Mangrove forest management guidelines

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FOREWORD

Mangroves are unique ecosystems. As a source of renewable resources, they are second to none in terms of its natural productivity and the wide range of goods and services they provide on a continuing basis. The economic potential of mangroves stems from three main sources, namely, forest products, estuarine and near-shore fisheries, and ecotourism. In addition, mangroves play a pivotal role in coastal protection and maintenance of habitats for a large range of common, threatened and endangered species.

Due to pressures from growing populations, which lead to changes in land use and over-utilization of the resources, mangroves are being rapidly depleted and degraded. A balance needs to be struck between meeting increasing present-day needs, on the one hand, and conserving the environmental support system provided by the mangrove forests, on the other.

Growing awareness of the protective, productive and socio-economic functions of tropical mangrove ecosystems, and of the consequences of their deterioration, has highlighted the need for the conservation and sustainable, integrated management of these valuable resources. Given their multiple-use potential, it is imperative that the management of mangrove based terrestrial and aquatic ecosystems be undertaken within the context of integrated coastal area management planning.

In many countries, much of the basic information needed for development and execution of management plans in mangrove forests, is presently not available. These guidelines present a synthesis of mangrove forest management systems which have been developed and successfully used in a number of countries and regions, and examine experiences gained and lessons learned.

The guidelines focus specifically on the management of the forest resources contained in the mangrove ecosystem, including wood and non-wood forest products. A chapter on mangrove ecology is included in order to ensure adequate understanding of the dynamics of these ecosystems, as a basis for their conservation and sustainable use.

The guidelines further include chapters on inventory and assessment of mangrove resources, and on traditional and potential uses of products provided by them. Environmental impact assessment is finally reviewed, and conclusions and recommendations are given to summarize the findings in the document.

It is hoped that the present guidelines will contribute towards improved understanding of the mangrove ecosystem and the natural renewable resources contained in them, and that they will aid in the development and implementation of integrated, multiple-use management plans to ensure the sustainability of these resources, now and in the future.

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In this study of mangrove forest management, the section on Assessment of Mangrove Resources is based on the Manual on Mapping and Inventory of Mangroves prepared by D. Benessalah and issued as a draft miscellaneous paper by the FAO Forestry Department in 1988 (FO:MISC/88/1). Most of the information contained in the sections on The Ecological Basis for Mangrove Management Planning; Traditional and Potential Uses of Mangrove Resources; and Sustainable Resource Management was provided by P.W Chong in a study prepared for the FAO in 1993. A case study on Multiple-use Management of the Sundarbans Forest in Bangladesh was prepared by M.Z. Hussain of IUCN. J. Troensegaard contributed the chapter on Environmental Impacts of Mangrove Management and provided valuable comments on the first draft of this paper. M. Loyche Wilkie consolidated the above studies and comments to produce the present synthesis. Final editing was by P. Vantomme. FAO is indebted to the above authors and to the numerous individuals and institutes, which provided the basic information contained in this document.

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GLOSSARY

Afforestation The planting of trees in unforested areas.

Allochthonous Of inhabitants from the outside (as opposed to ***Autochtonous***).

Alluvium Material carried in suspension by rivers and deposited in sluggish water beyond the influence of the swiftest current. Some of the worlds most fertile soils are alluvial.

Aquifer A layer of permeable rock, sand or gravel that absorbs water and allows it free passage through the intervening spaces of the rock. When the underlying rock is impermeable an aquifer acts as a ground water reservoir.

Autochtonous Of original inhabitants.

Backplain That part of a river floodplain, between the levee and the backswamp, normally flooded for several months each year.

Backswamp The lowest part of a river floodplain experiencing prolonged flooding.

Benthos Community of organisms inhabiting the bed of a water body.

Biogeography The study of the distribution of animals and plants.

Bole Merchantable part of the stem from the stump cross-section to the merchantable limit which is defined as the crown point or a certain upper diameter.

Buffer zone A zone, peripheral to a national park or equivalent reserve, where restrictions are placed upon resource use or special development measures are undertaken to enhance the conservation value of the area. *(ICUN,1991)*

Bund A dike or embankment.

Cover Type (more commonly ***Forest Cover Type***) A descriptive term used to group stands of similar characteristics and species composition (due to given ecological factors) by which they may be differentiated from other groups of stands.

Conversion A change from one silvicultural system or species to another.

Conversion forest Forests assigned for conversion to agriculture (*Agri-conversion*) or other non-forestry use.

Deforestation The clearing of forests and the conversion of land to non-forest uses.

Degradation (more commonly ***Forest Degradation***) Biological, chemical, an physical processes that result in loss of productive potential of natural resources in areas that remain classified as forests. Degradation may be permanent, although some forests may recover naturally or with human assistance.

Depletion Reduction in forest area or volume as a result of deforestation.

Ecosystem Any complex of living organisms together with all the other biotic and abiotic factors which affect them that is isolated for purposes of study, e.g. a forest ecosystem is a part of a forest being uniform in climate, parent materials, physiography, vegetation, soils, animals, and microorganisms.

Ecotourism Nature tourism (*low-impact tourism*)

Edafic Of the soil.

Environmental services Beneficial functions performed by natural forest ecosystems, including the maintenance of biodiversity, protection of soil and water resources, moderation of climate, influence on rainfall, sequestering of carbon dioxide, provision of habitat for wildlife, and maintenance of the earth's natural balance.

Externality A cost (or a benefit) of an economic activity by one party that is unintentionally imposed on (or received) by another party without compensation (or payment) that leads to inefficiencies in competitive markets.

Facultative halophytes Plants inhabiting, but not restricted to, salty soils as opposed to ***Obligate halophytes***, which will grow only where the salt levels in the soil are high.

Felling cycle The interval between successive main fellings in the same area under the selection system.

Felling Series A forest area forming the whole or part of a working circle and delimited so as, (1) to distribute felling and regeneration to suit local conditions, and (2) maintain or create a normal distribution of age classes.

Forest biomass The biomass of trees, shrubs and lesser vegetation in a forest ecosystem including their below-ground parts.

Geomorphology The study og the origin, evolution and configuration of the natural features on the Earth's surface.

Hydromorhpic soil A soil in which the effects of poor drainage is the main factor in determining its morphology, giving rise to a predominance of gley colours.

Land Use Planning The process by which decisions are made on future land uses over extended time periods, that are deemed to best serve the general welfare.

Levee That part of a river floodplain closest to the river and above the main floodplain level, built up by the deposition of relatively coarse textured material which settles when the river overflows its banks.

Littoral Of, on or near the shore. Region lying along the shore, especially land lying between the high and low tide levels.

Multiple Use Spatially three somewhat different ideas are involved: (1) different uses of adjacent sub-areas which together form a composite multiple-use area, (2) the alternation in time of different uses on the same area, and (3) more than one use of an area at one time. In the first two ideas it is implicit that direct competition between uses is avoided by alternating spatially or in time. The last idea involves multiple use in the sense of simultaneous use of one space and must concern itself with complementary versus conflicting activities, compatible and incompatible uses.

Where spatially coincident uses are involved at a given time, conflicts between resource users will almost always occur and the concept of such forms of multiple use should be realistically interpreted as a dominant use with secondary uses integrated only insofar as they are compatible with the first. However where the idea of incompatibility relates to the economics of productivity maximization of single resource yield, management and multiple use can perhaps be validated in terms other than single-resource production efficiency.

Nonwood forest products Tangible minor forest products, such as fruit, nuts, bushmeat, fishery.

Photic zone (Also called *Euphotic zone*) The part of the water column in which there is sufficient light for photosynthesis to occur. The lower limet varies from a few matres in estuarine waters, which typically contain a considerable amount of suspended material, to more than 100 m in clear oceanic waters.

Planning The determination of the goals and objectives of an enterprise and the selection, through a systematic consideration of alternatives, of the policies, programs and procedures for achieving them. An activity devoted to clearly identifying, defining, and determining courses of action, before their initiation, necessary to achieve predetermined goals and objectives.

Planning Horizon The time period which will be considered in the planning process.

Potential evapotranspiration The maximum possible loss of soil moisture under a given climatic condition, by transpiration through the leaves of plants and by direct evaporation.

Sustainable development Development that meets present needs without comprising the ability of future generations to meet their own needs.

Sustainable forest management Utilization of forests (including aquatic resources in the mangroves) without undermining their use by present and future generations.

Strategy A broad non-specific statement of an approach to accomplishing desired goals and objectives.

Tree biomass The biomass of vegetation classified as trees including foliage, stump and roots. (*FAO defines a tree as a woody plant having a main stem which, when growing under normal conditions, reaches a mature height of at least 7 metres*)

Wood biomass The biomass of woody vegetation such as trees and shrubs including stumps and roots

LIST OF CONVERSION FACTORS

1 acre (ac)	0.405 hectare
1 cubic metre (m^3)	35.31 cubic feet
1 cubic foot	0.028 cubic metre
1 cord	3.625 cubic metre (stacked)
1 pikul	0.0605 tonne
1 tonne (t)	0.9842 long ton

ABBREVIATIONS

A.A.C.	Annual Allowable Cut
C.V.	Coefficient of Variation
C.A.I.	Current Annual Increment (m^3/ha/year)
das	Diameter above stilt roots (30 cm above the highest stilt root)
D.B.H./dbh	Diameter at breast height (1.3 m above ground level)
ffb	Fresh fruit bunch (Oil palm production)
IUCN	International Union for Conservation of Nature and Natural Resources (World Conservation Union)
Ln	Logarithm to natural base "e"
M.A.I.	Mean annual increment (m^3/ha/year)
M.C.	Moisture content (*in percent*)
o.b.	Overbark
ppt or ‰	per thousand (parts per thousand)
UNDP	United Nations Development Programme

SUMMARY

Growing awareness of the protective, productive and social functions of tropical mangrove ecosystems has highlighted the need to conserve and manage them sustainably. Given their multiple-use potential, it is imperative that mangrove-based terrestrial and aquatic resources be managed in an integrated manner. This implies that no-single resource use should be maximized *per se* to the point where the sustainable potential of another resource is adversely affected. The traditional "*management paradigm*" implying that if forests are well managed than, *ipso facto*, the non-wood ecosystem components will remain stable, is notionally flawed. Mangrove fishery, mariculture and wildlife management programmes have to be structured and integrated into the overall policy, implementation, and control levels of an integrated resource management system.

These guidelines, while promoting an integrated coastal area management approach to mangrove ecosystems, focus on the forest management aspects. They provide a broad synthesis of management systems that have been successfully practised in Southeast Asia, and the experiences of FAO in promoting sustainable forest management in Africa, the Caribbean, Central America and in other tropical mangrove areas. The present document looks at mangrove management from a broad perspective that goes beyond wood production *per se*. It is organized as follows:

Part I focuses on the ecological and biological foundation for sustainable management planning within a multiple-use framework, including a brief review of relevant literature.

Part II deals with the multiple-use potential of mangroves and discusses the utilization of selected mangrove-based products. Land use and protection aspects are also covered.

Part III covers the assessment of mangrove forest resources through the use of remote sensing, surveying, mapping and forest inventories; highlighting areas where these techniques differ from conventional approaches due to the specific characteristics of the mangroves.

Part IV focuses on the application of technical, managerial, economic and human resources to manage and use mangrove resources sustainably to meet the needs of people, and as a tool in rural development without impairing the environment. An objective assessment of the environmental impacts of mangrove forest management is attempted. Conclusions and recommendations are also presented.

Five small case studies dealing with various aspects of mangrove resource assessment are included in the back of this document together with a larger case study on Multiple-use Management of the Sundarbans Forest in Bangladesh.

In structuring an appropriate response to manage mangrove ecosystems sustainably, within an integrated multiple-use context, it is necessary to recognize that there are as yet many information gaps and constraints. These *per se* should not be considered as impediments to initiating mangrove management, as much empirical knowledge can be obtained by following and adapting the experiences gained in other countries.

MANGROVE FOREST MANAGEMENT GUIDELINES

1 INTRODUCTION

The mangrove formation is the gift of the land and sea. Mangroves depend on terrestrial and tidal waters for their nourishment, and silt deposits from upland erosion as substrate for support. The tides nourish the forest, and mineral rich river-borne sediments enrich the swamp. Thus the mangroves derive their form and nurture from both marine and terrestrial influences.

It is one of the most productive ecosystems and a natural, renewable resource. However, on all sides, the world's mangroves are beleaguered. Mangroves in particular are losing their habitats, as rivers are dammed, their waters diverted and the intertidal zone extensively developed for agriculture or aquaculture and generally dried up. Large tracts are converted to rice fields, industrial and land development and other non-wood uses. In response to the lucrative shrimp export trade, a new breed of small and large-scale farmers are carving out large chunks of tidal flats for shrimp farming and pisciculture. In parts of Asia, the mangrove is home to thousands of families. Mangrove areas are over-exploited for fuelwood and charcoal-making. In over-populated and acute fuelwood deficit areas, even small branches and saplings are removed primarily for domestic fuel.

The depletion of mangroves is a cause of serious environmental and economic concern to many developing countries. This stems from the fact that at the interface between the sea and the land, mangroves play a pivotal role in moderating monsoonal tidal floods and in coastal protection. At the same time their primary production supports numerous forms of wildlife and avifauna as well as estuarine and near-shore fisheries. Consequently, the continuing degradation and depletion of this vital resource will reduce not only terrestrial and aquatic production and wildlife habitats, but more importantly, the environmental stability of coastal forests that afford protection to inland agricultural crops and villages will become seriously impaired.

Habitat protection is the ultimate goal of conservation, to which all other approaches are subsidiary. For conservationists worldwide, mangroves present the great immediate challenge.

Technically, mangroves are easier to manage compared to the species rich humid tropical forests. There are typically only a handful of mangrove species, many of which coppice or regenerate freely. However, whereas the terrestrial forester is concerned primarily with managing forests grown on stable and firm ground, in the tidal swamps he has to manage aquatic resources as well, on a substrate that is ever changing and dynamic over time.

Given the multiple use potential of mangrove ecosystems and their linkages to terrestrial land use, an integrated approach is needed. Clearly, an integrated conservation and sustainable management approach, in the face of weak informational database prevailing in most countries, will require years of management research. Modern agricultural farming systems based on high yielding crops have evolved through centuries of concerted field research.

Mangrove forest management, in comparison, is a relatively new science, and unlike its agricultural counterpart, deals with long term tree crops rather than short term food crops. The economic and social reality in most developing countries is simply that forests cannot be conserved unless they are productively used. However, mere use of a resource is not management. It is important therefore to demonstrate potentially viable management alternatives to convince decision-makers to forestall some of the mangrove forest conversions and destruction until more detailed and reliable information is available.

In support of the foregoing, the Forest Resources Division of the Forestry Department in FAO has singly, and in cooperation with other UN agencies, promoted seminars and workshops on mangrove management, notably in Central America, the Caribbean, West Africa and the Asia Pacific region. Through Technical Cooperation Programme arrangements, integrated forest management models have been developed for Cuba, Costa Rica, Vietnam and several other countries. FAO has also provided technical expertise in mangrove management to assist countries such as Panama, Guyana, Ecuador, Sierra Leone, Kenya, Bangladesh, Myanmar, Thailand, Indonesia and Papua New Guinea to name a few.

Diverse management approaches designed to meet location-specific situations, priorities and needs have been tried. Thus, in Cuba, the acute shortage of railway sleepers has prompted the experimental use of portable cable winch systems, adapted to swamp working conditions. The management plan in this instance includes ecosystem management, honey production as well as improved carbonization techniques. In Costa Rica, an innovative integrated management plan to promote multiple use of molluscan resources, along side bark production and charcoal has been introduced for the very first time. Restoration of the degraded coastal mangrove belt to control the ingress of salt water constitutes a major technical support element in Guyana, where most of the coastal agricultural land is below sea level. In Sierra Leone, the main thrust is to restore the biological diversity and productivity of overcut mangroves, afforestate degraded mud-flats and rehabilitate other human impacted coastal areas. In Bangladesh, studies are conducted in the Sundarbans to devise viable management alternatives in the face of the natural and/or man-induced decline of productive growing stocks of Sundri (*Heritiera fomes*), coupled with an integrated multi-disciplinary approach to diversify and enhance the multiple-use potential of the area, including conservation of the endangered Royal Bengal tiger. In Myanmar, a feasibility study focusing on species trials to restock the degraded Ayeyarwady (Irrawaddy) delta mangroves is initiated and a "coppice-with-standards" system is now being tried in place of the selective felling system. In the Ca Mau peninsula in Southern Vietnam, a shrimp and tree farming model has been promoted as a sustainable land use option, to harmonise the competing use of tidal swamps for shrimp farming on the one hand, and the maintenance of ecological functions and fuelwood production on the other.

Experience suggests that many degraded mangrove ecosystems can and do recover from intensive and sometimes catastrophic human activities such as the massive herbicidal destruction of the mangroves around Ho Chi Minh City and the Ca Mau peninsula in Southern Vietnam during the Indo-China conflict. Nevertheless, the fact that ecosystems recover from gross human disturbance does not mean that the costs and socioeconomic consequences of such impacts are low.

An appreciation of key physico-biological interrelationships and ecological-human development interactions against the background of prevailing human needs is pivotal in the formulation of successful management strategies, consequently peoples' participation is crucial. In many situations the technical problems are less insurmountable than the social ones. Traditionally, foresters are conservative and tend to think in terms of management within the narrow territorial confines of reserved forests and applying sustained yield management to such reserves, and then only onto the so-called productive parts. The productive forest areas may constitute only a small part of the overall tidal swamp which has many ecological sites and niches, all of which play an important part in the overall ecological complex. Nowhere is the need to take a holistic environmental approach more crucial than in mangrove ecosystems where terrestrial, coastal and human influences are key interacting factors.

Until and unless foresters are prepared to share their "reserved mangrove domain" with other land-users and accept that, in certain cases, non-foresters, who may be marine biologists or ecologists, can manage the mangrove ecosystem better than they do, an integrated approach will be difficult to apply. Indeed, one of the key institutional constraints common to most integrated projects is weak or lack of coordination between different land-users and concerned agencies. One way to alleviate this problem is by creating a National Mangrove Committee, comprising concerned ministries and departments, research and education institutions and NGOs and charge it with the development and implementation of integrated mangrove management plans and/or the monitoring and evaluation of these. In some countries an agency responsible for integrated coastal area management (ICAM or ICZM) may already be in place, which could perform the above task given additional assistance from mangrove specialists.

Where the concern is environmental, the data needs must not only be comprehensive enough to cover all aspects, but the manner in which the data is collected and analyzed has to be undertaken in an integrated way using a multi-disciplinary approach with the identification and characterization of key inter-relationships in mind. A useful method for the design of integrated resource management plans and sustainable land use is to conduct extensive resource and land use surveys supported by selected ecological and social studies. The people are the key actors in any plan. Their support and participation from the very beginning are crucial in implementing a successful participatory forestry programme.

These guidelines, while promoting an integrated coastal area management approach to mangrove ecosystems, focus on the forest management aspects. They provide a broad synthesis of selected approaches applied, experiences gained and lessons learned. However, the present document looks at mangrove management from a broad perspective that goes beyond wood production *per se*. The aim of this wider perspective is to highlight and promote management approaches to environmentally sustainable, multiple-use management through commitment towards rational land use and greater responsiveness to people's concerns and needs. This does not imply that classical management paradigms are unsound but rather that these should be modified as appropriate in response to the heightened expectations of people and the imperatives for sustainable environmental management that transcend sustainable timber management.

The guidelines are organized as follows:

Part I focuses on the ecological and biological foundation for sustainable management planning within a multiple-use framework, including a brief review of relevant literature.

Part II deals with the multiple-use potential of mangroves and discusses the utilization of selected mangrove-based products. Land use and protection aspects are also covered.

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Part IV focuses on the application of technical, managerial, economic and human resources to manage and use mangrove resources sustainably to meet the needs of people, and as a tool in rural development without impairing the environment. An objective assessment of the environmental impacts of mangrove forest management is attempted. Conclusions and recommendations are also presented.

Five small case studies dealing with various aspects of mangrove resource assessment are included in the back of this document together with a larger case study on Multiple-use Management of the Sundarbans Forest in Bangladesh.

For additional case studies on mangrove management and utilization the reader is referred to two previously published papers by the FAO dealing with Asia and the Pacific (FAO Environment Papers 3 and 4) and the FAO Miscellaneous Paper (FO:MISC/86/4) 'Ordenacion Integrada de los Manglares' by B.Rollet which covers Latin America. ISME/ITTO (1993a) also present a summary of the status of mangrove management in Latin American countries. With regard to Africa only limited studies are available, and the reader is referred to SECA/CML (1987) and ISME/ITTO (1993b) for initial information.

For further information on integrated costal area management refer to FAO Fisheries Technical Paper 327 (FAO, 1992) and Chue *et al.* (1991). A series of integrated management plans for coastal zones in South East Asia have also been published by ICLARM (International Center for Living Aquatic Resources) as part of the ASEAN/US Coastal Resources Management Project. A number of these zones include mangrove areas.

PART I THE ECOLOGICAL BASIS FOR MANGROVE MANAGEMENT PLANNING

This chapter reviews some ecological and biological relationships of mangrove ecosystems, particularly in respect of those biophysical aspects relevant in designing appropriate silvicultural systems and in sustainable, multiple-use management planning. A brief review of relevant literature is also presented.

2 THE MANGROVE FOREST ECOSYSTEM

2.1 DEFINITION OF MANGROVES

Mangroves are the characteristic littoral plant formations of tropical and subtropical sheltered coastlines. They have been variously described as 'coastal woodland', 'tidal forest' and 'mangrove forest'.

Generally mangroves are trees and bushes growing below the high-water level of spring tides (FAO, 1952). Their root systems are thus regularly inundated with saline water, even though it may be diluted due to freshwater surface run-offs and only flooded once or twice a year.

Macnae (1968) suggested that the word 'mangrove' should be used for the individual trees and bushes, whereas 'mangal' be referred to communities of such plants. This usage has not been followed here because the context usually makes it clear whether one is referring to 'mangrove trees' or a 'mangrove forest'.

2.1.1 Floristics

The most noteworthy features of the mangrove forests, apart from their unique habitat, are the relative paucity of the species comprising them; the arch-formed stilt roots of the *Rhizophora spp*; the clusters of blind root suckers or pneumatophores from other genera such as *Avicennia* and *Sonneratia*, which protrude from the ground in such numbers as to be an impediment to walking; the curious adaptation to environment by which the seeds of the *Rhizophora* germinate on the trees; as well as the high incidence of trees with lenticellated bark.

The mangrove forests are evergreen. The paucity of species occurring in them is due to the peculiar conditions of their existence, few plants being able to tolerate and flourish in saline mud and to withstand frequent inundation by sea-water. They also differ from the inland forests in that certain species are practically gregarious over extensive areas. Apart from the *Rhizophora spp*, many of the principal species coppice readily. The flora that comprises arborescent species with forestry importance is confined to a few families, *viz.*, *Rhizophoraceae*, *Combretaceae*, *Avicenniaceae/Verbenaceae*, *Meliaceae*, *Sonneratiaceae*, *Sterculiaceae*, *Euphorbiaceae*, *Theaceae* and *Pelliceriaceae*. Other families are sparingly represented, chiefly in situations where the limits of the mangrove are not sharply defined.

In the supra-littoral and inter-terrestrial zone, where brackish water conditions prevail, there are species that occur in the mangrove habitat proper, but which are not restricted to it, e.g. *Acrostichum aureum, A. speciosum* and *A. danaefolium*. Recognizing this, Saenger *et al.* (1983), has divided the mangroves into two broad groups comprising the *exclusive species* that are restricted to the mangrove habitat, and the *non-exclusive species*, which may be important in the mangrove habitat, but are not restricted to it.

Species normally found in seasonal swamps that are subject to occasional saline influences, are dealt with superficially in this report, as their silviculture and management requirements are distinctly different (e.g. *Mora oleifera, Annona glabra,* and *Pterocarpus officinalis*).

2.1.2 Mangrove taxonomy

Depending on the concept of mangroves and definition of mangrove habitat applied, the number of species cited by different sources varies significantly (**Table 2.1**). This points to the need to standardize the criteria used in the definition and delimitation of mangrove habitats (Jimenez and Soto, 1985).

Table 2.1: Number of mangrove species

Source	Family	Genera	Species
Lugo & Snedaker, (1974)	23	32	75
Saenger et al, (1983)	16	22	60
Cintron & Schaeffer-Novelli 1/, (1983)	13	17	56
Chapman (1970)/Walsh (1974)	11	16	55
Chapman, (1974)	10	15	53
Blasco, (1984)	16	22	53
Mercer & Hamilton, (1984)	8	12	?

Source: 1/ based on Chapman (1970, 1974)

In **Table 2.2** on the following page, most trees and shrubs of the world's mangroves are listed after Saenger *et al.* (1983) and in **Figures 2.1 - 2.4** representatives of some of the most common genera are illustrated. For additional information on the individual mangrove species and keys to their identification, the reader is referred to Chapman (1976); Tomlinson (1986); Watson (1928) and a recent field guide by Aksornkoae *et al.* (1992).

2.2 BIOGEOGRAPHY

The general distribution of mangroves corresponds to that of the tropical forests, but they extend further North and South of the equator, sometimes beyond the tropics, although in a reduced form.

Floristically, two main zones can be distinguised : An Eastern zone comprising the East African coast, South Asia and the Pacific including the islands down to Australia, and a Western zone including West Africa, the coasts of America and the Carribean (FAO, 1952).

Table 2.2: A list of mangrove species world wide

A-Eclusive species	Life-form	B-Some important, non-exclusive species	Life-form
Acanthus ebracteatus Vahl.	S	*Acrostichum aureum* L.	F
Acanthus ilicifolius L.	S	*Acrostichum danaefolium* Langsd. & Fish	F
Acanthus volubilis Wall.	S	*Acrostichum speciosum* Willd.	F
Aegialitis annulata R.Br.	S	*Barringtonia racemosa* Roxb.	T
Aegialitis rotundifolia Roxb.	S	*Brownlowia argentata* Kurz.	T
Aegiceras corniculatum (L.) Blanco	S	*Brownlowia tersa* (L.) Kosterm.	S/T
Avicennia alba Blume	T	*Cerbera floribunda* K.Schum.	T
Avicennia bicolor Standl.	T	*Cerbera manghas* L.	T
Avicennia eucalyptifolia Zipp. ex Miq.	T	*Clerodendrum inerme* (L.) Gaertn.	S
Avicennia germinans L.	T	*Cynometra mannii* Oliver	T
Avicennia intermedia Griff.	T	*Dimorphandra oleifera* (Triana ex. Hemsl.)	T
Avicennia lanata Ridley	T	*Dolichandrone spathacea* (L.F.) K.Schum.	T
Avicennia marina (Forsk.) Vierh.	T	*Hibiscus hamabo* Sieb & Zucc.	T
Avicennia officinalis L.	T	*Hibiscus tiliaceus* L.	T
Avicennia rumphiana Hall.f.	T	*Mauritia flexuosa* (Linn.f.)	P
Avicennia tomentosa Willd.	T	*Maytenus emarginata* (Willd.) Ding Hou	S
Avicennia tonduzii Moldenke	T	*Myristica holtrungii* Warb.	T
Bruguiera cylindrica (L.) Blume	T	*Oncosperma filamentosa* Bl.	P
Bruguiera exaristata Ding Hou	T	*Pemphis acidula* Forster	S/T
Bruguiera gymnorhiza (L.) Lam.	T	*Pterocarpus officinalis* Jacq.	T
Bruguiera hainesii C.G.Rogers	T	*Thespesia acutiloba* (E.G.Backer)Excell & Mendonca	T
Bruguiera parviflora (Roxb.) Wight & Arn.	T	*Thespesia populnea* (L.) Soland. ex Corr.	T
Bruguiera sexangula (Lour.) Poiret	T	*Thespesia populneoides* (Roxb.) Kostel	T
Camptostemon philippinensis Becc.	T		
Camptostemon schultzii Mast.	T		
Ceriops decandra (Griff.) Ding Hou	T		
Ceriops tagal (Perrottet) C.B.Robinson	T		
Conocarpus erectus L.	T		
Cynometra iripa Kostel	T		
Cynometra ramiflora L.	T		
Excoecaria agallocha L.	T		
Heritiera littoralis Aiton ex Dryander	T		
Heritiera fomes Buch.-Ham.	T		
Kandelia candel (L.) Druce	T		
Laguncularia racemosa Gaertn.f.	T		
Lumnitzera littorea (Jack) Voigt	S/T		
Lumnitzera racemosa Willd.	S/T		
Nypa fruticans van Wurmb.	P		
Osbornia octodonta F. Muell.	S		
Pelliciera rhizophorae Planchon & Triana	T		
Phoenix paludosa Roxb.	P		
Rhizophora apiculata Blume	T		
Rhizophora harrisonii Leechman	T		
Rhizophora x larmarckii Montrouz	T		
Rhizophora mangle L.	T		
Rhizophora mucronata Lam.	T		
Rhizophora racemosa G.Meyer	T		
Rhizophora x selala (Salvoza) Tomlinson	T		
Rhizophora stylosa Griff.	T		
Scyphiphora hydrophyllacea Gaertn.	S		
Sonneratia alba J.Smith	T		
Sonneratia apetala Buch.-Ham.	T		
Sonneratia caseolaris (L.) Engl.	T		
Sonneratia griffithii Kurz	T		
Sonneratia ovata Backer	T		
Xylocarpus australasicus Ridley	T		
Xylocarpus gangeticus Parkison	T		
Xylocarpus granatum Koenig	T		
Xylocarpus moluccensis (Lam.) Roem.	T		
Xylocarpus parvifolius Ridley	T		

T = Tree
S = Shrub
P = Palm
F = Fern

Source: Saenger *et al.* (1983)

Figure 2.1: ***Rhizophora apiculata* with ripe propagules**
Vietnam. Photo by M.L. Wilkie.

Figure 2.2: ***Nypa fruticans* with fruits.**
Vietnam. Photo by M.L. Wilkie.

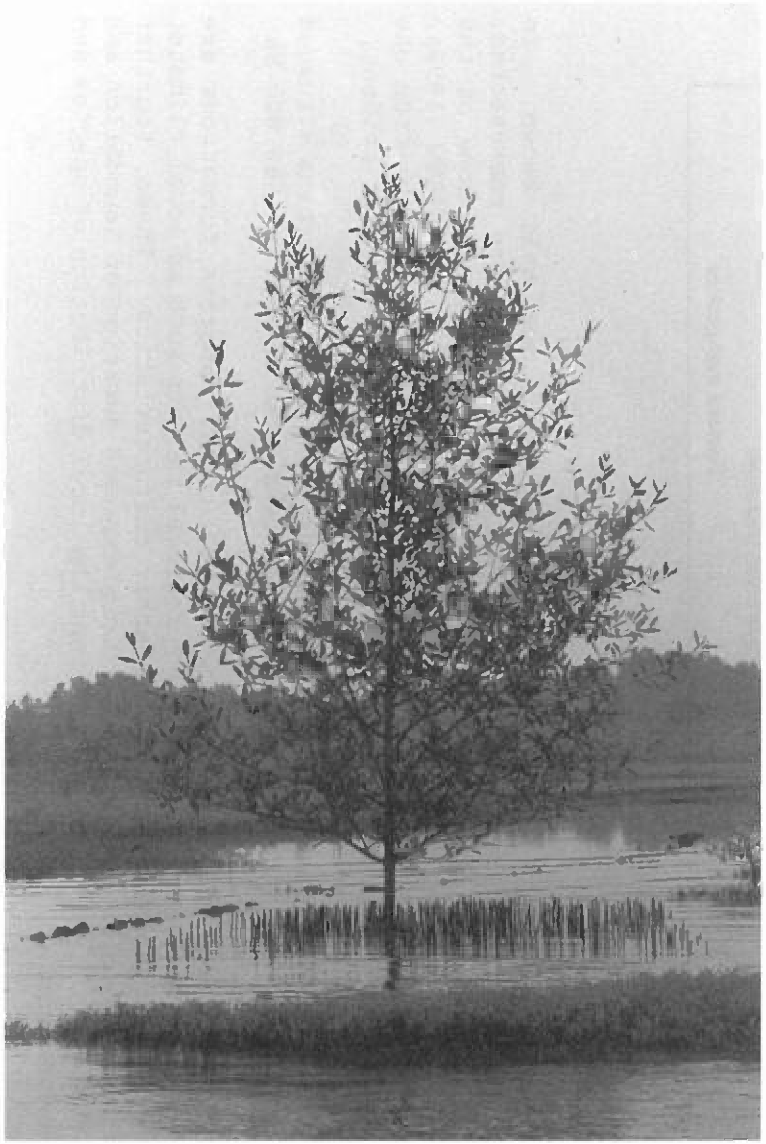


Figure 2.3: *Avecinnia africana* with pneumatophores
Sierra Leone. Photo by M.L. Wilkie.

Figure 2.4: *Bruguiera gymnorrhiza* with flowers.
Indonesia. Photo by M.L. Wilkie

All the genera (but not all the species) of the Western mangroves are found in the Eastern zone, but the latter is far richer in number of different species. Numerically, there is a five-to-one disparity in species numbers in the two groups. Chapman (1975) theorizes that the oceanic current around the Cape of Good Hope prevents the drift and migration of species from the Indo-West-Pacific biogeographic region to West Africa and the Atlantic. A generalized global distribution of mangroves and the number of species in various regions is shown in **Figure 2.5**

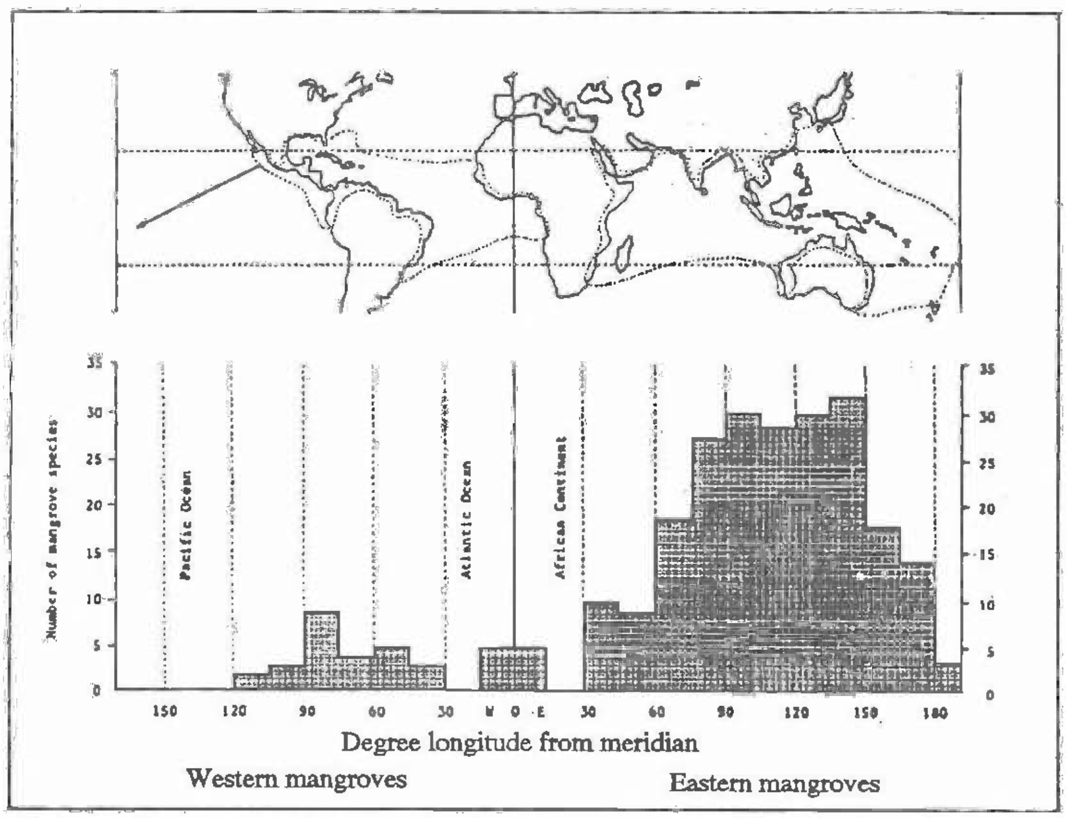


Figure 2.5: Generalized distribution of mangroves

The total area of mangroves in the world is not well known. In **Table 2.3** approximate mangrove areas in various countries are represented. More recent data on the extent of the mangrove formations in some of the countries in Latin America and Africa have been reported by ISME/ITTO (1993a, 1993b). However, as the accuracy of the estimates varies widely from one country to another, the need for an updated, world wide survey is evident.

The world's greatest contiguous mangrove area is the Sundarbans situated in the Bay of Bengal, which covers a total land area of approx. 660 000 ha.

Due to their situation along coastal lines, mangrove formations are constantly controlled by marine and terrestial factors such as local climate, geomorphology, salinity and other edaphic characteristics. These, together with the distance from the sea, the frequency and duration of inundation and tidal dynamics, govern to a great extent the local distribution of species and their succession.

Table 2.3: Approximate mangrove areas in various countries

ASIA	Area (Ha)*	AFRICA	Area (Ha)**	AMERICA	Area (Ha)***
Australia	1,162,000	Angola	50,000	Belize	75,000
Bangladesh	410,000	Benin	3,000	Brazil	2,500,000
Burma	812,000	Cameroon	273,000	Colombia	307,000
Brunei	7,000	Gabon	250,000	Costa Rica	39,000
Fiji	20,000	Guinea	260,000	Cuba	448,000
India	96,000	Guinea Bissau	243,000	Dominican Rep.	9,000
Indonesia	2,500,000	Gambia	60,000	El Salvador	36,000
Kampuchea	10,000	Kenya	45,000	Ecuador	196,000
Malaysia	674,000	Liberia	40,000	French Guiana	55,000
Pakistan	345,000	Mauritania	few ha.	Guadeloupe	3,000
Papua New Guinea	553,000	Madagascar	320,700	Guatemala	50,000
Philippines	240,000	Mozambique	85,000	Guiana	150,000
Sri Lanka	4,000	Senegal	440,000	Haiti	18,000
Thailand	288,000	Sierra Leone	100,000	Honduras	145,000
Vietnam	320,000	Nigeria	973,000	Jamaica	7,000
		Tanzania	96,000	Martinique	2,000
		Zaire	20,000	Mexico	660,000
				Nicaragua	60,000
				Panama	486,000
				Peru	28,000
				Surinam	115,000
				Trinidad and Tobago	4,000
				USA (Florida + P. Rico)	178,000
				Venezuela	260,000
TOTAL	7,441,000		3,258,000		5,831,000

Sources: (*) Wacharakitty (1983)
(**) Saenger et al. (1983)
(***) FAO (1981, 1986)

Best developments of the mangroves are found at locations with deep, well aerated soils, rich in organic matter and low in sand, usually in estuaries. Christensen (1983) indicated that *Rhizophora* may attain heights of more than 40 m in such areas.

The inland extend of mangroves depend on the morphology of the soil and the factors mentioned above, and the forests can vary in size from a few clusters of small trees or shrubs to extensive areas of well developed stands.

2.3 MANGROVE ECOLOGY

"Ecology is the science of the interrelationships of organisms in and to their complete environment". (Spurr and Barnes, 1980). For forest communities, the names of the predominant tree species which make up the characteristic physiognomy of any given stand are used to classify the forests into "forest types". Thus a "*Rhizophora* forest type" is characterised by the predominance of *Rhizophora* species, conjuring mental images of trees typified by prop or aerial roots as well as elongated pendulous propagules.

The forest community and its habitat constitute an *ecosystem*, in which the constituent organisms and their environments interact in complex processes and life cycles of carbon, water, and nutrients. Studies of the *forest ecosystem* takes into account both the organic and inorganic aspects of the cyclic processes of life, and are increasingly given greater focus due to the growing need for environmentally sound forest management.

The physical forest ecosystem environment and its biotic factors constitute the *habitat* or *site*. The forest environment is the composite end product of many interacting forces, hence *site* is the sum total of environmental conditions operating at any one place.

The ultimate goal of forest management, economic considerations aside, is to exploit to the fullest the natural energies and resources available for any given site so as to produce maximum carrying capacity for the production of the desired products. A careful examination of forest site conditions will prove to be a worth while investment both in time and effort for any forester, in so far as it portrays the potential stand productivity under ideal conditions.

Forest ecosystem analysis requires multidisciplinary investigations for a comprehensive understanding of system dynamics. The purpose of all these studies is to better understand and to predict changes that are likely to occur when ecosystems are subject to stresses and manipulations. However, in practice, a total analysis is seldom possible given the human and financial resources available. Forest managers should therefore be aware of the limitations under which they work and partly because of this awareness, conventional wisdom dictates that natural forests should be managed conservatively rather than rigidly according to economic goals. However, a gravitation towards the systems approach, which involves an assessment of systems productivity and their underlying process functions, is inevitable given the fact that increasingly forest managers are expected to resolve environmental issues. Systems-oriented studies allow us to perceive and resolve environmental problems in a different way. As stated by Reichle (1971):

> *"Ecologists cannot continue to respond to each new environmental crisis by simplistic "cause and effect" studies of isolated ecosystem components. The totality of environmental systems must be recognized and an understanding developed of the interactions and interdependencies of systems components. Only in this way can the effects of perturbation upon individual components be interpreted in the total context of the system". Reichle (1971).*

In the following the main abiotic factors influencing the mangrove ecosystem, *viz.* climate and edaphic factors, are described followed by a more detailed description of the main biotic elements constituting the ecosystem i.e. mangrove flora and fauna, their inter-relationships and the management implications of these.

2.4 CLIMATE

Pannier and Pannier (1977) broadly summarized the present knowledge concerning the distribution of mangrove forests in relation to climatic regions. According to Walter (1977), mangrove ecosystems are mainly found in three climatic divisions, viz., (a) the equatorial zone, between approximately 10°N and 5°-10°S; (b) the tropical summer-rainfall zone, north and south of the equatorial zone, to approximately 25-30°N and S, partly in subtropical dry zone of the deserts, still further poleward; and (c) partly in warm temperate climates that do not have really cold winters, and only on the eastern border of the continents in this zone.

Blasco (1984) suggests that both temperature and rainfall should be shown in a single climatic diagram, because they are essential bioclimatic factors for mangroves and other terrestrial plants.

The length of the rainy season determines the influx of freshwater in each site. In equatorial climates, the upland runoff is usually adequate to maintain freshwater in contact with the saline water table throughout the year. In dry monsoonal climates, salinity in the upper soil layers increases during the dry season. The number, duration and intensity of dry seasons, therefore, directly influence the distribution of salinity in the intertidal zone. The alteration of upland drainage may have an impact on those mangroves requiring recharge of freshwater.

Shoot growth of seedling and sapling trees is closely correlated to water potential within the plant and to environmental soil moisture deficits. In favourable sites, shoot growth occurs in varying degrees throughout the year but in high-stress sites, shoot die-back occurs during prolonged dry seasons and vigourous growth occurs mainly during the rainy season.

2.4.1 Temperature

In the equatorial belt, temperature is usually not a constraining factor with regard to plant growth. However, periods of intense physiological stress may be experienced when high temperatures are combined with full sunlight and prevailing winds giving rise to high evapotranspiration and increased surface salinity due to capillary uptake. In such cases the formation of heavy salty crusts on the soil surface can be harmful to plant growth. In the Guanal area in Cuba, "salitrales" are common in the more exposed coastal sites. (Chong, 1989b). Salt-flats (*albinas*) also occur naturally in the Aguadulce area in Panama.

2.4.2 Winds and storms

The impact of severe storms on the forest can be profound. In areas that are exposed to severe storms the canopy of the forests along the coasts is usually broken. Structurally, the trees are also shorter. This partly explains the fact that high mangroves are found generally in more sheltered situations.

Severe storms (cyclones/hurricanes) affect the waves, swell, storm tides, and current system, as well as the volume and rate of fresh water discharge from the land. (Riggs, 1977). Mangroves play an important role in moderating coastal storms at the interface between the land and sea. The coastal belt, particularly near and along the foreshore, is a zone of intense atmospheric turbulence due to the interplay of land and oceanic atmospheric influences. The impact of cyclones on densely populated deltas can be tragic. In November, 1970 a cyclone, combined with high tide, killed more than 200 000 people in Bangladesh. The 1991 cyclone reportedly killed over 100 000 people and rescue work was hampered by high tidal floods. Without the moderating influence of the forest, the loss of human life and property is catastrophic. *Environmentally, therefore, the coastal mangroves are vital shelter-belts which afford protection to inland homesteads, agricultural crops, livestock and aquaculture.*

Along the coasts, a belt of protective mangrove vegetation should always be retained not only to reduce the damaging effects of tidal waves and storms but also to reduce the severity of tidal flooding.

2.4.3 Rainfall

Mangroves do not rely absolutely on rainfall for survival because they can extract fresh water from the sea through salt excreting glands. (Chapman, 1976). However, the amount of rainfall influences mangroves in two ways: (1) as rainfall determines the rate of weathering it accounts for the amount of silt brought to the mangrove swamp, and (2) high rainfall reduces the incidence of hyper-salinity. According to Macnae (1966, 1968), Australian mangroves thrive best in areas receiving more than 2 500 mm of rain per year, as salt flats are often formed in areas with a precipitation of less than 1 500 mm/year.

Where the mean potential evapotranspiration (PET) is high and the amount of rainfall is insufficient to reduce the accumulation of salt, salt flats becomes predominant as is the case in Cuba, parts of Panama, West Africa and West India.

2.4.4 Life Zones (Zonas de Vida)

In Central and South America, Holdridge's Life Zone system for classifying of vegetation and climate has been applied to the compilation of ecological maps. The ecological map for Costa Rica prepared by Tosi (1968) at a scale of 1:750 000 provides a good classification even for the coastal mangroves (Holdridge 1947, 1971).

