arguments may be considerations. It is the duty of the analyst to recognize relevant factors, make explicit any assumptions, and then place monetary values when possible. Merely stating that the values of a natural mangrove ecosystem are large or infinite does not provide much assistance or guidance to the decision maker. The emerging literature on valuation techniques provides considerable guidance in this area.

What is quite surprising is the the extent to which conventional market-oriented tools of economic analysis can be used to value many of the goods and services of mangrove ecosystems. Once a broader boundary of analysis is accepted and externalities are counted, the usual quantity times price relationships can be powerful. The difficulty in valuing mangroves lies less with the availability of valuation techniques than it does with accepting the concept of a wider boundary of analysis—one that explicitly incorporates many goods and services that were formerly excluded or ignored.

When attempts have been made to place values on the various goods and services produced by mangroves, reasonable answers frequently have been derived. As illustrated in Table 20, these values vary considerably, depending of course on the country, the type of mangrove system, and the use of the product in each place.

In a 1979 report on the Caroni swamp in Trinidad, values were placed on the annual production of various goods and services by this 4,000-ha mangrove swamp (Trinidad Division of Forestry 1979). Values were assigned to fish catch in the swamp, potential forest product development, and recreation-related benefits. The total annual value of these goods and services was about US$2 million, or US$500 per ha (in 1974 dollars). Capitalized at 5 percent, this represented a capitalized value of US$10,000 per ha. The analysis did not include the value of many other mangrove products or the terrestrial and aquatic benefits of the mangrove.

Attempts in Indonesia to place values on mangrove products have been hampered by lack of knowledge of the extent of utilization of Indonesia's 3.6 million ha of mangroves. In 1978, for example, the catch of mangrove-dependent fish species totaled US$194 million, or about US$50 per ha over the entire country. The exact relationship between the fish catch and the mangrove ecosystem is only poorly understood. It is very likely that this catch uses only part of the mangrove ecosystem as habitat or a food source. Similarly, estimates of sustainable mangrove wood chip and charcoal production for 1978 indicated a potential of US$18 million worth of exports and an equal amount for domestic consumption of charcoal, tan bark, and other mangrove products. This sustainable use rate equates to roughly US$10 per ha per year for these uses.

These estimates indicate the need for more research on the actual physical productivity of mangroves and mangrove-dependent systems. Of particular need is more information on incremental changes in a mangrove system. For example, if 10 percent of a mangrove area is destroyed by conversion will this affect fish catch? What if 50 percent is destroyed? Such information is valuable in balancing development and preservation needs. Use of an appropriate analytical framework and valuation techniques can lead to much better estimates of the values of the various goods and services produced by a mangrove system.

Analyzing Management Options for Mangroves

Having established that the products and services provided by mangrove areas play an important role in many economic activities, we are in a stronger position to consider the relative benefits that would be gained by alternative forms of mangrove development. As mentioned earlier, there are three main management options, namely: (1) preservation, (2) utilization of mangroves based upon the sustainability of the mangrove ecosystem, and (3) conversion (or destruction) of the mangrove. In addition, the appropriate use of design and locational variables can help to maximize the benefits (and minimize the costs) of both development opportunities and the existing mangrove resource.

The management practice that offers the greatest potential for maximizing economic development without reducing long-term development options probably is based upon the sustained management of the mangrove system. This option will most likely be the one that is attractive to planners who wish to conserve mangrove areas until it can be clearly demonstrated that major alteration to the system is the only option available. It is important to recognize, however, that all these options have related costs and benefits.

These main management options can be presented as follows:

1. Preservation — If preservation of mangroves is determined to be a desirable objective, then future options still remain open. These options include using the mangroves for one or a series of sustainable forms of use, or converting the mangroves. No options are foreclosed. This, however, imposes opportunity costs in the form of lost revenues from developing one of a number of nondestructive mangrove uses or even the revenue from total conversion to a use such as a fish pond. Direct costs of preserving the mangrove (such as for policing) may, however, be small.