According to the Life Zone system, the most suitable life zone for silvicultural management is the Tropical Wet Forest (bmh-T), followed by Tropical Moist Forest (bh-T), and the least suitable is the Tropical Dry Forest (bs-T). Forests lying outside these life zones have strong silvicultural limitations.

Chong (1988) observed a similar correlation between the life zone types and forest productivity classes in the Terraba-Sierpe mangrove area in Costa Rica. However, given the multiple-use potential of even the least productive forest types, their potential uses cannot be easily discounted.

2.5 EDAPHIC FACTORS

2.5.1 Mangrove geomorphology

Delta formation

Large mangrove formations are typically found on relatively sheltered deltaic littoral plains. In Bangladesh, the Ganges and Brahmaputra monsoonal waters overflow the river banks almost every year, depositing sediments over alluvial flats, riverine and tidal plains gradually extending the delta Southwards into the shallow waters of the Bay of Bengal.

Delta formation is a delicate balance between the type and amount of river sediment, compatibility of the sediment, vegetation, changes in sea levels, the underlying geology and geomorphology, and the wave and tidal forces where the river meets the sea.

Subsidence of sediments is a common phenomenon. Rivers carrying muddy sediments that compact much more that sand or silt produce deltas that are more prone to subsidence. When this clay settles, as much as 80 per cent of its initial volume is water, which is gradually squeezed out by new sediments deposited on top. This causes the land of the delta to gradually subside unless new superficial mud is regularly deposited. Due to natural subsidence, the central portion of most tidal swamps, which is not well flushed by tides, tends to be more prone to deep flooding. However, where the deposits are calcareous, the substrate is more compact and consolidated, and the rate of subsidence is slower (e.g. in the Sundarbans and the Ayeyarwady deltas in Bangladesh and the Union of Myanmar respectively).

When river silt load is reduced by human interference, such as river diversion, dams or channels dug to facilitate navigation, the dynamic balance between land erosion and accretion will be adversely affected, leading to land subsidence in many areas. The Aswan High Dam, acting as a silt trap, has effectively halted the Nile delta-building process and initiated an active process of coastal retreat due to erosion and subsidence. (Kassas, 1972). Farmers that settle along rivers often build levees that can impede water movement thereby disrupting the natural siltation process.

Even without human intervention, delta building is not uniform. Rivers change their courses, to seek shorter, steeper paths to the ocean. Little or no sediment then accumulates along the abandoned channel, and the land around it subsides. The river's sediments are carried along the new channel. The delta thus goes through a natural cycle of growth and decay (See **Box 2.1** on the following page.)

Subsidence is also assisted by a rise in sea levels due to geological processes. In the gangetic plains a general westward tilt in the landmass has been advanced as a cause for the eastward drift of rivers and accounts for the increasing salinity levels in the western part of the Sundarbans due to the reduction in fresh water flow.

However, the scale of change associated with these localized geological phenomena is very small compared to the ecological and physical effects on water levels due to global warming: experts generally agree that temperature and sea level changes of the magnitudes as shown in **Table 2.4.** to the left are entirely probable.

Table 2.4: Global warming scenarios

Climate effect of emission scenarios - Year 2090

Alternatives	Temperature rise (Centigrade)	Sea Level Rise (cm)
Business as-usual	4.0	60
Scenario B	3.0	400
Scenario C	2.3	35

Source: Second World Climate Conference, Geneva, 1990.

The socioeconomic and ecological costs to countries with substantial low lying coastal plains and populated tidal swamps can be very high. In some of the Pacific atoll countries, Bangladesh and Guyana, the social cost in the loss of agriculture land due to salt water intrusion, increased flooding and depletion of productive mangroves could be very high indeed.

The Delta building process

Deltas are the end products of erosion. Rain washes soil and weathered rock fragments into streams and rivers towards the sea. Most of the debris is deposited along the way, where it forms sediments, and eventually sedimentary rocks. Deposits formed at the river mouth are known as the delta, named after the Greek letter Δ, because the ancient Greek historian Herodotus noted that the Nile delta in Egypt, was similarly shaped.

How far the debris travels depends on how heavy it is, and how fast the river flows. The lighter the grains of sand, silt and mud, and the stronger the current, the farther the river can carry it. Particles settle as the river slows. Deltas form as the river water spreads out and slows down where it flows into the sea.

Large boulders and rocks, are rarely transported very far downstream, except during catastrophic floods. They generally form broad, sloping "alluvial fans" that can spread out onto lowlands at the edge of a range of hills.

The form of the sediments is dependant on the parent material of the eroded substrate, whether it is sandy (arenaceous) or clayey (argillaceous). Similarly, the chemical nature of the debris will mirror the chemical composition of the eroded material, such as calcareous limestone.

Smaller particles, such as sand and silt, settle as the river slows down while it travels over plains. These sediments build plains lying close to sea level, such as those that make up Bangladesh, the Mekong and Ayeyarwady deltas.

Sediment settles in a river's channel, especially where it meanders, and eventually blocks it. This forces the river to seek a new path, unless the silt is removed by dredging. When rainwater overflows its banks after heavy monsoon rains, silt and mud spread over the surrounding flood plains. Such floods generally carry more material than normal river flow adding sediments across the land when they recede. Flooding brings fertile silt to the plains and tidal swamps, thereby enriching the mangrove ecosystem.

Sediments are not deposited evenly. Sometimes, the river deposits more debris along its banks, where it floods most frequently. This builds up "natural levees" along the edges of the river, making these banks higher and drier than the surrounding land. Confined between these natural embankments, the river rises as silt settles, and can become higher than the surrounding land.

The size and shape of a delta depends on the sediment load, river flow rate and the wave power as well as tidal range of the ocean. These combination of factors enable geomorphologist to classify deltas as "river, wave or tide" dominated. Where the waves and tides are weak, the coast can be irregular; convoluted in shape, e.g. the Mississippi. This is because the river has carried more sediments than the tides and current can carry, so the delta grows out to the sea. Where waves are powerful such as at the mouths of the Nile, Ayeyarwady and Senegal Rivers, the coast line is smoothly curved. Differences in wave energy can be enormous, for example it takes the Senegal coast only a little over 2 hours to receive as much wave power as the Mississippi receives all year round. Large tidal amplitudes, like strong waves, tend to smooth the coastline, giving a delta the simple triangular shape.

BOX 2.1: The Delta building process

The restoration of protective mangrove belts must now be given prominence in areas such as these. At the interface between the land and sea, mangroves form the first line of defense against the elements and thus will have an increasingly important role to play if the adverse scenarios in terms of human suffering and economic costs associated with the predicted rise in sea levels are to be averted.

Hydrology and drainage

The quantity of freshwater discharge into the mangroves depends on the size of the watershed, the climate, river flow characteristics and diversion of water for other land uses. Where the flow is highly seasonal, extensive flooding usually occur during the monsoon months, especially when peak flows coincide with high spring tides.

Snedaker *et al.*, 1977, have summarized the role of fresh water from the Ganges through its distributaries' discharge into the Sundarbans estuaries as follows:

- as a salt water dilutant;
- in protecting fry, shrimp and shell-fish and other biota;
- in modifying water temperature;
- in osmoregulation of marine animals;
- as a vehicle for primary nutrients and metabolic waste removal;
- as a moderator of concentration-dependent reactions in salt water;
- as a resource-partitioning mechanism in coastal waters;
- in the vertical movement and distribution of organisms;
- as a cutting and filling mechanism;
- in maintaining a salt wedge and mixing zone;
- in the delivery of allochthonous materials to estuaries as a function of precipitation, drainage and topography;
- as related to times of arrival and departure of migrating species.

Sediment load and turbidity

The amount of suspended matter transported by a river is dependent on its velocity. The greater the rate of flow or current, the larger the bed load and particle size carrying capacity. This has many implications for any given mangrove ecosystem, in that it affects the estuarine depositional pattern as well as the biology of many of the organisms living in the aquatic and terrestrial systems.

The discharge of large volumes of colloidal mud from the Amazon river for instance makes even the establishment of hardy mangrove species such as *Avicennia spp* very difficult as the mud tends to clod up the lenticels in the pneumatophores. This body of mud is carried by the current all the way to French Guiana and Surinam, and is commonly referred to as the "mud sling".

Coastal-estuarine classification

There are several definitions of 'estuary' and 'coastal area' in relation to mangrove formations. Many are based on geographical or geomorphologic descriptions. Estuaries are dynamic in behaviour, in that their boundaries exhibit temporal and spatial fluctuations reflecting local changes in river flow, wind stress, wave-tidal dynamics, or far-field forcing such as the synoptic wind stress on the coastal ocean surface and continental shelf waves. Thus the dynamic definition proposed by Kjerfve (1984) is useful in ecosystem management where an understanding of habitat dynamics, salinities and other factors is required.

Kjerfve recognizes three zones as follows: (a) the estuarine riverine zone; (b) the estuarine mixing zone; and (c) the coastal boundary layer zone. An idealized estuary - coastal system is shown in **Figure 2.6**.

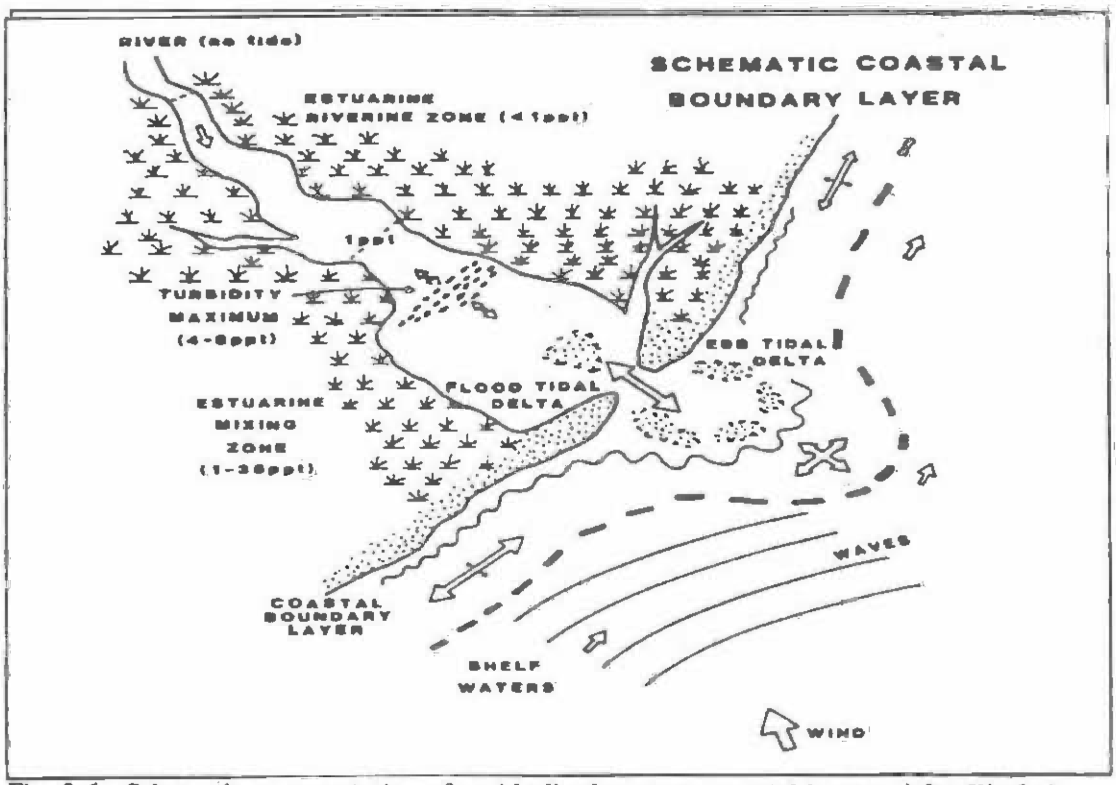


Fig. 2.6: Schematic representation of an idealized estuary - coastal lagoon (after Kjerfve)

The <u>estuarine mixing zone</u> is commonly referred to as the estuary proper. Kjerfve sets the upriver limit at the 1‰ isohaline, which fluctuates up or down river depending on river flow and tidal influences. In forest management, the 10‰ isohaline is significant because the ferns *Acrostichum sp.* can become a major threat to regeneration in areas where the salinity is less than 10‰. This is for instance the case in some areas in the Matang mangrove reserve, in Peninsular Malaysia. It also represents the lower salinity limit for the white prawn *Penaeus vannamei*, which is the most commonly cultured species (Kapetsky, J.M. 1986).

The ebb tidal delta or river mouth bar forms the seaward boundary. Here the prevailing salinity is similar to that in the ocean waters (35‰). The flood tidal delta and associated tidal flats, where they exist, are part of the estuarine mixing zone and located inside the geographical entrance. Typically the estuarine mixing zone shows marked salinity gradients and has a very intense turbidity zone in which fine grain sediments are suspended. This is the zone where gravitational circulation may exist, and where reversing tidal current occurs. Depending on the geomorphology, the estuarine mixing zone is sometime referred to as a lagoon in shallow systems with elliptical configurations as in the Costa del Sur mangroves of Cuba, as a fjord in glacially formed systems or sunken rivers as in the case of Sierra Leone (Chong, 1986).

The estuarine riverine zone is the freshwater region of the coastal system that experiences periodic tidal rise and fall in river level. In the lower regions of this zone, near the 1‰ isohaline, the current typically reverses direction according to tidal influences. This zone can be very extensive as in the case of the Amazon. Fauna requiring substantial amounts of freshwater or which can tolerate only low salinities may be reared in this zone, as for example crocodiles.

The coastal boundary layer zone is the active interface between the nearshore and offshore coastal oceans. It is usually characterized by high turbidity, high nutrient concentrations and weak salinity gradients. The width varies from about 1 km seawards from the river's mouth to more than 30 km in the case of a river or estuarine plume. Depending on the amount of river discharge, the configuration of this boundary varies and it represents the seaward extent of tidal influences.

Accretion and erosion

The mangrove habitat is a dynamic ecosystem. For optimal development mangroves require freshwater influence and adequate tidal flushing, consequently, the better stands are situated along waterways. In addition they are associated with a highly dynamic process of continual erosion and accretion which is essential to their existence as the continual tendency for mangrove streams to erode on one side and accrete on the other keeps the overall level of the formation within the altitudinal range of the mangrove association.

In the case of prograding shorelines, (e.g. Matang in Peninsular Malaysia and in the Bay of Bengal) where extensive mud-flats are accreting seawards, new coastal mud-flats are formed annually. Over 80 000 acres of newly consolidated mud-flats have been planted with *Sonneratia apetala* and *Avicennia sp* in the Bay of Bengal. In Matang, substantial areas of new mud-flats (new forests) are recorded during each 10-year working plan period.

Not all mangrove systems have prograding shorelines however. Three physiographic states occur in mangroves, viz., accretion, erosion and steady-state varying in scale. Accumulation of sediment influx or accretion may lead to changes in the superficial extent of a site and/or changes in levels, which could alter water-movement.

These changes are particularly noticeable near the river mouths where water turbulence or reduced velocity of flow lead to a corresponding decrease in the load carrying capacity of the river and hence depositional behaviour. Erosion may lead to site destruction by scouring. In the Ca Mau peninsula in Southern Vietnam, the Eastern shorelines are eroding at a rate of some 300 m/year, whereas along the Western flank, new mud-flats are accreting at a rate of 100 m/year. The shoreline sedimentary pattern shows a south-westerly drift conforming to the general direction of coastal current and wind during the northeast monsoon. The third state represents a stable condition in which the deposition and removal of silt and mud appear to be in balance. This appears to be the position in the Ayeyarwady delta area in the Union of Myanmar.

A distinction, however, should be made between natural deposition and erosional processes and those induced by man. Excessive silt load and frequent flooding due to upstream erosion and denuded river banks may lead to the "drowning" of mangrove roots. Similarly, the raising of levee banks by farmers for shrimp farming or swamp paddy often impedes the natural movement of water into the interior of swamps leading to a decrease in nutrients. Erosive waves and turbulence produced by motorized boats can also damage river banks, as will the indiscriminate removal of vegetation along streams and rivers. The riverine forests not only protect the river banks but are usually the prime source of propagules, and their removal will therefore adversely affect propagule supply and dispersal.

Tides and current

Water movement is very important to the survival of mangroves, in that nutrients are brought into the system by tides and from upstream flows. Tides carry the remains of these nutrients and dissolved detritus from the mangrove ecosystem further downstream to the estuarine systems (Dwivedi, S.N. *et al.*, 1974; Lugo, A.E. *et al.* 1973). Water transports dissolved oxygen to the root systems of plants and recycles nutrients in the ecosystem (Clough, B.F. and Attiwill, P.M. 1974). Tides remove accumulated carbon dioxide, sulphurous toxic wastes, organic debris, and maintain soil salinity levels. The dispersal, distribution and successful establishment of propagules are also partly influenced by tides (Chapman, 1976, Rabinowitz, 1978).

Tides regulate benthonic activity. Filter feeders, such as clams, mussels, oysters (Mollusca) depend on the tides. Gocke, K. *et al.*, (1981) have shown that tidal range and duration of immersion affect the relative percent of oxygen consumption of benthic organisms in different habitats along the Pacific coast.

Tide is a periodic rising and falling of sea level caused by the gravitational attraction between the Moon, the Sun, and other astronomical bodies acting on the rotating Earth. The vertical rise and fall is called *tide or astronomical tide*; the horizontal movements of water are termed *tidal current*. Tides follow the moon more closely that they do the sun.

Along the Pacific coast of Costa Rica, the lunar day is about 42 minutes longer than the solar day, hence tides occur about 42 minutes later each day. The two daily tides on the Atlantic coast are of nearly the same height, but along the Pacific coast the tides have a pronounced diurnal inequality. The coasts of Thailand are influenced by 3 tidal regimes; viz., semi-diurnal along the Andaman coasts, diurnal tides along the Northern part of the West coasts of the Gulf, and the remaining coastline receives mixed types of tides, but prevailingly diurnal (**Figure 2.3**). The Dat Mui mangroves in Southern Vietnam are characterized by two tidal regimes, originating from the Eastern coast and the Gulf of Thailand. The former is diurnal with a tidal range of 1-2 m, while the latter is semi-diurnal having a smaller tidal range of 0.2-1.0 m.

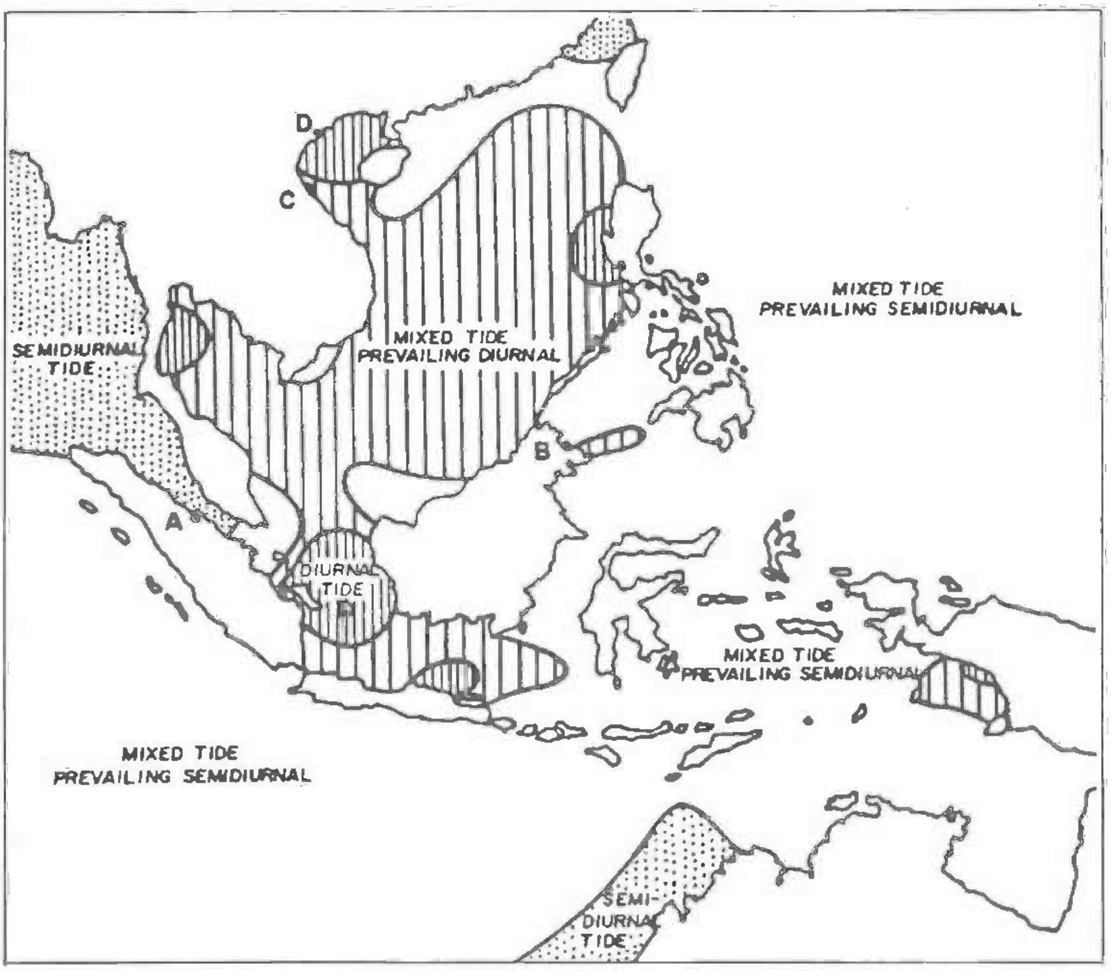


Fig 2.7: Distribution of tidal types in Southeast Asia (after Wyrtki, 1961)

The level of water in any particular coastal system is the combined result of tidal forces that may be modified due to the nature and extent of the estuaries, coastal configuration, and terrigenous river discharge. The response to these forces can be determined from an analysis of tide gauge records.

Tidal amplitude varies from place to place. A marine tidal chart will give a good idea of tidal conditions. Where the amplitude is high, the area subject to periodic tidal flushing is corresponding large and usually gives rise to a wide range of ecological sites. This is particularly so in areas where the continental shelf slopes gently towards the sea and the coastal current is weak enough to allow the mangrove formation to extend seawards. Generally in the Caribbean area, due to the lower tidal amplitude, the range of ecological sites is restricted, and accordingly, the vegetational types are relatively smaller in numbers and extent.

2.5.2 <u>Salinity</u>

A saline environment is required for stable mangrove ecosystems, as many species are less competitive under non-saline conditions (Lugo, A.E., 1980).

However hypersalinity can adversely affect mangroves and a given site is considered to be *hypersaline when the salinity (surface or interstitial soil levels) exceeds that prevailing in the sea* (In most areas this level averages 35 ppt). The effect due to salinity and the resulting strongly negative osmotic pressure of soil water, is a progressive stunting of the mangrove canopy inland from the water's edge. This can be almost universally recognized and takes place regardless of species composition.

Zonation of species is partly influenced by salinity, although the extent of its influence depends on local climatic and edaphic factors (Chapman, V.J., loc.cit.; Mukherjee B.B. and Mukherjee, J., 1978; Watson, J.G., 1928; Hann, J.H. de, 1931; Frodin, D., 1985; Thom, B.G. 1967). Similarly, Saenger *et al.* (1983) conclude that the efficiency with which each species deals with high soil salinities largely determines its position in the intertidal zone.

Mangroves are considered to be *facultative halophytes*, i.e. they can often survive though not necessarily thrive in non-saline habitats (Cintron, G. and Schaeffer-Novelli, Y., 1983a: Walsh, G.E., 1974). It has often been reported that the growth of many halophytes is depressed without sodium chloride in the external environment (Jennins, 1970; Flowers *et al.*, 1977; Greenway and Munns, 1980). In the case of mangroves a number of studies now available point to a similar physiochemical trend and support the hypothesis that the presence of limited amounts of sodium chloride in the external medium is required. **Table 2.5** summarises the data for 2 species.

Table 2.5: Effect of salinity on maximum growth of mangroves

Species	Percent of 1/ seawater (%)	Sources
Avicennia marina	50%	Connor, 1969
Avicennia marina	20%	Clarke and Hannon, 1970
Avicennia marina	10 - 50%	Downtown, 1982
Avicennia marina	25%	Clough, 1984
Avicennia marina	25%	Burchett, Field and Pulkownik, 1984
Rhizophora mangle	100%	Stern and Voigt, 1959
Rhizophora mangle	25%	Pannier, 1959
Rhizophora mangle	25%	Clough, 1984

Note: 1/ Concentration of NaCl required for maximum growth 2/
2/ The growth criterion used, is the accumulation of total dry weight.

Despite the apparent differences in salinity levels recorded above, which may be due to seasonal variance of the seawater salinity, there is an optimal salinity range for maximum growth. At extreme levels mangrove species suffer damage and even mortality. The die-back of Sundri (*Heritiera fomes*) has been ascribed to an adverse increase in soil salinity (Christensen, B. and Snedaker, S.C., 1984; Chaffey, D.R. *et al.*, 1985). Different range of salinity values are, however, quoted by different authors. (Cintron, G.Y., and Schaeffer-Novelli, Y., 1983b; Soto, R. and Jimenez, J.A., 1982).

In afforestation where matching species to site is required, the salinity range required for optimum plant growth and regeneration for any given species is more useful than its wider 'ecological' survival limits. Yeo and Flowers (1980) have stressed that the phenomenon of growth response to an increase in salinity should be considered quite separately from the tolerance to extreme salinities, which must be considered to be much higher than the optimal salinity for growth. Information on ecological tolerance limits are nevertheless important in predicting the continuance or displacement of species growing under altered or high-stress habitats. In this respect, when rehabilitation programmes are carried out in ecologically degraded areas that may be hypersaline, it is prudent to use propagules collected from individuals that grow in similar sites, because there may be ecotypes or hybrids that are better adapted to such stressed environments. Jimenez and Soto, (1985) have prepared a list of Pacific coast Central American mangrove species and their maxima salinities, including herbaceous plants such as *Hymenocalis littoralis* and *H. pedalis (Liliaceae)*. *Hymenocalis sp.* appear to be good site indicators for habitats that are relatively well flushed and which have a low salinity. These sites are optimum for *Rhizophora mangle* and *Pelliceria rhizophorae*.

Salinity is also an important physiological factor affecting marine and brackish water animals, and is used as one of the parameters to assess aquaculture potential. Very high or low salinity will affect growth, and if extreme can be lethal. Salinity of less than 10‰ can produce an off-flavour in shrimps (Clifford, H.C., 1985). *Penaeus vannamei*, one of the most desirable species for culture, does best at salinities ranging from 15 to 20‰. According to Midget (1985) the salinity-growth relationships for most penaeid shrimp species are as follows:

Table 2.6: Salinity-growth relationship for penaeid shrimp

Salinity (ppt)	Growth
< 5 & > 40	poor
5-15 & 30-40	fair
15 - 30	good

2.5.3 Other edaphic factors

Mangrove soils are usually alluvial. They are normally featureless, hydromorphic with varying degree of gleying in the subsoil horizons. Troll and Dragendorff (1931) considered that the black colour of many mangrove muds is produced by anaerobic bacteria reducing sulphates to sulphides.

The acid sulphate problem

The high organic and iron content in mangrove soils combined with the ever present sulphate from tidal seawater renders them particularly susceptible to acid sulphation due to oxidization, as often happens during pond construction. See **Box 2.2** on the following page.

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 pyrite sediments lead to their oxidization and to formation of Sulfuric acid (H_2SO_4), which is abundantly released in the absence of calcium carbonate ($CaCO_3$) (Pons and Zonneveld, 1965; Vieillefon, 1974; Marius, 1977).

Source: Hamilton and Snedaker (1984)

Box 2.2: The acid sulphate problem

When this occurs, the pond pH often falls to 3 or less - a condition that presents problems for both aquaculture and agriculture (Watts, J.C.D., 1969, and Kanapathy, K., 1975). Potter (1977) cites low natural production, poor response to fertilizers, and slow fish growth as some of the effects of using such soils for fish culture. Cook and Rabanal (1978) recommend liming for soil pH below 6.5 but the cost may be prohibitive, as about 30 t/ha of limestone may be required to increase the upper 30 cm of an acidic mangrove soil by only one pH unit (Kanapathy, K., loc.cit.). The potential danger of acid sulphation should be considered in the physical conversion of mangrove soils, as well as the threat of acid contamination to the environment and fishery. Dunn (1965) reported the mass killing of fish in some cases where heavy rains washed the soil acids into rivers.

The problem of acid sulphate soils in relation to conversion of mangrove soils to salt ponds and rice fields has also been studied by Thomlinson, (1957) and Hesse (1961a and 1961b). In Sierra Leone, where rice has been cultivated in mangrove areas since 1855, Hesse found that soils previously covered with *Rhizophora sp.* tend to develop soil conditions adverse to rice growth due to these soils being sulphidic and highly fibrous in nature, which results in the formation of acidic sulphate and the release of aluminium ions when empoldered. Soils previously covered by *Avicennia* on the other hand, were non-fibrous and did not pose any problems when empoldered. One of the reasons behind these findings may be that in Sierra Leone, *Avicennia* is usually found on sandy soils, which generally have a lower content of phosphorus and oxidisable sulphur than clayey soils, often dominated by *Rhizophora sp.*

Soil sampling provides an idea of the nature of the soils which are texturally influenced by silt deposits within the estuary. For example the high silt transport of the Terraba river precludes or reduces the significant development of benthic communities in the rivers, which may have an effect on mangroves via the reduced rate of turnover of the soil, and on aquatic productivity which depends on phytoplankton production and the organic detritus from the mangrove forest.

Soil characteristics affect natural and artificial regeneration. Plant species growing in the intertidal zone are exposed to many stresses.

Firstly, the high salinity (and its fluctuations) creates physiological stress. Secondly, water-logged soils have a low content of interstitial oxygen. Such anaerobic conditions compel the plants to get oxygen either from the air or from the very top layer of the soil. In the less aerated soils, the *Rhizophora spp* take on a different physiognomic form with large numbers of hanging aerial roots that originate from both the stem and upper branches, as well as, lateral "running" roots. Aerial roots serve not only an aeration function but also stabilise the stems as "prop" roots, although these functions vary according to species (Percival, M., and Womersley, J.S. 1975). Thirdly, fluidity of the soil substrate is still another major constraint, especially for tree species.

2.6 MANGROVE VEGETATION

2.6.1 Vegetal formations and communities

In Central America, Jimenez and Soto (1985) recognized 3 mangrove zones along the Pacific Coast in Costa Rica, viz. North, Central and South Pacific. The vegetation is grouped into 3 types according to their distribution, biological characteristics, soil salinity and inundation intensity as follows:

(i) Nuclear vegetation

This type constitutes the mangrove forests *sensu stricto* as it comprises species in the intertidal zone that are dependent on saline influences, the so-called obligate halophytes. Most species have special adaptations which enable them to grow in the mangrove substrate, such as vivipary, high salt tolerance, ability to withstand tidal submersion, pneumatophore or aerating roots, succulence and salt excreting glands.

The 5 most important species are *Rhizophora mangle* L., *Rhizophora harrisonii* Leechman (Rhizophoraceae), *Pelliciera rhizophorae* Triana and Planchon (Pelliceriaceae), *Avicennia germinans* L. (Avicenniaceae) and *Laguncularia racemosa* L. Gaertn. (Combretaceae).

(ii) Marginal vegetation

The species here are commonly associated with the mangroves in the landward fringe, in seasonal freshwater swamps, beaches and/or marginal mangrove habitats. Though they exist in the mangroves, these species are not restricted to the littoral zone. *Conocarpus erecta* (Combretaceae) is not found in the mangrove proper. *Mora oleifera* (Triana) Duke (Leguminosae) is abundant in the south Pacific coast, particularly in Peninsula de Osa, where it grows in seasonal swamps that may be quite saline (25‰). Other species present include *Annona glabra* L. (Annonaceae), *Pterocarpus officinalis* Jacq. (Leguminosae), *Hibiscus tiliaceus* L. and *Pavonia spicata* Killip (Malvaceae).

The fern *Acrostichum aureum* L. (Polipodiaceae) negraforra is very extensive in the brackish water zone and poses a threat to seedling regeneration.

(iii) Marginal facultative vegetation

Carapa guianensis (Meliaceae) grows in the South and partly South of the central Pacific coast in salinity around 10‰. Other species are *Elaeis oleifera* and *Raphia taedigera*. This is the inter-terrestrial zone which in the more equatorial climate would correspond to the *Melaleuca leucadendron* swamps (e.g. Southern Vietnam). This vegetational type has limited forestry potential. It is highly modified due to human development and more suited for other land uses.

Lugo and Snedaker (1974) identified and classified mangroves according to six community types based on forest appearance, and related to geological and hydrological processes. Each type has it own characteristic set of environmental variables such as soil type and depth, soil salinity range, and flushing rates. Each community range has characteristic ranges of primary production, litter decomposition and carbon export along with differences in nutrient recycling rates, and community components. A brief description of the community types based on the Floridian experience as shown in **Figure 2.8** is as follows:

(1) Overwash mangrove forests - the red mangrove is the dominant species on these islands that are frequently inundated and flushed by the tides, resulting in high rates of organic export. Maximum height of trees is about 7 m (23 ft).

(2) Fringe mangrove forests - these mangrove fringes are found along waterways, best defined along shorelines whose elevations are higher than mean high tide levels. Maximum hight of mangroves is about 10 m (32 ft).

(3) Riverine mangrove forests - this type may be tall forests along tidal rivers and creeks, subject to regular flushing. All the three Floridian mangroves, viz., White (*Laguncularia racemosa*), black (*Avicennia germinans*) and red mangroves (*Rhizophora mangle*) are present. Stand height may reach 18 - 20 m (60 - 65 ft).

(4) Basin mangrove forests - this generally stunted type is located in the interior of swamps in depressions channelling terrestrial runoff toward the coast. Red mangroves are present where there is tidal flushing but towards the inland portion white and black mangroves predominate. Trees may reach 15 m (49 ft) in height.

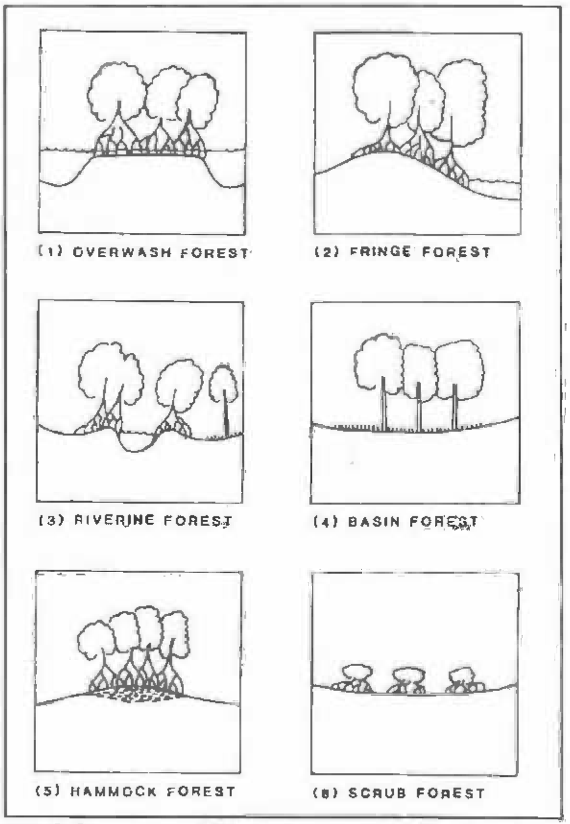


Fig 2.8: Mangrove community types
Lugo & Snedaker, 1974

(5) Hammock forests - generally similar to type (4) above but they are found on slightly elevated sites relative to surrounding areas. All species are present but the height is seldom more than 5 m (16 ft).

(6) Scrub or dwarf forests - this community type is typically found in the flat coastal fringe of south Florida and Florida Keys. All three species are found but rarely exceed 1.5 m (4.9 ft). Nutrient appears to be the limiting factor.

In Vietnam, the better mangroves are confined to the relatively sheltered coasts in the South, with the best mangroves located in the Ca Mau peninsula. San and Hong (1984) classified these mangroves into 4 principal distribution zones. The principal pioneer species are *Avicennia lanata, Sonneratia caseolaris, S. alba* and *Avicennia alba*.

Vegetational changes away from the waterways and associated values of water properties in Thailand have been studied by Aksornkoae (1975) and are shown in **Figure 2.9**.

2.6.2 Zonation and inundation

While air and water temperature determine the latitudinal limits of mangrove species, rainfall generally governs the distribution and zonation of mangrove species along many non-mountainous coasts (Blasco, F. 1984). In Australia, temperature and water balance are considered more important.

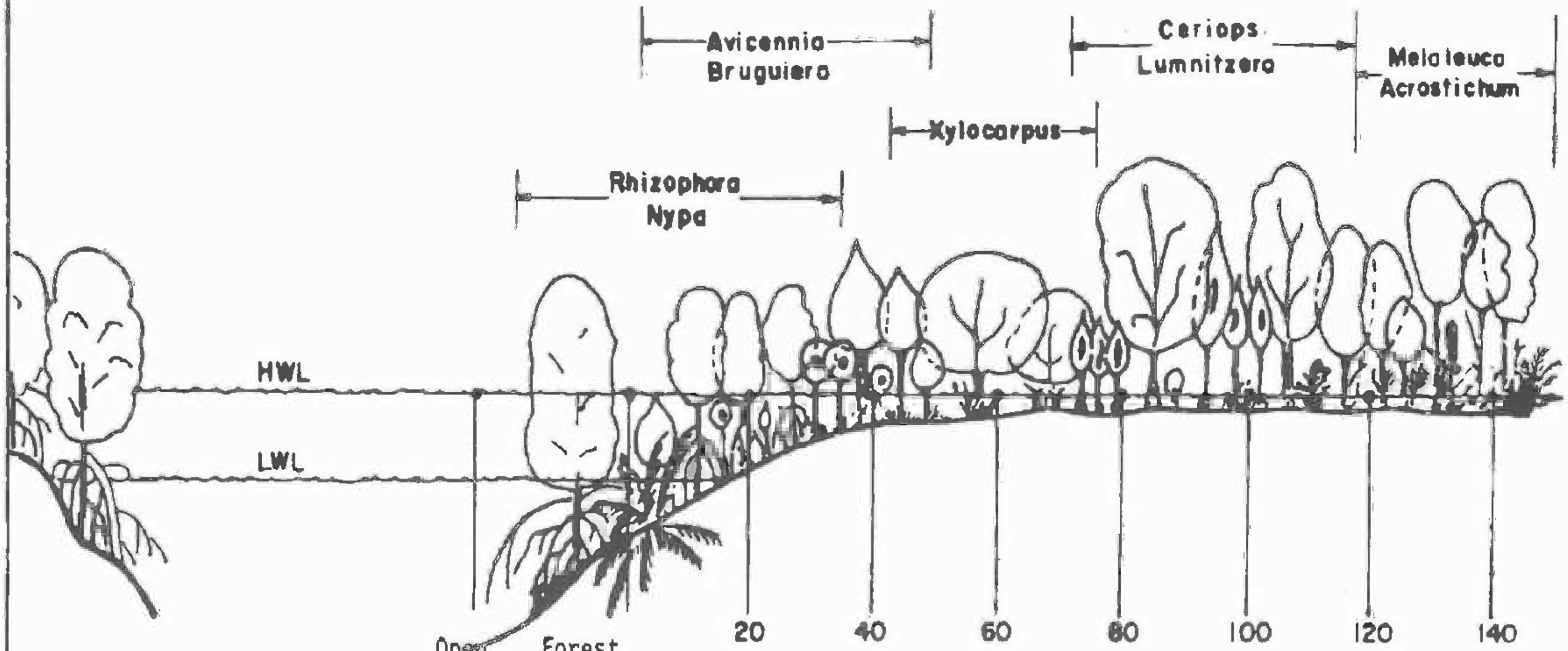
Macnae (1966) attributed the distribution of mangrove trees and hence their zonation to the interaction of, (a) frequency of tidal floodings, (b) salinity of soil water; and, (c) water logging of the soil (drainage). Walter and Steiner (1936) consider the degree of flooding, soil nature and salinity as important factors. With respect to tides, Chapman (1976) considers that the most important factor is the number of consecutive days with no tidal flushing.

Whereas the degree of flooding, which depends on soil level, is important in the establishment and dispersal of propagules, its effect on mature stands may be less pronounced. Rabinowitz (1978) has suggested that the morphology of the propagules controls the zonation of mangroves in Panama because smaller propagules can be transported further inland through already established vegetation by tides.

Although there are many descriptions of the contributory factors that account for zonation (cf. Floyd, 1977; Paijmans and Rollet 1977), it is Lugo (1980), Woodroffe (1983) and, in Papua New Guinea, Johnstone and Frodin (1982) who have attempted more thorough analyses. Johnstone and Frodin have proposed six types of likely causes:

- Inundation and depth of water
- Wave action
- Drainage
- Salinity/freshwater regime
- Substrate
- Biota and biotic interactions

Some or all of the above factors have been emphasized by different authors, but the last-named factor has often been neglected.



Water Properties:	Open area	Forest margin	20	40	60	80	100	120	140
			Distance, m						
Temperature, ^{0}C	29.5	29.1	28.7	82.2	27.9	27.8	27.6	27.5	27.6
pH	7.2	7.0	6.9	6.8	6.7	6.7	6.7	6.6	6.6
Salinity, o/oo	22.21	22.04	21.46	21.18	20.96	20.67	19.87	18.62	19.49
Dissolved oxygen, ml/l	4.40	3.37	2.99	2.68	2.36	2.15	1.99	1.55	1.70
COD, mg/l	16.00	17.91	18.88	17.73	16.48	16.82	19.88	19.82	20.62
PO_4, Ug-at P/l	1.179	1.290	0.967	0.966	0.823	0.838	0.869	0.834	0.859
NO_3, Ug-at N/l	2.025	2.220	2.388	2.533	2.418	2.365	2.461	2.407	2.590
SiO_2, Ug-at Si/l	87.57	94.33	94.73	91.61	99.72	92.46	103.31	100.82	107.84

Figure 2.9: **Vegetational changes and average value of water properties along a transect line at different distances from the waterway in Thailand** (After Aksornkoae, 1975)

Vegetational patterns or zones are often easily recognizable in mangroves. Zonation studies provide a useful indication of the ecological and silvicultural management requirements of the forest stands, particularly in selecting the appropriate habitats for preferred species and in evaluating *in situ* stand productivity under natural conditions. Regeneration problems can often be reduced by avoiding the promotion of species outside their natural habitats. In peninsular Malaysia, for instance, where intensive mangrove management has been practised since 1902, the refinement of the floristic composition, with emphasis on a few preferred species, has spawn many regeneration problems. *Rhizophora apiculata* is planted in landward zones that are marginal for its development, and, as a result, natural regeneration is often inadequate after clear-felling, and an extensive afforestation programme is required.

Three classifications, *inter alia*, are usually used to describe zonation in mangroves. Two of these are based on the gradient concept while the third follows the Braun-Blanquet system broken down into orders, alliances and associations (Chapman, 1976).

(i) Watson (1928) in a pioneering study on the ecology of Malaysian mangroves, divided the West Malaysian mangrove communities into five classes based on the frequency of inundation. The silvicultural significance of this classification is that a species is allotted to a particular inundation class based on *its ability to regenerate itself, and not merely being present*. This type of work has been extended to include an appreciation of the functional properties of different species and assemblages of species along environmental gradients (Lugo and Snedaker, 1974).

(ii) De Hann (1931) considered salinity as the primary factor in controlling distribution and tidal inundation as a subsidiary factor. His scheme has two main divisions each with subdivisions as follows:

A. A brackish to saltwater zone with salinities at flood tide of between 10 - 30‰ and inundated

- A1 once or twice daily on each of the 20 days/month
- A2 10 - 19 times per month
- A3 9 times or less per month
- A4 only few days per month

B. A fresh to brackish water zone with salinities between 0 - 10‰

- B1 more or less under tidal influence
- B2 seasonally flooded.

The relationship between Watson's and De Haan's classifications is compared in **Table 2.7** below.

Determining tidal inundation

Three methods may be used to determine the position of forest communities and species in relation to tidal levels :

(a) conduct a local levelling survey based on a bench-mark above high-tide level, this bench mark being referenced to a tide level in the nearest harbour,

Table 2.7: Inundation classes according to Watson's and De Hann's classification

Class flooded by		Height above datum (feet)	Inundation frequency	
			Times/month (Watson)	Day/month (de Hann)
1.	All high tides	0 - 8	56 - 62	20+
2.	Medium high tides	8 - 11	45 - 59	10 - 19
3.	Normal high tides	11 - 13	20 - 45	4 - 9
4.	Spring high tides	13 - 15	2 - 20	2 - 4
5.	Abnormal or equinoctial tides	15	2	2
6.	Wet season only			Seasonally flooded

(b) a levelling survey based on a tidal pole established in the swamp and related to the nearest harbour tidal gauge, or

(c) establish a local tide gauge.

However, a simpler method, which may prove sufficient for most situations, is to tie a number of horizontally tilted bottles one on top of another in a vertical array held in place by two small stakes and record the tidal levels by noting the height of the topmost bottle filled with sea-water. Care should be taken to ensure that the measuring device is located away from exposed positions. Once the spring tide height is determined, a permanent tidal pole may be established. Again by means of local level surveys it is then possible to extrapolate this crude bench mark to other positions.

A knowledge of the depth and frequency of flooding is useful in plantation establishment, where special attention should be paid to areas with inadequate tidal flushing or subject to deep flooding. The above method can also be used to estimate the relative amounts of silt deposition between sites. For example if several of the recording devices are constructed and placed in different sites, water turbidity can easily be compared. It can also be used to gauge the effects of logging operations on substrate stability, by observing the quality of the water collected in the bottles before, during and after logging operations.

The position of some New and Old World species with respect to Watson's and De Haan's classifications is summarized in **Table 2.8** on the following page.

(iii) Walter and Steiner (1936) working on mangroves at Tanga in Tanzania named the zones after the dominant trees. This scheme was adopted and modified by Macnae (1966), who recognized the following zones:

(a) Landward fringe
(b) Zone of *Ceriops* thickets
(c) Zone of *Bruguiera* forests
(d) Zone of *Rhizophora* forests
(e) Seaward *Avicennia* zone
(d) *Sonneratia* zone

These zonation patterns are not universal and are modified by climate, salinity, coastal morphology and freshwater outflow. The Sundarbans forest in the deltaic plains of the Ganges and Brahmaputra rivers falls within the "landward fringe" category, the most variable zone.

Table 2.8 New and Old World species occurrence according to inundation classes (after Chapman, 1975)

Watson's inundation classes (1928) - Type of flooding	de Haan's inundation classes (1931) based on salinity/frequency	Old World dominant species	Chapman (1944) floods/yr	New World dominant species
	A. Brackish to saline 1-3% salinity at high tide			
1. All high tides	A1. 1-2 times/day; at least 20 days/month	*Sonneratia alba* *S apetala*	530 - 700+	*Rhizophora mangle*
2. Medium high tide	A2. 10-19 days/month	*Rhizophora* *Bruguiera*	400-530 per year	*Avicennia germinans*
3. Normal high tides	A3. 9 days/month	landward fringe *Xylocarpus granatum*		
4. Spring tides only	A4. Only a few days/month	*Lumnitzera littora* *Bruguiera sexangula*	150-250 per year	*Laguncularia racemosa*
5. Storm high tides only	B. Fresh to brackish water; salinity 0-10‰	Halophytes or salt flats	4 - 100 per year	*Salina* or *Laguncularia* *Conocarpus*
	B1. More or less under tidal influence	*Nypa fruticans*		

The use of inundation classes in this report does not imply a successional relationship but rather highlights the usefulness of such a classification in forest management, where a knowledge of tidal conditions and depth of flooding is required in the planning for harvesting methods and reforestation. In Costa Rica, for example, the frequent occurrence of *R. mangle* in wet and softer soils precludes the use of tramways for wood extraction, whereas *A. germinans* stands in the drier and more consolidated soils can often be accessed from the landward side using semi-mechanized harvesting systems as the soil has a higher load-bearing capacity. Artificial regeneration in *Watson's Inundation Class I* (W.I.C-I) is usually difficult because of the depth of the inundation, its frequency, and very soft immature soils.

2.6.3 Succession - ecological aspects

Succession refers to the replacement of the biota of an area by one of a different nature. There has been much debate in the literature concerning the relationship between zonation and succession (Lugo, 1980).

The idea that zonation recapitulates succession (Davis, 1940), implying an inevitable development towards a non-mangrove 'terrestrial' vegetation type has been much criticised (e.g. Rabinowitz, 1978) as such a progression of events is not universal. (Johnstone and Frodin, 1982; Lugo and Snedaker, 1974).

However, the relationship between zonation and succession has been clearly documented in mangroves with prograding shorelines, high rainfall during all seasons and considerable intertidal range (Watson, 1928; Putz and Chan, 1986).

The formation of newly accreted mud-flats in prograding shorelines gives rise to a permanent ecological transfer of sites on the landward fringe to dryland forest above tidal influences. However, this successional model emphasizes the physiographic role of mud in the formation of accrescent shorelines rather than the classical model of mangroves as land-builders.

Geomorphic processes and severe, episodic climate events determine the status of the intertidal habitats. Thom (1984) has suggested that a system for classifying mangrove shores into *prograding, eroding or stable* states is of fundamental importance in understanding present vegetational distributional patterns within a local region, as well as the time scale of vegetation dynamics. The prograding shoreline is only one of many geomorphic landforms, therefore, the successional model cannot be universally applied to all coastal ecosystems.

Putz and Chan (1986) in an analysis of stand growth and dynamics in a mature forest in Malaysia, monitored since 1920, conclude that observed species replacement patterns resemble the classical successional process observed and propounded by Watson. *Rhizophora apiculata*, a fast growing but less shade tolerant species is gradually being replaced by another fast growing but shade tolerant species, viz., *Bruguiera gymnorhiza* (Rhizophoraceae) as well as, other typically more landward species. The same investigators suggest that shade tolerance and dispersal characteristics should be included among the ecological factors influencing the distribution of tree species in mangrove forests.

The Terraba-Sierpe mangroves along the Pacific coast of Costa Rica and the Ayeyarwady mangroves in Myanmar are example of wave-dominated delta systems (*sensu* Thom, 1984). The high upland silt load would normally produce an accrescent shoreline had it not been physically checked by the erosive actions of waves and tidal currents at the river mouths. This leads to the formation of elongated shoals and sand bars and rounded shorelines. The high silt load of the terrigenous run-off provides an annual silting of the forests, contributing to soil fertility and forest productivity. At Playa Garza in Costa Rica, mechanical analyses of soil samples indicate that samples located close to the river mouth have a higher percent of sand, which usually improves soil firmness and drainage (aeration). Such sites carry good stands of *R. harrisonii* and *P. rhizophorae*.

Where the tidal environment is very fluid and dynamic, the rate of physical environmental change in localised sites may approximate or even exceed endogenous ecological processes of change, (cyclical changes, gap regeneration or succession). In this respect mangrove vegetation dynamics must be viewed in a broader perspective than that accorded to terrestrial vegetation where environments are normally stable in relation to such processes.

Many ecological studies on vegetational pattern rely on species-level analysis (floristic attributes alone) to show segregation and development of dominance, based on the implicit assumption that different species have sufficiently different niche requirements (*sensu* Grubb, 1977). There is little doubt that species shifting takes place.

In the field, this can be observed by an initial change in individual life form collectively expressed as changing community structure. Silviculturally, some of the significant changes are i) potential above-ground biomass (site quality/productivity), ii) tree species composition (site specificity) and iii) community structure (form quality).

Although there appears to be an optimum range of sites for the principal species, and interspecific competition may be low due to the small number of species, their physiognomic form may vary from high forest to thickets or scrubs. The probable presence of interbedded lenses of alluvium is another factor that causes changes in micro-habitat and there are many processes which are not well understood, such as for example that of 'deep flooding' in some areas (Noakes, D.S.P. 1956 in p. 187) and the occurrence of 'estructuras circulares de vegetation' in Gabon (Legigre, J.M. 1983 in p. 20). The latter may be caused by lightning and/or incidence of commencing subsidence. In the Matang area along the west coast of Peninsular Malaysia, circular blanks due to trees killed by lightning are quite common especially towards the seaward side.

In Malaysia the conditions under which the *Rhizophora spp* form the bulk of the economic growing stock may be regarded as the optimum stage of development of the mangrove swamp. These conditions are briefly i) inundation by ordinary tides, ii) moderate salinity (20-35‰), iii) aeration and enrichment of the soil through organic accumulation and iv) an abundance of small streams and gullies to assist propagule dispersal and promote efficient tidal flushing. The natural regeneration potential is usually good. The mangroves and their surrounding mudflats or lagoons are ideal sanctuaries for various crustacean species. There is usually also an active crab population, principally the fiddler crab, *Uca sp* and various species of *Sesarma*. Their innumerable burrows help to aerate the subsoil. Some organic matter is also transferred into the subsurface soil, consequently such soils may have a higher level of organic matter. It is interesting to note that the better forests usually do not have festoons of hanging aerial roots, and this is in agreement with Watson's observation that stilt root development is more accentuated in inferior soils or deep flooded area.

In Central America, *R. mangle* may be regarded as the principal pioneer species in the mangroves *sensu stricto*. As it is relatively intolerant of shade it is normally found in the immature and softer soils along sunny river banks, where it regenerates freely. Where the soil is firm and more elevated, it is replaced by other species such as *Pelliciera rhizophorae*, which is more shade tolerant and can be found on quite sandy soils. In the less sunny and firmer creeks and channels, the gallery forest may comprise a mixture of *R. mangle* and *R. harrisonii*. In newly formed mud-flats *Laguncularia racemosa* sometimes is the pioneering species. The landward fringe is a very variable zone and does not contain many mangrove species of economic importance. The principal species is *Avicennia germinans*, which generally has poor form. *L. racemosa* and *P. rhizophorae* also occur in this area.

In SE Asia, the pioneering species are usually *Avicennia lanata* and *alba* or *Sonneratia alba*.

2.7 MANGROVE FAUNA

2.7.1 Wildlife

A compilation of wildlife species (mammals, reptiles and amphibians) and birds found in the Sundarbans, the world's greatest contiguous mangrove area, is presented in Das and Sidddiqi (1985). McNae (1968) gives a general account of the fauna of mangroves in the Indo West Pacific Region and Saenger *et al.* (1983) look at the global status of mangrove ecosystems including their fauna.

Mammals

Many mammals frequent mangrove habitats but only a few live there permanently and fewer are restricted to them (FAO, 1982). In many countries however, the mangroves represent the last refuge for a number of rare and endagered mammals.

Fig. 2.10: Proboscis monkey feeding on *Rhizophora* propagule.

During low tide monkeys (*Macacus irus*) are commonly seen foraging for shell-fish and crabs in Malaysia, and the white-faced monkey (*Cebus capucinus)* feed on pianguas (cockles) in Costa Rican mangroves. Reportedly, where such monkeys are numerous, the area is poor in pianguas. They also do a certain amount of damage to newly established seedlings by uprooting them. The Malaysian proboscis monkey (*Nasalis larvatus*) is endemic to the mangroves on Borneo, where it feeds on the foliage of *Sonneratia caseolaris* and *Nipa fruticans* (FAO, 1982) as well as on *Rhizophora* propagules. The monkeys, in return, are preyed on by the crocodiles and hunted by poachers.

Other mammals include the Royal Bengal Tiger (*Panthera tigris*), the leopard (*Panthera pardus*) and the spotted deer (*Axis axis*) in the Sundarbans; wild pigs (*Sus scrofa*) and mousedeer (*Tragulus sp*) in *Nipa* swamps throughout South and Southeast Asia; and small carnivores such as fishing cats (*Felix viverrima*), civets (*Viverra sp* and *Vivererricula sp*) and mongooses (*Herpestes sp*). Otters (*Aonyx cinera* and *Lutra sp*) are common, but rarely seen.

Dolphins, such as the Gangetic dolphin (*Platanista gangetica*) and the common dolphin (*Delphinus delphis*) are also found in the rivers of mangroves, as are Manatees (*Trichechus senegalensis* and *Trichechus manatus latirostris*) and Dugongs (*Dugong dugon*) although these species are becomming increasingly rare and in many places are threatened with extinction.

Reptiles and amphibians

Crocodiles and alligators are some of the most significant reptiles that naturally inhabit marine and estuarine environments.

Two species *Crocodilus acutus* (lagarto), *Caiman crocodilus* (largarto cuajipal) are found in Costa Rica, where they are listed as endangered species, largely due to international trade in their hides. *C. acutus* has a very wide geographic range and is found in Cuba, Pacific Coasts of Central America, Florida and Venezuela. The Cuban species, *Crocodilus rhombifer* is found in Cienaga de Lanier and is endemic. The American alligator *Alligator mississippiensis* is listed as endangered in Florida (Hamilton and Snedaker, 1984). In West Africa the Long Snouted Crocodile (*Crocodilus cataphractus*) is found in mangrove areas and in Asia the saltwater crocodile *Crocodilus porosus* is endangered over a large part of its range. Efforts are, however, being made to conserve it in India, Bangladesh, Papua New Guinea and Australia (FAO, 1982).

The large lizards, *Iguana iguana* (iguana) and *Cetenosaura similis* (garrobo) are commonly found in the mangroves in Latin America, where they are eaten by the local people, as are their cousins in West Africa (*Varanus exanthematicus*) and Asia (*Varanus salvator*).

Riverine tortoises are common and marine turtles are known to lay their eggs on the sandy beaches in many mangrove areas throughout the world. Along the Pacific coast of Costa Rica, the two most important egg-laying sites visited by the Pacific Ridley Turtle (*Lepidochelys olivacea*) is in the Playa Nacite in the Santa Rosa National Park and in the Playa de Ostional near the Rio Nosara. This turtle is relished for its meat and weighs an average of 40 kg. Its numbers are diminishing because of predation and over-exploitation in some countries, notably Mexico and Equador.

A number of snakes can also be found in mangrove areas especially in the landward fringe.

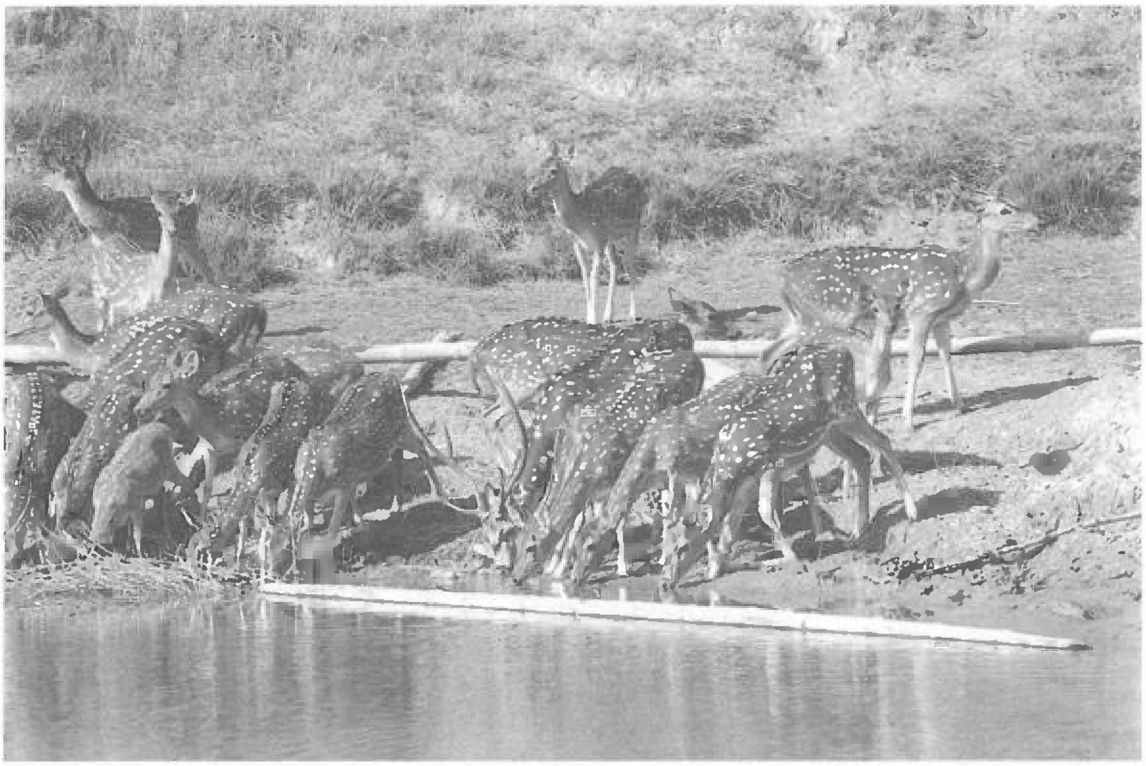


Figure 2.11: The spotted deer (*Axis axis*) in the Sundarbans.
Photo by M.L.Wilkie

Figure 2.12: The saltwater crocodile (*Crocodilus porosus*) in Indonesia.
Photo by M.L.Wilkie

2.7.2 Avifauna

The tidal swamp is an ideal sanctuary for avifauna, some of which are migratory. According to Saenger *et al.* (1984), the total list of mangrove bird species in each of the main biogeographical regions include from 150 to 250 species. Worlwide, 65 of these are listed as endangered or vulnerable. Several surveys of avifauna in mangrove areas in South East Asia have been carried out. (See for instance Das and Siddiqi 1985; Erftemeijer, Balen and Djuharsa, 1988; Howes, 1986 and Silvius, Chan and Shamsudin, 1987.)

In Cuba, there are several endemic species which occupy highly specialized ecological niches such as the canario del manglar (*Dendroica petechis gundlachi*) and the smaller oca del manglar (*Rallus longirostris caribaeus*).

The most numerous birds are the waders, herons, egrets and storks.

Birds of prey include the sea eagles (*Haliaetus leucogaster*), brahminy kites (*Haliastur indus*), ospreys (*Pandion haliaetus*) and fish eagles (*Ichthyphagus ichthyaetus*).

Kingfishers and bee-eaters are among the most colourful birds commonly observed in mangroves.

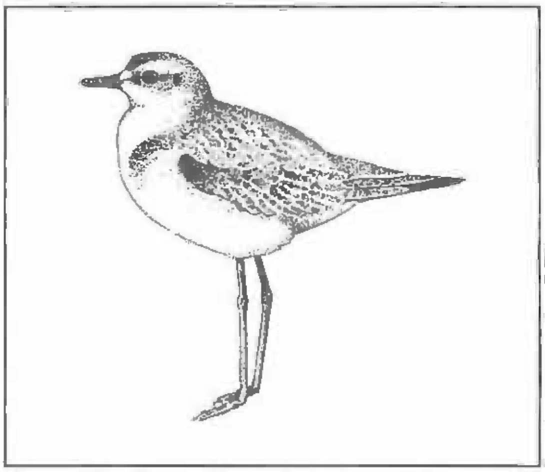


Fig. 2.13: Large Sandplover - by D.Beadle.

2.7.3 Aquatic resources

The importance of the mangrove areas as feeding, breeding and nursery grounds for numerous commercial fish and shellfish is well established (Heald and Odum, 1970; MacNae, 1974; Martosubroto and Naamin, 1977). Similarly, Chong (1987) reported that the location of fishing grounds in Sierra Leone is geographically correlated to the distribution of coastal mangroves. See also **Table 3.7** on page 63.

The development of soft clayish mud, where the crabs can make their burrows, and the growth of seagrass or turtle grass have been observed to attract the crustacean fauna along the mangrove areas.

Matthes and Kapetsky (1988) have prepared a worldwide compendium of mangrove-associated aquatic species of economic importance including such information as geographical extension of each species; the parts of the mangroves in which it is found; the organism's dependency upon the mangroves and its quality/use in fisheries.

Fish

There are reported to be over 120 species of fish caught by fishermen in the Sundarbans (Seidensticker and Hai, 1983), almost all of which are brackish water and esuarine species.

Ulloa (1978) reported 92 species of fish belonging to 13 families caught in Jiquilisco Bay in El Salvador.

Species of commercial interest include mullets (Mugilidae), snappers (Lutjanidae), milkfish (*Chanos chanos*), sea bass (*Lates calcarifer*) and tilapia (Cichlidae). The most conspicuous fish is perhaps the mudskipper (*Periophthalmus sp.*), which is endemic to the mangroves.

Shellfish

Despite the presence of the more spectacular mammals and reptiles, indications are that the animals which contribute the greatest biomass in the mangroves are the shellfish [*a collective term for crustaceans (crabs and prawns) and molluscs (bivalves and gastropods)*].

The fiddler crab, *Uca sp* and the various species of *Sesarma* are common inhabitants in the intertidal mangrove zones throughout the Indo-Pacific region. Crabs of the *Portunidae* family have been observed in the Arabian Gulf area and the United Emirates.

The edible crabs (*Scylla serrata* in Asia and East Africa and *Callinectes latimanus* in West Africa) are a highly valued mangrove product.

The most common prawns include the giant freshwater prawn (*Macrobrachium rosenbergii*) and the marine penaeid prawns (*Penaeus indicus, P. merguiensis, P. monodon, Metapenaeus brevicornis*). All of these species probably have a similar basic life history with spawning occurring offshore, an inshore migration of larvae, an estuarine juvenile stage followed by an offshore breeding migration to complete their biological life-cycle. However, the species differ in the extent to which they move offshore during this migration. Surveys in Malaysia showed that the genus *Penaeus* was abundant across all depths up to 50m, while *Metapenaeus* were most abundant in the 11-30 m range and *Parapenaeopsis* were more restricted to the 5-20 m zone.

Reportedly, penaeid shrimps off the coast breed throughout most of the year but with observed peak-periods during May-July and October-December, which coincide with the coming of the monsoons. In Western Malaysia peak ingress of P. merguiensis postlarvae was reported during November and December.

After three to four months in mangrove estuaries, juvenile shrimps migrate into the shallow coastal waters from March to June where sexual maturity takes place. When larger, they move further offshore to spawning grounds in depths exceeding 10 fathoms. Major spawning migrations begin in June and continue to late January.

Regarding molluscs, in Central America, the larger bivalve *Anadara grandis* (chucheca), is now rare due to over-exploitation. The smaller ark clams 'pianguas' comprising principally two species *Anadara multicostata* and *A. tuberculosa* are now exploited in place of chucheca. *Anadara tuberculosa*, Sowerby, is the molluscan bivalve commonly found in mangrove ecosystem from Lower California to Peru (Keen, 1971).

The most important bivalve in the Indo-Malayan mangroves is the blood cockle (*Anadara granosa*) and gastropods commonly collected include *Cerithidia obtusa, Telescopium mauritsii* and *T. telescopium*.

Oysters are also important sources of aquatic production, which like shellfish can be cultured provided suitable substratum is provided to attract the spats and the estuarine conditions are right.

The importance of shellfish as a source of readily accessible protein and an economic renewable resource for coastal dwellers makes it the single most important exploited species in the mangroves.

<u>Benthos</u>

Until recently, studies on the benthic fauna of inter-tidal mudflats in tropical regions have been exceptionally rare in spite of the fact that such studies would provide indications of the value of mudflats as potential feeding habitats for water birds and marine and estuarine fish (Erftemeijer, Balen and Djuharsa, 1988; Silvius, Chan and Shamsudin, 1987). Recent studies have however been carried out for instance in Hong Kong, China and Taiwan - often in connection with feasibility studies on the use of mangroves for waste water treatment (refer to HKUST, 1993).

Benthic fauna includes juvenile fish, crustaceans, crabs and bivalves and are divided into two classes : Macro-benthos > 1 mm and Meio-benthos < 1 mm.

2.8 TROPHIC RELATIONSHIPS IN MANGROVE ECOSYSTEMS

The successful integrated management of mangrove wood and non-wood resources depends on an understanding of, firstly, the ecological and silvicultural parameters for forest management (primary production) and secondly, the biological role that the primary production from the forests plays in the mangrove food web of aquatic resources (secondary production). An understanding of the role of key species in maintaining the equlibrium of a particular ecosystem is likewise essential.

2.8.1 <u>The food web</u>

Our present knowledge on energy flow in mangrove ecosystem is mainly based on the pioneering work on food chains in Florida (Heald, 1971; Heald and Odum, 1970; Odum, 1971; Odum and Heald, 1972; 1975; and Odum <u>et al</u>., 1972). Briefly, the principal energy flow follow the path below.

Mangrove leaf detritus ----> Bacteria and fungi ----> Detritus consumers (herbivores and omnivores) ----> Lower carnivores ----> Higher carnivores

The chain begins with the production of carbohydrates and carbon by plants through photosynthesis.

Leaf litter is then fragmented by the grazing action of amphipods and crabs (Head, 1971; Sasekumar, 1984). Decomposition continues through microbial and fungal decay of leaf detritus (Fell *et al.*, 1975; Cundell *et al.*, 1979) and use and reuse of detrital particles (in the form of faecal material) by a variety of detritivores (Odum and Heald, 1975), beginning with very small sized invertebrates (meiofauna) and ending with such species as worms, molluscs, prawns and crabs, who in turn are preyed upon by lower carnivores. The food chain ends with higher carnivores such as large fish, birds of prey, wild cats or man himself.

The earlier findings have now been extended to include other energy and carbon sources to consumers in mangrove ecosystems. (e.g., Carter *et al.*, 1973; Lugo and Snedaker, 1974; 1975 and Pool *et al.*, 1975). In a recent appraisal of food chain dynamics, Odum et al. (1982) have enlarged the earlier basic trophic model to include inputs from phytoplankton, benthic algae and sea grasses, and root epiphytes. For example, phytoplankton may be important as an energy source in mangroves with large bodies of relative clear deep water.

On this basis, the benthic algal contribution in estuaries with high levels of suspended sediments is likely to be lower. Similarly, where the continental shelf is truncated or very steep sloping, combined with high energy coastline and tidal amplitude, there is little sea grass or turtle grass. Where shading is not excessive, mangrove prop root epiphytes may also be highly productive. Values for periphyton production on prop roots of 0.14 and 1.1 gcal/m^2/d have been reported. (Lugo *et al.* 1975; Hoffman and Dawes, 1980). A generalized food web in mangrove ecosystem is depicted in **Figure 2.14**.

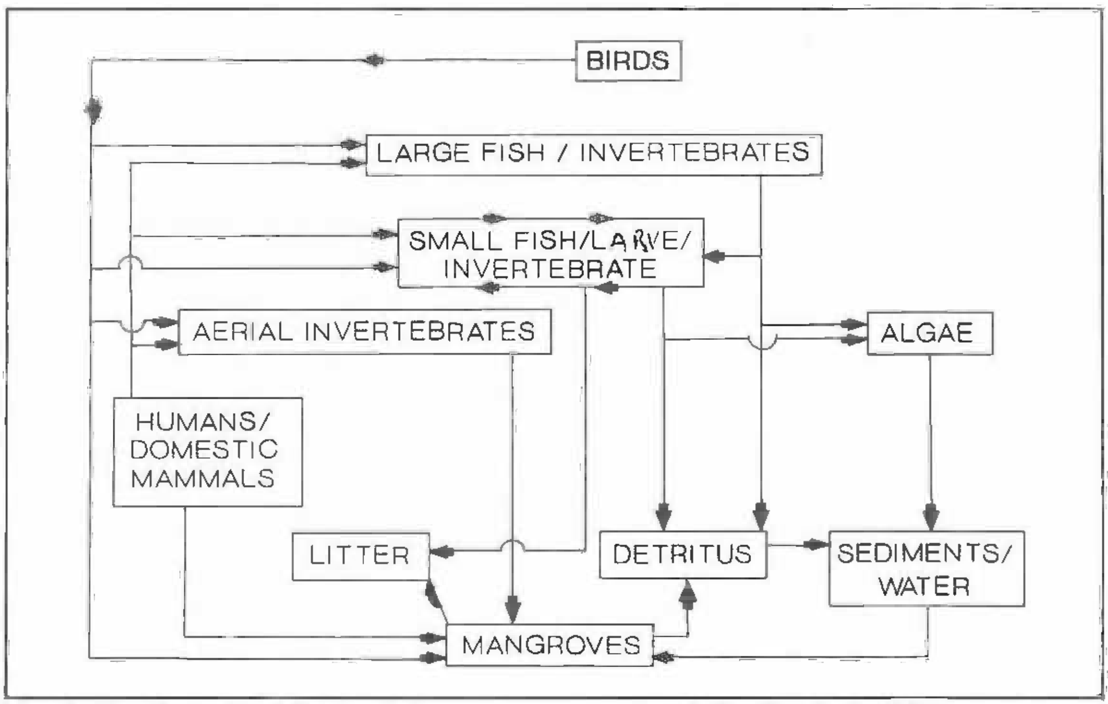


Fig. 2.14: Generalized food web in mangrove ecosystem (after Burchett, 1985)

However, Odum *et al.* (1982) have stressed that in spite of innumerable studies, the Florida food chain model remains hypothetical and qualitative. Indeed, some recent data from the Indo-West Pacific region suggests that the Caribbean model requires some modifications.

2.8.2 Primary wood production

Estimates of total net primary production for mangrove forests are few because below-ground biomass is difficult to measure. The biomass, net productivity and annual litterfall of *Rhizophora apiculata* in the Matang, Peninsular Malaysia are shown in **Table 2.9** together with figures from Phuket in South West Thailand. The biomass at 15 years in Thailand was less than in Malaysia, but productivity and the proportion of woody parts were similar.

Wood is maintained as wood biomass, and what proportion enters the detrital pathway each year has not been determined.

Table 2.9: Above ground biomass of *Rhizophora apiculata*

Location	Age	Biomass	Litter-fall	Net productivity (tonnes/ha/yr)	
	(ys)	(t/ha)	(t/ha/yr)	Woody parts	Total
Matang, Malaysia	5	16	7	3	10
	10	180	10	18	28
	15	200	10	13	23
	25	300	11	12	23
Phuket, Thailand	15	159	6.7	20	27

Source: Ong et al. 1980 - 400 m2 plots
Christensen, 1978, 16 month observation of a 25 m2 plot.

Lugo (1974) and Blasco (1984) record that measurements taken in some of the best mangroves indicate an average of 150 tons/ha of standing matter, which is quite low compared with other plant formations. Mangroves are therefore characterized by a particularly high productivity of organic matter in spite of a relatively low standing biomass.

Termites and other organisms capable of breaking down the main components of wood (cellulose and lignin), also called wood decay organisms, are important in nutrient recycling in the mangroves. The rate that slash decomposes due to these organisms also affects regeneration because slash not only hinders the distribution of propagules but impedes tidal flushing and reduces the amount of light available to seedlings. Furthermore, smaller plants are mechanically damaged by slash that moves with the tides.

Litter-fall

Litter fall is easily measured as a component of net primary production. Estimates of total litter fall in eleven locations world-wide range from 0.2 to 1.6 kg/m^2/y dry matter (Woodroffe, 1982; Sasekumar and Lai, 1983). Litter fall estimates in the Indo-Pacific mangrove forests are usually higher.

What happens to these leaves once they reach the forest floor? The Caribbean trophic model suggests that there is little accumulation of leaves in the forest as most of the leaf production is flushed out to channels and water bodies in the mangrove estuaries. In their riverine forest site Odum and Heald thus estimated that about 50 percent of the mangrove litter was exported from the estuary (Odum *et al.*, 1972).

In the Indo-West Pacific crabs are voracious feeders, and consume and/or bury a large proportion of the daily litter fall before it is washed away by the tides even in low tidal regions of the forest that are regularly flushed. Sasekumar and Lai (1983) estimated that crabs may consume or remove between 10 and 70 percent of the daily litter-fall before it is removed by the tides. Potentially, therefore, crabs are vectors of energy transfer between mangroves and forest sediments. Such rapid removal of litter by crabs, together with the potentially large amounts of wood production which may be processed within the forest, suggest that in contrast to many of the Caribbean mangrove systems that have been studied to-date (e.g Carter *et al.*, 1973; Lugo *et al.*, 1975), where there appears to be little retention of primary production (and hence nutrient stocks) within forests, primary and secondary production in the mangrove forests of the Indo-west Pacific region may be more closely linked. If this is correct, then pesticides which depress crab populations may cause a reduction in primary production in the long-term.

As can be seen in **Table 2.9**, Ong *et al.*, (1982) showed that in Matang, Peninsular Malaysia, ten years old *Rhizophora apiculata* produces 10.5 t/ha/year of litter compared to 6.9 t/h/year at 5 years. This is biologically and ecologically important because of the importance of litter fall in the food web. Forests should ideally be managed not only to optimize wood production but also to sustain an active ground meiofauna (microbial) and macrofuana. Environmentally therefore, well managed forests should promote vigorous growth with high biomass increments capable of producing high levels of litter fall. In this context, the impact of pesticides and herbicides on the meio-macrofauna should also be considered, particularly in habitats where bivalves (*Anadara sp*) abound. In the Sierpe-Terraba area in Costa Rica, copper-based contaminants from the banana plantations have significantly reduced the once thriving molluscan population.

2.8.3 Secondary production

A wide range of food-energy resources is available for secondary production in the mangrove ecosystem, including the primary productivity of phytoplankton in the photic zone, the production by benthic macrophytes, and the particulate and soluble organics that originate from the productive mangrove forests. Ong (1985) estimated that the primary productivity contributed by the mangrove forests to the Straits of Malacca is about 0.22 $g/m^2/day$, a figure at least equal to that of the phytoplankton productivity of the Straits of Malacca.

The importance of the primary productivity of mangrove forests as a source of food for especially aquatic resources is further supported by the series of studies conducted in the Selangor mangroves (Sasekumar *et al.*, 1984; Thong and Sasekumar 1980).

Leh and Sasekumar (1984) found that various inshore penaeid species consumed 12%-36% of plant matter, of which 11%-59% was identified to be of mangrove origin. Mangrove detritus formed 32%-42% of the gut content of the planktonic shrimp *Acetes sp* (Tan, 1977). This shrimp is a key linkage organism because the adult white prawns *Penaeus merguiensis* feed heavily on *Acetes sp* and mysid shrimps (Chong and Sasekumar, 1981). Several omnivorous fish species likewise feed on *Acetes sp* as well as on mangrove detritus (Ong, 1977).

2.8.4 Keystone species

In the coastal ecosystem certain wildlife species play pivotal roles in maintaining an equilibrium in the fauna. If these keystone species, as for example a predator is removed, the community will be thrown out of equilibrium. *Crocodilus porasus* is one such keystone predator in the Sundarbans. Crocodiles feed largely on less commercial fish, some of which at some stage prey on the more valuable fish and fish eggs (Bustard, 1975). Their movement also activate the movement of nutrients in the water and is a keystone in maintaining a productive fishery (**Box 2.3**).

The role of caimans

"Fishermen in the Amazon had for some time noticed that wherever caimans disappeared, fishing declined. This decline was rather unexpected, fishes being the main food of the caimans. It seemed to the natives that in the absence of the predators, fish would multiply. It is now clear from research undertaken in Amazonian mouth-lakes that this is the reverse of the truth. Biomass in tropical aquatic systems consists almost exclusively of animals (whereas the fauna represents only a small fraction in rain forests). Limnologist E. J. Fittkau has researched the amounts of nutrients released by caimans in the course of their metabolism and the impact of these nutrients on primary production. Measurements proved that caimans daily add nutrients (mostly of allochthonous origin) in sufficient quantities to effect an increase of primary production and an attendant enlargement of the autochthonous food chain."

Source: Prof. Federico Medam, 1978.

Box 2.3: Caimans as keystone species

Foresters and other ecologists are also familiar with the role of monkeys (*Macaca mulatta*) and deer (*Axis axis*) where a significant portion of the food of deer may come from food particles dropped by foraging monkeys.

Yet another example is found in the Sundarbans, where, if the tiger population is reduced, both deer and wild pig (*Sus scrofa*) would increase to the point of reducing forest regeneration and damaging the forest. In Malaysia, bats, which shelter in mangroves, are important in pollinating durian flowers.

In Australia, birds feeding on sweet flora exudate of *Rhizophora spp* also reduce the insects that destroy terminal buds and shoots (Primark and Tomlison, 1978).

2.8.5 Management implications

As our knowledge on trophic relationships and interactions improves, foresters will be able to manage their resources better without harming the environment. **Figure 2.15** shows some of the positive and negative impacts associated with the use of mangrove areas under production forestry, open-water aquaculture, capture fishery and conversion to agriculture and pond culture.

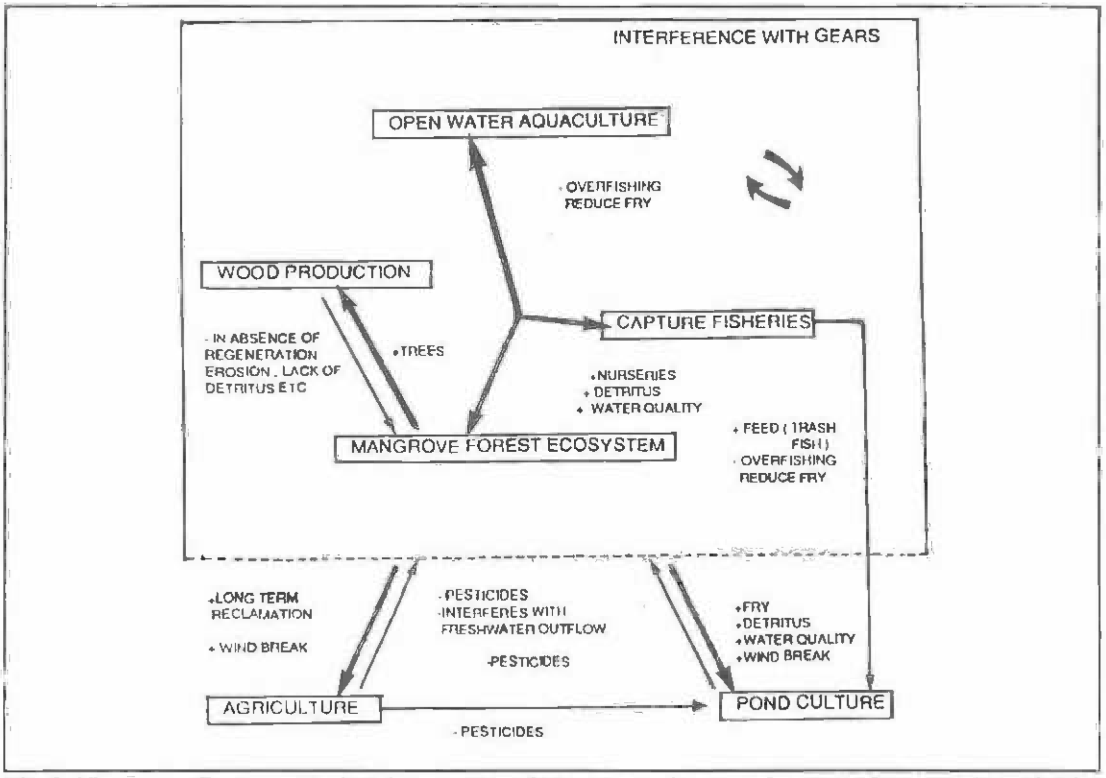


Fig 2.15: Some ecological interactions between various land uses and economic activities in mangrove areas. (FAO Environment Paper No. 1, 1982).

In mangrove management it is thus essential to take a holistic approach and to secure the survival of the entire ecosystem. Conserving or promoting biodiversity through the selection of species to be felled and regenerated and the protection of habitats for various marine and terrestrial animals is an imperative as is the maintenance of the protective role the mangroves play along river banks and coastlines.

Riverine vegetation should therefore never be felled indiscriminately, as bank erosion will increase water turbidity and adversely affect aquatic fauna, particularly shrimp larvae, molluscs and the breeding of important estuarine species. Protective areas should also be set aside in the mangrove area proper for the conservation of wildlife and plants of special interest.

Where the demand for land for agriculture or aquaculture necessitates the conversion of mangrove areas, the sites should be properly evaluated prior to the conversion in order to minimize the damage to the mangrove ecosystem as a whole.

PART II TRADITIONAL AND POTENTIAL USES OF MANGROVES

This Part highlights the multiple-use potential of mangroves as a renewable resource. It gives a coverage of selected major wood and non-wood uses as well as their interrelationships.

3. UTILIZATION OF MANGROVES

To be conserved, a resource must be managed sustainably and seen to be useful to local communities. In this context, extractive activities should produce a positive impact on the surrounding community - such as generating local employment - without impairing the environment. It is almost impossible to conserve a resource without the support of the local population. Local participation may involve *information sharing, consultation, decision-making* and at the highest intensity *initiating action*.

Given the multiple use potential of mangrove ecosystems, an integrated approach to mangrove management is essential and should cover the full range of products and services which can be obtained from these areas.

3.1 MANGROVE-BASED PRODUCTS AND SERVICES

The uses and values of the products obtainable from mangroves are many and important. The importance of the resource stems from the many products taken directly from the mangroves, including the non-wood products, as well as amenities provided from within and beyond its boundaries. Wood products range from timber, poles and posts to firewood, charcoal and tannin. Non-wood products include thatch, honey, wildlife, fish, fodder and medicine. In addition, mangrove lands are often converted to salt ponds or to agriculture or aquaculture purposes.

Many of the non-timber species found in mangroves are extremely versatile. The Nipa palm (*Nypa fruticans*) for example, is used mainly as thatch for roofing but can also produce a sugary syrup, alcohol and vinegar. *Phoenix paludosa* palm stems are used in fencing and construction purposes. Nibong (*Oncosperma filamentosa*) is a very useful palm in the landward fringe of mangroves. Whole stems are used for house and bridge posts and split stems for flooring, decking, fish drying platforms, backbones for nipa thatch, roof gutters, water pipes, and many other uses.

Other plants are used as fodder. *Avicennia* leaves, for instance, are grazed by camels, goats and cattle in India, Pakistan, and the Arabian coast. In Australia, wild buffaloes graze on mangroves in the Northern Territory. This sight can also be seen in Vietnam. The stall feeding of sheep and pigs has been practised in a number of countries using mangrove fodder in conjunction with other feedstock.

Cockles (*Anadara sp*) collected from estuarine mud-flats are a source of protein for local inhabitants, as are crabs and the fishery in the tidal aquatic system.

A list of some mangrove-based products is shown in **Table 3.1**.

Table 3.1: Mangrove-based products

A. Mangrove Forest Products

Fuel
- Firewood
- Charcoal

Construction
- Timber,scaffolds
- Heavy construction
- Railway sleepers
- Mining props
- Boat building
- Dock pilings
- Beams and poles
- Flooring, panelling
- Thatch or matting
- Fence posts, chipboards

Fishing
- Fishing stakes
- Fishing boats
- Wood for smoking fish
- Tannin for net/lines
- Fish attracting shelters

Textile, leather
- Synthetic fibres (rayon)
- Dye for cloth
- Tannin for leather preservation

Food, drugs & beverages
- Sugar
- Alcohol
- Cooking oil
- Vinegar
- Tea substitute
- Fermented drinks
- Dessert topping
- Condiments (bark)
- Sweetmeats (propagules)
- Vegetables (fruit/leaves)

Household items
- Glue
- Hairdressing oil
- Tool handles
- Rice mortar
- Toys
- Match sticks
- Incense

Agriculture
- Fodder

Paper products
- Paper - various

Other products
- Packing boxes
- Wood for smoking sheet rubber
- Fuelwood for:-
  - salt making
  - brick kilns
  - bakeries
  - tobacco drying
- Medicines

B. Other Natural Products

- Fish/Crustaceans
- Honey
- Wax
- Birds
- Mammals
- Reptiles/Other fauna

SOURCE: Adapted from UNEP, 1983

Among the "intangible" benefits, often taken for granted, are: (a) coastal protection against wave and wind erosion; (b) moderating the effects of coastal storms and cyclones; (c) shelter and habitat for diverse wildlife, particularly avifauna; (d) nutrient sink-effect and reduction in excessive amounts of pollutants, and (e) entrapment of upland runoff sediments thus protecting nearshore reefs and reducing water turbidity. Mangroves also provide opportunities for education, scientific research, recreation and ecotourism.

3.2 UTILIZATION OF WOOD PRODUCTS

Mangrove forests have favourable silvicultural characteristics which lend themselves to intensive forest management for woody products. Some of these characteristics are as follows:

- **Rapid growth:** Mature stands under suitable conditions may yield over 270 m^3/ha within 30 years, equivalent to an MAI of 9-10 m3/ha;
- **Good regeneration potential:** Most mangrove species flower and fruit regularly and the propagules are dispersed by tides. Thus, mangrove stands can recover rapidly from natural or man-made disturbances, including intensive logging.
- **Tendency to form homogeneous/even-aged stands:** Pure stands of *Rhizophoras* or *Avicennias* are not uncommon and even in mixed stands, the principal components are restricted to a handful of species;
- **Diversity of forest products:** A wide range of products are produced and as bioenergy plantations even the smaller thinnings may be used as firewood.

Environmental, biological and social considerations require that harvesting operations must not impair the ecosystem. In particular, wood and non-wood removals should avoid the following:

- deny indigenous communities of their traditional access to a reasonable harvest of mangrove products
- significantly alter substrate composition;
- alter the local patterns of surface water circulation;
- exceed the biological productive potential of the site;
- reduce the regeneration potential of desired species;
- reduce the protective functions of the forest; or,
- damage wildlife breeding, nursery or shelter sites.

Large scale capital-intensive operations are not advisable. For this reason the clear-felling of large mangrove areas for exporting chips to developed countries may be detrimental to local ecologies and economies in the long term, although for a time it may generate some foreign income.

Although a clear-felling system has been practised in the Matang mangroves for almost a century without apparent adverse impact upon the environment and ecosystem, this is the exception rather than the rule. Blessed with a buoyant economy, abundant fuelwood supply, natural petroleum and gas, and guided by a sound land use policy, the pressure on mangroves in Peninsular Malaysia is less than that in most other countries.

More importantly, individual felling areas are relatively small and sufficient funds are provided for reforestation. However, when clear-felling systems are applied to other situations without reference to local ecology and the country's socioeconomic context, the mangrove resource can be destroyed or degraded very rapidly.

3.2.1 Timber

Under favourable conditions, mangrove trees can grow to large sizes. *Rhizophoras* over 40 m tall are not uncommon and individuals over 62.5 m have been reported (Sukardjo, 1978). However, large trees are becoming scarce, especially in South East Asia, as most of them are removed before they can attain such sizes.

Rhizophora spp are however, not valuable as timber because of their tendency to split and warp when dried. The wood is dense and difficult to work. The sapwood is easy to preserve but not the hardwood. It is resistant to decay but not to marine borers. Its possible uses include agricultural implements, boat construction (knees and ribs), general heavy construction (rafters, beams, joists), marine and bridge construction (underwater, non-teredo infested waters), marine and bridge construction (above water), fence posts and poles. In the Ca Mau peninsula in Southern Vietnam, a small amount of *Rhizophora* is used for walling and flooring. Sugden and Von Cube (1978) also indicate that *R. racemosa* can be used for a variety of products including particle board, railway ties and posts.