   The preservation option safeguards many of the off-site and on-site, nonmarketed and marketed values at relatively small cost.
2. Utilization under conditions of sustained management — A wide variety of single purpose activities may be able to occupy the same area of mangroves at the same time or at different periods without causing damage to the system. This implies reasonably sophisticated management of the individual activities and, depending upon the mix of activities (e.g., fuelwood cutting, gathering of medicinal materials, collection of fish fry), no single use can be maximized without constraints being imposed on other uses. A variety of activities can be developed and sustained, however, without foreclosing options to either change the mix and intensity of uses or to alter the overall use to either preservation or conversion. Care must be taken; utilization can be pushed too far and can lead to irreversible economic or ecological results.

   The mix of management inputs (e.g., skilled management, other resources) usually will be higher than the preservation option and will vary with the uses adopted. Generally, the greater the range or intensity of use, the greater the management inputs required. Similarly, the value of the outputs will rise if more people are given access to the mangrove and are allowed to utilize more of the goods and services.
3. Conversion — The conversion of a mangrove system generally so alters the condition of the mangrove ecosystem that all other potential uses are foreclosed. Irreversibility can take the form of biophysical conditions that cannot be reversed or that would be so costly to reverse as to be unacceptable. The value of the mangrove uses is lost and represents a cost which must be subtracted from the benefits attributed to the conversion process.

   The inputs required to bring about the

conversion (land, labor, and capital) are likely to be very much higher than either preservation or sustained management. To these initial costs must be added ongoing management costs that are required to counteract many of the biophysical features of the mangrove area (e.g., storm hazards, flooding, saline conditions, acid sulphate soils) and to maintain the productivity of the changed system under the new intended use.

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SECTION V DEVELOPMENT OF NATIONAL MANAGEMENT PLANS

Introduction

In the majority of the countries containing mangrove resources, both the types of plants and animals associated with mangroves and the distribution and extent of the mangrove plant communities are poorly known. Such an inadequate knowledge of the resource, together with the intense pressure on the resource in many countries, is resulting in rapidly diminishing opportunities for integrated management of mangroves, including the early establishment of reserves that will protect unique and threatened species and communities.

In addition, decisions on future use of mangrove ecosystems which are based on inadequate knowledge of the resource may result in unanticipated and irrevocable loss of valuable mangrove resources. An essential first-order priority for proper management of a nation's mangrove resources must be to develop a national mangrove management plan.

Ideally, a plan for managing a country's mangrove resources should be part of an integrated national coastal zone management plan. It is recognized, however, that coastal zone management planning has not been undertaken in many countries. Such planning is difficult because it involves many interests (often extremely conflicting), resources, government agencies, and political jurisdictions. For smaller island nations coastal zone planning represents a national plan for land, water, and adjacent seas. Because of the particular vulnerability of mangrove ecosystems it is appropriate to proceed with the development of national plans for the mangroves and to integrate such plans with any existing national land-use policy or general coastal zone plans. If mangrove planning embraced the adjacent, linked, living resource systems such as coral reefs, seagrass beds, and lagoons, such a plan would be especially appropriate.

The framework for the plan should be developed by an expert multidisciplinary group assembled in each country. Some countries have already formed national mangrove committees (e.g., Indonesia, Malaysia, Thailand, Philippines, Australia, Fiji) and in many cases these committees would be the most appropriate group to assume responsibility for the detailed preparation of a national mangrove plan. Implementation of national plans must be a government responsibility. However, the planning process can allow specialists outside of government departments to provide necessary information for managing mangrove resources effectively for local and national (and international, e.g., India/Bangladesh or Venezuela/Trinidad-Tobago) needs. It also permits integration of mangrove planning into general coastal zone and national land-use plans.

The establishment of a mangrove data base should proceed hand-in-hand with the development of a national mangrove management plan. Linkages to maintain an up-to-date flow of information between them are essential to ensure the incorporation of the latest findings into the management plans (see Figure 44). Even where resources for compiling mangrove data bases are limited, national management plans can still be developed, although later modification may be needed as more information becomes available.