The wood of *R. mangle* is exceedingly heavy with a specific gravity varying from 0.9-1.2. It is comparable in density to Greenheart (*Ocotea rodiaei*) and Bulletwood (*Manilkara bidentata*). The green weight was determined to be 1 200 gm/m3 (75 lbs/cu.ft.) at 46% m.c. (FAO). *Avicennia germinans*, which has a lower density (about 0.64) and good nail holding qualities, is often used as railway ties in Cuba. In Venezuela *A. nitida* is used as mining props, telegraph and transmission poles. **Table 3.2** shows the densities of selected species.

Table 3.2: Wood density for selected species

SPECIES	Wood Density		
	Oven-dry	Green	Air-dry
Avicennia nitida	0.639	1.097 (72.3)	0.803 (14.7)
Rhizophora harrisonii	0.844	1.179 (39.6)	1.045 (12.9)
Rhizophora mangle	0.844	1.202 (42.4)	1.036 (12.9)

Source: Arroyo, 1971 (Figures within brackets denote moisture content %)

In the Bangladesh Sundarbans, *Heritiera fomes* (Sundri) is the prime timber species used for house and boat construction, while the tops are used for hardboard and as firewood. Creosoted *Bruguiera gymnorhiza* transmission and telegraph poles were used in the Andaman Islands.

3.2.2 Charcoal

The energy given off from a piece of wood is about the same on a weight basis irrespective of species (Openshaw, 1983). Wood density largely determines charcoal yield, consequently a given volume of wood will result in different yields of charcoal (measured on a weight basis) dependent on the species. For example, a cubic metre of air dried wood (15% m.c.) will give the following approximate weight of charcoal including fines for various species.

Table 3.3: Yield of charcoal for selected species

SPECIES	Pines	Tropical Hardwoods		
		Average	Heavy	Rhizophora
Weight of charcoal in kg/m3.	115	170	180	285

For bioenergy plantations, the potential energy yield per unit area (*i.e. above-ground biomass*) rather than volume is the important measure. For example, a pine plantation with twice the standing volume of a *Rhizophora* forest has 24% less potential energy per unit area. The high heat value of *Rhizophoras* varies between species, but a value of 4 400 kcal/kg has been cited for *R. mangle* in Ecuador (Doat, 1977).

Rhizophoras are preferred for charcoal making. Their moisture content (MC) when felled is about 40% (as % of oven dry weight) compared to *Avicennia* wood which ranges from 70-95%. *Rhizophora* wood dries to about 25% MC after two months, whereas *Avicennia* requires up to six months to dry to 35% MC. This partly explains the popularity of *Rhizophora* wood, as predrying stock can be kept to a minimum. Charcoal outturn is improved when dry billets are used because less energy is needed to dry the wood.

Other species (*Bruguiera gymnorhiza* and *Ceriops sp*) are also used but in smaller quantities.

Charcoal is the main mangrove product in Thailand, Peninsular Malaysia, Sumatra (Indonesia), Myanmar and Southern Vietnam. Industries are well developed at the village and cottage industry levels in most Asian countries where mangroves still abound. Charcoal is mainly used for cooking purposes and small-scaled industries. However, in West Africa firewood is more commonly used.

In Matang charcoal is produced in dome-shaped, masonry kilns. These are located along small rivers or creeks to facilitate transport of billets. The battery of kilns is covered with Nipa roofs. The roofing requires little attention as the tar-laden smoke emitted by the kilns preserves the Nipa thatch. However, if the kilns are not fired regularly, the masonry structure and Nipa thatching deteriorate rapidly. Masonry kilns are long-term, location specific and costly to construct. To be economically viable there must be an assured supply of billets and reasonably low land costs. In contrast, earth pits are easy to build, costs are low and the structures are often temporary.

Freshly cut billets are normally debarked in the forest. Billets of 18-23 cm diameter and 1.6 m in length are stacked vertically inside the kiln. High grade charcoal of uniform quality is made when air-dried, debarked billets of uniform sizes, densities and species are used. Bricks are used to support the standing billets for even burning. This reduces the amount of partially carbonized ends or "*brands*" produced. Where *Rhizophoras* are limited in supply, inferior species such as *Avicennias* and rubber wood (*Hevea brasilensis*) are substituted for kindling wood.

The conversion efficiency is still far from efficient. In Matang, a standard 6.7 m diameter dome-shaped kiln operates at only 19% efficiency. About 55 t of greenwood per kiln is required for an efficient burn (**Table 3.4**). Current use of smaller and lower density billets compared to wood harvested from the virgin stands may partly account for the reduced conversion efficiency in Matang. (Harun, 1981).

Table 3.4: Greenwood input and charcoal output per burn (tonne)

Range	Kiln No.	Kiln Diam. (m)	Greenwood Required		Total input (tonnes)	Charcoal produced		Total output (tonnes)
			As charcoal	As fuel		Good quality	Broken	
Port Weld	1	6.7	39.7	14.5	54.2	11.0	0.2	11.2
	2	6.7	38.5	14.7	53.2	10.5	0.2	10.7
Kuala Trong	1	6.7	39.3	15.6	54.8	10.8	0.3	11.1
	2	6.7	38.9	15.6	54.4	10.9	0.2	11.1
Sungei Kerang	1	6.7	39.9	17.4	57.2	9.9	0.5	10.4
	2	6.7	39.8	15.6	55.3	7.7	1.0	8.7
Average/kiln		6.7	39.4	15.6	55	10.1	0.4	10.5

Source: Matang Forest Reserve Working Plan (1980-89)

Frisk (1984) estimated that a kiln of 6.7 m diameter and 7 m in height requires 9 t of clay, 9 t of fine sand and 15 000 - 17 000 pieces of bricks (6 cm x 11 cm x 23 cm) to construct. It costs about $7 000 including the roof shelter.

In Yeesarn, Thailand, the estimated cost, including Nipa thatch roofing, was $2 284 for kilns of 5-6 m diameter and 3 m high. Kilns last a long time provided worn out, porous or broken bricks, caused by thermal cyclical stress and normal wear and tear, are regularly replaced. Cracks should also be sealed immediately.

Charcoal making can be profitable, but it is less lucrative than shrimp-farming. In Matang, a hectare of mangrove managed for charcoal yield the government a net revenue - in form of royalty, premia, license fee, fines etc. - of US$ 478 (Othman and Khan, 1984). The market value of the same forest is very much higher at US$ 8 333/ha.

In West Africa, Central America and the Caribbean Islands, charcoal is mostly made by the earth pit or mound method. Generally, these are less efficient, and produce charcoal of variable quality. Greater care is also required in tending and controlling the carbonization process.

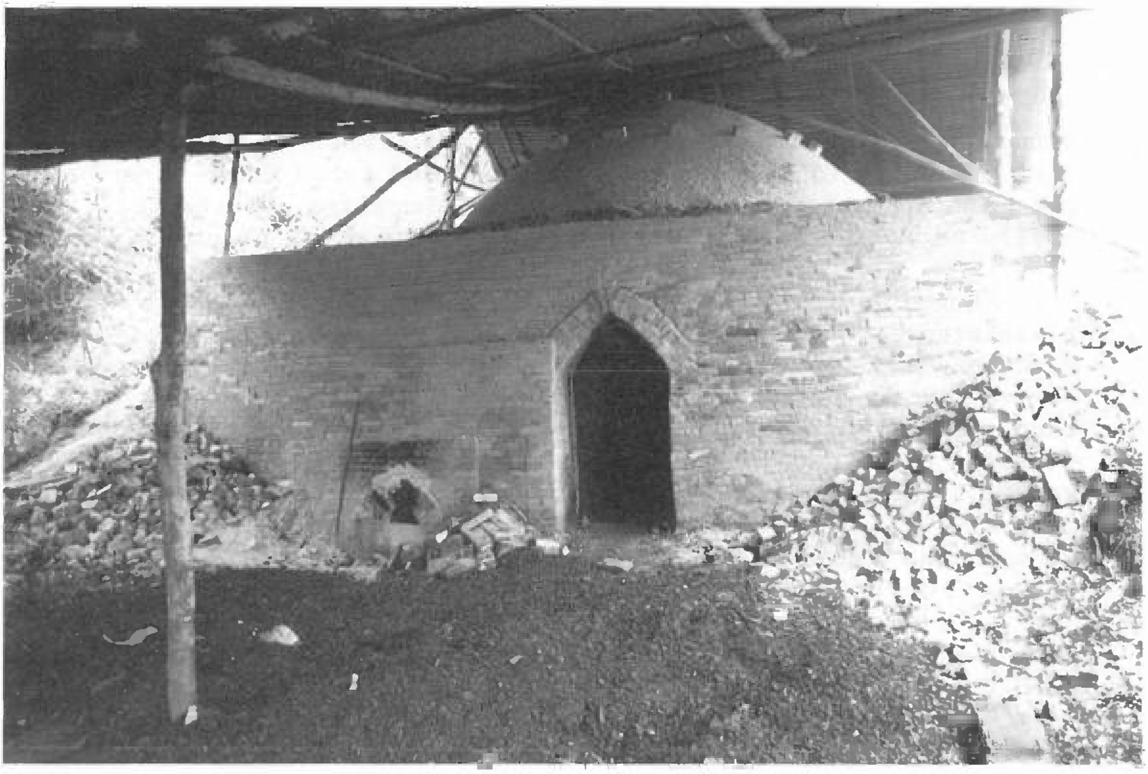


Figure 3.1: Masonry kiln for charcoal making in Indonesia.
Photo by M.L.Wilkie

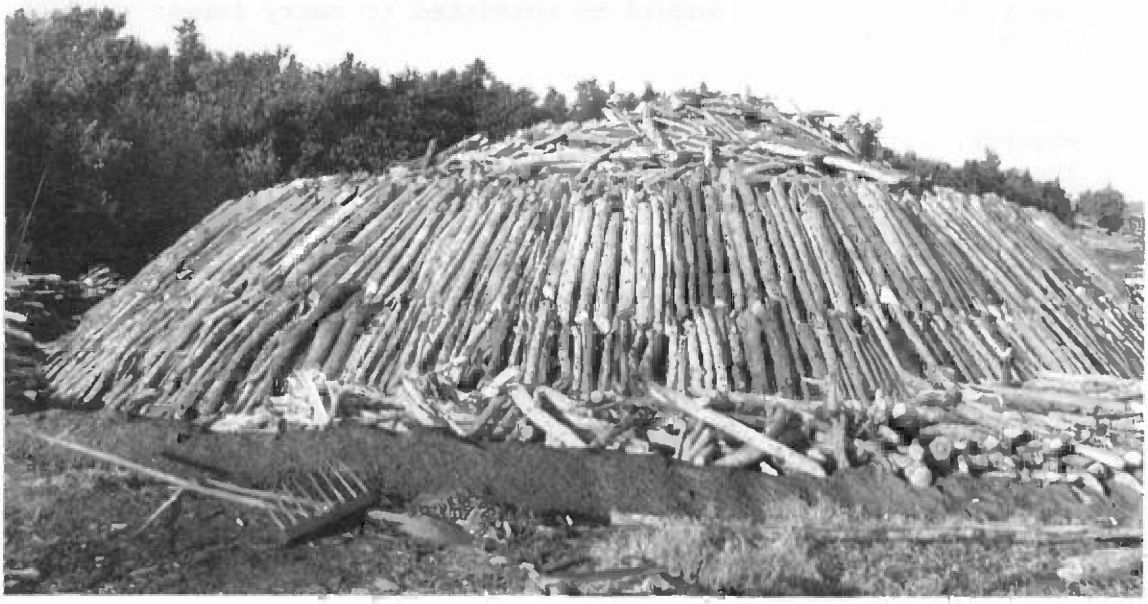


Figure 3.2: Charcoal making by the earth mound method in Guanal, Cuba.
Photo by P.W.Chong

In Cuba, billets of all sizes and lengths are arranged vertically to form a large circular stack. This is then covered with fern fronds and sand and sealed with mud.

In Costa Rica, the "carboneros" construct their charcoal-pits along the beach above the normal high tide level. The dimension varies from 3 to 27 m in length, 0.3 m in depth and 1.1 - 2.1 m in width. The pits are oriented perpendicular to the shoreline, so that billets can easily be rolled into the trenches to form a stack about 0.9 m high.

Running along the length of the trench are two rows of supporting billets to facilitate the positioning of the billets and to improve air circulation. The billets vary in length from 1.1 - 1.5 m. and are not debarked. The fully charged stack is partly above ground level. It is then covered and sealed with *Acrostichum* leaves, earth and sand, and a plastic cover to keep out the rain. One end is fired, and carbonization progresses along the stack at the rate of about a metre per day. This is monitored and controlled by several crudely made vents. The charcoal produced is of variable quality, mixed with sand.

A conversion efficiency of about 13% is achieved, equivalent to an input/output ratio of 1 : 7.7, based on dry weight. Higher output is possible with pre-dried billets but the added costs of holding stock must be considered. For masonry kilns the conversion efficiency is around 19% to 22%. Higher conversion efficiency means that less wood needs to be grown, harvested, pre-dried, transported and used for charcoal making.

Unplanned promotion of charcoal industries, without proper resource assessment and forest management, will, however, only hasten the ecological destruction and depletion of the mangroves. To avoid this, the construction of new or enlargement of existing kilns and earth-pits should be monitored and regulated by the responsible forestry authorities. Similarly, only boats which are registered with the Forest Department should be permitted to carry forest produce to minimize illegal felling.

Agricultural activities are essentially seasonal in nature, whereas, forestry activities can be carried out throughout the year. Thus, forestry activities such as charcoal making can offer employment opportunities to counter seasonal unemployment.

Well organized charcoal industries linked to sustainable supplies derived from *regulated* State forests and/or private plantations and woodlots can contribute significantly towards rural employment, economy and rural industrialization. Where the commodity is produced efficiently and marketed competitively, it can be transported over vast distances to serve the needs of urban and rural consumers alike. Surplus charcoal may even be exported to neighbouring countries. Furthermore, charcoal production can be strategically planned to complement and support a country's rural coastal dendro-energy plan within the national energy framework thereby reducing its over-dependence on non-renewable fossil fuels.

It should be emphasized that the market for charcoal varies widely between and within regions.

Southeast Asia has always had a large internal market and a lucrative export market that supports large charcoal industries. In turn, this has made the management of the mangrove forests in Malaysia and recently also in Thailand economically viable. In tropical Ameraica however, the population does not have the same tradition for cooking with charcoal and investments in the management of mangroves can today rarely be justified by charcoal production alone. Mangrove regions in Africa lies in general between the above regions in respect of conditions of charcoal markets and hence the prospects of basing the economy of mangrove management on charcoal production.

Access to credit and finance is an important institutional requirement as improved carbonization methods require substantial capital investment, organization and training of operators.

3.2.3 Firewood

Rhizophoras are favoured as fuelwood for domestic purposes and are commercially removed as in the case of Matang and Thailand, or collected by fishermen and villagers.

In Sierra Leone, large quantities of *Rhizophora racemosa* firewood are used for fish smoking (banda process). Since the weight of firewood consumed in processing more than equals the throughput of fish, it is not surprising that cutting of mangroves for fuelwood has become a major occupation within the fishing community. **Table 3.5** below on fuelwood/fresh fish weight ratios for smoking fish using the "*banda*" method is based on studies conducted at Yelibuya Island. (Chong, 1989).

Table 3.5: Fuelwood/fish ratios in fish-smoking - Sierra Leone

	Fresh Dry Fuel ratio	Sample size	Hard Dry Fuel ratio	Sample size
Bonga	1.03	46	1.80	11
Awefu	1.39	38	2.29	19

Source: Seymour. T; 1987. KFDP Technical Report 6/87.

Fuelwood is also used in boiling brine to produce salt. The heating value of selected mangrove species are shown in **Table 3.6** below:

Table 3.6: Heating value of selected mangrove species

Species	Cal/gm
Rhizophora apiculata	5.017
Ceriops tagal	4.731
Sonneratia alba	4.554
Bruguiera parviflora	4.552
Avicennia officinalis	4.528
Xylocarpus granatum	3.899

Figure 3.3: *Rhizophora* **firewood bundled with split mangrove stilt-roots.**
Sierra Leone. Photo by P.W.Chong

Figure 3.4: Bark collection in southern Vietnam.
Photo by P.W.Chong

3.2.4 Fishing stakes/poles

In Singapore, Hongkong and Malaysia, there is an established demand for mangrove piling poles used in land reclamation and the construction industry. Used in wet sites which are not infested by shipworms, such mangrove piles can outlast non-treated inland hardwoods. Currently poles are imported from the Indonesian islands and from southern Thailand.

Along the coastal waters, Nibong (*Oncosperma filamentosa*) is normally used as fishing stakes in Southeast Asia, but sometimes mangrove poles are also used. These have to be regularly replaced.

Along the muddy river banks, small fishing stakes are used to support tidal fish nets. Mangrove poles are also used for scissor nets in housing construction. In the Cuban waters and in countries in South East Asia, fishermen cut mangroves and dump them into the shallow coastal waters as a way of creating shade and thus attract fish (fish attraction devices).

3.2.5 Pulp

Gewa (*Excoecaria agallocha*) is the principal pulping species used in the newsprint mill in Bangladesh. *Sonneratia caseolaris*, *Excoecaria agallocha*, and *Avicennia marina* produce strong Sulphate pulps.

Large mangrove concessions have been granted for chipping operations in the east Malaysian states of Sabah and Sarawak and in Indonesian Kalimantan and Saluwesi based on *Rhizophoras* and *Bruguieras*. The chips are exported mainly to Japan for making dissolved pulp and cellulose derivatives such as rayon, used in the textile industry. The African species of *R. racemosa* is reported as suitable for making dissolved pulp although some problems exist due to the inorganic crystals present in the wood (Sugden and von Cube, 1978).

The production and export of chips from mangroves have in parts of Indonesia led to the clearfelling of large areas in one harvest. The regeneration of these areas has proven unsuccessful in many cases and it is now recognised that harvest areas should be kept small and scattered if satisfactory regeneration is to be obtained.

3.2.6 Tannin

Rhizophora bark produces very fine tannin of the phlobaphene-yielding catechol group which is not broken down by ferments and is thus very suitable for leather work. Tannin from mangrove species has also been used for curing and dyeing of fishing nets made of natural fibre to make the nets more resistant to biological decay.

The amount of tannin varies somewhat with bark thickness, position on tree stem, location of tree, dryness of the bark, as well as between species. The bark must be fresh and transported to the tanneries as soon as possible in a moist condition. *Ceriops candolleana*, *Carapa obovata* and *Rhizohpora mucronata* were at one time the favoured tan-bark species exploited in Malaysia.

Although the number of *tinteros* (bark collectors) is small in Panama, Costa Rica and some Latin American countries, their impact on the mangroves may be much greater than felling activities undertaken by other groups because commercial quality bark is harvested from only the largest and better *Rhizophora* trees with straight boles. When these dominant stems are felled, considerable damage is caused and innumerable gaps are created in the forest canopy. The debarked stems are left to rot in the forest thereby creating large amounts of debris that encourage termite infestation in the drier sites. It takes about 2 year for the smaller slash to decay but a much longer time is required for the large stems to decompose.

In Costa Rica because of the high regeneration potential in the Sierpe-Terraba mangroves, these gaps revegetate quickly but not necessarily with the desired species, since *P. rhizophorae*, which is not exploited, may dominate these gaps.

The production of tannin has declined greatly in recent years, in particular since local demands have been reduced after the introduction of nylon fishing nets and the use of chrome as the predominant agent for leather curing.

In Colombia, the extraction of bark for tannin has been prohibited several years ago because of over-exploitation of the mangroves on the Pacific coast. Today, mangrove exploitation for wood and bark is totally forbidden in this country.

3.3. UTILIZATION OF NON-WOOD RESOURCES

The traditional "management paradigm" implies that if the forests are properly managed then the non-wood ecosystem components will, *ipso facto*, remain stable. This is notionally flawed, because unless the non-wood components are integrated into the planning, implementation, and monitoring levels of the forest management system adopted, they will often be marginalized or ignored.

The inland margin of the mangroves and the upper tidal limits of estuaries constitute the brackish water zone, where the water is mildly saline. Economically, this is an important zone because, the brackish-water creeks are fringed by the salt water palm, *Nypa fruticans*. The mangrove Date Palm, *Phoenix paludosa* and Sago (*Metroxylon sagu*) are also found in this formation. The inhabitants of the mangrove-*Nypa* palm zone along the Gulf of Papua New Guinea subsist almost entirely on a diet of sago, which is very rich in carbohydrates, and crabs, as a protein source.

Mangrove forests are the habitat of numerous species of fish and shellfish. Coastal fisheries depend on these and they provide much of the protein needed by coastal people. Some mangroves are converted to fish- or shrimp-ponds. Near urban centres, much mangrove forest has been lost to provide land for industry, tin-mining, solar salt-works and for hotels. There has also been conversion to paddy fields, often unsustainable because of acid sulphate conditions. A review of selected mangrove-based, non-wood resources including minor forest products, fishery and conversion of mangrove land to other land uses is given in the following paragraphs.

3.3.1 Nipa palm

The uses of this palm are many and diverse. It yields an important thatching material, which is used for the roofs and walls of rural houses. The villagers cut the fronds leaving behind about 2-3 younger fronds per culm. The leaflets are removed from the main stalk and usually soaked in salt water for several days to soften them. The leaflets are then folded over a spine of split Nibong (*Oncosperma filamentosa*) 4-6 feet long, stitched in place with fine split rattan, and dried in the sun.

The completed shingles (in Malaysia known as "atap") are made in several qualities. They are cheap, light to transport, easy to fix and can last several years, particularly when used in houses with open stoves. One of the unintended effects when improved cooking stoves with chimneys are introduced into rural households is that their atap roof will not last as long! Cigarette wrappers are also made from the young shoots of Nipa.

Another potential of the Nipa lies in the sugary sap of the flower stalk, which can be used to produce a sugary fluid. As the removal of mature fronds will reduce the sap yield, Nipa plantations managed for alcohol production cannot be harvested for thatch making. In the Philippines the cultivation of Nipa for alcohol production has been practised on a considerable scale for many years.

Plantation establishment

The seedlings are ready for transplanting when they are about 18" high. About 450-500 palms are planted per hectare. Split bamboo guards are used to protect the shoots of the young plants from being destroyed by crabs. Nipa fully matures within 5-6 years but bears fruits after three years or earlier.

Extraction of sap

The fruits, borne in a cluster on a large flower stalk, take about three months to develop. When the head is well developed, but before the skin of the fruits begins to darken in colour and becomes hard, the stalk is massaged.

This process known as "*gonchang*" involves swaying the stalk, gently at first but with increasing severity for about 3 weeks, at the end of which time it is violently shaken. The fruit head is severed, and the exudate is collected. A thin slice is made every day or even twice a day and the stalk will continue to yield for several months. As many as 26 fruiting heads at various developmental stages have been observed on a single palm.

In Malaysia, tapping is undertaken all year round without any apparent ill effect. Reportedly, each spathe daily produces about 0.49 litres of sap. Two spathes per palm can be tapped continuously to yield annually about 252 litres based on 260 working days. In Papua New Guinea, a mature palm produces about 200 litres per year. With a plantation of 250 palms/ha, the annual sap yield will be some 50 000 litres.

Figure 3.5: Collection of *Nypa* leaves in the Sundarbans, Bangladesh
Photo by M.L.Wilkie

Figure 3.6: Shingles (Atap) made from *Nypa* leaves in Sumatra, Indonesia.
Photo by M.L.Wilkie

The sugar content, mainly sucrose, varies from 6-17 percent. A conservative estimate of only 6 percent sugar content would yield some 3 000 kg/ha/year of sugar or about 5 400 l/ha/year of alcohol. To be economically viable, large scale Nipa plantations are needed. Additionally, as the juice ferments very rapidly, an efficient and rapid juice collection system is very important.

Apart from alcohol, three alternative products might also be profitably made from Nipa sap. The simplest product is *sugar syrup*, which can be marketed as a speciality sweetener like maple syrup. This is noteworthy because in 1986 maple syrup production plummeted and retail prices rose to nearly US$ 50/gallon. Another potential product is *brown sugar*, which is popular in developed countries as a form of "health" food. The third and possibly most important product is *vinegar*, which can be used in domestic cooking, industry and for preserving food. Nipa vinegar could be an important substitute for industrially produced vinegar.

3.3.2 Apiculture

Honeybees, from the genus *Apis*, have been beneficially and destructively exploited by man for thousands of years. *Apis mellifera*, which is native throughout Africa, most of Europe and the Middle East, is the best known and most widely spread species.

In Africa, honey is still being collected from wild nests, but the common types of traditional beekeeping use hollowed log, bark, basket or clay hives placed on tree branches. In West Africa, the nectar and honey and pollen potential of the mangroves has yet to be fully exploited. (See **Figure 3.7**)

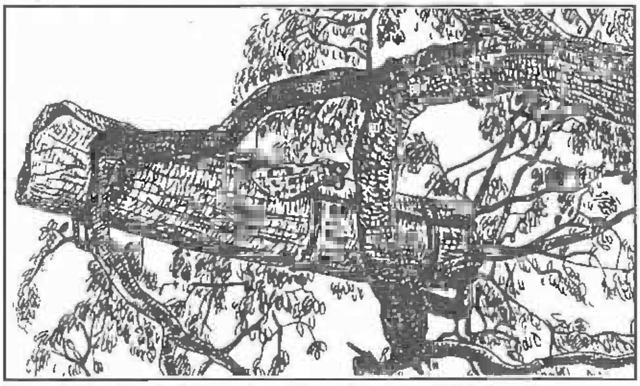


Fig. 3.7: Bark hive placed on tree in Africa

There are no honeybees native to the Americas, Australia or the Pacific area although during the last 400 years or so *Apis mellifera* has been introduced from Europe to these areas (Bradbear, 1990).

Avicennia germinans, Laguncularia racemosa and *Conocarpus erectus* are important sources of nectar and pollen in these areas, and *Rhizophora mangle* is also reported to be a melliferous plant (Hamilton and Snedaker, 1984). Off-season flowering plants enable bees to build up sufficient stores to survive during stressed periods such as cold weather, drought, monsoon rains and floods, or devastating bush fires.

Within the mangroves modern beekeeping with comb-hives are practised in Florida, the United States and Cuba. About 40 000 hives are relocated to the fringes of mangroves in Cuba between April to June when pollen and nectar production from inland natural vegetation and crops are very much reduced.

Apiculture in Cuba is based on local hybrid (*Apis mellifera mellifera x Apis mellifera lingustica*). About 25% of the annual total honey production in Cuba (some 8 - 10 000 t) is derived from the mangrove sources.

In Asia, apiculture is an important activity in Burma, Bangladesh and India (1984, loc.cit.). At least three honeybees are native to Asia and all are exploited by man. Two of these, the Little honeybee (*Apis florea*), and the Giant honeybee (*Apis dorsata*), cannot be kept in hives as they nest in the open air, on a single comb. The former builds its small comb (about 25 cm diameter) hanging from branches within bushes, while the latter suspends its much larger combs (around 1 m in diameter) from tree branches, rocky ledges and buildings. The Giant honeybee's nest may well contain 50 kg of honey. The third species, *Apis cerana*, is known as the Asian hive bee and can be kept in a hive (Bradbear, 1990).

Honey production depends on the type of bees, the availability of pollen and nectar, prevailing wind, temperature, salinity, contaminants, availability of freshwater and other factors. Aerial spraying of pesticides can seriously affect beekeeping. Seasonal burning of the inter-terrestrial zone and the mangrove landward fringe will also destroy a number of melliferous plants.

In the Sundarbans, beeswax and honey are produced by wild bee swarms that build hives on branches, in tree holes and crevices. The hives and trees are often destroyed during collection. It was estimated that about 9 300 trees were felled in the 1982/83 season to produce 233 tonnes of honey and 58 tonnes of beeswax, whereas under proper management about 1 550 hives would have sufficed (Christensen and Snedaker, 1984). It has been suggested that the setting up of top-bars suitably baited with swarm attractants could reduce the number of trees felled or damaged.

Beekeeping fits in well as part of integrated rural development programmes, and the best projects are those which promote sustainable beekeeping on a long-term basis making use of indigenous expertise, knowledge and materials. Imported equipment should be avoided as supplies may be unpredictable, or may later be obsolete because of lack of spare parts or suitably trained maintenance technicians. Some beekeeping management objectives are given below:

- To alleviate rural poverty by creating *in-situ* income generating activities through beekeeping;
- To improve the potential for beekeeping by planting melliferous mangrove species toward the landward fringe;
- To improve the quantity and quality of beekeeping products through sound management;
- To assist in the making of beekeeping products;
- To overcome specific problems, e.g. disease or pesticide misuse;
- To transform destructive honey-hunting from wild nests to sustainable methods.

Some points on good bee colony management practices are summarized in **Box 3.1** below:

(1)	**Use good hives that are made from local, durable and inexpensive materials that are suited to the biological requirements of bees, permitting their full development;**
(2)	**Use baited hives and locate them close to melliferous plants.** Bees-wax, propolis or other materials are used as baits to entice bee swarms;
(3)	**Access to freshwater must be provided** close to hives;
(4)	**Hives should be ventilated and well-protected** against theft and predators;
(5)	**Beekeeper must use protective clothing and equipment;**
(6)	**Bees should be regularly inspected;**
(7)	**Use good strains of bees;**
(8)	**Honey and bees-wax must be harvested in time;**
(9)	**The honey and bees-wax must be separated;**
(10)	**The honey should be stored in a cool place and the bees-wax rendered.**

Source: Ntenga, G.M and Mugongo, B.T. 1991

Box 3.1: Notes on good bee colony management

3.3.3 Wildlife

As in other forest types, the wildlife in the mangroves is an important source of protein for the local community. In addition, some species, especially reptiles, are hunted or reared for their hides. Examples of traditional utilization of selected wildlife species found in mangroves are described in the following:

The rodent Hutias (*Capromys sp.*), that live in the mangroves, are endemic to Cuba, comprising *C. sanfelipensis*, *C. garridoi*, *C. angelcabrerais*, *C. auritis* and *C. oilorides*. The meat is highly relished by the local people.

The giant forest hog (*Hylochoerus meinertzhageni rimator*) is often found marauding in the swamp margin and it is a source of bush meat to the West Africans, similar to the wild boar (*Sus scrofa*) in Asia.

In Central America, the large lizards, *Iguana iguana* (iguana) and *Ctenosaura similis* (garrobo) are found in the mangroves, the former is quite common. These two out of six species present are most commonly eaten by the local people. Hunting pressure does not seem to have diminished their population. *Ctenosaurs* may be amenable to large-scale captive breeding as a pile of cinder blocks can support flourishing populations! On the other hand, iguanas have been virtually exterminated in some Central American areas (e.g., El Salvador).

The West African Monitor Lizzard (*Varanus exanthematicus*) is also hunted for food.

In Costa Rica, the Pacific Ridley Turtle (*Lepidochelys olivacea*) is relished for its meat and weighs an average of 40 kgm. Its numbers are diminishing because of predation and over-exploitation in some countries, notably Mexico and Equador. About 60,000 turtles are slaughtered annually in Mexico.

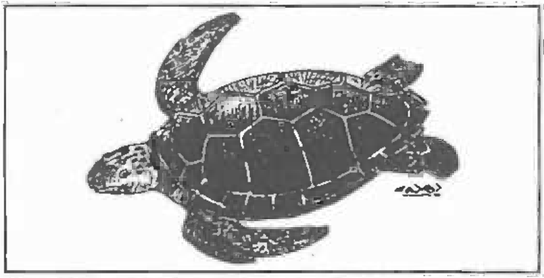


Fig. 3.8: Marine Green turtle

The marine Green turtle, *Chelonia mydus*, found in Myanmar and other Asian countries grows up to 400 lbs in weight and 4-4.5 feet long. It lays about 100-200 eggs at a time. Both the eggs and flesh are eaten by the local people.

Crocodiles and alligators are being hunted all over the world for their valuable skin. One way to diminish the hunting pressure might be to encourage crocodile farming under strict regulations.

Crocodile farming

Crocodile farming may be undertaken for commercial exploitation of its hide and meat and/or as a way for improving the conservation of endangered species and for attracting ecotourism. Cuba has well organized crocodile farms that are opened for viewing by tourists. A survey should be conducted to determine the status of wild populations with respect to their population size, length class distribution, location, habitat preference, breeding sites and habitat availability prior to the implementation of such farms. An evaluation of potential farm sites is also required. Some of the points to be considered, depending on the objective of the farming programme, are as follows:

- access to food for adult and young animals
- availability and quality of water;
- access to tourists;
- demand for hides;
- micro-relief and drainage;
- local support and labour supplies.

Adults are fed waste products from cattle, horse and poultry slaughter houses. Small crocodiles are fed "trash fish" (10-12 cm) caught by trawlers. There are many successful examples of crocodile farming undertaken by private entrepreneurs, and these initiatives have tended to reduce the pressure on illegal hunting of adults in the wild. However, some of these private farms are known to purchase eggs or juveniles from the wild and this should be regulated.

International trade in crocodile skins and other products is largely regulated by the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITIES) and should be considered when planning marketing operations.

3.3.4 Capture fishery

From an economic point of view, mangroves are often far more important for the aquatic production they support than for the wood production potential. Kapetsky (1985) estimated that the average yield of fish and shellfish in mangrove areas is about 90 kg/ha, with maximum yield being up to 225 kg/ha. According to this author, the total halieutic production of the world's mangroves would be around 1 million tons per year (for an estimated area of 83 000 km^2 of open water in mangroves), which is slightly more than 1% of estimated total world production in all waters per year.

In the part of the Sundarban Mangroves situated in Bangladesh, an average of 9 000 tons of fish and shellfish was caught annually in the late seventies and early eighties. With 169 908 Km^2 of waterways, this corresponds to approximately 53 kg/ha being caught within the mangrove area itself. To this figure should be added the portion of the off-shore fisheries of mangrove dependent species. Whereas over 120 species of fish and shellfish are known to be caught in this area, the main portion consists of shrimps (Penaeidae family) and hilsa (Clupeidae family).

In Africa, Durand and Skubich (1982) report 6 700 tons fish landings in 1977 from Ivory Coast lagoons, and Balarin (1984) estimates the average annual yield of Benin lagoons for the period 1959-1969 to be around 3 700 tons.

An indication of the strong relationship between fish resources caught (including mangrove as well as off-shore fishery) and the extent of coastal mangroves is shown in **Table 3.7** below.

Table 3.7: Capture fishery production in relation to mangroves, 1981

Peninsular Malaysia	Extent of mangrove cover (ha)	Capture fishery production (x 1.000 tonnes)[1]					
		Overall	Non-mangrove species	Mangrove species[2]			
				Total	Mollusca	Crustacea	Fish
West Coast	96.000 (85%)	433 (100%)	249 (58%)	184 (42%)	71	62	52
East Coast	17.000 (15%)	216 (100%)	191 (88%)	25 (12%)	-	12	12
Overall	113.000 (100%)	649 (100%)	440 (68%)	209 (32%)	71	74	64

Notes: 1 = Mangrove and non-mangrove resident fishery;
2 = includes casual, seasonal migrant and/or mangrove resident species.
Source: Adapted from Jothy, A.A., 1984 (figures rounded to nearest 1.000).

Fish statistics do often not separate catches offshore and in coastal waters and, apart perhaps from the Sundarbans, accurate "Fishing effort data" are seldom available for mangrove areas. Such data are, however, essential in order to assess the biological and economic status of a fishery and to formulate appropriate management measures. Data, covering a sufficiently long period, should include information on the number of fishing units by various size classes, the catching power per unit and the amount of time spent fishing.

The state of the fish and shellfish stocks can be determined by one of three methods. The first is a simple *catch and effort analysis* based on a surplus production model. The second approach is the so called *yield per recruit analysis*. Basically this approach attempts to determine how the growth and natural mortality of a population interact to determine the best size of shrimp to harvest after they have been recruited into the fishery. The final method is the *analysis of species interactions*, which is often ignored due to its complexity.

Fish

In Thailand, the main commercial fish species caught in or close to mangrove areas include mullets (*Liza subviridis*), sea bass (*Lates calcarifer*), snappers (*Lutjanus spp*), tilapia (*Tilapia spp*), groupers (*Epinephelus spp*), sea catfish (*Arius spp*), threadfins (*Eleutheronema spp*) and snake eel (*Ophihctus microcephalus*) (Christensen, 1982).

The most important fish in West Africa is the "Bonga" (*Ethmalosa fimbriata*). Other genera of importance inthe same family (Clupeidae) are *Sardinella* and *Pellonula*. *Tilapia* is also very important. In East Africa, *Tilapia* and *Cyprinus* are among the sought after genera, followed by mullets, eels and milkfish (*Chanos chanos*).

In Latin America, mullets and snappers are among the most common fish caught in and around mangrove areas.

Shellfish

The term shellfish is used here collectively to describe crustaceans (crabs, shrimps) and molluscs (bivalves and gastropods).

The main edible crab (*Scylla serrata* in Asia and East Africa and *Callinectes latimanus* in West Africa) is a highly valued mangrove product, and are caught by locally produced traps or by using crab hooks to fish the crabs out of their burrows. Other edible crabs that are diversely valued depending on countries include some *Sesarma*, *Cardisoma* and *Thalamita* species (SECA/CML, 1987).

Shrimps are usually caught with push nets along shallow creeks within the mangroves and by off-shore trawlers. In Matang, eleven commercial species of shrimps are landed, with the bulk of the catch consisting of *Metapenaeus affinis*, *M. brevicornis*, *Parapenaeopsis sp.* (notably *P. hardwickii* and *hungerfordi)* and *Paenaeus merguiensis/penicillatus*.

In a number of countries mysid shrimps are caught for the production of shrimp paste, a popular condiment in Southeast Asia. In the Sundarbans, numerous fishermen are engaged in catching post larvae shrimps to stock the aquaculture operations, as the hatching of shrimps is yet in its infancy stage in Bangladesh. Unfortunately, this is a very ineffective utilization of the resources as only a few species are sought after at this stage and the rest discarded and the mortality of the preferred species is high due to storage and transport. In such areas care should be taken not to over-exploit the small-sized shrimps to the detriment of the more valuable larger adults, which are caught by the off-shore trawlers.

Figure 3.9: **Setting traditional fish traps in Matang, Malaysia**
Photo by M.L.Wilkie

Figure 3.10: **Boat load of Blood cockles (*Anadara granosa*), Matang**
Photo by M.L.Wilkie

In Central America the ark shell clams (*Anadara sp*) are undoubtedly the most important economic mollusc resource that thrive in the mangrove. In Costa Rica the larger bivalve *Anadara grandis* (chucheca) has practically disappeared due to over-exploitation. In its place, two smaller ark clams 'pianguas', viz., *Anadara multicostata* and *A. tuberculosa* are now being exploited. The latter bivalve is commonly found from Lower California to Peru (Keen, 1971). Its importance as a source of protein and an economic renewable resource for coastal dwellers makes it the single most important exploited species in the mangrove ecosystem of the littoral Pacific. Due to the heavy pressure on these species, only bivalves of 45 mm diameter and over are permitted to be harvested in Costa Rica. *Anadara similis*, a smaller bivalve is also found and collected in the mangroves of tropical America.

In Malaysia, the blood cockle (*Anadara granosa*) is a species of great commercial importance, that forms the basis of a flourishing coastal industry, as well as, being a major protein source. Around the Indian Ocean, *Gelonia* is collected.

Some wild oysters, as for instance *Crassostrea tulipa* in West Africa, grow naturally on the stiltroots of *Rhizophora spp* and are locally exploited. It should be noted however, that oysters can be dangerous to eat during outbreaks of the so-called red tide.

For information on the biology and culture of *Anadara sp.* and tropical oysters, refer to Broom (1985) and Angell (1986) respectively.

Other groups of bivalves harvested and used as food are the jack-knife clams and mussels. The clam, *Polimesoda inflata*, is closely associated with certain crabs (*Pinnotheres sp*). *Modiolus capax* (Mytillidae) has a triangular shell and bundles of filaments that enable them to attach on to mangrove roots.

Various species of edible snails are found in the mangroves, and some of these are locally commercialised. *Terebralia* and *Telescopium* are usually eaten by cracking their shells, while the insides of the smaller *Cerithideae* are taken out with a toothpick or simply sucked out when the closed end is broken. Species of *Nerita* and *Salinata* are also gathered as food. (Christensen, 1982).

3.3.5 Mariculture

Traditionally, mariculture, involving the use of a system of man-made ponds in rearing specific marine or brackish-water animals, has been practised in Indonesia for hundreds of years. Ponds "tambaks" were constructed to rear milk-fish (*Chanos chanos*). Along the mangrove waterways, creeks and estuarine waters, a rich tradition of artisanal mariculture has evolved and fish constitute an important part of the peoples' protein supply.

Unlike many cultures of Asia, the Pre-Columbian cultures of America had no significant tradition of aquaculture, nor did the Europeans who came in the fifteen century. Consequently, there are few mariculture traditions. The preferred protein is meat rather than fish, where only a few species are consumed.

Several mariculture practices are used in the mangroves, and these may broadly be classified into those methods which make use of the natural fertility of the estuarine aquatic system without destroying the vegetation (open-water estuarine culture) and those that are practised on the land (pond culture).

Open-water estuarine mariculture

Three main types of open-water estuarine mariculture can be distinguised *viz.* Bottom culture, where no enclosures are used, Cage culture and Raft and cultch culture.

Bottom culture

The genus *Anadara* has wide mariculture potential and the Blood Cockle (*Anadara sp.*) is a good example of bottom culture. The substratum and the exposure period at low tide appear to be the more important factors limiting the distribution of cockles. *Anadara granosa* is a major protein source, that grows naturally on mangrove mudflats in West Malaysia, Thailand, Kampuchea and South Vietnam.

Cockle farmers collect the seeds (measuring 6-12 mm) from spatfall areas on the higher mudflats at low tide and sow them in the cockle beds in the lower areas up to 4.5-5.5 thousand litres/ha. (Hamilton, L.S. and Snedaker, S.C., 1984). Predators such as starfish and *Natica* are removed at low tide. Sown seeds mature after 8-12 months and are harvested when they are about 3 cm in diameter. The yields in the better areas are about 20.7 and 24 t/ha/yr in Malaysia and Thailand respectively (Sribhidhad, 1973). Malaysia is the largest producer and exporter of cockles among the tropical countries, with 4 700 ha of cockle beds producing about 65 000 t annually (equalling an average 13.8 t/ha/year), valued at over US$ 12 million.

Anadara tuberculosa found in tropical America is another species which offers excellent prospects for commercial development (Ellis, 1968, Hagberg, 1968).

Bivalves being filter feeders are very sensitive to water quality and contaminants. In 1970, for example, waste discharge from sugar refineries into the Mae Klong river in Thailand practically destroyed the cockle farming industry in the estuary. Reportedly, bivalves in the Sierpe mangroves in Costa Rica were reduced drastically due to copper-based pollutants discharged by the banana plantations.

Seaweed culture

China, Hongkong, Vietnam, The Philippines, Taiwan, Japan and Korea are the Asian countries that consume large quantities of seaweeds as food, and also for medicine and cosmetic purposes.

In Thailand seaweed farming based on *Gracilaria* is carried out in shallow coastal waters along mangrove shore lines, where the bottoms comprise silty sand. Large quantities are exported to Japan. In West Malaysia, the best seaweed farming sites are located inshore of the shrimping grounds, in the lower intertidal zone.

Seaweed farming is also practised in the Philippines with good financial results and similar potentials exist in Vietnam and parts of Myanmar. The synergic relationship between seaweed and cockle farming has not been established, but given the generally known ameliorative effect of sea-grass meadows on aquatic productivity, these two activites are likely to be mutually beneficial (FAO, 1977). The biggest constraint now and for the future is the growing pollution of coastal waters.

Cage culture

In the sheltered estuaries and canals that are rich in organic detritus, the rearing of fish can be carried out in cages and enclosures. The use of cages made of synthetic net or bamboo screens measuring from 0.25 ha to 5 ha each have been successful in the culture of milk-fish (*Chanos chanos*) in the Philippines, producing as much as 4 t/ha/year. Some supplementary feeding was provided. (Delmendo and Gedney, 1974).

Floating net cages are suitable for species which can tolerate crowding, convert feeds efficiently, are easily available as fry, are highly priced and in good demand (Christensen, 1982). The two most cultured fish are the sea bass (*Lates calcarifer*) and grouper (*Epinephelus tauvina*) grown in cages (4-5 by 5-6 m and about 2.5 m deep). The stocking rate of fry of these two species range from 350-500 per cage. In Malaysia, a yield of about 75-125 kg can be obtained from each cage after 10-12 months (Chan and Salleh, 1987).

Raft and cultch culture

Oysters and mussels have been grown on nylon ropes suspended from floating rafts, yielding about 180 t/ha/yr of mussels.

In Lower Allen Town close to the capital Freetown in Sierra Leone, women used to gather the wild oysters (*Crassostrea tulipa*) during low tide by cutting the mangrove roots. Due to the destructive method used and overcutting for firewood, the coastal mangroves have been transformed into low shrubs and even destroyed, leading *inter alia* to a decline in the amount of oysters collected. However, by stringing oyster shells together with a nylon string, and hanging these on bamboo racks by the tidal creeks, oyster spat can be collected and mature oysters harvested without destroying the mangrove vegetation after about 12 months. This method has been applied with some success in the Lower Allen Town area (Chong, 1989).

In Thailand, concrete cylinders, 15 cm in diameter and 40 cm high, are mounted on short *Phoenix* palm posts at a density of about 1 post/m^2. The spats of *Crassostrea commercialis* attach to the cylindrical surface and can be harvested after 8-18 months. Christensen (1982) reported that about 17 t of meat could be produced per hectare per year with this method. In Panama and the Caribbean sea coast of Costa Rica, the mangrove oyster *C. rhizophorae* has been the subject of research. The seed could be collected from natural reproduction and planted in other areas for growth to market sizes. Culture methods have been well established in Puerto Rico, Cuba and in Bocas del Toro, Panama.

Figure 3.11: Cage culture, Matang, Malaysia
Photo by M.L.Wilkie

Figure 3.12: Oyster culture along a mangrove creek, Sierra Leone
Photo by P.W.Chong

Pond culture

Small-scale pond culture

Artificial fish ponds, comprise about 95% of the aquatic culture in the Philippines, where about 3,700 ha of mangroves were destroyed annually during 1952-1981. (Umali, 1985). Ponds about 0.1 - 1.0 ha are constructed within the mangroves to take advantage of the availability of fry, natural fertility of the mangroves and tidal flushing.

Another example of this is the 'tambak' fish-ponds in Java where mangroves and other useful trees are often grown on the dikes between the ponds. (Sukardjo, 1978). Sometimes, Nipa is also grown beside the ponds to provide shade. The ponds are mostly used for the culture of shrimps and milkfish.

Milkfish (*Chanos chanos*) fry is common in mangrove environment and coastal waters in Southeast Asia. It is generally caught after the post-larval stage and before the fingerling or late fry stage.

Large-scale pond culture

Mangrove areas in many developing countries are increasingly being converted into large aquacultural ponds used mainly for rearing shrimps rather than fish due to high export demand and shrimp prices. This occurs particularly in areas where the coastal waters are rich in nutrients, stocked with wild post-larvae and juvenile shrimps of commercial species, and the tidal range is favourably high (about 3 m). Shrimp-ponds are constructed in the mangroves because the sheltered and shallow estuarine areas are the natural habitat of a variety of commercial wild shrimp, providing gravid females and abundant postlarvae and juveniles.

The postlarvae of the Indo-Pacific species *Penaeus monodon*, *P. indicus* and *P. merguiensis*, and the eastern Pacific species *P. stylirotris*, *P. vannamei*, and *P. occidentalis* are normally found in the tidal creeks and do not migrate into the mangroves. Wild postlarval and juvenile stocks are declining in numbers due to the continuing degradation and destruction of their habitat.

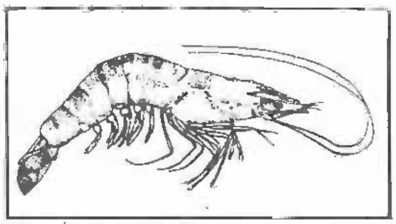


Fig. 3.13: Shrimp

The technology for producing postlarvae shrimps in hatcheries exist, but it is expensive, complex and not available to small operators. Consequently an adequate supply of fry is becoming a problem for small operators who cannot afford to buy stock from the hatcheries. The dependence on unreliable wild fry supply is the weakest link in the production chain for small shrimp operators.

Compounding this problem is the cyclical occurrence of the "el nino" phenomenon, which causes the coastal seawater to warm up. This has caused hardship to shrimp farmers in Central America, due to flooding and destruction of their ponds, salinity changes in coastal waters and steep decline in wild fry supply.

Figure 3.14: **Clearing of mangrove area for shrimp ponds, Malaysia.**
Photo by M.L.Wilkie

Figure 3.15: **Monitoring the shrimp production, Malaysia.**
Photo by M.L.Wilkie

In Panama, where mariculture practices are quite sophisticated, production is constrained by the high salinity (47-50‰) experienced during the dry season and the shortage of wild fry. An account of the major problems, as reported by Cintron, (1985), is summarized below:

- Availability of seed: Wild seed stocks are unpredictable and low during the dry months. *P. vannamei* is plentiful during the wet period, while *P. stylirostris* is more during the dry season.
- Feeds. Supplementary feed pellets constitute 20-40% of the annual production cost.
- High cost of postlarvae: Laboratory seed is 250% costlier than wild seed. Postlarve stocking accounts for 16-20% of production costs.
- Climate: Salinity becomes excessive (>50‰) in dry months (January-April), and bunds are often damaged by heavy rains during the wet season.
- Diseases: These are becoming more common as the intensity of production increases.
- Predators: Aquatic predators and birds reduce yields.
- Contamination: Coastal and estuarine waters are becoming more polluted.
- Theft: Security costs must be considered.

In the Philippines, Rabanal (1977) recommended lands which are flooded during ordinary high tides and drained at low tides as the most favourable for pond construction (**Figure 3.16** on the following page).

3.3.6 Salt production

Solar salt production is a traditional and important industry in many coastal dry and semi-dry regions. As a basic commodity salt is required in the human diet and in some agricultural and industrial applications. It is used also for preserving fish, beef, fruits and vegetables. In 1980 about 25% of the world's salt production of some 175.5 million tonnes was produced using solar energy.

Seawater is guided into and trapped in bunded ponds constructed on higher ground during spring tides. Upon evaporation the salinity in the evaporation ponds increases until salt crystals precipitate from the concentrated brine. Few plants can survive under such hypersaline conditions. Development of salt flats depends on the following factors:

- supply of seawater with high salinity;
- a pronounced hot and dry season when potential evapotranspiration exceeds precipitation (PET > P);
- flat coastal land;
- restricted surface/underground freshwater inflows that can dilute or leach the accumulated salt/brine;
- prevailing drying wind to accelerate evaporation.

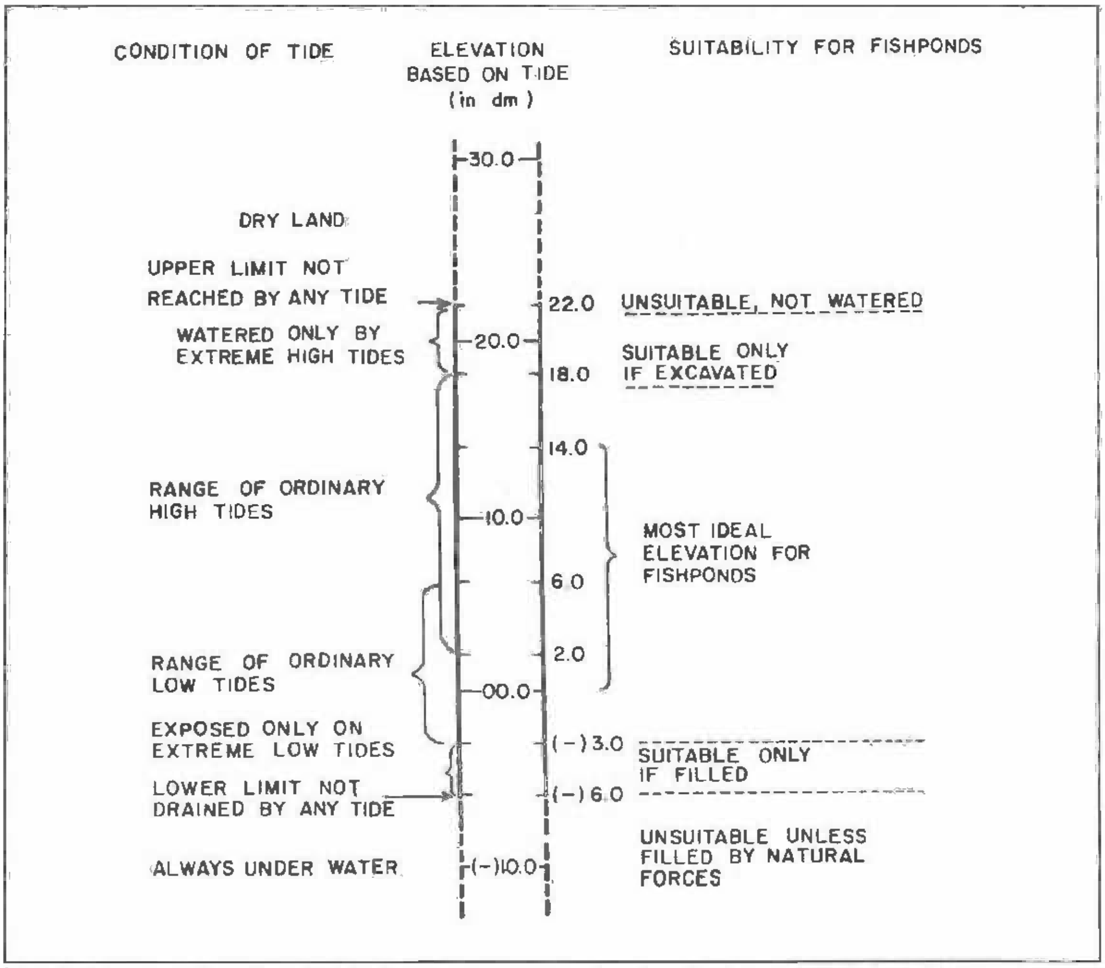


Fig. 3.16: Lands suitable for pond construction in relation to tidal elevations in the Philippines. (Rabanal, 1977).

Solar salt can be produced more efficiently in semi-arid climates, or in regions having a pronounced dry and hot season, when the potential evapo-transpiration exceeds precipitation. Equatorial climates are not favourable as evidenced by the aborted Sungei Merbok scheme in West Malaysia. In the arid zones, salt can be produced throughout the year. Solar salt production is generally situated on the seaward side, where mangroves are climatically restricted and "salt-flats" (known as *albinas* in Panama, *salitrales* in Cuba and *tannes* in parts of West Africa) develop naturally.

The following description of the salt-making process is extracted mainly from Cintron's report on Panama (1985).

Modern saltworks comprise several evaporation ponds where the brine is evaporated to three broad salinity levels. In the *preconcentrators,* sea water of 30-40‰ is evaporated to about 80‰, at which point ferric oxide and some calcium carbonate precipitate out. The brine is drawn into *concentrators,* where its salinity is concentrated to about 180‰, removing the rest of the calcium carbonate, borates and calcium sulphates; and "*nodrizas*" where, with salinities greater than 190‰, the remaining calcium sulphate is removed as precipitates.

Finally, the concentrated brine, which may be kept in holding tanks, is fed into "*destajos*" or crystallizing ponds, where sodium chloride precipitates are collected and further dried under the sun. All the salt is sold to the government.

The profits of the saltworks may be augmented by raising brine shrimp (*Artemia sp.*) as a side operation. Brine shrimp occurs naturally in waters of 80-260‰ salinity, but develops best between 140-180‰. *Artemia* is sold to shrimp farmers and the cysts are in great demand (US$ 70/kg.). During the wetter months, ordinary shrimp may be raised.

In Puntarenas, Costa Rica, an effort was made to utilize existing salt ponds "*salinas*" for the production of mullets or liza (*Mugil curema*) a low value product for the regional market and shrimp, a high value product, for local consumption and for export.

In Sierra Leone, which has an equatorial and very humid climate salt making through solar evaporation is not possible. However, great quantities of salt are produced in the mangrove areas in the dry season with a slightly different technique: The top layer of the mangrove soil is scraped off and loaded into a V-shaped vessel lined with straw and mud and leached with sea water. The resulting brine solution is boiled in big pans until the water evaporates and the salt is left as a residue (**Figures 3.17 and 3.18**). This method, if practised on a big scale, can be very destructive as mangrove wood is used for the boiling process. However, in most areas in Sierra Leone it is undertaken on a small scale in the drier, less productive parts of the mangroves and utilizing *Avicennia* wood, which regenerates through coppicing.

3.3.7 Agriculture on mangrove soils

Generally mangrove soils are marginal for long term agriculture due to the chemical nature of the soil, salinity, and shrinkage and subsidence when the soil is tilled. During the dry months, shortage of potable water causes hardships and sanitation problems.

Farmers in tidal areas experience a number of problems related to their specific environment and soil conditions. In the first place because the land is flooded during high tide, a system to keep out the saline water must be devised. This takes the form of low bunds, dikes and/or drainage canals. Dikes would curb the flood hazard in shallow levee of rivers but the construction is expensive. Close to the shore saline or brackish water creeps in from the sea (salt intrusion). Where mud bunds are constructed, these have to be continually maintained especially in areas where the mud-lobster (*Thalassina*) is common. Yields are low when the soil acidity is high.

Due to the high incidence of potential acid sulphate and acid sulphate conditions in the mangrove mud, an adequate supply of water is not only necessary but water control to maintain the water-table above the sulphitic layer is a precondition to the successful reclamation of mangrove land. The field may be rain-fed or irrigated. This will keep the soil moist for most of the time, but this also limits the range of crops that can be planted.

Figure 3.17: Leaching of mangrove soil with salt water, Sierra Leone
Photo by courtesy of M.P.Wilkie

Figure 3.18: Boiling of the brine solution in big pans, Sierra Leone
Photo by courtesy of M.P.Wilkie

Large-scale reclamation of mangrove lands for agriculture requires very careful planning, including a realistic economic analysis (See **Box 3.2** below) and an analysis of its impacts on other resources. Additionally, where the land is close to the sea and prone to cyclonic storms, the toll in terms of human lives and destruction of property and crops could be very high.

An attempt to determine the economic viability of reclamation of mangroves in Fiji for sugar cane and rice production was made, using data from existing schemes, a social discount rate of 5 % and a planning horizon of 50 years.

With regard to reclamation for sugar cane production without irrigation and with a small shrimp pond component the Net Present Value was negative even without taking into account the net benefits foregone for forestry and fishery.

Concerning the reclamation for rice cultivation with irrigation and using salt tolerant HYV rice, the NPV was also negative when undertaken on mangrove soils - again without taking the net benefits foregone into account.

The main reasons were the problems incurred due to the formation of acid sulphate soils including low yields and the special farming practises needed and the costs of bund wall maintenance.
The NPV estimates for the above were still negative under the assumption of accelerated desalination process and using higher social discount rates and longer planning horizons. Only at one to zero discount rate and 100 year planning horizon with no further capital investment did the rice project give a positve NPV. The NPV for sugarcane was however still negative.

It was thus concluded: '*if the effects of ecological characteristics of mangrove soils, which determine the time taken for freshly reclaimed soils to become productive, were to be incorporated in the benefit-coat analysis, then even with irrigation rice cultivation is not economically viable.*'

Source: Lal (1990)

Box 3.2: An economic analysis of mangrove reclamation for agriculture in Fiji.

Paddy cultivation

Rice cultivation became a major food crop in mangrove areas in Guinea and Sierra Leone aroung 1855 and much later in Madagascar (1935). In Myanmar (1852), the colonial administration, who considered the luxuriant Kanazo (*Heritiera fomes*) forests to be "wastelands", transformed the Ayeyarwady delta mangroves into paddy fields.

Traditionally, the Buginese and Banjarese farmers in Kalimantan and Sumatra have planted rice along the tidal coastal swamps for over seventy years. Rice yields of up to 3 t/ha are produced on highly pyritic soils, due to careful water control and tidal flushing of the top soil. The farmers use a system of closely spaced parallel shallow drains that effectively removes any acidity developed in the surface layer while keeping the subsurface saturated with water.

Apart from toxic levels of iron and aluminium ions, the level of available phosphorous is very low. Copper, Zinc, and Manganese contents are also low in many coastal soils. In any case, the adequate maintenance of canals and waterworks is a precondition for sustained rice production.

The four main types of rice cultivation systems are summarised in Table 3.8 below.

Table 3.8: Rice cultivation systems

A. Flooded rice cultivation

1. Tidal rice: Freshwater discharge during the rainy season for a period ofmore than 100 days is necessary. Flooding during high tide. Mostly executed in upper estuarine zone;

2. seasonally flooded rice: Sufficient discharge (flood-height) is necessary to maintain fresh water influx and levels during the growing season.

B. Rain-fed rice cultivation

"Rainwater polders": During the rainy season high water tables are maintained within small basins. Rice is often cultivated on small ridges. At least 1.000 mm of rainfall during 4 months is needed. During the dry season the fields are kept moist with brackish water to avoid acid-sulphation.

C. Controlled high water-table agriculture

In humid climates with no pronounced dry season high water-tables are maintained with minimal drainage. In the tropics often used for palm-oil cultivation. Intrusion of salt-water is controlled by sluice gates;

D. Total reclamation:

Complete control of drainage and irrigation. Soils have to be fully reclaimed;

Source: Adapted from Dent. 1986.

The International Rice Research Institute (IRRI) has classified mangrove lands according to their suitability for paddy cultivations as follows:

- Most suitable: soil salinity is low, rainfall is high and well distributed;
- Moderately suitable: soil salinity due to evaporation and rising of the water table is not very high;
- Unsuitable: high salinity, acid sulphate soils; soil exposure and dryness in the dry season and deep flooding in the wet.

Apart from irrigated rice, shallow rooted crops such as vegetables, or oil palm and coconut are the only crops suitable on these reclaimed areas, especially in the initial stages of reclamation. On mangrove swamps which have been reclaimed for a longer period, mango and other fruit trees have been established successfully. Rubber does not yield well on these marine clay soils, due to the high amount of exchangeable calcium and magnesium.

Coconuts

Coconut has often been the first crop planted on reclaimed mangrove swamps, due to its salt tolerance. Yields are however affected by pH changes brought about by drainage especially in the potentially acid sulphate and acid sulphate soils. Experimental trials showed that a drop in pH caused by drainage resulted in yields plummeting from 5 154 to 2 818 nuts/ha/yr (Zahari, 1983)

Sometimes cocoa and bananas have been successfully intercropped with coconut on acid sulphate soils, assisted by the application of limestone powder around the palm clumps.

Oil palm

In Malaysia potential oil palm yields (about 55 t of ffb/ha/yr) from reclaimed mangrove soils are higher than those planted on upland soils (average 20 tonnes ffb/ha/yr). (Poon, 1983). Proper water management is the key to successful cropping and the present drainage control system used in Malaysia, which aims to maintain the water-table at about 60 cm from the surface of the soil, has overcome the problem of the formation of acid sulphate soils. (Poon, 1983).

3.4 SERVICES PROVIDED BY MANGROVES

3.4.1 Coastal protection

Coastal protection is often referred to as either "shoreline" or "coastline" protection. The measures taken in the form of seawall barriers and other anti-erosion structures are collectively referred to as *seawall defence* in this document. The coastline is defined specifically as *the high spring tide shoreline*.

Many wetland and mangrove areas are destroyed due to the construction of protective structures. These are frequently located at or seaward of the estuarine low water mark. Large areas of productive wetland and tidal flats may be sealed off from marine influences and, likewise, the seaward areas of the estuary or lagoon are deprived of freshwater inputs. Highly productive wetland/tidal swamps areas may be lost. Refer to **Box 3.3** on the following page.

Mitigatory measures

Prevention is better than cure. This particularly applies to coastal protection, where the remedial costs can be phenomenally high. Structures should be placed behind the line of annual flooding which marks the landward limits of coastal wetland. Walls should be constructed from rubble ("rip-rap") to allow the movement of water-borne nutrients from inland areas to the estuary. Rip rap has the added advantage of reducing wave scour and providing new niches for estuarine organisms.

Guyana's dilemma - crumbing coastal defence

Guyana cannot afford to ignore the sea. Not only is sugar the heart of its economy, but 90 per cent of it's 750,000 people live along the narrowly stretched coastal zone that constitutes less than 3 percent of it's total land area. This narrow strip, 500 km long and never more than 16 km wide, carries the most fertile soils; the rest of the country has marginal or no agricultural potential. This coastal strip that accounts for over 70% of the country's GDP unfortunately lies below the high tide mark, making it particularly vulnerable to flooding, seas erosion and salinization.

Coastal protection, however, is expensive consuming more than 30% of the country's capital expenditure up to the mid-1970s. However, due to economic recession, most seawall defence are neglected, requiring complete replacement in many places.

As if keeping out the sea water problem is not enough, a rise in sea level of even 0.5 m due to global warming will flood most inhabited areas. A sea level rise of 1.5 m could potentially destroy an income of $107 m from the sugar industry, $46 million from rice, $84 m from other crops and $11 m from livestock; putting about $800 m of economic activity at risk.

To replace even the worst affected 130 km of the coastal defence would require $260 m. A typical type of physical protection required would cost about $2 000 a metre to build.

However, experience gained by an ODA project on sea wall defence in the vicinity of the Essequibo River between 1979 and 1984 indicates that the "*best coastal protection you can have in Guyana is a long sloping foreshore, leading to mangroves and a small earthen dam behind that*". The foreshore stretches out to sea, sometimes for 5 km or more, and mangroves at one time protected large part of the coast. The pencil-like aerial roots of the black mangroves Avicennia sp. dissipate much of the tidal and wave energy. The water is relatively calm, gently rising and falling with the tides. The early Dutch settlers took advantage of the mangroves, and only needed simple earthen dams, about 1.5 m high and 4 m wide at the crest, to keep out the gentle waves from flooding the adjacent agricultural land.

The mangrove protective belt has deteriorated due to: firstly, the lack of cooking fuel has forced many people to cut mangroves and secondly, the natural cycle of erosion and accretion resulting from the body of mud that emanates from the Amazon, coupled with coastal currants. The Guyanese refer to it as sling mud. The very fine mud particles, always remains in suspension and tends to clog up the "breathing pores" of the mangrove pneumatophores, except for the hardier Avicennias.

Box 3.3: Coastal protection in Guyana

It may be possible to circumvent the need for any kind of structure by planting tidal vegetation as a flood prevention and erosion control measure. These are much cheaper and almost maintenance-free when fully established.

Avicennias are choice candidates because of their hardiness, coppicing ability and as they are able to withstand high salinity. However, potted seedlings may have to be used and appropriate protection provided.

Low mangrove shrub vegetation bordering estuaries and low energy coastlines can be established to form a protective barrier against sea attack. They decrease erosion along unconsolidated coastlines by breaking the force of waves and dissipating wave energy. In estuarine locations, mangroves perform the additional role of trapping silt and gradually raising the level of the shore. Dense thickets of mangroves present an effective barrier to storms along low-lying tropical and sub-tropical coasts and may be planted specifically for this purpose. **Box 3.4** on the following page describes such an example.

3.4.2 Recreation and Ecotourism

Tourism accounts for one-third of the trade in goods and services of developing countries and the World Tourism Organization (WTO) projects that it will become the world's largest industry by the year 2000 (WTO, 1989). There were 390 million international tourists in 1988, who created 74 million jobs and produced $195 billion in local and foreign receipts. Adventure travel, which includes ecotourism, commanded almost 10% of the market in 1989 and is increasing at the rate of 30% a year. (Kallen, 1990).

Ecotourism potential can only be realized if the resource on which it is based is well protected. In turn, it can empower local communities, give them a sense of pride in their natural resources and heritage and control over their communities' development. It can educate travellers about the importance of the ecosystems they visit and actively involve them in conservation efforts. In sum, it has the potential to motivate rural population, maximize economic benefits and minimize environmental costs.

Activities that may be promoted in mangrove areas are nature trails, bird watching, nature photography, crocodile-farms, fishing, river rafting/canoeing/kayaking, and botanical studies.

Ecotourism is an excellent economic option, with positive and wide-ranging social, political, and environmental benefits. However, it should not be viewed solely as an avenue for short-term financial gain.

The requirements for making ecotourism profitable and beneficial over the long term are, firstly, to train tour promoters and operators; secondly, to select sites which provide appropriate recreational and educational opportunities for visitors; and lastly, to ensure that activities are environmentally compatible. *Low impact tourism* is less intrusive than *resort tourism*, and therefore, more suitable for protected areas which cannot sustained any direct use.

Planting of mangroves for protection of dykes

Each year several typhoons and strong storms hit the coast of Vietnam, causing damage to the coastal dykes and losses to agricultural crops and infrastructure. The worst affected area is situated in the Central Region of the country, from Than Hoa province in the North to Quang Nam Da Nang province in the South.

These typhoons are accompagnied by increases in sea level of 0.5-2.5 m and by waves with amplitudes of two metres. The existing dykes were unable to contain or withstand such forces and were breach every one or two years. In order to alleviate the problem, assistance was sought from the World Food Programme to upgrade the dykes through a Food for Work project.

A forestry component was included in the above project with the following objective:

> *To protect the rehabilitated and upgraded dyke systems in 7 provinces against erosion by wind, waves and water currents through the planting of trees in front of dykes.*

This objective reflected past observations on the positive effects of a tree cover on the seaward side of the dykes. The occurrence of such natural stands in front of dykes have, according to local farmers, in many instances resulted in only minimal damage to dykes by typhoons, whereas neighbouring dyke sections without this protective barrier suffered severe damage.

It should be mentioned here, that although the dykes are referred to as coastal dykes or sea dykes, they are in fact not located along the coast itself, but along rivers, estuaries and lagoons which are uder the influence of tidal water from the sea. There is thus normally no direct breaking of waves in front of the dykes.

A total of 454 km of dykes are to be rehabilitated and upgraded under the project and along 195 km of these trees are to planted in front of the dykes for protection purposes. The remaining areas are either unsuitable for the establishment of mangrove plantations or do already possess natural mangrove stands.

The species to be planted are *Rhizophora sp., Kandelia candel* and *Nypa fruticans* with a few hectares of Filao (*Casuarina sp.*) on higher elavations and sandy soil. All of the above species can be found within the project area.

The width of the areas planted depends on the soil type, the topography and the tidal regime. Whereas a width of 50-100 m is desirable, the average width will be 30-50 m due to the above constraints in particular the steepness of the shores. The spacing adopted is very dense with the major part of the plantations to be established at 1x1 m equalling 10 000 trees/ha.

A total of 1 010 hectares are to be planted during this project and a mechanism for maintenance and protection of the plantations by the local communities has been incorporated.

Source: Loyche (1992)

Box 3.4: Protection of coastal dykes by mangroves in Vietnam

Some recommendations for low-impact activities in mangrove areas are summarized in **Box 3.5** below:

- conduct a survey to determine the seasonal and yearly site carrying capacity;
- the permissible carrying capacities for humans, boats, wildlife, domestic animals should be determined and enforced;
- control poaching and illegal hunting of wildlife;
- observe strict hygiene to avoid the spread of water-borne diseases;
- conduct environmental impact assessments for all tourism development projects that have the potential to degrade natural and cultural resources;
- integrate tourism development planning with other agencies;
- incorporate visitor management into the area management plan;
- continually monitor the sites, identify impacts, and take measures to eliminate environmental degradation;
- include a strong environmental education component that provides guidelines for "low-impact tourism", stimulates an ecosystem awareness, and provides for direct participation in conservation efforts in the tourism programmes;
- maintain close links between the local communities concerned and mangrove resource managers to well protect and manage the tourism resource;
- information- and data-gathering efforts related to tourists and tourism should be improved and standardized.

Box 3.5: Guidelines on planning ecotourism in mangroves

Ecotourism and its role in sustainable development

People must be provided with simple and viable alternatives to destroying their natural resources. Ecotourism has the financial potential to provide a viable economic alternative to the exploitation of the environment. If properly organized, ecotourism can be sustainable business at the national and local levels. It creates local employment and income to local communities, as well as foreign exchange to national governments, while conserving the natural resource base in a productive manner.

3.5 INTEGRATION OF USES

3.5.1 Integrated coastal area planning

The mangrove swamp is closely linked to terrestrial land use practices. In particular, changes in water-flow regimes affect the mangroves, and the overdrawing of groundwater or excessive removal of mangrove vegetation may increase the danger of aquifer salinization and contamination.

Consequently, the coastal zone should be considered as an integral component of overall regional land use planning and development so that appropriate land use policies and action programmes may be formulated. Priority should be given not only towards the rehabilitation of degraded coastal lands but also the rational use of land on a sustainable basis, including the planned development of sustainable forest/marine products.

Through *in-situ* rural socioeconomic development programmes geared towards optimizing the use of available resources, the coastal zone will be rendered more productive and environmentally stable.

Many of the uses and services of mangroves are compatible such as for instance forestry, honey collectión, coastal protection and small scale capture fishery. Others are less so and a zonation of the area according to primary land use objectives might be necessary. This underscores the need for a holistic approach within the framework of integrated coastal area management planning.

3.5.2 Land use issues and conservation

The main management land use options in mangrove areas are:

(a) Conservation;

(b) Sustainable utilization, and

(c) Conversion to other non-wood uses.

(a) Conservation is defined as "*the management of human use of the biosphere (i.e. all living things) so that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations*" (ICUN, 1980).

In short, conservation means the maintenance of all living resources and management in the use of such resources. Once conservation is recognized as maintenance of the means of development, then, with proper planning, it becomes possible to integrate the two processes, viz., maintenance and utilization and hence to make development sustainable. Integration, however, depends first on recognizing the roles that ecosystems play in human economics.

Protected Areas: Ecologically unique and fragile ecosystems should be preserved as "protected areas", not only to afford protection to endangered wildlife and flora but more importantly to maintain biodiversity.

(b) Sustainable utilization: Single use options should be avoided because they sub-optimise the multiple-use potential of mangrove ecosystems. Wood removal for instance does not conflict with capture fishery and open-water mariculture, if the character of the forest is preserved and timely regeneration measures are undertaken.

(c) Conversion: Outright conversion to non-wood uses forecloses many of the biological and financial advantages that a natural ecosystem can offer. In some cases the changes become irreversible due to biophysical factors or simply because the restoration costs are too costly.

To minimize adverse impacts on the mangroves, the following suggestions are made:

(1) The mangrove swamp is intertidal and becomes progressively higher in the tidal zone as it develops. It is suggested that only the driest mangrove swampland be developed for non-wood purposes, such as large-scale pond mariculture or agriculture, as such areas are marginal for wood production.

(2) It is recommended that potentially acid and sulphate soils should be avoided for paddy cultivation. If possible, consider only soils that do not require any reclamation. Excessive clearing of the natural vegetation should be avoided. Fresh water must be assured in adequate amounts and proven salt-tolerant varieties of rice should be used.

(3) Where land reclamation for industrial development is contemplated, the negative ecological effects and economic costs associated with the loss of natural coastal protection provided by the mangroves and the possible decrease in fishery revenues and other benefits should be evaluated.

(4) Before conversion is undertaken an environmental impact assessment should be undertaken.

Figure 3.19 below illustrate what should be avoided. Examples of integration of uses are described and illustrated in **Case Study 6**, **Box 3.6** and **Figure 3.20**.

Figure 3.19: Effect of road on mangroves, Cuba
Photo by P.W.Chong

In the Ngoc Hein district in Southern Vietnam, mangroves are seen as habitats for food, shelter and as land to carve out an economic future for the many settlers. In Dat Mui Forest enterprise, rich *Rhizophora apiculata* forests along waterways have been converted to shrimp farming. The production varies from 150-350 kg/ha. Declining yields in more than 45% of the established ponds due to pond acidity, poor management, reduced postlarvae supply and impoverished forest-cum-aquatic habitats are forcing some farmers to expand the size of their holdings or create new ponds. A seven fold increase in pond area was registered during 1979-88. The number of households within the area rose from 35 to 399 during the same period. Unless an ecological balance is struck between shrimp-farming, fishery and forestry development within a sustainable context, there will be no economic nor environmental future for those who toil the land now and for their children.

To optimize the multiple use potential of the mangroves, a management plan was prepared, which considers not only tree resources and shrimp farming but also advocates the *establishment of growth centres and forest villages* as one of the means of marshalling available human resources into ecologically viable sites, so that social services and infrastructures can be provided in a cost effective manner. At the private farm level, a simple shrimp-tree farming model was proposed based on four hectares of woodlot to about one hectare of grow-out ponds. (Chong, 1988; Karim, 1988). Private woodlots, managed on 9-12 year rotations, are situated behind the fish/shrimp ponds. Access and irrigation canals (1.2m deep) at intervals of 250-280 m for extracting forest produce and also to guide tidal flows into the ponds are provided. Each household is allotted 2 ha of land for shrimp ponds and house and 8 ha of woodlot. A 20-30m protective mangrove belt bordering the waterways is retained. Refer to **Figure 3.20** below.

Source: Chong (1988)

Box 3.6: Integration of uses in mangroves in Vietnam

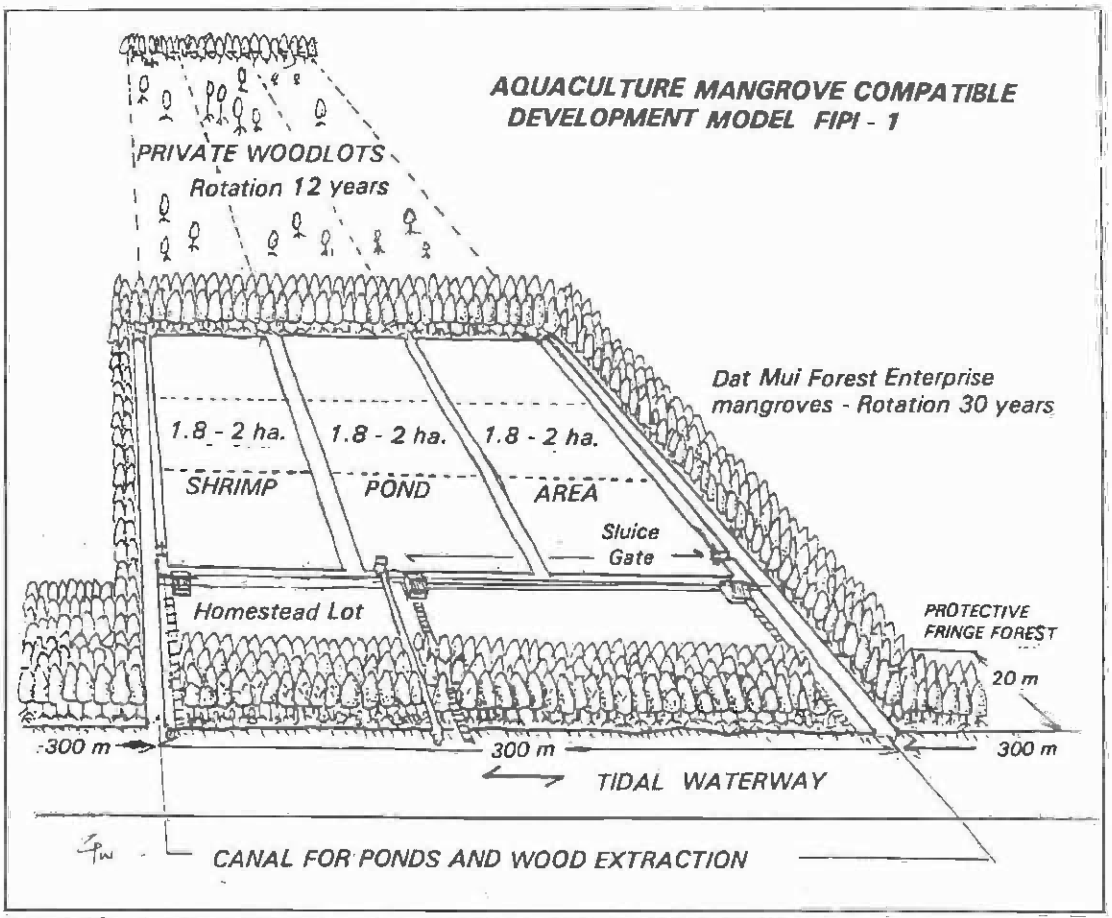


Fig. 3.20: A shrimp-tree farming model (UNDP/FAO:VIE/82/002)

3.6 THE SOCIO-ECONOMIC VALUE OF MANGROVES

The socio-economic value of mangroves stems from a variety of sources some of which are difficult to value as they either are services and goods which are non-marketed or they occur off-site, that is they are economic externalities.

Three examples at attempts to put a value on mangroves are described below and in **Box 3.7** on the following page.

ESCAP (1987) estimates that the probable direct employment offered by the Sundarbans in Bangladesh is likely to be in the range of 500 000 - 600 000 people for at least half of the year, added to which the direct industrial employment generated through the exploitation of the forest resources alone equals around 10 000 jobs. The Bangladesh Forestry Department obtained revenues from the Sundarbans equalling Tk 140 mill. in 1982/83, but this is a severe under estimate of the value of the area, as some of the royalties collected were exceedingly low. For Sundri (*Heritiera fomes*) fuelwood for instance, the market rate was nearly 40 times the royalty rate and for shrimps the minimum market rate to royalty rate ratio at the time was 136:1.

Tang, Haron and Cheah (1980) estimated the market value of a 30 year old mangrove stand in Peninsular Malaysia, clearfelled for charcoal to be as much as M$ 20 700 per ha (US$ 8 333/ha); whereas stands allocated to fuelwood or pulpwood would yield a gross revenue of M$ 7 600 and 2 200 per ha respectively. As a comparison, inland forests were estimated to have a market value of M$ 11 500/ha after a rotation of 60 years.

Ng (1987) compared the economic productivity of the Matang mangroves, which have been under continous forest management since the beginning of this century for charcoal and pole production, with the productivity of fishery and agriculture crop systems in comparable sites. According to his study, the management of the mangroves yielded a range of forestry and fishery products, of which the aggregate value was of the same order of magnitude as that realisable from a well-managed agricultural system. Also, after over 80 years of managed exploitation, there was no evidence of decline of overall productivity.

Most reports mention only benefits derived from forestry and fishery products of the mangroves. Furthermore, since mangrove forests have so far only been managed sustainably in a few countries over a sufficiently long period to generate relevant data on costs and revenues, such data are extremely rare and in many cases have only localised value.

There is thus a need to develop standard criteria for valuing intangible benefits from mangroves and to include these in order to arrive at discounted values per unit area, which can then be used as a basis for cost comparisons with other forms of land use. Unless and until this aspect is clarified, through case studies such as the ones illustrated in **Boxes 3.2 and 3.7**, the value of the mangrove resource will not be realistically appraised to reflect both its tangible and intangible contributions to local, regional and national economies.

Using actual data on amount of wood and fish obtained from mangrove areas and their market value and harvesting costs the Net Present Value (NPV) of forestry and fishery were estimated using the **incomes approach** with a 5% social discount rate and a 50 year planning horizon.

Forestry Net Benefits

Commercial net benefits were calculated as amount of wood harvested x market value – harvesting costs.

Subsistence net benefits were calculated using the actual amount of wood harvested x the shadow value in the form of the price for inland or mangrove firewood sold by licenced wood concessioners.

Taking the species composistion of the mangrove area into account the weighted average Net Present Value was estimated for each of the three main mangrove areas yielding the following result:

Total Net Present Value: $ 164-217/ha

Fishery Net Benefits

Only in one of the three areas was the fisheries potential judged to be fully utilized and the data are based on this area.

Annual catch (commercial and subsistence):	3 026 tons
Area of mangroves:	9 136 ha

thus averaging 331kg/ha equalling $ 864/ha/ in market value anually.

Taking harvesting costs into account gave the following result:

Net Present Value: $ 5 468/ha, or $300/ha/yr

This is assuming a proportionate decline in the fisheries. With only a 50% decline (as some of the fish are not entirely dependent on the mangroves) the figure for the NPV is $ 2 734/ha.

Other Services:

The value of mangroves for nutrient filtering has been estimated using the **alternative cost method** by Green (1983), who compared the costs of a conventional waste water treatment plant with the use of oxidation ponds covering 32 ha of mangroves. An average annual benefit of $ 5 820/ha was obtained. This figure is however only valid for small areas of mangroves and as it represents the average and not the marginal value it should be treated with caution.

The **option value** and **the intrinsic value** of mangroves are not captured using the above incomes approach and an attempt to include these values was made by using the **compensation approach**, as the loss of fishing rights in Fiji caused by the reclamaition of mangroves has been compensated by the developers. The recompense sum is determined by an independent arbitrator within a non-market institution. Large variations in recompense sums were however recorded ($ 49 - 4 458/ha) according to the end use and the bargaining power of the owner of the fishing rights. Using 1986 prices the following results were obtained:

Average:	$ 30/ha for non-industial use
	$ 60/ha for industrial use
Maximum:	$ 3 211/ha

Only the last result is comparable to the benefits foregone in terms of forestry and fishery ($ 164 and $ 2764 respectively).

It is thus concluded that the minimum value of the mangroves of Fiji is $ 3000/ha under present supply and demand and existing market and institutional organizations.

Source: Lal (1990)

Box 3.7: Socio-economic value of mangroves in Fiji

PART III ASSESSMENT OF MANGROVE RESOURCES

The following chapters review the information needs with regard to mangrove management, and describes in detail some of the tools used in obtaining information on the distribution and extent of mangrove forest resources, viz. remote sensing techniques, surveying, mapping, area computation and forest inventories. Emphasis is put on areas where these methods differ from conventional methods due to the special characteristics of mangroves and some prior knowledge of the subject is thus assumed.

4 INFORMATION NEEDS

In order to develop an appropriate national or regional plan for the management and conservation of mangroves, a comprehensive data-base should be available, including information on the distribution and extent of mangrove areas, forest composition, actual and potential production and ecological factors which govern mangrove dynamics. Studying mangrove ecosystems for management purposes is not an easy task. Its complex nature and the different land-uses it may be allocated to, call for the concourse of expertise in various disciplines including Forestry, Ecology, Geomorphology, Aquaculture and Agriculture.

As a first step towards integrated management of mangroves a survey of the mangrove areas should be undertaken. The kind of survey to be applied depends on various factors such as the size of the area to be covered, the type of vegetation, the purpose of the survey, the funds available, etc. In mangrove areas, the pressure on the resources (wood and non-wood products) and the land (agriculture, aquaculture, etc.) is increasing every day. Alternative uses of the forest land and the resources should be evaluated efficiently and quickly. The information needed for this evaluation includes the entire range of biological, physical and socio-economical data. One might be inclined to use a multi-resource survey approach to gather data which will be used in the evaluation of the production trade-offs and conditions of resources. However, the application of such an approach in mangrove areas involves problems of different types such as:

- The identification of information needs is a complicated matter as each application field has particular information requirements, and different data collection techniques. This discordance makes the designing of a single survey to provide all the information required rather difficult.

- The requirements for management information of all resources are not the same in complexity, in detail and coverage. In mangrove areas, potential sites for aquaculture or agriculture may for instance not be present everywhere in the forest.

Consequently, with different data requirements, multi-resource surveys could increase rather than decrease survey costs, and it might thus be advantageous to conduct a stratified or multiple-phase survey instead, where, based on the national/regional survey results, certain areas are allocated for more detailed and specific surveys.

In the context of these guidelines, only forest related survey aspects will be dealt with. It should however be kept in mind that information from other disciplines in many instances is essential to the integrated management and utilization of the mangrove resources.

For information on surveys covering other aspects of mangrove ecosystem management, such as geomorphology, fisheries resources, wildlife and ecology, please refer to more specialized textbooks and the literature cited in the relevant sections of Part I. For socio-economic surveys refer to Chapter 3. An excellent account of the legal and institutional issues with regard to integrated coastal area management, using a case study from Tanzania, is given by Young (1993).

4.1 PLANNING LEVELS

The information needed for management planning purposes vary in importance, detail and complexity depending on the planning level. Whereas land use planning is often undertaken on a regional or national level and thus requires large scale surveys of areas of a considerable size, forest planning requires more detailed information on the forest types, the amount of wood available etc.

An outline of some of the information needs at the different planning levels is illustrated in **Table 4.1** on the following page.

4.1.1 Land-use planning

In order to formulate plans and adopt procedures to implement them, it is first necessary to evaluate and classify the land according to its various present uses and future potential. The principles and basic concepts of land evaluation are extensively discussed in the FAO forestry paper "Land evaluation for forestry" (FAO, 1984).

A land-use classification in mangroves should reflect the actual ground uses both for forestry and non-forest, land-based uses. In the forestry portion of the land, the information generally required for integrated management planning includes:

- **The geographic distribution of mangroves and their extent**: the area and the location of mangroves is probably the primary element to be acquired in a classification process. In fact, before a detailed classification of land uses within a mangrove area can start, the boundaries of the mangrove itself are to be identified. One must therefore be able to distinguish between mangrove formation and other vegetation. At this point, a clear definition of vegetation categories must be given in order to assure a consistent classification and to subsequently obtain reliable area figures.

- **Mangrove forest resources and their potential supporting sites**: The extent and distribution of productive and protective forest stands and areas where mangrove species could be introduced compose the most relevant information needed.

Table 4.1: Examples of information needs at different planning levels

LEVEL OF PLANNING	TIMEFRAME	FORESTRY RELATED ISSUES		OTHER ISSUES
		Information needed	Relevant disciplines	
Land-use planning	Long term	Location and extent of forest and non-forest resources Land tenure system Land-use potentials Estimation of forest resources	Remote sensing (often satellite images) Classification and mapping Land-use planning Classification, mapping and forest surveys	Legal and institutional issues Geology and drainage Socio-economic aspects Aquaculture & Agriculture Infrastructure Wildlife
Forest management planning	Medium term (10 years)	Productive and non-productive areas Forest types Ageclasses Volume & growth estimates Regeneration status Management objectives Manpower and equipment needs Demand forecasts	Remote sensing (aerial photography) Classification and mapping Surveys and Forest inventories Silviculture Mangrove management and Utilization	Geomorphology Infrastructure Demographic and socio-economic surveys Wildlife
Operational planning	Short term (1 year)	Wood volume Nursery and planting techniques Thinning and other silvicultural treatments Harvesting systems Accessibility Markets Manpower and equipment needs Conservation and protection needs	Forest inventories Silviculture Management and Utilization Conservation	Construction and maintenance of roads, canals and buildings

Regarding non-forest land-uses within mangroves, interests might be placed in the areas to be used for:

- Aquaculture: Areas to be alienated for fish ponds and shrimp farms;
- Agriculture: Areas to be cultivated with rice and other agricultural crops;
- Mudflats, embankments and sand dunes, as well as areas reserved for construction, infrastructure and urban settlements;
- Waterways and drainage networks;
- Alluvial deposits.
- Protected areas and wildlife habitats

The experience acquired in various countries where the management of mangroves has started, shows that most of the information above can best be presented in the form of small scale thematic maps (about 1:250 000). Maps at such a scale cover large areas, and at a national or regional planning level most of the items cited above can be represented with sufficient precision. Since the purpose of land-use planning is to allocate different lands to different utilization purposes, compatible with their suitability, the information required is mainly the land location and area by classes using sound and clear classification criteria.