Like the administrative arrangements for the formulation of national management plans, the content and approach must reflect the specific conditions in each country. For example, the approach in the Philippines, an archipelago of thousands of islands, will not necessarily be applicable in Australia, which is essentially a single, large island. Nevertheless, there are general guidelines that can apply to most countries. National management plans should consist of two major components — the assessment of the mangrove resources and the management of the resources, and these steps are discussed here.

Assessment of the Mangrove Resources

In this component of the national plan the basic status of the resource is determined. Three aspects are relevant to this assessment — resource delineation, current and potential uses of the resource, and the international significance of the resource.

RESOURCE DELINEATION

Included here are the maps and inventories of mangrove communities throughout the coun-

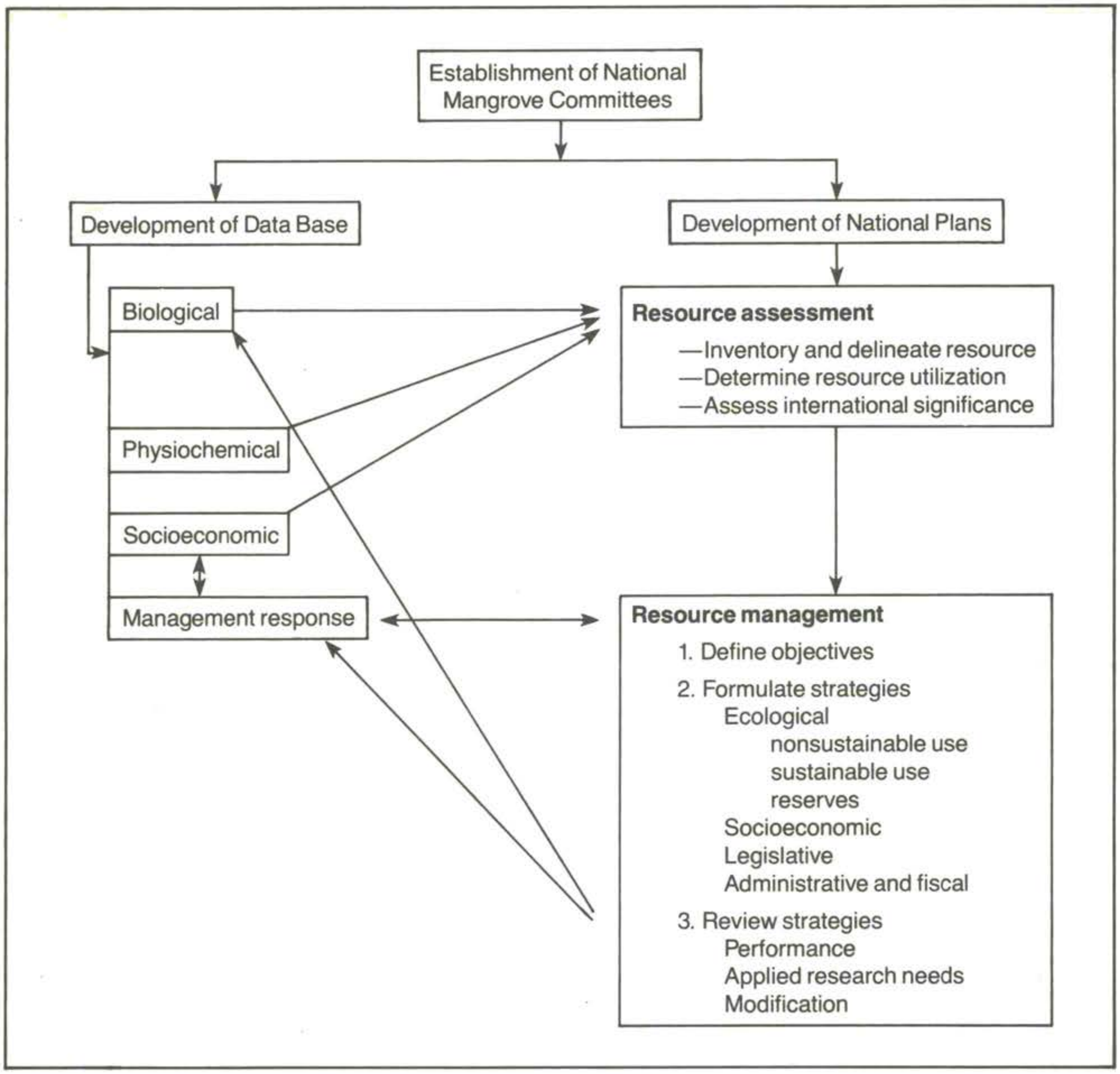

Figure 44. Major features of national plans and mangrove data bases, with the most important linkages.