4.1.2 Forest planning

Management planning

The particular ecological conditions of mangrove formations, and the important socioeconomic value of the products and the services they provide, predestine these formations to some kind of multiple-use management. It is only by such an approach that conservation, production and recreational functions of mangroves can be fulfilled.

Not all mangrove areas are equally productive or have the same potential. Allocation decisions should therefore take into account potentially compatible uses in order to allow a diversity of activities, prevent irreversible situations that may be caused by single use options, and ensure the integrity of the ecosystem. The objectives of managing mangroves for wood production as a primary use are briefly outlined below:

- Maintain continuous supplies of domestic and industrial wood products, such as poles, fuel-wood, posts, etc.

- Assure the regeneration of commercially valuable species and stands using adequate techniques.

- Conserve and intensify the protective function of the forest in designated areas and along river banks, estuaries, and all other marginal forest lands.

The primary information required to achieve such objectives include a thorough knowledge of forest type composition and location, the volume of the growing stock, the growth rate and the regeneration status.

Operational planning

Operational planning deals with the techniques and strategies to be implemented in forest operations, such as for instance logging and drainage. Primary information needed includes the timber volume per species, size and quality. In addition, the knowledge of the precise timber location and the accessibility of the areas to be harvested, thinned or planted is essential.

For forest planning purposes a more detailed forest inventory is thus needed as opposed to land-use planning, where a forest survey and a rough estimate of total volume in most cases would be adequate.

4.1.3 Monitoring & evaluation

The general concern over the progressive deterioration of tropical forests and the need for reliable information necessary for management decisions and conservation measures have led several countries to initiate national monitoring & evaluation programmes. Although the objectives of such programmes might be specific to various natural conditions inherent to differences from one country to another, they primarily aim at the assessment of forest cover changes over time.

Guidelines and procedures for planning a monitoring & evaluation programme are dealt with in several reports and documents (FAO, 1985). The purpose of including this section in the present guidelines is solely to indicate that such programmes refer to comparisons of forest conditions at two or more occasions, based on periodic surveys. They involve many activities common to other applications of forest surveys and remote sensing treated in later sections. These activities concern forest classification, mapping procedures, designing, planning and implementation of surveys.

4.2 HOW TO OBTAIN THE INFORMATION NEEDED.

Effective management of forest resources calls for large amounts of current information. For most forest areas, primary information needs include the extent and distribution of forest cover and an assessment of woody biomass, vegetative production and forest conditions. Due to the particular forest structure, composition and difficult accessibility of mangrove forests, the task of collecting this information is often time consuming and therefore very expensive.

The implementation of a survey, which can result in classification and mapping of the resources and the potentials of the area concerned should be the first step in obtaining the above information. In this respect, various remote sensing techniques have proved to be extremely valuable tools for rapid and relatively inexpensive collection of primary data, and a short description of their usefulness in mangrove areas is found in the following chapter.

Chapter 6 deals with the aspects of planning and implementing mangrove surveys on different planning levels including classification of mangroves and presentation of the survey results in the form of maps. These surveys range from cartographic and multiple-phase surveys for land-use planning to more detailed surveys for forest planning purposes.

The next chapter deals with the aspects of resource assessment and forest inventories conducted to obtain more detailed information on particularly the wood resources available in mangroves.

Then follows **Part IV** of these guidelines focusing on the more detailed information needs for mangrove management on a regional/district level, viz. silviculture, management practices, harvesting techniques, conservation issues and multiple-use of the resources on a sustainable level.

5 THE USE OF REMOTE SENSING IN MANGROVES

The need for accurate information by forest managers and policy makers is crucial in mangroves, where absence of data in many countries has been a real obstacle to any management. This situation might be due to lack of knowledge of existing techniques, lack of necessary funds and skilled personnel, or merely because information obtained with remote sensing techniques has been reserved for non civilian use.

When remote sensing techniques are to be used, any data analysis requires from the user a minimum knowledge of the subject for which these techniques are applied. He or she must also be aware of the limitations of these techniques with respect to practicality and accuracy as well as the quality and quantity of the information which can be extracted from air or space remote sensing data supports.

The ability of remote sensors to distinguish between terrestrial features depends on various factors among which are the spectral characteristics of the objects on the ground and their morphology as well as the discrimination capabilities of the sensor used.

Among the wide range of systems available and procedures developed in using remote sensing for identifying vegetation cover, its classification and mapping, one should use the technique or the combination of techniques which:

- Permit a rapid acquisition of data;
- Provide the required information ;
- Are cost effective.

The major remote sensing systems which are recognized to have a veritable place in vegetation classification and mapping - particularly with regard to mangroves - include aerial photography, multi-spectral scanners (MSS) and radar. The principal advantages of each are:

- Aerial photography is simple to use, and lends itself to wide scale applications;
- MSS provides a wider range of information than other systems, and is suitable for automatic data processing and satellite applications.
- Radar presents all weather capability, which is particularly useful in cloudy areas such as the tropical zones, and is also suitable for regular monitoring;

A summary description of the technical characteristics of various remote sensing sources is presented in **Appendix 1** in the back of this paper.

5.1 CHOICE OF SENSOR

In mangrove forests the application of remote sensing can be envisaged in three planning levels: national level, regional/local management level and operational level, each one aiming at specific goals.

To these planning levels one might associate three levels of land classification which can be identified as :

- Mangrove land-uses;
- Forest site classification;
- Forest type mapping.

The level of detail may also determine the criteria to be considered for classification. Geographical and ecological criteria for example are often adopted at the most general level of investigation, whereas functional criteria are more appropriate at the most detailed level. In case of extensive surveys using remote sensing techniques, physiographical criteria are important.

The principal elements on which the choice of a sensor is based - for each one of these situations - are data characteristics which in essence determine the quality and amount of information, and the size of the area concerned by the survey. Most of the currently applied remote sensing systems - using these criteria - can tentatively be ordered in a hierarchical manner, to fit more or less the planning levels mentioned above. An exact fit is obviously not attainable due to the overlapping ground resolution ranges between sensors but it gives a somewhat useful indication on the ability of remote sensors to meet the requirements of the type, quality and quantity of the information really needed in a given situation. **Diagram 5.1** below indicates approximate resolution requirements associated with data survey levels and major sensors used as might be applied to mangrove forest surveys.

TYPE OF SURVEY	**RESOLUTION (m)** 0--1-------------10-------------100
NATIONAL LEVEL Physiographic features Pattern of human activities Drainage pattern	------------------
MANAGEMENT LEVEL All of the above items Land use classification Broad vegetation classification	---------------------
OPERATIONAL LEVEL All of the above items Forest type identification Forest measurements	-----------
REMOTE SENSORS Aerial photography Spot imagery Landsat Thematic Mapper Landsat Multi Spectral Scanner Side Looking Airborne Radar	 ------------AP---------- -----SPOT--------- --TM--------- -MSS---- -SLAR---

Diagram 5.1: Resolution requirements and survey levels

5.1.1 Application of aerial photography to mangrove areas

Panchromatic, colour and infrared colour aerial photography have been the basis for various mangrove forest surveys and inventories. At small scales, they can be used in reconnaissance surveys, or for broad forest type classification in extensive areas. From medium scale photo coverage, one may obtain detailed forest stratification - based on tree cover sizes or forest stand heights- and land use identification. Large scale photography is a valuable support for forest stand measurements. In many cases it can be used as "ground truth" in surveys where small and large imagery are combined. Low level aerial reconnaissance survey using a light aircraft and small format cameras may play a crucial role in this respect. Through such flights, it is possible to gather accurate information about mangrove forest conditions, denuded areas, fish ponds, plantations and other land uses and coastal features.

From examples of aerial photography applications to mangroves, with the objective of **species recognition**, Rollet (1974) showed that on 1:33 000 scale panchromatic images, pure stands of *Avicennia* and *Rhizophora* can be distinguished. Species separation is, however, more difficult in mixed species stands. On 1:20 000 scale panchromatic films, *Avicennia* could very well be separated from *Rhizophora* stands due to their grey tone and coarser texture (see **Figures 5.1 and 5.2**). Hamilton and Snedaker (1984) indicated that on 1:25 000 scale, black and white aerial photography, the mangrove genera were easily recognized by crown size, tone and relative height.

The introduction of infrared photography in combination with panchromatic films improves the ability to recognize mangrove species a great deal (Rollet, 1974). This is illustrated in **Figure 5.3**. The author also pointed out that crown texture is a major element to take into account for improving species recognition accuracy based on colour hue.

With regard to **mangrove land utilization**, black and white aerial photography proved to be useful in identifying and mapping newly accreted lands, based on tonal differences of surface dryness and moisture conditions. It has also been used to classify new mangrove plantations according to tree height and stand density (Rahman *et al.*, 1986). In another study for the assessment of location and extent of shrimp and fish ponds, Shahid and Pramanik (1986) pointed out that black and white (1:30 000) and infrared coloured aerial photography (1:50 000) revealed to be valuable.

In mangrove areas where accessibility is a real problem, low altitude aerial photography is a useful tool which can be used successfully in conjunction with limited ground data to document forest canopy and other non-forest land-uses.

This type of photography, usually at a large scale, contains precious information which can be used as "ground truth" either to correct misinterpretation or as reference data for construction of a photo-interpretation key. Being very versatile, it can also be combined with satellite imagery, to document environmental conditions which prevail at the time when the photographs were being taken.

Figure 5.1

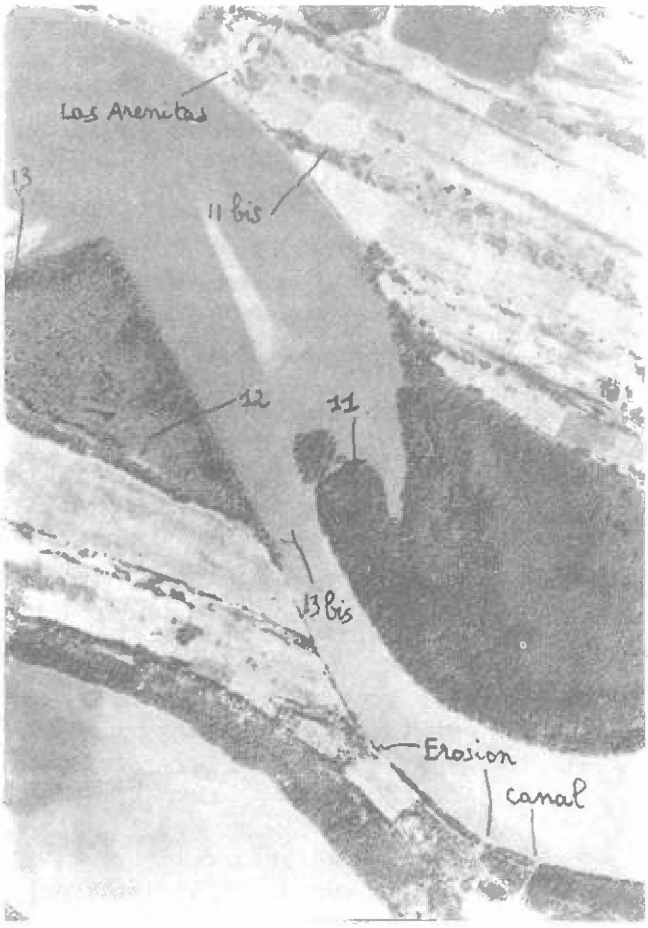


Figure 5.2

Mb pur : Pure stand of large *Laguncularia* (Mangle blanco)

15 bis : Large *Laguncularia* trees (Mangle blanco)

15 ter : Low *Avicennia* stand

11 : Pure stand of large *Laguncularia* trees with regeneration of *Rhizophora* and some *Avicennia*

11 bis : Patches of semi-deciduous thicket

11 ter : Dominant *Laguncularia* (mangle blanco) behind a band of *Rhizophora*

12 : Pure low *Avicennia* with many large rotten *Laguncularia* trunks

13 : Pure stand of *Laguncularia* (25 m high and 30 cm DBH)

Fig. 5.1 and 5.2: **Aerial photos showing mangrove vegetation types in Mexico.** Scale: 1:20 000. (Source: Rollet, 1974)

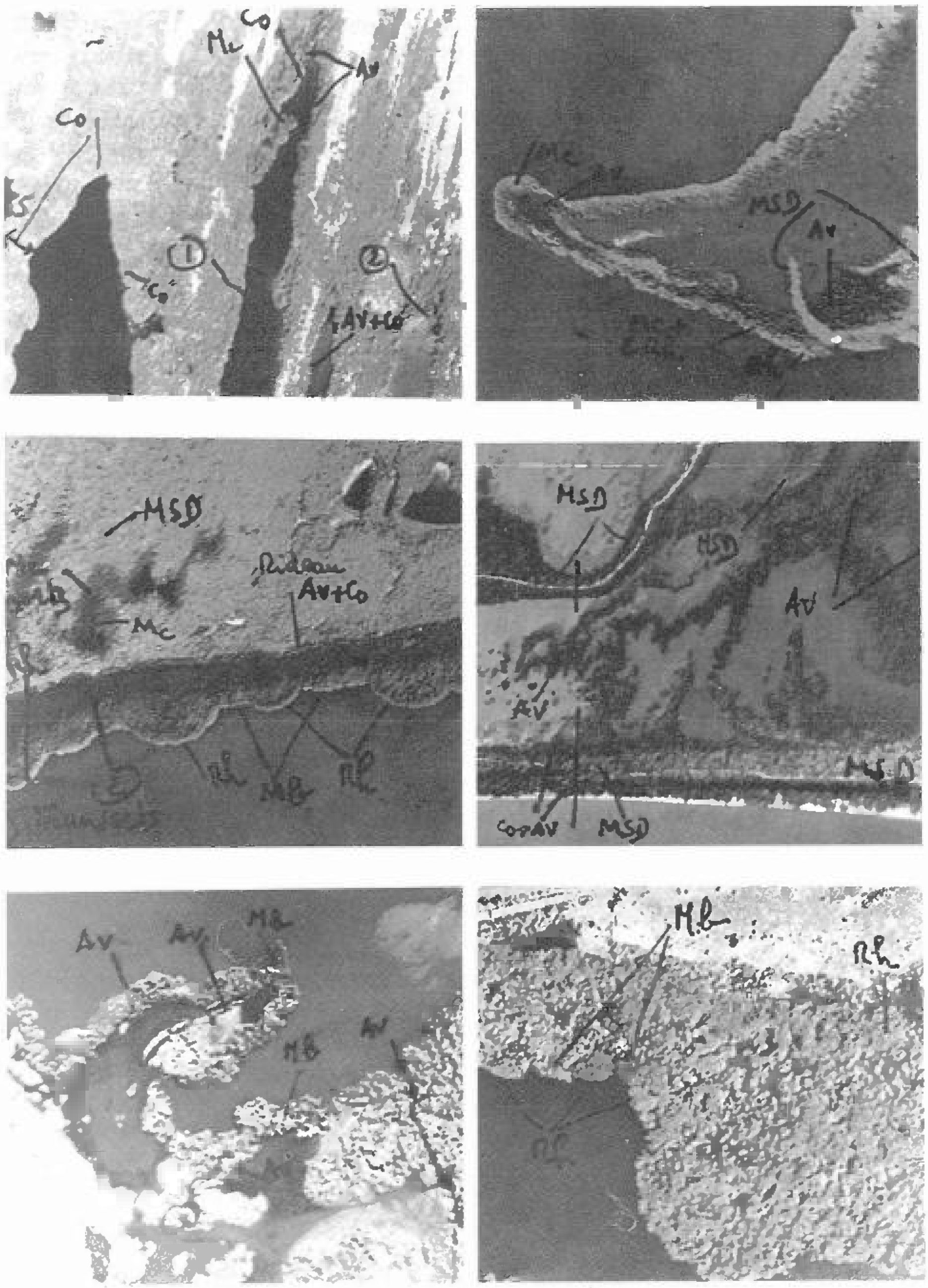


Fig. 5.3: **IR colour aerial photos showing mangrove vegetation types** (Mexico).
(Source: Rollet, 1974)

Co : *Conocarpus*
Mb : Large *Laguncularia* (Mangle blanco)
Mc : *Laguncularia* thicket (Mangle chino)
MSD: Semi-deciduous thicket
Av : *Avicennia sp.*
Rh : *Rhizophora sp.*

5.1.2 Application of satellite imagery to mangrove areas

In tropical countries where vegetation survey programmes have started, classification and land-use mapping include mangroves as one of the vegetation classes within the whole forest land group. Few studies, however, have been conducted specifically to gather information on mangroves. Landsat imagery using the Multi Spectral Scanner (MSS) has been the main source of information and both visual and digital data analysis have been applied with varying degree of success. On photographic images, mangrove vegetation is often characterized by a smooth texture due to small tree crowns and relatively dense stands. The association of mangrove vegetation with estuaries is also a valuable element for its identification.

Numerous studies have reported that mangrove forests can be easily separated from other vegetation formations on satellite images (Charuppat, 1983; Chaudhury, 1983, 1985, 1986; Silapathong, 1983). When image interpretation is carried out on black and white and diazo prints for instance, Ishaq-Mirza *et al.* (1986) indicated that mangrove vegetation could be classified into dense, normal and sparse vegetation, based only on tonal differences. Also, at the original scale of 1:1 000 000, diazo colour prints may give better tonal contrast than black and white images at a scale of 1:250 000.

Mangrove cover types classification based on species and density has also been attempted using Landsat MSS data. Not all species could be separated and the persisting confusion between cover types indicates that cover type maps from Landsat data would not be successful in mixed mangrove forests. However, natural mangroves are easily distinguished from planted areas (Chaudhury, 1986).

From the few Return Beam Vidicon images available of mangrove areas, the same author pointed out that most rivers, canals and creeks could be identified and enlarged images (1:250 000) have been used to compile a map of the Sunderbans in Bangladesh. In addition to the precise location of mangrove features in this extensive formation, this map is also used for navigation purposes. The advantages of this system is that it can produce more planimetrically correct results than MSS images.

More detailed classifications of MSS data within mangrove formations have been tested and most results showed that visual interpretation of low resolution satellite imagery should be limited to broad forest and land-use classification.

Digital classification of satellite data has also been considered in numerous vegetation studies including mangroves. Various attempts have been made for mangrove surveys, land-use identification and even forest type mapping.

In terms of classification accuracy, computer processing of satellite imagery was found on various occasions to be superior to visual classification. By using image data in computer compatible format, greater flexibility in image processing can be achieved. Moreover, no radiometric details are lost as it happens through photographic processing.

Fig. 5.4: A partial view of a False Colour Composite obtained from combinations of ratios 5/4, 5/7 and 6/5 of Landsat MSS bands. The mangrove appears as orange-red, marsh vegetation as reddish black, shrubs as yellow, crops as bright red and saline areas as white.
(Gulf of Kachc Landsat Data, India, 1982)
(Courtesy: Nayak)

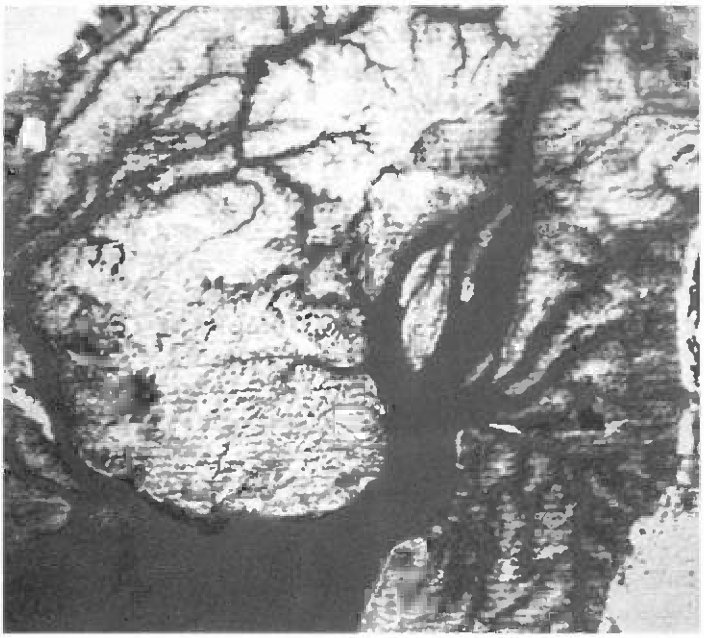


Fig. 5.5: An FCC of the same area as above, obtained from combinations of band 5 and ratios of 5-7/5+7. Mangroves appear as yellow, marsh as greenish black, swamp vegetation as red and crop-barren land as whitish blue.
(Courtesy: Nayak)

Figures 5.4 and 5.5: Examples of Landsat MSS imagery of mangrove areas.

From the results obtained, it also appears that spectral data transformations are essential as they bring out differences among land cover categories. The most successful techniques include contrast stretching, principal component analysis, and band ratioing. (Refer to **Appendix A2** for more details on these techniques). Ratios of Landsat band 5 and 7 and 5-7/5+7 performed best. Nayak et al. (1985, 1986) mentioned that ratios based on these combinations greatly enhanced subtle differences between mangroves, swamp and marsh vegetation (see **Figures 5.4 and 5.5**). Mangrove vegetation could also be separated from marsh vegetation on false colour composites issued from principal component transformed data. Digitally processed Landsat data was also found to give useful information on the location of mudflats, sandy areas and newly accreted lands.

The application of image smoothing to mangrove classification resulted in the distinction of two different classes: dense and open vegetation. An even better definition of forest boundaries was obtained when the central pixel value of the blocks was replaced by the median of block values instead of their mean.

In addition, in order to obtain more accurate outputs, sufficient "training areas" should be established and scattered over all cover types of the mangrove area, where ground truth data can be established. Since mangrove types in most cases follow a more or less distinctive zonation pattern, such training areas can often be uniformly distributed along a transect line extending from the sea shore to the main land.

As to major **mangrove species identification**, and forest type (species-density) separation, supervised and unsupervised classifications of Landsat data were applied without satisfactory outputs. Because of the inherent limitations of Landsat MSS - due to its low spatial resolution - resulting in unsuccessful identification of individual tree species, attempts have been made, based on SPOT simulated data. A few recent applications to mangrove classification showed that although a complete separation of individual species could not be achieved, substantial improvements could be expected in both forest and other non-forest mangrove classification (Abdus Shahid, 1985; Berenger, 1985; Hossein, 1985). From SPOT images, enlargements are also used and scales of 1:100 000 and even 1:50 000 are feasible.

As it appears in **Figure 5.6**, Lantieri (1986) indicates that mangrove forest could be mapped accurately (90% accuracy at 1:50 000 scale), but major species separation is possible only in case of large, pure stands. The author also pointed out that when contrast enhancement or band decorrelation is performed, colour composite interpretation shows that some mangrove areas could be separated by their density. Other encouraging results were achieved by Blasco *et al.* (1986) in classification of a coastal tropical zone including major species of mangroves (See **Figures 5.7 and 5.8**).

Fig. 5.6 **False colour composite of a SPOT image after band correlation**
Scale: 1:50 000 Resolution: 10 m
(Coastal zone at Ngomeni, Kenya)
(Source: Lantieri, 1986)

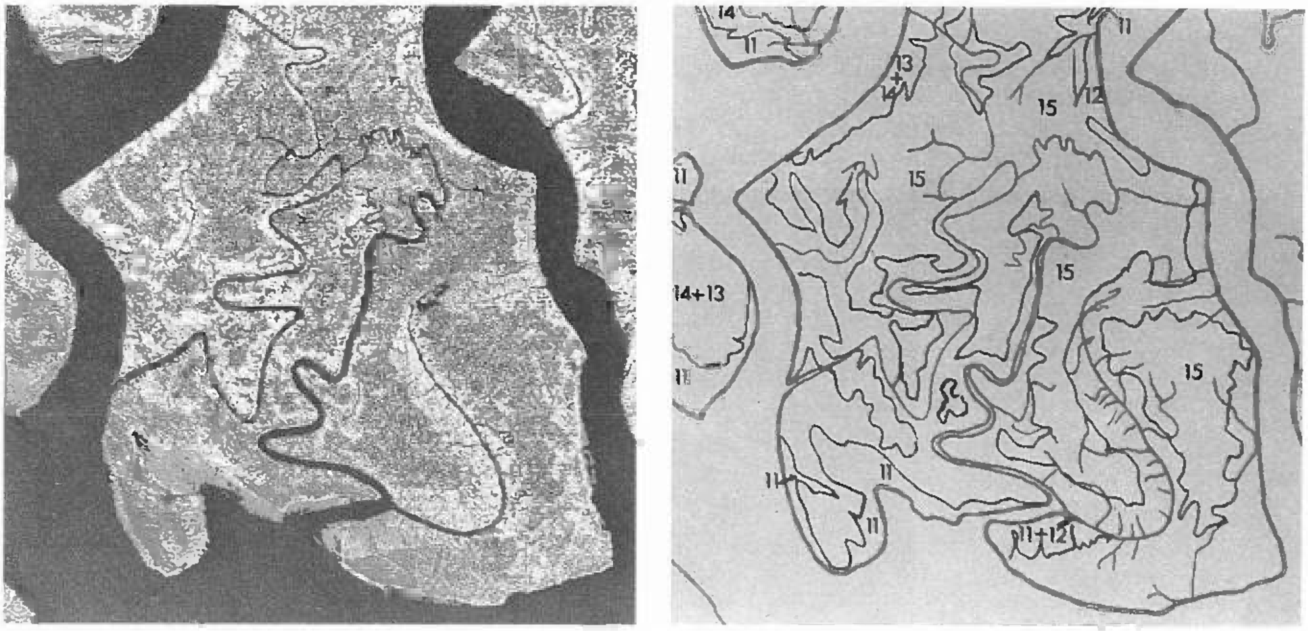


Fig. 5.7: Colour composite of SPOT image and corresponding sketch map showing main mangrove species
Resolution: 20 m (Bangladesh)
(Source: Blasco *et al.*, 1986)

Legend:

1: Natural dense mangrove (mainly *Sonneratia*)
2: Natural open mangrove (deciduous *Sonneratia*)
3&4: Plantations
5: Nursery
A: Brackish water
C: Sandbar

11: Grass
12: *Nypa fruticans*
13: *Sonneratia apelata*
14: *Excoecaria agallocha*
15: Predominantly *Heritiera fomes*

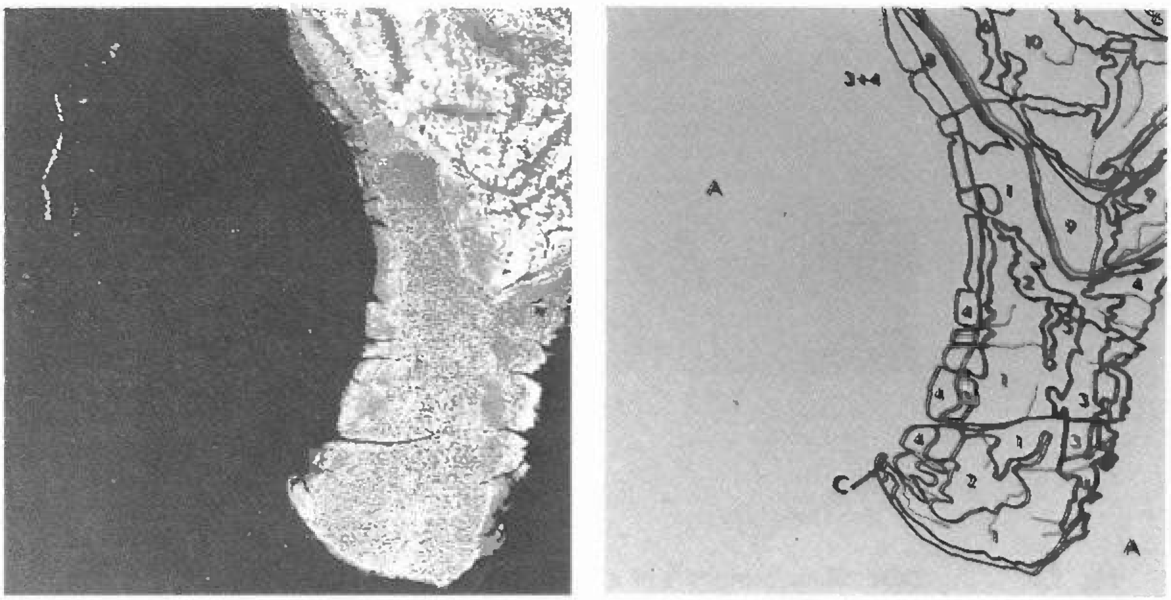


Fig. 5.8: Colour composite and map showing mangrove plantations (Bangladesh)
(Source; Blasco *et al.*, 1986)

From SPOT simulated data, Loubersac (1983) and Hossein (1985) reported that it was possible to achieve accurate classification of mangroves, by using a prior stratification before analyzing multi-spectral images of each unit. With this procedure the variance is reduced, and the results obtained can be optimized by statistical algorithms.

Based on experimental results obtained from various applications of satellite imagery to mangrove mapping, it appears that no procedure of interpretation is absolute. It is up to the image analyst to examine all combinations of image products at hand in order to find the one which leads to the best output as, for the extraction of each category of interest, different enhancement procedures might be necessary. With all the systems available, the success in converting image data into useful information still depends primarily on the depth of the user's knowledge of the specialized subject for which these techniques are applied, and the ability to comprehend the effects involved in interpretation analysis.

5.1.3 Application of radar imagery to mangrove areas

In many tropical countries, persistent cloud cover during long periods prevents the acquisition of cloud free images with photographic or MSS sensors. In spite of their proven performances, their limitations are their incapability of cloud cover penetration and their sensitivity to atmospheric disturbances (See **Figures 5.9 and 5.10**). One approach to overcome the problem is to use synthetic aperture radar (SAR).

Among the various applications of SAR to forest resources studies, mapping of coastal forests and mangroves is a case where the system has been the most successful (Imhoff and Vermillon, 1986). This sensor can be used for surveying extensive areas and can be useful in the preparation of small scale (1:200 000-1:500 000) regional or reconnaissance maps of vegetation types. These maps can subsequently be used to select priority areas for more detailed remote sensing and ground survey studies.

On radar imagery, **forest species cannot be identified**. All information required for forest management, such as species composition, forest structure and stand description, should be obtained from ground and/or air reconnaissance surveys. In addition, all water bodies display the same dark tone, and sand bars and mud banks near estuaries must be above water level to be recorded on the image. In spite of this limitation, radar imagery provides a good impression of the physiographic conditions of the terrain, and as a result, in low land areas such as mangroves, the drainage pattern is clearly visible. Furthermore, inundated zones can easily be separated from dry land forest (Sicco-Smit, 1975). This is illustrated in **Figure 5.11**, which is a partial view of an image showing a coastal tropical area.

Fig. 5.9: **Air photo showing cloud cover over a mangrove area** (Colombia)
(Courtesy: Sicco-Smit)

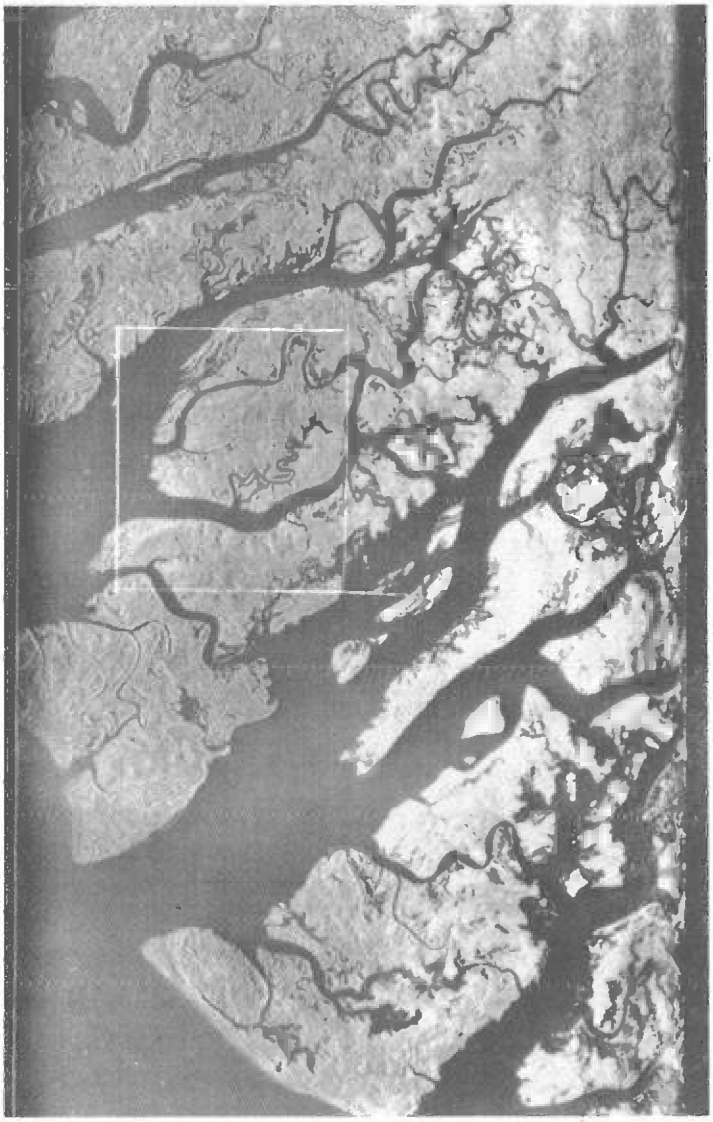


Fig. 5.10: **A radar image of the coastal zone of Colombia**
(The area covered by the air photo in fig. 5.9 is indicated for comparison)
(Courtesy: Sicco-Smit)

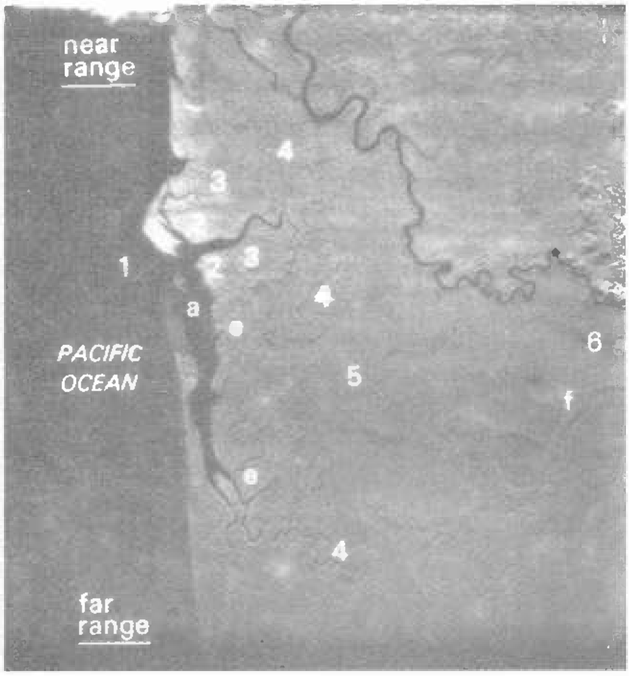


Fig. 5.11: **A radar image showing mangrove formations**
Scale: 1:220 000 (Colombia)
(Courtesy: Sicco-Smit)

Legend:

1: Bank above water level
2: Mangrove forest
3: Swamp, salt or brackish water
4: Limit between mangrove vegetation and fresh water swamp forest
5: Swamp with herbaceous vegetation
6: Low swamp forest
a: Salt water of estuary
e: Tidal creek
f: Old meander

5.1.4 Comparison between major sensors

In order to choose the sensor and technique which provide the information needed, the fundamental question that should be asked is what kind of data and with what precision it can be obtained through a given technique, in order to meet the planner or manager's information needs? To answer this question, the user should be aware of the technical performances of different sensors, i.e. their ability to discriminate between various terrestrial features according to the resolution and the requirements which are appropriate to the type of information he/she seeks. In addition to the kind of information needed for planning purposes, the choice of remote sensing systems depends also, and to a great extend, on the size of the area to be surveyed and on the funds available.

In a comparative study of interpreted aerial panchromatic photography and Shuttle Imaging Radar (SIR-A) images, Castellu found the results presented in **Table 5.1** below.

Table 5.1: Comparative photo-interpretation of panchromatic photography and SIR-A images (Partial results from Castellu, 1985)

Type of vegetation		Panchromatic photography	SIR-A images
	M1	Small dense crowns dark tones, 60% of the mangrove area	Very fine granularity salt and pepper (*)
Mangrove	M2	As M1 but with lighter tones	Confused with M1
	M3	Scattered trees on coast, light tones; pioneer trees.	Not identified
Nypa fruticans	N1 dense	No granularity Medium to dark grey tones; Homogeneous	Dark grey tone Slight granularity (**)
	N2 mixed	As N1 but less homogeneous	As N1 but lighter (*)
	P1	Very fine granulation, light tones low vegetation	White narrow coastal strips (*)
Coastal areas	P2	No granularity uniform slightly mottled tones low vegetation	No identification (Newly created areas)

(*): Good identification
(**): Very good identification.

In order to improve the interpretability of the image, as it is illustrated in **Figures 5.12 and 5.13**, Imhoff and Vermillon (1986) indicate that contrast enhancement techniques, filtering, and density slicing of the radar image can also be used.

Below a summary of relative advantages and disadvantages of aerial photography, MSS and radar is listed, as reported by Roberts (1975).

Table 5.2: Relative advantages of major sensors

Advantages of MSS vs. Aerial Photography	Disadvantages of MSS vs Aerial Photography
■ Wider range of spectral information; ■ Easier calibration of signals; ■ Good registration between spectral bands; ■ More suitable for digital conversion and automatic processing; ■ More suitable for satellite application and more suitable for regular multitemporal applications.	■ Poorer resolution; ■ Less suitable for local applications.
Advantages of MSS vs Radar Imagery	**Disadvantages of MSS vs Radar Imagery**
■ Greater variety of information allowing a greater ability to distinguish between different vegetation conditions; ■ Fewer problems of geometric distortion; ■ Better resolution possible.	■ Much greater interference from cloud and haze consequently much less all weather capability; ■ Inability to obtain imagery at night except from thermal infra red channels; ■ Reliance on variable levels and quality of sources radiations instead of constant output for instrument; ■ Less ability to obtain information from beneath surface of vegetation.

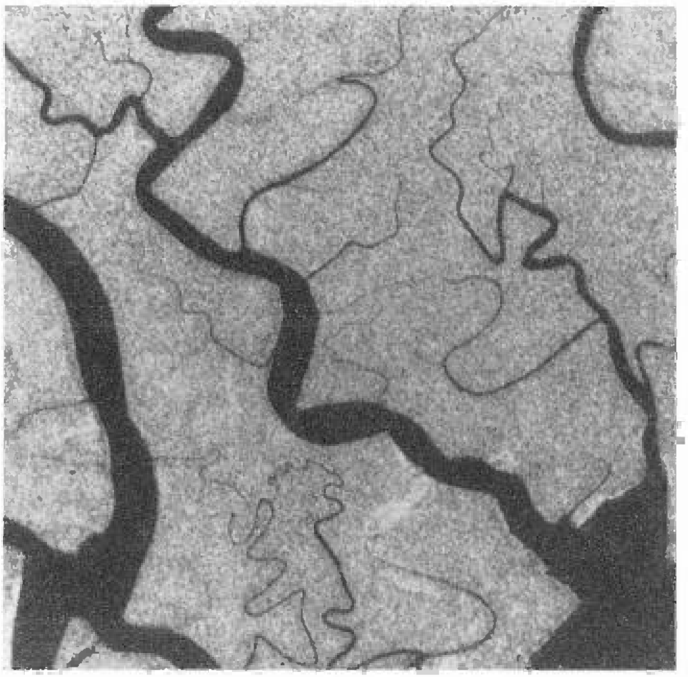


Fig. 5.12: **A black and white Shuttle Imaging Radar (SIR-B) image**
(Notice the salt and pepper appearance of the image before the filtering)
(Bangladesh)
(Courtesy: SPARRSO - Imhoff)

Fig. 5.13: **Enhanced colour composite of a SIR-B radar image**
(The same area as in Fig. 5.12 above)
(Courtesy: SPARRSO - Imhoff)

6 PLANNING AND IMPLEMENTATION OF FOREST SURVEYS IN MANGROVE AREAS.

The objectives of a forest survey are to obtain reliable and up-to-date information about the quantity and quality of the forest resources. The type and quantity of information concerned by a forest survey and the means to use for its implementation depend on the area to be surveyed and the funds available, and differ according to whether the information is required for land-use planning on a national or regional level, for forest land management on a district or forest level or for operational planning.

The degree of detail of a forest classification based on a survey depends on the information level required and the remote sensing data source used. Information derived from large to medium scale imagery can be used at all levels of planning. However, due to cost constraints at these scales, such imagery is commonly only used as a basis for operational planning and forest measurements where more detailed information is required, while land-use data can be obtained from medium to high altitude photography and orbiting satellite imagery at a small scale.

The use of satellite remote sensing in mangrove ecosystem studies is relatively recent, but significant advantages of satellite imagery have been identified in several applications. They include:

- The feasibility of large scale surveys at lower cost per unit area. This is a fundamental element to be considered as the land with mangroves and the coastal zones can be extremely large.

- The possibility of using computer processing to improve the information value.

- In mangrove ecosystems which are rapidly changing, the satellite ability of repetitive scanning makes monitoring changes much easier.

In extensive areas, land-use classification, which does not require detailed information, can adequately be carried out through space and/or aerial surveys, and the location of the lands may be properly presented on maps or aerial photography of a small scale. Area figures and a general description can also be provided to complete the information.

In spite of the advantages that satellites present, in terms of rapidity and regularity of providing data, the actual low spatial resolution of their imagery does not meet all the information requirements needed for management planning at district or forest levels. Aerial photography at medium and large scale is necessary for terrain data acquisition such as topography, physiognomy and accessibility. Information on stand and tree characteristics can also, to some extent, be obtained from large scale aerial photography but reconnaissance field trips are always necessary to complete and correct the data extracted from remote sensing imagery.

Considering the cost, the time constraints and logistics associated with the difficult task of surveying mangrove forests in the field, either to gather new information or to support a monitoring program, one should take advantage of both space and airborne remote sensing systems.

A combination of satellite and aerial (conventional and small format) photography can successfully be utilized in mangrove areas. It must however, be pointed out, that field surveys should be considered as an integral part of any land or forest survey at any level. In this regard it should be recalled that, the mangrove environment is very different from the inland forest from a logistical point of view, and special care should be taken for planning field operations (transportation means, supplies etc.).

6.1 CLASSIFICATION OF MANGROVES

Management decisions, at whatever level they have to be taken, require the development of a classification system subdividing terrain and vegetation features into homogeneous categories, made up of similar items, based on environmental and physical characteristics. Such a classification system should be an integral part of any forest survey.

Remote sensing plays an essential role in the establishment of classification systems, because it permits forest types and sites to be identified and mapped. A classification system is also the basis for forest stratification and is essential in the preparation of forest maps required in the planning and implementation of more detailed surveys and forest inventories, as well as in the preparation and execution of forest management plans. In the difficult natural working conditions characterizing mangrove forests, such tasks are hardly feasible without detailed maps.

A general scheme for a mangrove classification system is presented in Diagram 6.1. As can be seen, the first step in a mangrove forest classification is the distinction between forested and non-forested lands. Forest recognition may not be as simple as it sounds, particularly in areas where mangrove stands have been subjected to advanced degradation. Much care should thus be taken, in order to establish an appropriate definition of classes before the survey begins.

Non-forest areas occurring within the forest boundaries should also be classified according to some definite system based on the physical nature of the lands but also, whenever possible, according to the use to which the land will be devoted. Non-forested land may be :

- Agricultural lands and saltponds;
- Lands presently used for or to be allocated to aquaculture;
- Urban and mining areas, infrastructure etc.

Mangrove forest areas can be further divided into :

- **Productive forests**: comprised of well established and developed stands, where regeneration can be assured and,

- **Non-productive forests**: areas which presently do not have a productive forest cover. This includes degraded areas which might be turned ilxo productive stands (potentially productive areas), and lands suitable for protection of wildlife species and vegetation types where felling and extraction of wood should be avoided (protection areas). The latter also includes areas, which it is necessary to keep under permanent forest cover in order to counteract erosion and the resulting siltation of rivers and estuaries.

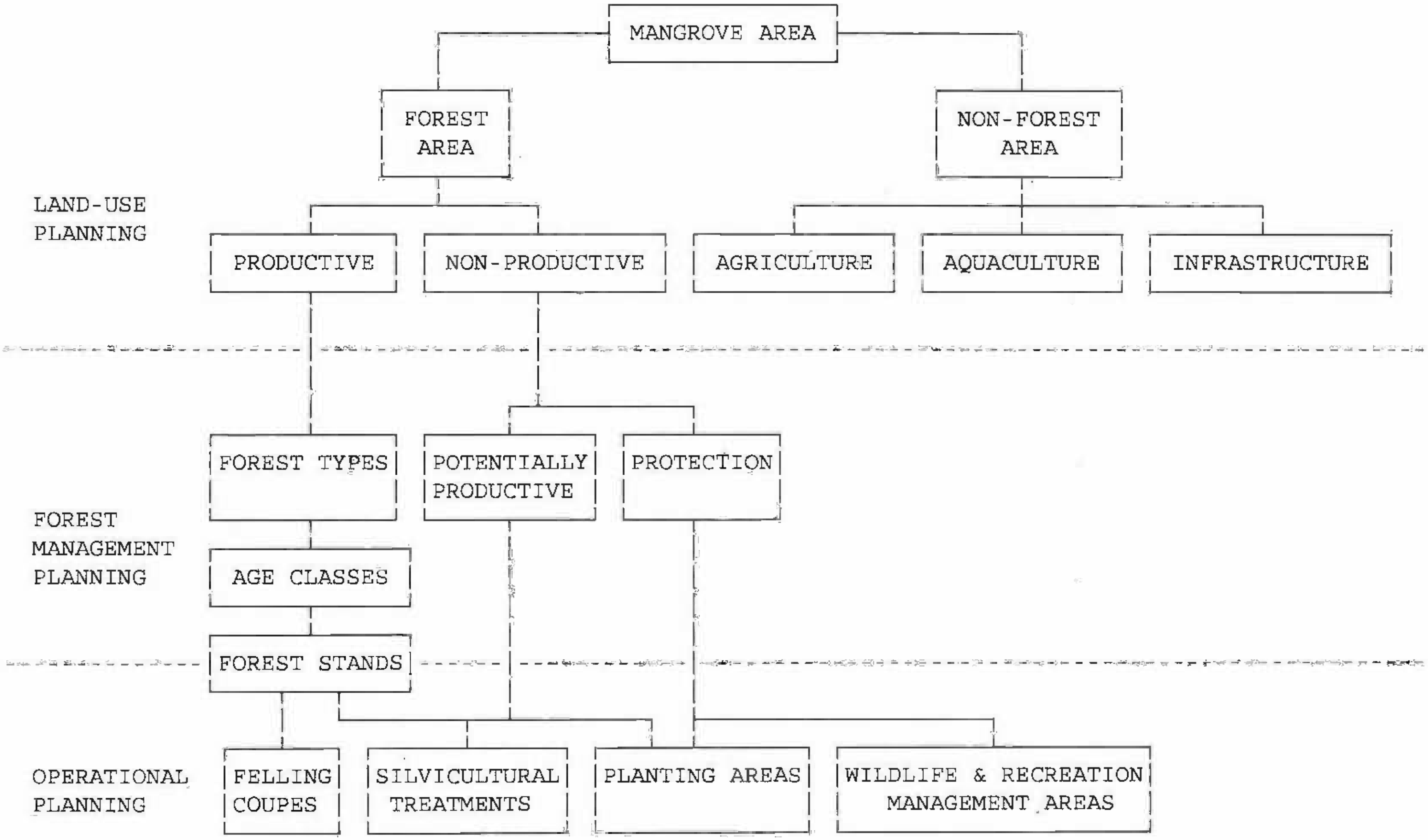


Diagramme 6.1. A schematic classification of mangrove areas.

Forest type classification is usually based on aerial photography. For this purpose, medium scale (1:10 000 - 1:30 000) will in most cases be appropriate to identify vegetation types and assess their pictorial characteristics. In regions where few forest tree species are present, black and white aerial photographs can be satisfactory. When forest stands contain numerous species, colour and IR coloured imagery may be best.

Colour photography provides a significant increase in accuracy in **species identification**, and the increase in accuracy contributes in reducing survey costs. Species identification is not only accurate on colour film but interpretation results are achieved more quickly. The difficulty of species identification is increased when small scale photography is used, (as is the case in many tropical studies), and also due to the lack of good standard descriptions of tree shapes on aerial photography. Field reconnaissance surveys should, in any case be undertaken to complement and rectify the photo interpretation.

Forest stands can also be identified using aerial photographs, but again field reconnaissance surveys as well as old maps, records and previous working plans are essential inputs to ensure an accurate classification.

Photo-interpretation procedures for visual and computer-aided classification of mangroves using aerial photographs and satellite imagery (including radar) are described in **Appendix A.2**.

6.2 SURVEY DESIGNS

Forest survey designs are numerous. In planning a forest survey, one should select the most suitable for the conditions which prevail. The survey may be designed to cover a whole country or a province for a global resources assessment; to support a forest management plan; or to evaluate timber volume production in small size units. At each one of these types of survey, the information to be provided varies in detail and accuracy.

A particular aspect to consider in mangroves is the change in area. This can be due to accreted land formed by coastal or riverine deposition, and may be used for new plantations, or a decrease in land area caused by chronic erosion due to a change in coastal currents. **Table 6.1** gives an indication of the relative importance of a few survey elements.

Table 6.1: Relative importance of forest survey elements in mangrove forests

SURVEY LEVEL	Area estimate	Accessibility	Transportation facilities	Volume estimation	Growth assessment	Land tenure	Soil stability erosion/accretion
National Level Survey	XX	XX	X	XX	X	XX	X
Forest Management Survey	XXX	XXX	XX	XXX	XXX	XXX	XXX
Operational Level Survey	XXX	XXX	XX	XXX	X	X	-

X : Little interest
XX : Medium priority
XXX : Very important

At any level of information, the forest survey should be well prepared. In the preparation phase, decisions are to be taken on:

- The type of information needed;
- The survey method to apply in order to acquire the data needed with the least cost possible.

At the same time, it is imperative to conduct a thorough study of all existing documents and data available about the area concerned by the survey. Such documents include past survey reports, maps, research papers, etc.

6.2.1 National level surveys

In a national level survey, the primary objective is to provide data which can serve for decision making on national (or regional) forest policy, and in the implementation of global development plans irrespective of whether the forest sector is already developed or not. In mangrove areas, a survey of this type is one where the main interest will be placed on the knowledge of the area extent of mangrove vegetation, its distribution and a broad classification of lands both for forest and non-forest uses. A few alternatives are discussed in the following sections.

Cartographic survey

A cartographic survey may be defined as a survey which is primarily based on image interpretation, and the objectives of which are often limited to the production of thematic maps. Over extensive areas, small scale aerial photography and/or satellite imagery are suitable data sources for such a task. Map compilation requires a 100% image coverage, and all images are interpreted following a classification scheme established prior to interpretation.

The low resolution of satellite images does not allow detailed classification of all forest types. They can be used for classification of evergreen and mangrove forests only, but the identification of mangroves on MSS imagery is facilitated by their location along estuaries. On colour composites, their dark red colour is also very indicative. To increase the accuracy classification, combinations of spectral bands are used. Landsat band 5, for instance, is interpreted for mangrove forest delineation, various land-use types and road network identification. Band 7 is mainly used for identifying mudflats, coastal shorelines and water bodies such as rivers and reservoirs. Prints are interpreted separately but their comparison with each other and with colour composites is useful.

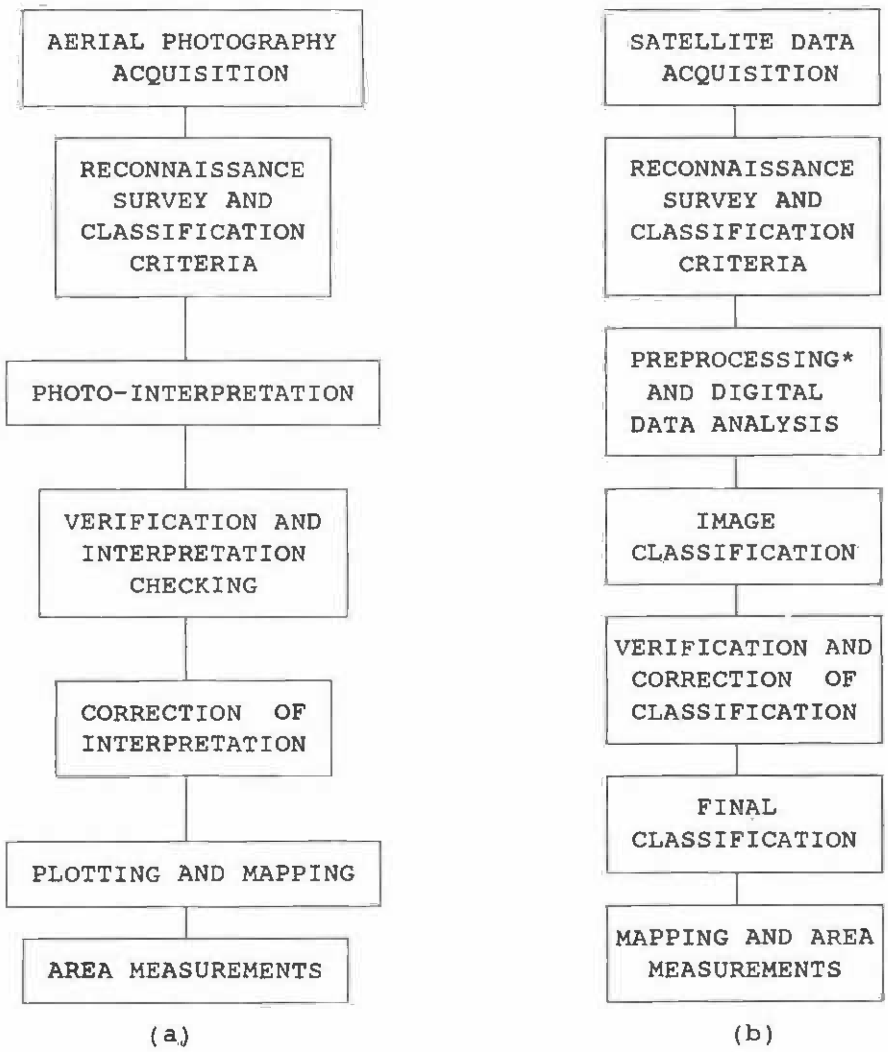
Maps and mosaics, such as those described and illustrated in **Section 6.3 and Appendix A3** are considered the main final outputs of the survey.

The evaluation of map accuracy and correction of misinterpretation can be achieved by means of a limited ground check in the field. Low flying plane missions could also be successfully made to rapidly check photo-interpretation and reduce the costly ground survey.

The procedure of ground checking consists of drawing a number of sample units on images, locate them in the field and check their classification. Since the purpose of the sampling in this kind of survey is primarily to assess image classification and mapping accuracy, the easiest technique is to use a regular grid with the dots representing the location of the samples. Image and field classifications are then compared, using error matrix procedures discussed in **Appendix A.3**. Stratified sampling may be applied by drawing an independent sample in each stratum, or following the selection technique presented in **Appendix A.3**.

Diagram 6.2 presents the sequence of activities in a cartographic survey based on a) aerial photography and b) satellite imagery respectively.

The combination of aerial photography and satellite imagery can also be successfully be applied, as presented in **Case Study 1**.



* : In case of visual satellite image interpretation, this step is skipped.

Diagram 6.2: Sequence of a cartographic survey based on (a) aerial photos and (b) Satellite images.

Multi-phase surveys

In this type of survey, mapping may or may not be required. Data are collected on sample plots, which are either randomly or systematically laid out over the image. The approach of using multilevel data is designed for the application of aerial photography (black and white or colour) in combination with satellite imagery in the form of black and white prints and/or colour composites.

The advantage of the method resides in combining the positive aspects of satellite images (the possibility of having a synoptic view of the area of concern at low cost), together with that of aerial photography which permits more details to be mapped. Aerial photography is used in this process, to complement, adjust and check the interpretation obtained from satellite images. In view of keeping the survey cost at low values, photo-interpretation of conventional photography is restricted to sample areas only.

The application of the procedure in forest surveys results in a multi-phase sampling design. With such a design, both data bases are used to produce classification statistics with a higher accuracy compared to a classification based on satellite image alone and at a lower cost than if aerial photography were the main source of information.

It is also here recommended to include in the process of interpretation any secondary information such as existing maps or any other documents, which may serve as a guide in the image analysis. Frequent reconnaissance field trips should likewise be undertaken while the interpretation is being carried out to enable the image analyst to become familiarized with the area of study and the objects to be identified and delineated.

A **double phase sampling design** is a particular case of the multi-level survey scheme mentioned above. A brief account on this design is given in **Appendix 4**. The first phase of its application involves aerial photography. Satellite imagery can also be used but because of the low resolution, it might be very tedious or even impossible to correctly locate the sub-sample units on the ground. The second phase involves classification in the field. This technique can also be successfully applied when the area concerned by the survey is only partially covered with aerial photography, which may have been flown in independent strips, i.e. without overlap. Although mapping of the results is not always required, the procedure is easier if an existing map or a mosaic is used.

The application of a **three-phase sampling** to mangrove forests using satellite imagery, aerial photography and field sampling as the 3 phases is illustrated with an example in **Appendix 4**.

Such multi-phase sampling methods are often used to obtain an estimate of the area covered with mangroves and also for a classification into different forest types. The same technique can be successfully applied in resource assessments and forest inventories as described in **Chapter 7 and Case Study 3**.

6.2.2 Forest management surveys

In mangroves, as in other forests, the increasing consumption and production demands require from managers to answer the questions : What, Where, and How much, through analysis of data acquired either from ground survey, aerial survey or both. The information wanted is in most cases the locations and distribution of resources, tree species, sizes and quality, growth and site quality. Although all this information cannot be obtained through remote sensing, procedures combining statistical analysis with limited ground surveys could be successfully applied.

While large scale (national) surveys concern extensive areas, forest management surveys are usually restricted to forests in a district or smaller unit. The information a forest manager expects from a management survey refers mainly to:

- An accurate area estimate;
- Classification of the forest into cover types and their description;
- Evaluation of the growing stock;
- Regeneration assessment;
- Assessment of tree and forest stand growth;

Methods for estimation of mangrove areas are briefly described in **Section 6.4** of this chapter.

Whereas classification into forest types can be successfully achieved using aerial photography of an appropriate scale combined with limited ground checks, the evaluation of the growing stock and the regeneration often depend on more intensive field enumerations and ground surveys. This is also, and especially, the case when an assessment of the tree and forest stand growth is needed. In these cases the surveys are often combined with information gathered through forest inventories described in the following chapter and illustrated in **Case Study 2**.

Forest type delineation

Prior to field enumeration, a precise classification of the forest into cover types should be completed. The goal of forest classification is two-fold: first, it is essential for stratification, which can permit a reduction of field enumeration, and second, it is necessary in the preparation of management maps. This classification is, as described in Section 6.1, most easily carried out using aerial photographs.

When planning the aerial photo coverage of mangrove areas, particular attention should be given to the season of the year and the time of the day to ensure an accurate interpretation. For vegetation mapping and interpretation, the best season is when differences between trees and vegetation classes can be easily detected.

In mangrove areas, this may correspond to the end of the rainy season. Also, photography should be taken when the sky is free of clouds and dust.

At the latitudes where mangroves are located, the best time for photography is between 9:00 am and 3:00 pm. However, at noon the high elevation of the sun may cause specular reflection in some spots especially when wide angle cameras are used. Moreover, consideration should also be given to tidal levels and amplitude as they may affect the photo-interpretation results. A few of the advantages (+) and drawbacks (-) associated with low and high tides are indicated below.

Table 6.2: The influence of tidal level on aerial photography coverage

Low tides	High tides
+ Mudflats in lower littoral zones are visible + Detection of areas with stagnant water made easier - Not adequate for studying inundation levels - Cannot detect interdistributary canals, which can be useful in planning field survey (access).	+ Zones of maximum inundation are visible + Most canals can be detected - May cause bias in tree height measurement on photos - Detection of rivers and canal systems in degraded or non-forested areas not possible.

It must also be pointed out that for forest classification, highly qualified photo-interpreters who are familiar with the mangrove environment are required.

Valuable additional aids to photo-interpretation, besides photo-interpretation keys, include terrestrial photography revealing the ecological sites of each forest type, stereogrammes and type description.

With regard to forest typing in mangroves, a principal element of classification is often the potential commercial value of timber and other wood products. A separation between productive and non-productive forests will result in a more rational utilization of the means used in the survey. In areas of poor wood production potential for instance, a visual description of the vegetation might be sufficient whereas in productive stands a more detailed forest inventory including information on species composition and volume is required.

According to **Diagram 6.1**, stands where the forest presents a potential value of timber and other wood products, can further be subdivided into more refined classes such as forest types. The latter can be defined as being groups of trees having the same characteristics, growing in the same conditions, and having the same utilization.

Their separation can be achieved using easily distinguishable criteria such as:

- composition
- tree height
- stand density

With regard to composition, genera can be used where the distinction between individual mangrove species is not feasible. In addition, ecological factors such as texture and condition of the soil, and inundation classes can be also incorporated to achieve a better classification of forest sites.

The age is also an important classification element to consider, but in mangrove forests, unless the stands are under intensive management, such as for instance in the Matang Mangrove Reserve (Perak, Malaysia), the age will usually not be known.

Tree height is also a useful criterion in forest stand classification. Its usefulness resides in the fact that tree height can be measured with acceptable accuracy on suitable aerial photographs. In mangrove forests, stand height can be divided for instance into three or four classes, allowing a sufficient description of stand development such as

Stand height	Description
0 - 9 m	Regeneration
10 - 19 m	Young stand
> 20 m	Old stand

Height classes may vary in amplitude from one species to another, but their number should be kept reasonably low (3 to 4). Due to variations in species and growing conditions between countries, and even within a country, standard height classes are not recommended here. The classes should be based on local observations and information needs.

It should be recalled here that, when tree height is determined from aerial photography by means of parallax measurements, it may be necessary to make adjustments to correct for tidal fluctuation.

Forest density is a measure of stocking in a forest. It is also a valuable classification factor, which is frequently used, because it is highly correlated with volume. Moreover, it can be directly expressed using crown closure measurements on aerial photographs. Like stand height, forest density can also be subdivided into several classes for instance as follows:

Crown closure in percent	Stocking
10 - 40	poor
40 - 70	medium
> 70	good

Again, it is not possible to generalize with regard to the number of classes and their limits. The classes should reflect the occurrence of the local species and their characteristics.

Most of the criteria mentioned above (and which are used in forest type classification) can also be the basis for the establishment of photo-interpretation keys. For their construction, it is first necessary to determine the photographic characteristics of the different species of mangroves under various conditions. Then, from observations of disseminated ground plots covering various vegetation types, sites, growth stages and degree of utilization, one can establish physical links with actual ground conditions.

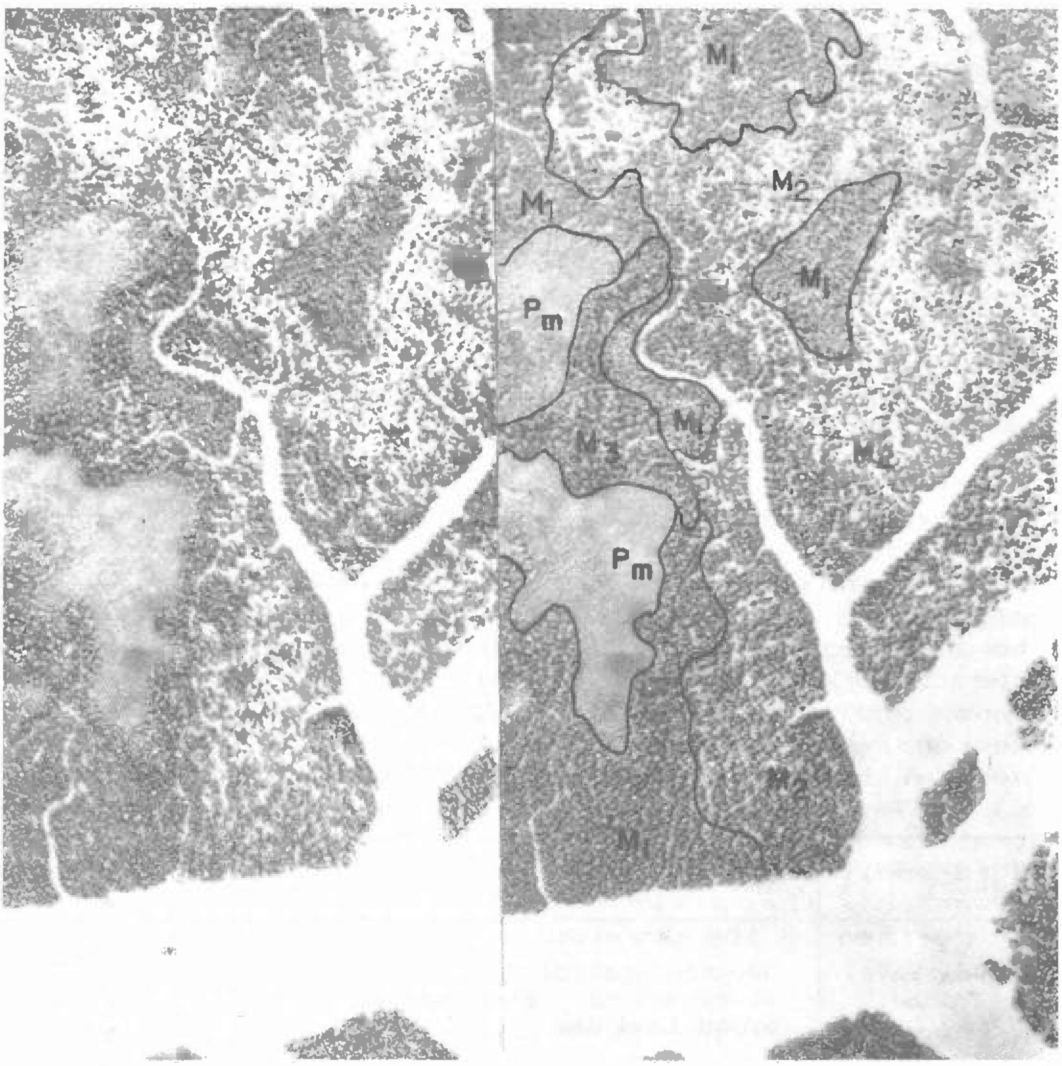
The simplest way of providing the photo-interpreter with useful reference material is probably by using annotated stereogrammes which show various objects to be identified. An example of such a stereogramme is presented in **Figure 6.1**. Supplementary information to stereogrammes can also include a clear description of the characteristics of the objects and statements describing the significance of each type.

Descriptive characteristics of vegetation corresponding to image aspects relevant to photo analysis are the texture (related to forest cover density); the height of trees and the size of dominant tree crowns; and the tonal variation of the different vegetation storeys. A ground description of accessibility such as water courses, and the impact of man's action on the environment, can also be a valuable information to be included with stereogrammes. The use of stereogrammes ensures a good control of photo-interpretation and their application results in a more uniform and consistent stratification.

Forest stand delineation

This delineation is concerned with the further division of forest types into mangrove forest stands. These units, which are often used as compartment units, consists of even-aged or otherwise homogeneous stands which are to be subjected to identical silvicultural and other treatments. A forest stand is thus an operational unit, which is identified during the forest management planning process and used extensively in the operational management of any forest.

If recent aerial photos on a large scale, say 1:10 000 are available, and the area has been under intensive management using the clear-felling system for a long time, it will be quite easy to distinguish the different stands on these photos. However, this is rarely the case when it comes to mangroves, and it is thus necessary to combine these with extensive surveys in the field.



M1 : Low mangrove forest. Partially marshy with small but dense tree crowns with a few large trees. *Avicennia sp.* dominant.

M2 : Medium high mangrove forest with a mixture of M1 and M3.

M3 : High mangrove forest with large tree crowns.

Pm : Marsh land, salty water, occurring between mangrove stands and lower areas.

Fig. 6.1: **Stereogramme showing mangrove forest types**
(Colombia)
Courtesy: Sicco-Smit.

6.2.3 Operational level surveys

On this level the surveys most often consist of either field enumerations (and/or observations) or area surveying on the ground, to complement the surveys mentioned above and to record changes since the last survey was undertaken.

Field enumeration to gather information on wood resources are described in the next chapter and a few case studies are presented in the back of this manual.

Land or area surveying is described in numerous forestry and surveying manuals and will therefore not be dealt with in this manual. Due to the constraints in conducting such surveys in the mangrove areas (the occurrence of many rivers and streams, the sometimes very soft ground, the high tides which make the recording of land near the borders and rivers rather difficult and the often very high erosion and accretion rates), it is recommended only to undertake such surveys of smaller areas and to obtain recent aerial photos in a sufficiently large scale to aid in any mapping and area estimation.

6.3 MAPPING OF MANGROVES

The presentation of survey results is often done in the form of a map. The purpose of making a map can be for the planning of more detailed surveys, or to assist in decision making regarding the use and development of resources at different application levels. With particular reference to mangrove forests, the information required for each application includes various items. A few of them are presented in **Table 6.3** below.

Table 6.3: Type of information and map scale requirements for different application levels

Application level	Type of information	Scale range
National level	-Geographical distribution of mangroves - area extent -Broad land use	1:50 000 to 1:250 000
Management Planning level	-Mangrove sites -Broad forest classes	1:25 000 to 1:50 000
Operational Planning level	-Mangrove forest resources -Forest stands and types	≥ 1:25 000

The accuracy and amount of the plotted detail should be correlated with the potential value of the land it represents. Also, in more intensively managed forests, scales should be larger as more data must be reported on a smaller area.

At a national level, mapping consists of presenting the general distribution of mangroves of a country or a region. Orbiting satellite imagery, combined with small to medium scale aerial photography are suitable for such a task.

The information which can be put on the map may include the following:

- Forest lands (natural and planted);
- Lands used for aquaculture (fish ponds/shrimp farms);
- Agricultural lands within mangrove areas;
- Mining and industrial zones;
- Infrastructure, settlements and urban areas.

Figure 6.2 is an illustration of a small scale map showing the extent of mangrove forest and other land uses.

At the medium level (management), semi-detailed land-use mapping can be carried out with the objective of producing maps at medium scales, on which various forest sites can be shown. The latter can be defined by forest density and development conditions. They may be:

- Areas where mangrove forests are well preserved and can be allocated to timber production and some kind of intensive forest management could be imposed, and
- Areas destined for conservation and protection purposes or allocated to other utilizations than timber production due to the nature of the forest stand.

Maps at medium scale can also give information on forest land and land-use distribution. This is illustrated in **Figure 6.3**.

Intensive forest management applications call for detailed stand type maps with a good planimetric acuracy. Forest stand classification should provide up-to-date information on certain important parameters including tree species or species groups, age classes, regeneration, cutting activities, degree of stocking etc. The classification of forest lands into distinct forest types can only be achieved with aerial photography having sufficiently high resolution, complemented with ground observations. **Figure 6.4** is an illustration of a managed mangrove forest, where compartments are shown and progress of cutting is indicated. For more detailed information on map and mosaic compilation please refer to **Appendix 3**.

6.4 AREA ESTIMATION

Different techniques have been used to develop area estimates. The most common is the use of a planimeter on a pre-established planimetric map of the entire area. Measurements are made on maps which contain photographic details such as forest types. Area measurements can also be performed directly on aerial photographs of relatively flat terrain, another common advantage in mangrove areas.

The main drawbacks of this method is however the shape of the mangrove areas, which are so often intercepted by rivers and creeks, and the size and shape of the minimum area in the classification units. **Figures 5.8, 5.10 and 6.2** are examples illustrating this point.

Fig. 6.2: **A small scale land-use map based on digital Landsat image classification with a smoothing process**
Scale: 1:230 000
(Source: Tikumponvarokis *et al.*, 1985)

Tropical evergreen forest
Mangrove forest
Rubber plantations
Deteriorated forests
Water and unclassified
Grassland/Savannah/paddy fields
Road

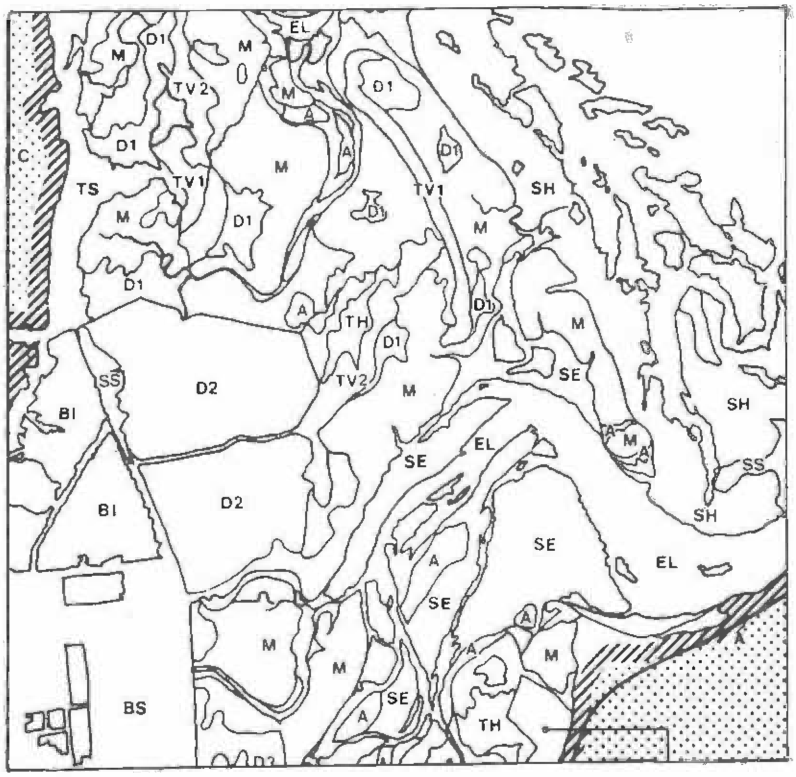


Fig. 6.3: **A medium scale land-use and forest type map based on a SPOT image**
(Same area as in Fig. 5.6)
(Ngomeni, Kenya)
(Source: Lantieri, 1986)

ZA: Agricultural zone
C: Non agricultural zone
A: Village

Road

Inter-tidal zone limit

TS: Dry barren lands
TH: Wet barren lands
TV1: Barren land with low vegetation cover
TV2: Barren land with high vegetation cover
BI: Flooded ponds
BS: Dry ponds
EL: Water
SS: Dry coral sands
SH: Wet coral sands
M: Rhizophora
A: Avicennia
D1: 30% of trees with no leaves
D2: 100% of trees with no leaves
D3: Cut areas. Wood on ground
D4: Non-mangrove wood. Wet soil

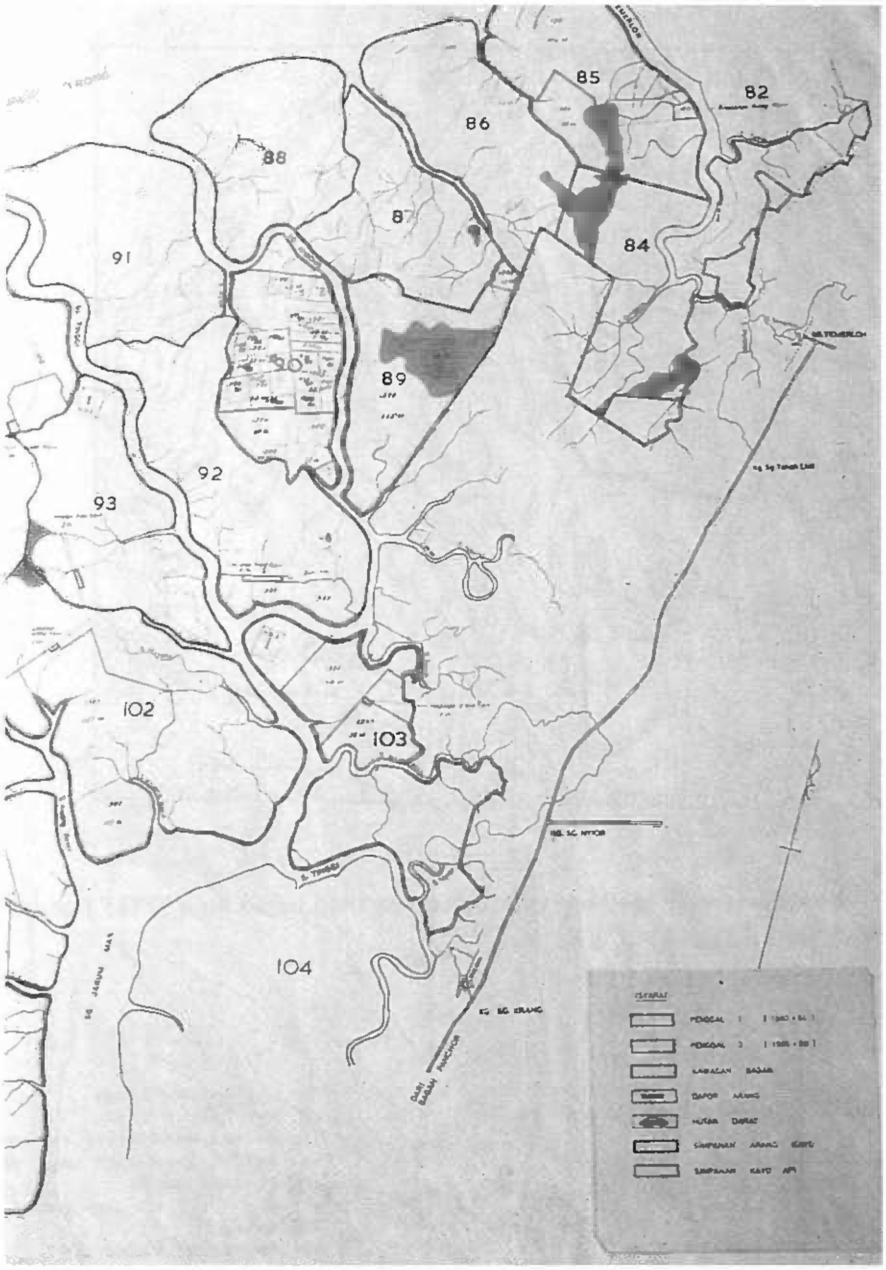


Fig. 6.4: **A large scale mangrove management map showing compartments and logging areas**
(Matang Mangrove Forest Reserve, Malaysia)
(Courtesy: Forest Dept, Malaysia)

Several sampling procedures including dot grid and transect methods have also been applied. Among these, the dot grid procedure is considered the most advantageous in practice.

The technique is easy to use and is widely applied. It consists of laying a transparent grid with equally spaced dots upon a map or a photograph. Each dot falling within a given class or a stratum is counted and used to estimate the total area of the class. The technique is described in detail in several forest inventory books and documents (Spurr, 1952; Loetsch and Haller, 1973).

If K is the total number of dots falling on the area of study and Kj is the total number of dots counted in stratum j, the area proportion of stratum j is obtained by:

$$Pj = \frac{Kj}{K}$$

When the dot grid is used with aerial photography, the scale variation can cause the area estimates to be biased, but on level terrain such as in mangroves, scale variation is minor and dot counts can be used without adjustments.

The dot grid and other sampling techniques are also affected by the minimum area on which photo-interpretation is based. The size of the smallest area unit varies according to photo scale and survey intensity.

Forestry literature shows that minimum areas between 1 ha and 20 ha have been commonly used. Moesner (1957) found that area proportion estimates and survey costs increase with increasing minimum area size. The cost is certainly affected by the size of the minimum area, but mostly by the increase in variability of vegetation, making photo-interpretation more difficult. For area determination however, it is generally recommended to use small minimum areas, because area estimates are more accurate.

The most important limitation of the dot grid procedure is the determination of the error on area estimates. The statistical problem encountered with the dot grid technique is that dots are systematically distributed over the area, and the utilization of the binomial model assuming a random distribution is not adequate. In order to get around this conceptual problem, several error formulas with varying degree of complexity, have been developed.

Chevrou (1979) suggests the following easy to use and correct expression:

$$CV\ (S)\% = 50\ P^{.5}\ N^{-.75}$$

where

- CV is the coefficient of variation or the relative error
- S is the area estimate
- N is the number of dots falling in the area S
- P is the perimeter ratio i.e. the perimeter of S divided by the perimeter of a circle of the same size.

When using image data or maps in digital form it is often possible to obtain an area estimate directly without any manual measurements apart from the ones needed to check the accuracy of the map and its scale in the field.

7. RESOURCE ASSESSMENT AND FOREST INVENTORIES OF MANGROVES

7.1 FOREST RESOURCE ASSESSMENT IN MANGROVE AREAS

Forest resource assessment is here used in the sense of a resource appraisal, a rough estimate of the wood resources available. This estimate is neither as accurate nor as detailed as the results from a forest inventory, but the method is found useful, when a rapid assessment of the resources is needed.

This assessment can be based on either measurements taken directly on remote sensing imagery or on limited field sampling or, of course, on a combination of the two techniques.

7.1.1 Volume estimation from remote sensing imagery

The rising costs of conventional inventory techniques and the urgent need for information have led forest mensurationists and managers to use procedures of volume estimation from remote sensing imagery in particularly aerial photography. Several forest and tree characteristics can be measured on aerial photographs of adequate scale and quality, and aerial photography has been used for direct volume estimation for many years.

The general procedure in volume estimation of a tree or a stand is the establishment of a mathematical model where the independent variables can be measured or estimated directly from aerial photos. These components of photo volume are related to the volume measured on the ground by regression techniques.

Height measurements

Among the parameters used, tree height has been found to be the variable most closely related to volume. The parallax method using simple devices, such as parallax wedge or parallax bar, is most commonly applied. Height accuracy has been tested in several studies and it is known to be dependent to a large extend on the flying height and camera type. Best results can be obtained with very large scale imagery, but fairly good height assessment could be achieved on medium scale (1:10 000 - 1:20 000) as well. The formula below is used for height determination:

$$h = \frac{D_p * H}{b + D_p}$$

where

h is the tree or stand height
H is the flying height above ground
D_p is the parallax difference between the top and the foot of the tree
b is the average photo air base

In order to increase the accuracy of the flying height, and subsequently of tree height measurements and photo scale, efficient and practical instruments have been developed. The foliage penetrating radar altimeter is an example. It can be attached to photographic systems on board a light aircraft to obtain reliable distance from the plane to the ground. This information is most of the times lacking when a light aircraft is used for photo coverage with small camera systems.

Tree crown measurements

Tree crown width, crown closure and crown area are other parameters which are also introduced in volume equation computations. They are directly measured on aerial photographs by means of simple devices. While crown area and crown width are determined for single tree volume equations, crown closure, which measures the percentage of crown cover, is used for stand volume equation determination. Crown density scales are constructed with black dots on white background or vice-versa. The density of dots represents different ranges of crown density. Crown density is determined by comparison of the standard of the scale and the photo density on plots.

Stand density

In some situations, stand density proved to be an interesting parameter to combine with crown closure for volume determination. Tree counts, however, become increasingly inaccurate as the photo scale becomes smaller, especially in young stands.

Volume estimation

Numerous studies have been undertaken to establish the relationship between the above parameters and the actual volume on the ground for various tree species and forest types found in the inland forests and savannas. However, only few studies of this kind have been carried out in mangrove areas. Khan, Choudhury and Islam (1990) report on attempts to study the possibility of estimating stand volume in the Sundarbans using variables which can be measured on aerial photographs. Fourteen stand volume equations were solved using combined photo and ground variables as independent variables. The standard error and correlation coefficient were estimated and the equations tested against corresponding volume calculated from ground data. Whereas the use of the basal area as the independent variable gave the best results, and the standard error of the estimate was 16% when using both photo and ground variables, it was found that four different equations using only variables, which can be obtained from aerial photos (number of trees/ha, crown cover percentage and average stand height) gave a standard error of the estimate in the range of 18-19% with correlation co-efficients of 0.887-0.898. These equations are presented in **Appendix 5**. However, it should be noted that in the above experiments the photo variables were in fact obtained from the field survey and the results thus only give an indication of the possibilities of using measurements taken directly on aerial photographs of a suitable scale (1:10 000 or 1:5 000 for timber volume estimation).

The same authors also reported on attempts to estimate the stand volume using Landsat data, but none of the initial equations showed satisfactory results.

7.1.2 Volume estimation with limited field sampling

Using this method, measurements of the diameter and height of the trees in a few sampling plots representative of the forest types (or other units of classification) are undertaken in the field. With the help of pre-established volume tables the volume in each plot is calculated, and the average volume for each of the forest types/classification units is then multiplied by the total area of each type and added up to obtain an estimate of the total volume of wood available. For more details refer to **Section 5.2** in this chapter.

The sampling intensity is often very low, and the sampling units neither randomly nor evenly distributed over the entire area, but often located in clusters in easily accessible areas. The volume tables used are likewise not verified and/or revised to reflect the local conditions.

The estimate obtained is thus not very accurate and it is impossible to determine the error on the result. As very little information is available on the mangrove resources, this method is however valuable in obtaining a first indication of the extent of the resources on a national/regional scale.

7.2. FOREST INVENTORIES OF MANGROVES

Forest inventories are concerned with more detailed and accurate estimates of especially the standing volume of wood. As such, they provide valuable information needed in the preparation of forest management plans and in preparation and execution of operational plans such as logging plans, where what is generally desired is a very detailed knowledge about the quantity and quality of the wood available and a reliable estimate of the size of the area where logging operations will take place.

This information requires generally an intensive inventory, mostly in the field, but maps and aerial photography are valuable aids in the preparation of the inventory in the location of compartments and tracts concerned by it.

7.2.1 Sampling designs

Strip and line plot sampling techniques are commonly applied in tropical forests. In the following sections, a brief account is given as to their application in mangrove forests. Other sampling designs are outlined in **Appendix 4**.

Sampling lines oriented perpendicular to the waterways often provide good data capture due to the natural tendency for mangroves to exhibit zonations parallel to the waterways. The difficult working environment and general absence of landmarks also favour systematic line sampling procedures.

Strip sampling

This sampling design consists of the laying out of continuous strips of uniform width, running across the topographic gradient and drainage pattern so as to cover most stand conditions. The strips can be randomly selected but in practice, regularly spaced strips are generally used. **Figure 7.1** is an illustration of a strip layout.

The sample strips are normally laid out at distances between 500 and 1 000 m and have a width of 10 to 20 m, depending on the sampling intensity.

In practice, strip sampling poses difficulties in the field, where a dense understorey and windfalls are frequent. In mangrove areas this is an even more acute problem because the progression in the field often is hindered by a muddy ground and dense stilt-roots, and the ensuing difficulty in maintaining a constant width of the strip results in considerable errors.

In addition, for the same sampling intensity, the number of sampling units using the strip sampling method is relatively small, compared to the line plot sampling method, which from a statistical point of view is rather unfortunate. Another disadvantage of strip sampling is the fact that its long narrow shape has a long edge, relative to its area, resulting in frequent border tree occurrence.

When strip sampling is used, field observations can be recorded using a cumulative tally for all strips, or a separate tally by strip or even within strips. The data is recorded in individual segments which are then the sampling units.

The strips may be equal or unequal in length. When they are unequal, regression or ratio estimator procedures should be used for estimating the mean volume and standard error of the mean. This provision also holds true for the case of strips divided into segments which in turn may be unequal in size, particularly at the ends of strips.

An example of strip sampling is presented in **Case Study 2**.

Line plot sampling

In line plot sampling, a set of field plots, generally of the same size, is located throughout the area of interest. For practical reasons, a systematic layout of plots (see **Figure 7.2**) is used in most inventories, where this technique is employed, in spite of the statistical difficulty associated with the estimation of the variance of the estimate.

For a given sampling intensity, different layout schemes can be devised, depending on the sample size, distance between plots on the line and distance between lines. In Thailand for instance, the line plot adopted consists of lines 100 m apart with circular plots of 5.64 m radius (100 m^2) 100 m apart on the line. This scheme gives a 1% sampling intensity.

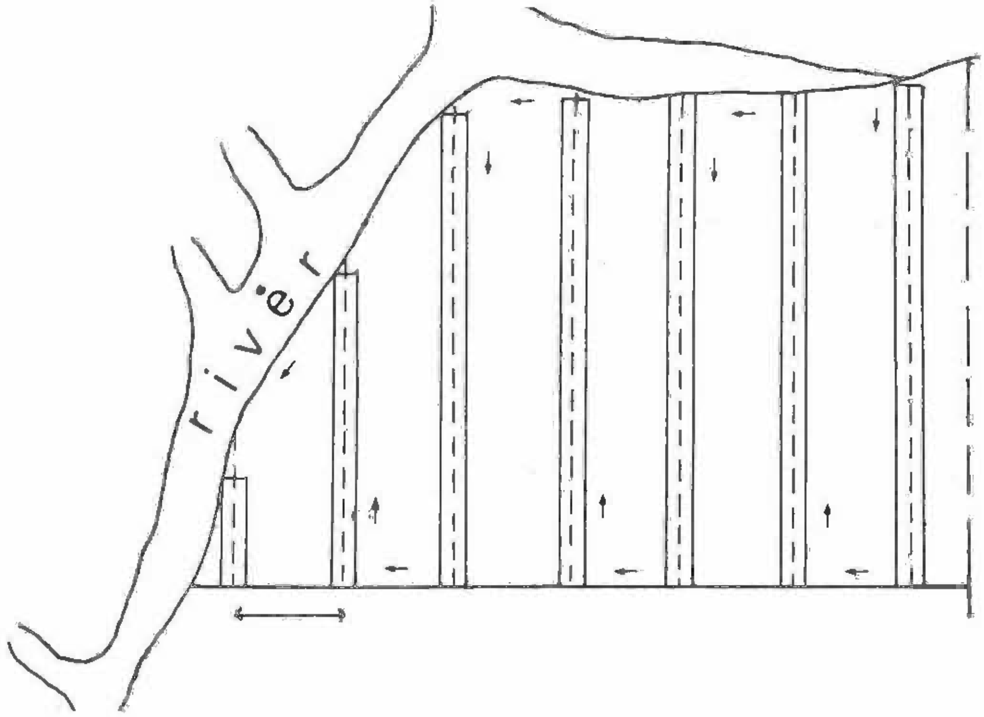


Fig. 7.1: An illustration of a systematic strip layout.