try, including data on the flora and fauna of the mangrove ecosystems and their geographic distributions and extent. Methodologies will vary from one country to another but many include satellite remote sensing techniques, aerial photography, ground surveys, and data acquisition from the published literature. The choice of suitable methods will be determined by the time, money, and personnel available; the total area to be covered; and the level of detail required for the type of plan envisaged. The LANDSAT series of remote sensing imagery can provide a base for delineation of major biophysical types, separating mangroves from other major types such as seagrass beds, saltmarshes, saltflats, and freshwater swamps. The Philippine mangrove inventory, forming the base for its national plan, utilized LANDSAT 1 and 2, supplemented with topographic maps and direct field observations (Bina et al. In press). Subsequent LANDSAT series are providing even a better basis for such inventories and delineations for other countries attempting this task. In Australia, with its predominantly linear coasts, air-photo mapping has been successfully used (Galloway 1982). Large-scale aerial photography can be used to delineate most community types and most dominant species.

A variety of mapping scales are also required; regional mapping can be accommodated on scales of 1:1,000,000; 1:250,000; 1:100,000; or 1:50,000, while mapping of local mangrove communities will require smaller scales, possibly of 1:25,000 or 1:10,000.

The mangrove area itself should not be mapped in isolation but should include related lagoon, reef, and delta systems and even related watersheds, since management activities have trans-system effects.

RESOURCE UTILIZATION

Planners need to quantify current and potential usage patterns and trends of the mangrove resource, both in direct and indirect products and in relation to other socioeconomic benefits (e.g., tourism) so that these present and future needs can be met on a sustainable-yield basis from managed mangrove ecosystems.

This involves a broadly based assessment of the role of mangroves in the national economy. Site-specific details should include the following:

- Direct products (e.g., forest production)
- Indirect products (e.g., fish, shellfish, honey)
- Economic activities amenable to sustained yield management (e.g., recreation, flood control, education). Does not include conversion uses; may or may not include aquaculture, depending on how it is done.
- Numbers of persons involved
- Numbers of persons dependent on benefits
- Mangrove extent and type involved
- Potential substitute areas for any destructive activities.
- Economic importance regionally and nationally
- Social importance regionally and nationally
- Market trends for mangrove products
- Current status of the area in present use (e.g., sustainable, presently not sustainable, threatened by conversion activities.)
- Need for afforestation or restoration of new areas

Decisions about the ultimate allocation of mangroves cannot be treated in isolation from a broad range of economic activities due to the direct or indirect dependence of those activities on the mangrove resource system. The economic influence of mangrove resources can extend well beyond individual national boundaries, and at the same time there can be a strong economic dependence on mangroves at the district or local level. This dependence may represent a small portion of the total gross national product or, as in the case of the Philippines, where 60 percent of the total fisheries harvest comes from small scale artisanal fisheries, the dependence on mangroves can represent a major contribution to both resource production and national income. Whether localized and small-scale economic activities represent large or small contributions to national economic activity, the significance of mangroves to the economic welfare and stability of local communities must be considered in evaluations of mangrove development options.

NATIONAL AND INTERNATIONAL SIGNIFICANCE

The significance of the national resource needs to be assessed at the national and international level to assist government in formulating national policies that take into account the broad perceptions of the resource.

At the national and international levels, the significance of the resource must be assessed in relation to several areas—waterfowl and marine species migrations, regional stability of the sediments, and genetic reservoirs.

Waterfowl Migration. In many countries, species of waterfowl migrate over short distances or widely, and many widely scattered mangrove or wetland areas are vital staging areas on these migrations or terminal wintering grounds. Because each staging area is an important link in the overall migration route, all staging areas need to be considered in this wider context. For example, a bilateral agreement was signed by Japan and Australia in 1974 to protect migrating waterfowl (about 70 species) and to protect essential staging areas within their respective national boundaries. The Ramsar Convention for wetlands protection is another international vehicle, if tropical countries would become signatories.

Marine Species Migrations. The essential features of waterfowl migrations can also be applied to a number of migrating marine species of fish, crustaceans, reptiles, and mammals. Critical areas can also be identified for some of these species, and, like waterfowl staging areas, these need to be viewed in a wider context.

Studies of coastal shrimp and fish species have demonstrated that many are dependent upon mangrove-dominated estuaries at some point in their life cycles (e.g., banana prawns, barramundi, bream, and mullet). Work defining the relation between mangrove and coastal fish stocks suggests that both the extent and conditions of mangroves influence the type and number of fish in nearby waters. These fish stocks migrate in response to factors such as seasonal climatic changes, currents, food supplies, and breeding requirements and may be found in different waters at different times of the year.

If neighboring countries have fishing industries that capture fish from these migratory stocks, then they have a common interest in the mangroves that supports those fish stocks. If one country decides to convert its mangroves to some alternative use, the resulting damage to the coastal fish stocks will have an effect upon the fisheries of its neighbors. On a small scale, such changes have only a marginal impact and may not be recognized as the cause of poor fishery yields. Such small alterations to mangrove add up, however, and the cumulative effect over time can have serious ecological, economic, and social implications.

Therefore, where resources such as mangroves have ecological and consequent economic linkages that go beyond discrete political boundaries, their development and management will involve a broader impact than is normally considered by individual nations. If this is recognized by politicians and policymakers in individual countries, then it can be used as a potentially constructive political bargaining tool in developing improved international management approaches to resources common to a series of nations.

This point is important when we consider the management problems resulting from current attempts to create national territorial jurisdiction over the seafloor and high seas areas formerly considered accessible to all nations. This can be demonstrated by the case of Thailand adopting a policy of converting mangrove areas to sites for aquaculture. This is being done to replace the loss of marine capture fisheries and fishermen's jobs due to the loss of access to some 6,000 km^2 of former high seas fisheries resulting from the declaration of exclusive economic zones in the Gulf of Thailand by Thailand and its neighbors, Kampuchea, Vietnam, and Malaysia. The reduction in area of Thai mangroves may result in a reduction of fish yields for Thailand's neighbors as well as for itself. This example illustrates the often-overlooked interdependence of nations concerning the management of mangroves.

Regional Sedimentary Stability. Areas of mangroves within national boundaries of one country may be vital to the sedimentary stability in an adjacent country via coastal currents, littoral sediment drift, or other geomorphological processes. Clearly, such linkages must be identified and evaluated on a bilateral (or even multilateral) level. The Gulf of Paria may offer a case in point involving Venezuela and Trinidad-Tobago.

Genetic Reservoirs. Each national mangrove resource undoubtedly includes species of plants and animals that are rare, endangered, or unique. Clearly, in that situation the mangrove resource of a particular country containing genetic material of such a species has a greatly enhanced value that should be recognized. The preservation of such genetic material should have priority over other competing interests.

Management of the Mangrove Resource

Given adequate knowledge of what the resource consists of, how it is currently being used, and what the future demands are likely to be, rational management of the resource can be undertaken within the context of national land-use planning. Such management entails three steps: (1) define objectives, (2) formulate strategies to meet those objectives, and (3) review the strategies on the basis of experience gained.

DEFINE MANAGEMENT OBJECTIVES

Management requires an objective. Because of the variety of values of the mangrove resource, it seems preferable to establish broad management objectives and then to elaborate on them using a series of country-specific subobjectives.

Broad objectives could be:

- To conserve the mangrove resource for maximum benefit to humans (involving preservation in some instances, sustainable product harvesting in others, and restoration in still other instances); and
- To minimize those nonsustainable or conversion activities that lead to the destruction of the resource.

STRATEGY FORMULATION

Having settled on suitable objectives for management, planners need to formulate strategies to realize those objectives. For effective management, strategies need to be formulated to cover ecological, socioeconomic, legislative, and administrative aspects.

Ecological strategies must establish criteria to be satisfied before the resources may be allocated for nonsustainable uses or conversion; delineate areas necessary for sustainable uses and, where compatible, for multiple-sustainable uses; and develop criteria for selecting necessary areas for preservation.

Socioeconomic strategies should include requirements for extended benefit-cost analysis of proposed new uses or conversions, including consideration of externalities and intangible costs and benefits. See the section on Economic Considerations in the Management of Mangroves.

Legislative strategies must consider the adequacy of existing legislation to implement the ecological strategies, the design of resource regulation covering those activities, and the effective implementation of any bilateral or multilateral agreements with other national governments. Certain international programs and conventions may be useful and helpful in assuring long-term allocation of valuable areas to nature conservation. These include Biosphere Reserves of the MAB program and World Heritage sites (both Unesco-sponsored) and official listing on the U.N. World List of National Parks and Equivalent Reserves.

Administrative and fiscal strategies must be concerned with the grass-roots implementation of the other strategies, their enforcement, quality control, and monitoring. In addition, the needs for training programs and experimental stations should be assessed.

REVIEW OF STRATEGIES

If they are to meet changing needs of the population or changing conditions of the resource, the strategies to be implemented must remain flexible within the broad limits of the overall management objectives. Flexibility is best maintained through periodic reviews of the strategies. These should take the form of an evaluation of their performance, the identification of applied research needs that may have arisen during the period under review, and finally any necessary modification of strategies. The opportunity for interested parties to provide input to the review process is likely to be beneficial.

Selling the Plan

A national plan is a useless document unless implemented. Implementation will not occur unless there is acceptance or support by the public, the political representatives at all levels of government, and the resource professionals planning or managing coastal resources. Presentations of a national plan for legislative action or even interagency adoption as policy must be preceded by an education program. Moreover, during the implementation of the adopted plan there must be a continual program of public education about mangroves, their uses and services, and how to maintain them.

Those interested in sustainable management and protection of mangrove areas and the furtherance of national planning activities for mangroves may wish to use two aids now available for use to increase public awareness about the values of mangroves. A slide-tape program entitled "Understanding Mangrove Ecosystems" has been produced for the IUCN Commission on Ecology (Hamilton 1982). This 60-slide, 18-minute program is available in English, French, and Spanish (and script and slides only in Indonesian) from WWF/IUCN International Education Project, Greenfield House, Guiting Power, Glos. GL54 5TZ, United Kingdom. In addition, IUCN has published *Global Status of Mangrove Ecosystems* (Saenger et al. 1983) that provides useful background information for lay persons and decision makers. This report is available from IUCN in Gland, Switzerland.

Another way to increase awareness and knowledge about mangroves among natural resource professionals is through nationwide symposia on mangroves. Such programs could appropriately be part of the plan development, as a state-of-the-art assessment, or they could be part of an implementation campaign. A good example of the former was a national interagency symposium in Fiji in 1983 (Lal 1983).

A recent publication by FAO contains much information on use and management of mangroves in many countries of Asia and the Pacific and a case study of a Thai mangrove area (FAO 1982). The local, specific material in that publication could be useful in educational programs.

The National Mangrove Committee in the Philippines, which oversees the national mangrove plan development and implementation, has issued a quarterly newsletter to alert natural resource professionals, politicians, and interested citizen user groups about recent developments and research activities (National Mangrove Committee 1980). The first issue (Vol. 1 No. 1) was published in December 1980 and the series bears the title "Bakawan." This is an example of adroit continuing education.

In preparation by the Mangrove Working Group of the IUCN Commission on Ecology is a brochure for decision makers that should assist in the task of educating high-level bureaucrats and politicians. The same IUCN group will also develop an audio visual presentation on mangrove management, based on this *Handbook for Mangrove Area Managers.*

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