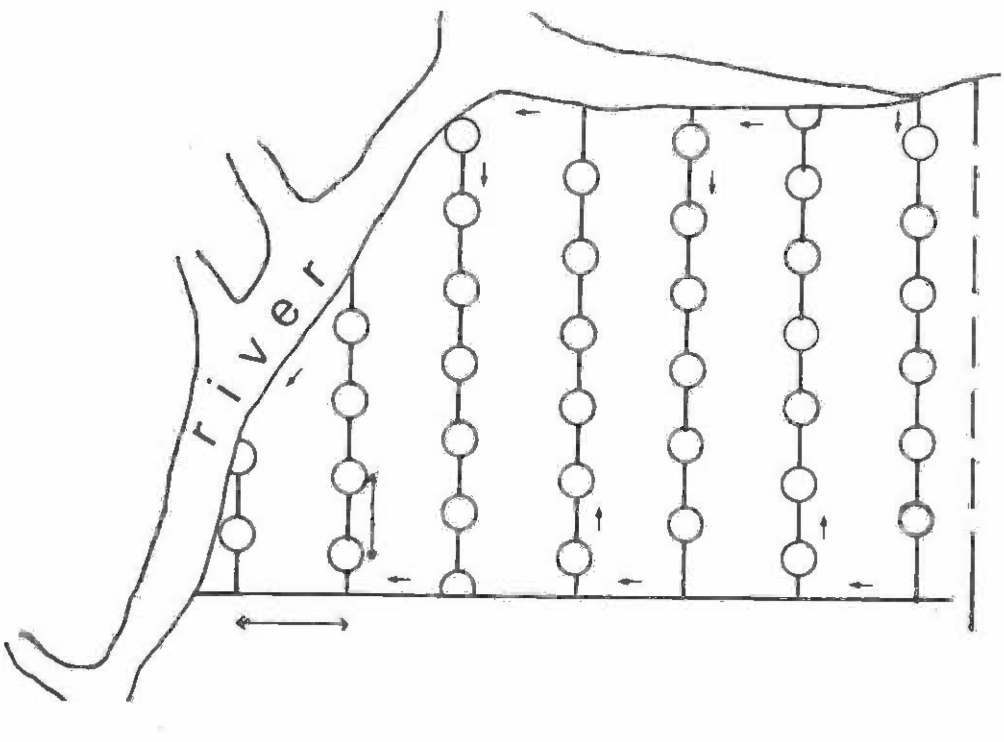


Fig. 7.2: An illustration of a line plot layout.

However, a more typical distribution of plots is where the distance between lines is greater than the distance between plots on a line. In this way, fewer lines are used, but because more plots occur on the same line, it is more likely that most vegetation and stand conditions are represented in the sample. Because of the zonal distribution of mangrove vegetation, this is generally ensured when lines are oriented in a direction perpendicular to topographic gradient and drainage pattern. This configuration is for instance adopted in the mangrove forest inventories of Matang, Malaysia, where the distance between plots on the line is 20m and the lines are 100 m apart. Each circular plot has an area of about 79 m^2 (5m radius) resulting in a 4% sampling intensity. Please also refer to **Case Study 4.**

When choosing a sampling intensity for a systematic line plot sampling, it might be useful to carry out a few trials to determine the variability of stand parameters. See also **Section 7.2.2**.

A line plot design can be drawn up as follows:

Let A be the total area concerned by the inventory,
Ap the forest area which is actually tallied,
a the area of the sampling unit,
n the number of sampling units,
f the sampling intensity,
Dl the distance between lines and
Dp the distance between plots on the line,

then

$$Ap = f*A \; ; \qquad n = \frac{Ap}{a} \; ; \qquad f = \frac{a}{Dl*Dp}$$

To determine plot or line intervals, either Dl or Dp has to be chosen on the basis of practical convenience.

When the sampling units are distributed according to a grid system, the calculation of the mean, the total and their variance is often carried out as though the units were randomly chosen. A closer approximation of the true variance of the mean can be obtained if the sum of squares of differences between successive plots is used instead of squares of deviations from the mean as in simple random sampling. Such an approximation is given by the following formula:

$$S_{\bar{x}}^2 = \frac{\sum_{j=1}^{L} \sum_{i=1}^{n_j} [x_{ij} - x_{(i+1)j}]^2}{2n \sum_{j=1}^{L} (n_j - 1)} (1-f)$$

Where

$S_{\bar{x}}$ = Standard error of the mean
L = number of lines
n_j = number of sampling units in line j
n = total number of units in the sample
f = n/N with N being the total number of sampling units in the population

Compared with the strip method, the line plot design has the following advantages:

- The delineation of strips is not necessary, therefore the progress in the forest is easier and less cumbersome.
- The uniform distribution of plots over the whole area provides more accurate data, especially in mangrove areas where the forest conditions vary from deep flooding to dry ground zones.

7.2.2 Sampling intensity

When a sampling inventory is to be implemented, the intensity of the sampling should be defined. It is a function of, among other things, the forest extent and accessibility, the sampling design chosen, the funds available and the precision required. Techniques of enumeration and sampling intensity will differ according to whether:

a) an extensive resource assessment is planned, the results of which may be required for large administrative units, or

b) the results of the inventory are to be used for intensive management, timber sale and exploitation which require fairly high accurate information on small area units or stands.

In general, a compromise between the cost of enumeration and the precision of the results has to be found. Obviously, the optimum solution is to achieve a high precision with the least cost, but in addition to all these theoretical considerations, feasibility and practicality are important factors.

In the case of a simple random sampling for which the precision has been specified, the number of sampling units n is given by the general formula:

$$n = \frac{t^2 s^2}{E^2 + \frac{t^2 s^2}{N}}$$

Where

t denotes the value of Student's t corresponding to a probability level $(1-\alpha)$
s^2 is an estimate of the population variance
N is the total number of units in the whole population
E is the maximum allowable error on the estimate.

The above mentioned formula can take on other forms and can be simplified if N is large (infinite population) to the following:

$$n = \frac{t^2 s^2}{E^2}$$

The cost of the inventory may also be fixed and the inventory is to be executed within a restricted allotment of funds. Considering the total cost C to be:

$$C = C0 + nC1$$

Where C0 is the overhead cost and C1 is the cost of enumerating one sampling unit. The number of sampling units can then be computed as:

$$n = \frac{C - C0}{C1}$$

In such a case, the precision of estimation is computed according to the resources available.

Where mangrove forests are characterized by relatively homogeneous stands and the species are of moderate economic value, a sampling intensity of about 2% is generally considered to be sufficient.

7.2.3 Sampling unit shape and size

The effect of plot size and shape on the variance of the estimates has been the subject of numerous studies. With regard to plot shape, the main factor influencing the choice should be the length of the perimeter and the ease of plot establishment. Circular plots should theoretically be more efficient as they have the largest area/perimeter ratio, minimizing therefore the occurrence of borderline trees. The walking time during plot measurement is also minimized for circular plots.

However, while some authors recommend the use of circular plots, others have shown that long and narrow plots can be efficient along a topographic or a fertility gradient. In practice, circular plots are often satisfactory and are extensively used in forest inventories, but for research purposes, such as permanent plots used in continuous forest inventories, square and rectangular plots may be more appropriate, as they are easier to demarcate and relocate accurately.

The sampling unit size is another item to determine before the survey starts. Theoretically, since the precision of estimates depends on the number of units - for the same intensity of sampling - units of small areas are more efficient than large area units. Conversely, several studies have shown that to some extend, large size units are associated with a small coefficient of variation, which is the primary variable that affects the sample size.

With regard to mangrove areas, small plots are usually adopted. This is because mangrove stands often are very homogeneous. Also by using small plots, the chance of having more than one forest type in the plot is small.

In mangrove forests, this takes on a particular importance because, in addition to the possibility of introducing bias, the procedure of moving the plot so as to include it entirely in one stratum for instance, may turn out to be more laborious in the field than to enumerate all portions of the plot which fall in different strata.

In any case, it might be necessary in the specific mangrove conditions and local situation, to determine the sampling unit size on the basis of preliminary trials using various kinds of sampling units, and choose the most adequate size on the basis of maximum precision, cost and practical convenience, keeping in mind that **the optimum size of the sampling units is an area which contains an average of 10 to 25 trees to be measured.**

In natural and/or mature mangrove stands, bigger plot sizes might thus be needed. See the discussion in **Case Study 4.**

7.2.4 Continuous forest inventory (CFI)

The actual trend in forest inventories for management purposes is to use information based on data from permanent plots. It may also be useful to consider combining permanent sampling units in the field and on aerial photography. This approach is an efficient method for assessing changes (Schmid-Haas, 1980).

The use of permanent plot based information for management decisions, requires that their choice and establishment be judicious. They must be representative of the varying forest conditions, and be subjected to the same silvicultural treatments as the non-sampled part of the forest.

To fulfill the requirement of their establishment, aerial photography is an invaluable aid for their location and also for their periodic relocation. It must be stressed that one should give a precise description of the sites, using bearing and distance measurements, topographic details and land marks.

To ensure that permanent plots will be subjected to similar treatments as the remaining parts of the stand where they are located, it is recommended to use concealed marks. Instead of tagging individual trees in the plot for instance, stem locations may be mapped on a plot diagram sheet, with their coordinate position and number.

Since the data collected on permanent plots will be used in the determination of yield and growth and the evaluation of changes over time, care should also be taken during field enumeration to ensure consistency with regard to the measurements of tree characteristics.

Plot information that may be recorded in each sampling unit includes the following items:

Plot data	Individual tree data
Date of measurement	Tree Number
Plot number and location	Species
Forest type	Diameter (DBH and other)
Stand size and condition	Total height
Density (class)	Form and quality
Soil type	Vigor
Inundation class	
Understorey vegetation	

7.3 FOREST MENSURATION IN MANGROVES

7.3.1 Tree characteristic measurements

As in other forest inventories, the diameter and the height are the main variables to be measured. The principle of their measurements and their relationships with volume are discussed in most inventory books. In the following discussion, it is however attempted to present a few practical aspects relevant to their measurements in the particular mangrove conditions.

Diameter (DBH)

The diameter can be measured with a calliper or a tape. The problem of error in dbh measurement, caused by eccentricity or oval form at breast height is of minor importance for most mangrove species, whose stem form is relatively normal, and a tape is thus often used as it is less cumbersome. In the highly moist conditions and salty air in mangroves, fiber glass tapes are preferred to steel tapes.

More important than the choice of measuring tool, is the level at which measurements should be taken. The general rules used in other forest formations are applicable. Some modifications may be necessary according to the local conditions and practical convenience. An important exception however, concerns the mangrove trees with stilt-roots, such as *Rhizophora sp.*, where the diameter measurements should be taken at 30 cm above the highest root resulting in a deformation of the stem (FAO, 1981). This might in some cases be as much as 4-6 m above ground level.

As to the diameter anomalies that may be encountered at the point of measurement, such as a fork, a swelling, or other abnormal form, conventional measurements procedures may be applied.

Height

Height is often measured with a clinometer. In mangrove forests, instruments which do not require distance measurements may be preferable. A cheap and handy instrument of this kind is the Christen hypsometer. Optical range finder may also be useful for a rapid height evaluation. The observer should however be placed directly under the tree to be measured to avoid overestimation of tree height.

In low stands, height measurements can be obtained with a telescopic rod. A wooden or bamboo stick - bearing a graduation scale - can also be used.

Because of the importance of height/diameter functions in providing information on the structural conditions of the stands, a few studies have been conducted in mangrove forest and several models have been established. (see Sandrasegaran, 1971).

Bark

The bark of some mangrove species is commercially valuable. Bark measurements must therefore be taken to evaluate the production. For timber estimation, the conversion of timber over bark to timber without bark (merchantable timber) requires the knowledge of the bark volume or proportion. Bark thickness measurements are made by means of a bark gauge or simply with a ruler after the bark has been stripped off on a limited area of the stem.

7.3.2 Volume determination

On standing trees the volume is usually determined indirectly through volume tables or volume functions. Generally, the volume is expressed as a function of dbh or girth sometimes combined with the height. In most mangrove forests where volume functions or tables have been established in former days, the data were not always adequate. During more recent forest inventories however, equations based on sufficient observations have been determined for some areas and species. (See for instance Boonyobhas, 1986 and ODA, 1985 as well as the examples given in **Apendix 5**).

Volume tables are usually monospecific but, in tropical forests with mixed species having the same utilization and growing in the same conditions, volume equations may be developed for mixed species stands. It is worth noting that in mangrove forests of relatively homogeneous stands, it might be useful to consider simplified volume functions based on the mean tree. The total stocking can be determined by multiplying the volume of the mean tree (the tree with the mean basal area) by the number of stems per unit area.

On felled trees volume determination involves the application of the universal log formulas (known as Huber, Smalian and Newton formulas). Refer to **Case Study 5** for a description of the steps involved in the construction of a local volume table for *Rhizophora racemosa*.

Determination of bark volume

Volume estimates often include the bark, which in some cases is a valuable product in itself, and measurements should therefore be taken in order to assess the volume or weight of the bark and to revise the volume estimates accordingly.

Table 7.1 on the following page shows an analysis of bark volume for *Rhizophora mangle* and *R. harrisonii* selectively felled and measured at Playa Garza in Costa Rica (Chong, 1988).

Table 7.1: Percent of total bark volume for *Rhizophora mangle/R. harrisonii* trees of different diameter classes

Diameter b.h. (cm)	10	15	20	25	30	35	40	45
Total Volume (overbark)	0.0550	0.1460	0.2917	0.4989	0.7734	1.1204	1.5447	2.0504
Total Volume (underbark)	0.0425	0.1169	0.2393	0.4173	0.6571	0.9647	1.3454	1.8041
Bark volume	0.0125	0.0291	0.0523	0.0816	0.1162	0.1557	0.1992	0.2462
Percent (%)	22.7	20.0	18.0	16.4	15.0	13.9	12.9	12.0

The bark-factor method (Meyer's method) may also be used to determine bark volume. An example is given in **Box 7.1** on the following page.

7.3.3 Growth determination

Attempts have been made to assess dbh, height and volume growth of mangrove species in several countries. However, in mangrove forests, yield and increment figures have in most cases so far been based on little and fragmentary data.

Whereas some attempts have been made recently to measure the diameter increment of mangroves through studies of growth rings in countries with a distinct annual dry season, the assessment of growth of mangrove trees can best be determined from permanent plots by means of periodic measurements of trees and stands, and growth determination is thus a lengthy and difficult endeavor. However, growth date are essential for forest management planning, in the determination of the forest yield potential and for establishing the optimal silvicultural system to be applied.

7.4 PRESENTATION OF RESULTS

The presentation of resource assessment results is often given in the form of a simple table showing the size of the area covered by each of the different forest types - corresponding to the type map produced earlier; the estimate of average standing volume/ha for each type and the total volume for the forest area in question.

Forest inventory results are more detailed and often relate to a smaller area such as a forest district. A compartment map is often available and some of the inventory results may be incorporated in the compartment register. However, separate tables and histogrammes are often used for presenting the bulk of information obtained.

For each major species or forest type, the area of each ageclass (or diameter class, when age is not known) is calculated and the result presented in a tabular form and/or illustrated in a histogramme. The more even the distribution, the closer the forest is to the '*normal forest*', and the easier it is to maintain a constant yield over time and thus ensure sustainable forest management (See **Chapter 9** for further information on the concept of the '*normal forest*').

In the Terraba-Sierpe reserve in Costa Rica, 27 *Rhizophora harrisonii* trees were felled and measured to establish the relationship between diameters overbark (d_o) and underbark (d_u) at breast height. A plot of d_u as a function of d_o gave a linear relationship with a y intercept close to the origin (0). The predictive equation for this relationship may thus be written in the general form $d_u = kd_o$, where k is the regression coefficient or ***bark factor***. As the regression coefficient k (0.936) was derived from diameter measurements taken at breast height, it is referred to as the **lower-stem bark factor**.

Given an average value for k, the bark volume (V_b) for any log section may be obtained using the following relationship:

Bark volume (V_b) = Volume overbark (V_o) - Volume underbark (V_u)

Given:
d_{mo} = diameter overbark at mid-section;
d_{mu} = diameter underbark at mid-section;
L = sectional length;
V_o = volume overbark

$$V_o = \frac{\pi(d_{mo})^2}{4} L \quad \text{and} \quad V_u = \frac{\pi(d_{mu})^2}{4} L \qquad \text{(A)}$$

As $d_{mu} = kd_{mo}$, therefore

$$V_u = \frac{\pi(kd_{mo})^2}{4} L = k^2V_o \qquad \text{(B)}$$

Substituting:

$$V_b = V_o - V_u = V_o - k^2(V_o).$$

Therefore
$$V_b = V_o(1 - k^2) \qquad \text{(C)}$$

Bark Volume
$$V_b(\%) = \frac{V_o(1 - k^2)}{V_o} 100$$

$$= (1 - k^2)100$$

In practice, V_b derived by equation (C) will be greater than the actual 'stacked volume' because overbark diameter measurements usually made with diameter tapes include the air spaces between the ridges of the bark whereas the stacked volume is smaller because of bark compression. The stacked volume for unpeeled logs will be smaller than that calculated in equation (C) and a correction factor may be included to equation C as for example:

$$V_b = 0.8V_o(1 - k^2) \qquad \text{(D)}$$

where a correction factor of 0.8 was used.

Box 7.1: Determination of bark volume

Stand tables for each major species/forest type showing the standing volume for each age/diameter class are also produced.

An example of a stand table for *Rhizophora harrisonii*/*R. mangle* and *Pelliciera rhizophorae* based on an inventory of 63 plots in Playa Garza, Costa Rica is shown in **Table 7.2** Note however, that this table shows number of trees/ha for each diameter class rather than standing volume/ha.

Table 7.2: Stand table for *Rhizophoras/Pelliciera rhizophorae*

Diameter classes (cm)	1	2	3	4	5	6	7	8	Total per hectare
	10<15	15<20	20<25	25<30	30<35	35<40	40<45	>45	
Rhizophora	121	88	73	34	18	15	4	1	354
Pelliciera	176	117	77	25	8	6	3	0	412
Total	297	205	150	59	26	21	7	1	769

Source: Chong, (1988a)

An illustration of a stand table for a 'normal forest' is shown in **Figure 7.3** below. A uniform annual increment is assumed.

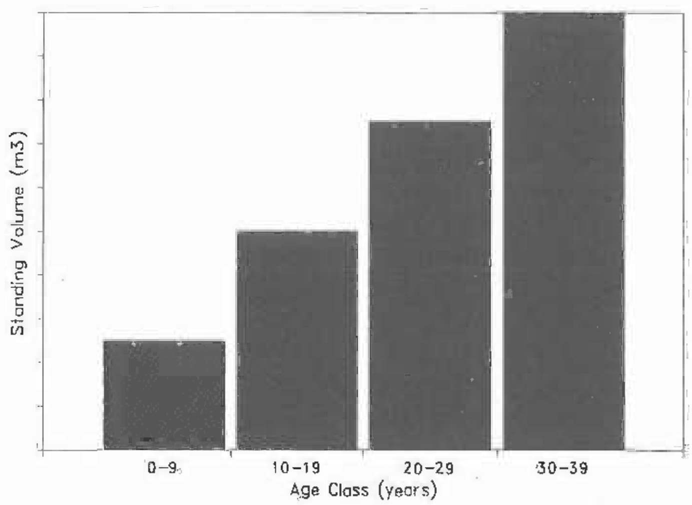


Figure 7.3: An illustration of a stand table for a '*normal forest*'

Local volume tables may be presented either in a tabular form with one or two entries or expressed as a volume regression and presented graphically. Examples are given in **Case Study 5 and Appendix A5**.

PART IV SUSTAINABLE RESOURCE MANAGEMENT

This part focuses on the application of biological, managerial, technical, economic and social knowledge, and manpower resources to manage the use of mangrove resources in a way that will provide sustainable benefits to the greatest number of people without impairing the environment.

8 NATURAL RESOURCE PLANNING PRINCIPLES AND POLICIES

8.1 PLANNING FOR MULTIPLE USE MANAGEMENT

Integrated management planning presupposes that the greatest societal benefits are realised when forests are managed for a mix of goods and services on a sustainable basis.

Wood and non-wood potential uses and their sustainable economic implications are analysed. A multiple-use strategy that harmonizes viable uses is formulated. Unlike traditional planning approaches, timber production is not over-emphasized at the expense of non-wood components of the ecosystem. Nowhere is the need to strike a balance between different uses more compelling than in mangroves, where more often than not, the non-wood opportunities may be economically and socially more important. Planning, therefore, is required to achieve the desired combination of forest uses over space and time, so that the various productive components of the forest production system can be optimally used and sustained to meet intended objectives.

Ideally, forest management should be based on a complete understanding of all of the social, economic and ecological parameters that are involved. That the current knowledge on the ecological functioning and biological interactions for some non-wood resources is incomplete, is however, not in itself an impediment to their sustainable management. Forest management is enhanced through practice, and its scientific foundation is strengthened through trials and experimentation. Management may be conducted empirically on the basis of limited inventory supplemented by eperience, sound reasoning and intuition.

A key question for the longer term is how to reconcile sound environmental activities with economic growth expectations. Part of the answer may well be founded on the design of policies that will foster a pattern of economic growth that makes use of a wider range and integrated mix of resource opportunities rather than over-exploiting any single-use. This diversified and less single resource-intensive approach is one aspect of integrated multiple-use planning.

Mangrove management planning should thus be part of an Integrated Coastal Area Management (ICAM) programme. ICAM ensures the sustainable use of the economic goods and services generated by the coastal ecosystems for meeting development objectives and to preserve the environmental health, resource quality and ecological integrity of the coastal area.

On a practical basis, as non-wood uses are usually managed by non-forestry agencies, it follows that coordination and linkages between concerned land uses and the relevant agencies/users will be required. Many different uses of the mangrove area (such as for instance production of wood, bee keeping, coastal protection and small scale capture fisheries) are totally compatible and can be carried out simultaneously. Others (such as large scale aquaculture, protection of wildlife habitats and intensive forest operations) are less so and a zonation of the area according to priority uses might be necessary.

Whereas integrated management of mangroves is strongly advocated, the focus of the present document is on the forest management aspects and additional information on management of other mangrove resources such as fisheries and wildlife must be sought elsewhere.

8.2 SUPPLY AND DEMAND

Although it is essential that mangrove resources be managed on a sustainable basis, a purely biological approach towards resource management is often unacceptable because the needs of socieMw may be quite different and very often do not conform to the capability of the land to support those needs. For example, in South Vietnam it was necessary to allot some prime mangroves for shrimp-farming because the local people could not survive on forestry activities alone. In other less populated areas, the forests may be able to produce more than is needed by the local communities and transport costs may prohibit the export of wood to other areas.

To formulate appropriate forest use plans, the peoples' demand for goods and services should therefore first be determined. The demand may be local or regional. In the economic sense, demand is gauged in terms of the cost, quality and location of the service to be provided in relation to alternate and substitute supplies. As forest benefits are not infinite, the use of one form of resource will often be at the expense of other alternative uses. For this reason, the loss of other opportunities for using a mix of resources must also be considered.

The next step is to analyse to which extent these demands can be met from the mangrove area in question, based on the assessment of current and potential resources.

8.3 PEOPLE'S PARTICIPATION

"*The basic fault in the conventional approach is that the rural poor are rarely consulted in planning or given an active role in development activities. This is because the poor have no organizational structure to represent their interests*". The first task therefore is to assess the needs of the direct and indirect beneficiaries and direct planning towards meeting as much as possible the needs of the target groups. The lesson is clear: unless the rural poor are given the means to participate fully in development, they will be excluded from its benefits.

8.4 POLICY FRAMEWORK

Planning for a multiple-use management is a complex task, in that problems must be viewed from different perspectives and needs. It will be necessary to relate the policy to be applied at regional, divisional and local levels to reduce planning conflicts.

Similarly, long term and short-term goals at different levels must also be harmonized. In most mangrove areas, a significant part of the production may be used to meet demands outside the forest area. The Ayeyarwady mangroves in Myanmar for instance, is highly depleted and degraded due to the high urban charcoal demand in Yangon estimated at some 700 000 t/year. Until recently about 500 000 tonnes were annually supplied from the mangroves. In other cases, fuelwood prices become so high that they exceed the buying propensity of local villagers, forcing them to cut fuelwood from public forests. Generally speaking, forest plans should be flexible enough to accommodate changes in political, economic and environmental conditions.

The forest plans should furthermore be part of an ICAM programme that is built on a multisectoral framework, which seeks to harmonize environmental linkages by minimizing the spillover effects of various types of sectorial development and by re-allocating and sometimes reducing access to natural resources.

8.5 PRINCIPLES OF PLANNING

The following principles are used as a guide in forest planning:

(a) Wood and non-wood resources are managed and used to meet local, regional or national needs:

The importance of a resource supply is not determined by it's physical or biological characteristics but by the priority that society places on its use. Development of national and regional policies will establish the required emphasis between the various sectors at a cost that is appropriate for the total level of returns desired. Planning will shape policies into programmes that are compatible with local conditions.

(b) An assessment of needs and public participation is an integral part of the planning process:

Managing natural resources to meet peoples' needs implies a knowledge of what they want. The people may hold views which are coloured by local customs, religious or other values. The involvement of people in the planning process is used as a tool for gaining information about peoples' views, values and priorities.

(c) Plans must be objective oriented:

When the problems or issues are understood, a set of objectives should be framed to address key issues. Objectives should be quantifiable targets that serve to focus management effort and measure performance.

(d) Plans must try to achieve the greatest good for the greatest number of people in the long run:

Minority interests must be weighed in relation to the general well-being of larger communties. In practice it is impossible to achieve a complete or unanimous support for all planning decisions.

(e) The ecological carrying capacity should never be exceeded and resource sustainability should be given high priority:

This is a non-negotiable requirement, if sustainable development is to be achieved. This requirement should be given high priority in the planning agenda.

(f) The need for biodiversity and wildlife conservation should be recognized:

This should be incorporated into the plan appropriate to the scale of the management area. For a small and/or highly fragmented area, it will be impractical to reserve large tracts of pristine vegetation for conservation purposes. Instead, the establishment of well placed control plots may be more feasible.

(g) Planning is an on-going dynamic process:

Planning must be flexible enough to accommodate shifts in demand/supplies and priorities. Because societal values change over time, planning is an on-going dynamic process. Change must be anticipated.

Generally the larger the geographic unit, the longer the planning horizon (time-frame). Regional policy objectives are necessarily *long-term* and are based on general trends that are affected only by macro changes. Forest District Management Plans, on the other hand, are based on *medium-term* plan objectives and are revised more frequently as the information base expands. Operational plans are *short-term*. (See **Table 8.1**).

(h) The plan must provide for improvements in data collection to reduce areas of uncertainty associated with an incomplete or weak information base:

The ultimate objective may be achieved in phases, taking into account an improved information base over time and applying a conservative approach where the uncertainty is perceived to be great.

(i) The decision-making process must be visible and equitable:

Involving the public in the decision-making process is necessary to promote local support and acceptance for integrated forest management planning. Just as it will be the duty of the forest service to explain to the public the implications of various decisions, the greatest value from the public will most likely be in using their knowledge of local conditions and needs.

Customary rights should be respected where possible. Decision-making should not marginalize the traditional incomes of local people nor their access to reasonable amount of forest products without offering practical and acceptable alternatives.

(j) Planning functions and responsibilities

The responsibility for planning functions should be clearly spelt out at different levels. Typically a national Forest Service is headed by a Director General of Forestry (Chief Conservator), who is assisted by his Deputy DGs (Deputy Chief Conservators/Assistant Chief Conservators), supported by several territorially based State/ Divisional/Provincial Forest Officers (Conservators/Regional Forest Officers) and District Forest Officers (Deputy/Assistant Conservators).

The terms used within brackets will, undoubtedly, be familiar to those who have worked under the British colonial forestry services. The Forest Service as a department is under the direction of a Minister in charge of forestry matters.

Planning may be undertaken by a macro-micro planning cell or by the Working Plans Branch or Division within the Forest Service. The different forest management levels and responsibilities are shown in **Table 8.1** as a guide.

Table 8.1: Forest management planning levels and responsibilities.

LEVEL	OBJECTIVE	DOCUMENTATION	CONTENT OF PLANS	PREPARED BY
NATIONAL POLICY	To provide the policy framework and define the criteria for management actions of forest resource ministries at federal or national level	Acts, Statutes, Regulations, Ministry and Departmental directives	National Policy Objectives and Priorities. Status Report on forest situation or to satisfy defined requirements of the Forests Act	The Minister in charge of forestry matters based on draft prepared by the Director General of Forestry (CCF).
REGIONAL PLAN	To establish broad resource management and development policies for the development of an entire geographic region or its major sub-areas or any specified region which includes a number of administrative divisions and township zones.	Director General/Chief Conservator of Forestry's (DGF/CCF) or State/Divisional/ Regional Forest Officer's forestry programme outlining one or more management alternatives based on a resource analysis	A plan where regional goals and priorities for integrated use are identified and production objectives determined (includes socioeconomic opportunities/constraints)	Divisional Working Plan Officer/Staff Working Plan Division in consultation with other Ministries/Departments.
FOREST DISTRICT MANAGEMENT PLAN	Prepare plans and development programmes based on defined management unit area needs/goals and land use. (includes a number of Working Circles)	A Forest Management plan approved by the Divisional Forester/SFO with the consent of the DGF for use by the Regional/District Forest Oficers	<u>Long-term</u>: Fix Annual Allowable Cut from an analysis of demand, inventory and resource uses data. <u>Short-term</u>: Schedules on roading; wood and nonwood harvesting, conservation, amenities and silvicultural activities.	Divisional/Regional/ District Forest Officer Forest Department Working Plan Division together with Divisional/Regional Forest Officer concerned.
WORKING PLAN	To resolve resource use conflicts and prepare guidelines and prescriptions for forest management implementation at operational level.	A Working Plan, approved by the Divisional Forest Officer/SFO and endorsed by the DGF's Working Plan Division, providing specific guidelines for resource development and use	Prescription of operating techniques and silvicultural treatments	Usually Regional/District Forest Officer working with Divisional Headquarters staff.
LOCAL OPERATIONAL PLAN	To identify what site-specific measures will be taken by the timber contractor (permittee/licensee) to ensure orderly extraction conforming to defined resource management objectives and priorities.	A detailed plan. In the case of timber, a Felling or Cutting Plan which, when approved becomes an integral part of the license/permit document.	Detailed specifications for on-site operations: e.g. logging systems, road specifications, layout of landings and skid trails, species selection, felling girth, order of felling blocks, etc.	District Forest Officer/Area Foresters and Senior Ranger Staff

9 MANGROVE FOREST MANAGEMENT PLANNING

Mangrove forest management is based on the sciences and skills of geology, pedology, climatology, hydrology, botany, ecology, silviculture, forest technology and economics in the selection and treatment of both wood and non-wood resources.

A concise plan, setting out the requirements and controls to be applied and the activities to be implemented over space and time in a logical sequence, to achieve desired objectives is referred to as a management plan.

Such a plan can be a **resource and development document** applicable to a country or a region; a **forest management plan/working plan** for a forest reserve or forest district, or an **operational plan** for (part of) a forest tract.

9.1 BASIC PLANNING STEPS

The basic planning steps applicable to each planning level, with minor modifications, may be described as follows:

(a) Setting the Terms of Reference

Define the management area, the planning horizon, the financial and human resources and the time-frame allotted to undertake the tasks. This will not be a problem in a plan revision exercise, where the area is known and past survey cost data is available. For an unmanaged area, however, attention should be focused on what is practicable and affordable.

(b) Assemble baseline information

Relevant socioeconomic, ecological and resource data are collected, compiled and documented in a structured format. Existing maps, available data and past inventory records are consulted and updated.

(c) Identify constraints

Constraints are generally inflexible but may be circumvented in some cases. For example, if the tract of forests to be managed is too small, a switch to higher value-added products or service management may justify the operating cost involved. Alternatively, where land is available the forest estate could be enlarged through land acquisition or reservation. Constraints are categorized as follows:

(1) Technical/biological: Technical or biological factors may constrain the extraction methods to be applied or the products to be produced. For example, site limitations will restrict the species that can be established.

(2) Financial: The rate of return on capital may be insufficient to meet the rigid standards set by lending institutions.

(3) Socioeconomic: A plan cannot not operate in isolation. The resources allotted to its use will become unavailable for other uses. The overall benefit to the community involves employment generated, environmental impact, and "invisible" benefits derived from savings in other sectors, such as improved fishery, ecotourism, coastal protection, etc. Local customs, culture and religious beliefs may constrain the use and promotion of certain products or services, such as alcohol from fermented *Nypa* sap or wild boar meat.

(4) Institutional: These are limitations imposed by the organization and managerial ability of the body executing the plan, the legal framework, social pattern and attitudes, low literacy rates, etc.

(d) Formulate objectives

Production goals should be designed to meet as much of the societal needs for each resource use as possible within the limits of sustainability. Other goals regarding the environment, soils and water protection and rural development are also considered.

(e) Develop management alternatives

Where economic and financial data are available, management alternatives may be compared in terms of their cost-effectiveness, taking into account other equally valid considerations, viz. social, cultural and environmental factors. The choice and ranking of priorities will depend on the alternatives that can best achieve the preferred set of objectives.

(f) Prepare Management plan

"Management plan" is here used in the generic sense to include plans applicable to each planning level. As mentioned earlier, this plan should be part of an Integrated Coastal Area Management programme to ensure sustainable multiple use of the mangrove resources.

(g) Implementing the plan

An activity schedule to implement plan targets is drawn up. Further data may need to be collected, as for example regeneration sampling prior to logging.

(h) Monitor and evaluate plan results

Periodic review of plan outputs is required to see how well objectives are being met and to make adjustments as required. To facilitate the evaluation process, "criteria" or "indicators" for measuring the success or efficiency of the adopted plan are drawn up. A desirable criterion should, (1) provide in a single figure all the information needed to make the decision; (2) be applicable to all alternatives, and (3) be readily calculable.

The Government's criteria might be:

- number of jobs created and their location;
- income generation and their distributional effects;
- impact on foreign exchange;
- the IRR, NDR, and/or Cost/Benefit ratio.

The Forest Department's criteria might be:

- rate of tree growth and areas of plantation created;
- profitability (revenue/expenditure relationship);
- rate of deforestation/degradation.

The lending institutions' criteria might include:

- rate of loan repayment;
- total capital sum invested.

From the conservation perspective, if we accept the premise that *biodiversity* is the variety, number of different species, and the quantity of each species in a forest and its associated environment, then the criteria for acceptance of a chosen management alternative must adequately reflect these concerns. This may give rise to conflicting interests. In any given location, the number of species will change due to ecological succession and longevity of species. However, a management system which maintains trees as the key structural element in the ecological landscape has a better chance of maintaining biodiversity than a degraded environment.

9.2 DEFINING THE MANAGEMENT AREA AND THE DURATION OF THE PLAN

Different management planning levels are tied to geographical units. (**Table 8.1**). **The regional management plan** is territorially divided into a number of forests or forest districts which are self sustainable units. It should be noted that, whereas provinces and districts are civil administrative units, which may be demarcated socio-politically, forest districts are delineated according to natural terrain features, which may or may not coincide with the administrative units above. As the area covered is extensive, the planning horizon is necessarily long-term, because large investments are needed for plan implementation. Regional forest plans often have a timeframe of 10-20 years.

At the forest management/working plan level, the management area is most likely to be a forest district, often constituted as a Forest Reserve. **The forest management plan** covers all of the forest and although predicted removals and a felling plan are prepared for the whole rotation (say 25-30 years), the plan period may be ten years or less due to the difficulties of forecasting the economic as well as the demand situation over long periods.

The working plan on the other hand only covers areas in which forest operations are to be undertaken within the working plan period, which is often shorter than the forest management plan for the district in order to take account of new factors or changes (normally 5-10 years). The working plan may be further divided into separate plans covering silviculture, harvesting operation etc.

An operational plan entails a further division of the area in that it deals with detailed specifications for on-site operations to be carried out in the near future (1-3 years at most) and may be prepared for each range within the forest.

9.3 COLLECTION OF BASIC INFORMATION

9.3.1 Data types

Data needs should be clarified before embarking on data collection in order to save time and money. Data are collected to assist in formulating realistic courses of action, to allow the possible courses of action to be evaluated and thus ultimately to facilitate the decision-making process. Five classes of data are required as follows:

(a) resource data;
(b) operational data;
(c) utilisation data;
(d) socioeconomic data;
(e) institutional data.

9.3.2 Resource data

For each resource, the main information required is (a) availability, (b) productivity, and (c) cost. The relevant data are summarized as follows:

- Land area and type
- Tree cover, fisheries, agriculture
- Material and equipment
- Finance
- Human resources

For the assessment of the land area and the mangrove resources, please refer to Part III of these guidelines. The productivity of the mangrove forest resources is described in **Chapter 11.** The remaining resource data are collected as for other forest types and thus not presented in detail in this document.

9.3.3 Operational data

The preferred operational method should be prescribed and the work activities defined as follows: (a) extent covered (ha or km); (b) the input (man-days, machine hours, materials, etc.); (c) the output (ha/day, km/day); and, (d) the cost per unit area or effort. The anticipated increase in MAI or survival rates are useful benchmarks for measuring performance. The operational data requirement may usefully be summarized as follows:

- Land clearing - including timber harvesting, hauling, burning, pond construction, canal construction, etc.:
- Site preparation - for afforestation/reforestation;
- Nursery establishment, propagule collection, etc;
- Planting;
- Maintenance and protection;
- Improvement and production control;
- River transportation logistics, canals, etc.

Please refer to **Chapters 10-12** for details.

9.3.4 Utilisation data

There should be an effective demand-forecasting system for the forest products and service expected to be produced from the forests at various levels. Thus this data type is required for timber/fuelwood producing mangroves. Even for environmental management areas, the objective may change over time to include production functions. Relevant factors to consider are as follows:

- Preferred species - type and properties;
- Spacing - size assortment, log size, quality, etc.;
- Area - wood volume, size and types of kilns, other cottage industries;
- Growth rate - production schedule;
- Location of forest, processing units and transport facilities;
- Site conditions affecting logging costs;
- Profile on traditional wood/nonwood uses

Most of these data can be collected from a review of past management and utilization and/or from specialized demand studies.

9.3.5 Socioeconomic data

Economic considerations are required over and above purely financial ones simply because strict analysis of cash expenditure and revenue do not fully account for the real cost and the real benefit to the community as a whole. In multiple-use management timber production may be reduced or even curtailed to preserve or enhance aquatic production and the trade-offs between alternatives compared. As the economic quantification of intangible costs is still at an early stage as applied to forestry in general and mangroves in particular, and informed estimates may be used instead.

The socioeconomic data needed are as follows:

- Shadow labour costs;
- Labour opportunity costs;
- Associated social costs - e.g. public investments in housing, water supply, canalization, crossings, etc;
- Discount rate to be used;
- Shadow price for produce to reflect price distortions due to taxes, duties and price control mechanisms;
- Value of non-marketable benefits - e.g. improved environment, health, shelter, erosion control, recreation, etc.;
- Development impact of intangible benefits to local or regional economy, training, etc.

9.3.6 Institutional data:

Institutional factors are mainly political by nature, but also include the legal framework. The management plan should include the following statements:

- Legal obligations;
- Legal privileges and rights;
- Policy guidelines;
- Support to communities, education and training;
- Reactional facilities;
- Local attitudes and impact on local society;
- Research linkage and support.

9.4 MANAGEMENT GOALS AND OBJECTIVES

The first task is to define the productive forest potential, and identify the main constraints. [6.1 (c)] The productive, protective, and social functions of the forests are defined as the *objects of management*, according to priorities. Whereas goals refer to the desired long-term perspective, objectives refer to measurable activities (outputs) prescribed within the plan period. Examples of management objectives are given in **Box 9.1**. Sustained production of wood and non-wood forest produce is an important function. Protective functions, *inter alia*, include the following:

- Riverine and coastal protection;
- conserving wild plants and animals through habitat management;
- Preserving unique forest stands or ecosystem;

A: Production forestry

(1) To produce a sustained yield of quality greenwood for charcoal processing to meet domestic demand as well as for export;
(2) To produce bark (tannin) as a by-product of (1);
(3) To produce quality poles, posts for local consumption;
(4) To produce a sustained yield of firewood to supplement the domestic and industrial fuelwood and energy requirements of the nation;
(5) To produce fishing stakes, and structural materials for the local communities;
(6) To produce such other related mangrove forest products that may be required for tertiary or rural cottage industries;
(7) To plan for integrated utilization of mangrove resources.

B: Environmental forestry

(1) To protect, rehabilitate and manage mangrove ecosystems that are required as breeding ground or source of nutrition or shelter for shrimps, molluscs, fish and other high protein sea-foods;
(2) To maintain the integrity of mangrove vegetation along the coasts and estuaries to serve as storm barriers, flood and erosion control; and to provide environmental support and protection to coastal agricultural cropping and communities;
(3) To preserve and keep inviolate sufficient areas of natural mangrove ecosystems as reservoirs of species diversity and for conservation of plant and animal genetic resources;
(4) To set aside sufficient areas as may be required for research, education and training purposes;
(5) To manage areas required for recreation and/or tourism.
(6) To promote social acceptance for forestry, better utilization and forest management.
(7) To generally regulate the use of waterways, channels and creeks within the mangroves so that their navigational value will not be impaired.

Box 9.1 Management objectives

In Vietnam, mangrove forest enterprises are managed as profit centres. Funds generated from the forests are used to finance forest development and to improve the social wellbeing of communities in the enterprise area.

The production strategy may comprise a mix of products ranging from fish, shrimps, charcoal, poles, timber, Nypa thatch, bricks, etc. (Refer to Box 9.2 below)

1 **Production forestry goals**

1a *Generally* to manage, develop and protect the mangrove resources in order to achieve sustainable production of wood and non-wood benefits in order to fulfil local and coastal demands for energy, construction materials and other wood products;

1b *Specifically* to produce a sustained yield of the following products for local consumption at affordable and stable prices:

- quality greenwood for charcoal processing for domestic cooking, industrial and other energy requirements;
- firewood at equitable prices;
- fishing stakes, poles, posts, and structural materials for local communities;
- adequate sawlogs for local use;
- bark (tannin-based dyes)
- related mangrove forest products, including nipa, for tertiary or cottage processing industries.

2 **Social forestry goals**

2a *Generally* to improve the standard of living and quality of life of the mangrove dependent population (including fishermen and shrimp-farmers) within the Dat Mui forest enterprise with particular regard to the following:-

- sustainable meaningful employment;
- adequate and improved quality of housing;
- availability of essential medical care;
- adequate and improved education facilities;
- improved cultural and community facilities;
- adequate and affordable communication services to promote greater social interaction, marketing of products and efficient distribution of social goods and services; and,
- enhance the scenic and amenity values of the forest.

2b *Specifically* through extension, demonstration and training activities increase the peoples' awareness and acceptance of forestry programmes.

3 **Environmental forestry**

3a *Generally* to maintain the integrity of mangrove vegetation along the coasts and rivers to serve as storm barriers, flood and erosion control; and to provide environmental support and protection to coastal agriculture, aquaculture and homesteads;

3b *Specifically* to protect, rehabilitate and manage mangrove ecosystems that are required as breeding ground or source of nutrition or shelter for shrimps, molluscs, fish and other high protein sea-foods;

- preserve natural mangrove ecosystems as reservoirs of species diversity and for conservation of plant and animal genetic resources;
- set aside sufficient areas required for research, education and training purposes;
- manage recreation and tourism areas;
- promote social acceptance for forestry programmes; and
- maintain navigability of channels and waterways.

Box 9.2: Dat Mui Forest Enterprise - management goals and objectives

9.5 PLAN STRATEGY

Based on the objectives of management, a plan strategy is chosen to reflect the local conditions. In countries such as Vietnam, where local authorities are non-existent or are unable to provide the basic social amenities to the mangrove dependent communities, it will for example often be the responsibility of the local forest enterprise to take on rural community development activities as well. During the plan period the strategy may thus include, *inter alia*, some of measures listed in **Box 9.3** below.

- promote sound local land use management and coordinate with other land users;
- upgrade the technical, managerial, and extension capability of the enterprise;
- enhance the business knowledge of the forest enterprise through diversification of investments to increase its profitability so as to provide a wider range of social benefits to target beneficiaries;
- promote the welfare of forest workers by providing adequate accommodation, health, recreation, education and training facilities;
- devise a resettlement programme for the mangrove dependent population onto less ecologically fragile and agriculturally suitable sites;
- emphasize on people-oriented management and participation through extension;
- develop an adequate local energy plan;
- apply rational multiple-use forest management.
- develop an adequate and sufficient energy plan;
- fuller utilization and minimize processing wastes;
- promote rural cottage industries and other rural income generating opportunities and employment.

Source: Chong, (1989a)

Box 9.3: Plan strategy for a forest enterprise in Vietnam

Another example of a plan strategy is from the Sierpe-Terraba mangroves in Costa Rica, where, given the large extent of irregular forests that were selectively logged and the need to regularize and introduce management control as quickly as possible, the strategy outlined in **Box 9.4** was recommended to augment and conserve the fuelwood resource.

Whenever possible, alternative management strategies should be drawn up and evaluated according to their ability to meet the desired set of management objectives with due regard to the concept of sustainable development of the mangrove forest ecosystem.

- temporarily retire and rest over-cut stands;
- regulate and improve removals;
- silvicultural transform forest into uniform stands of higher productivity;
- create local village woodlot;
- incorporate environmental monitoring and control measures;
- upgrade the mangrove management capability of the Forest Service; and,
- provide local training and technical support to focal cooperatives/NGOs.

Source: Chong, (1988b)

Box 9.4: Plan strategy for the Sierpe-Terraba mangroves in Costa Rica

9.6 THE CONCEPT OF SUSTAINABLE ECOSYSTEM DEVELOPMENT

The concept of sustainable development with regard to forest resources has often been described as the sustained yield principle. This term, however, brings connotations of the production of timber and does not evoke the production of environmental services, which - especially in the case of mangroves - are of equal importance. A holistic approach is thus needed and the environmental impacts of different management strategies, including the production of wood, should be evaluated in order to ensure the sustainable development of the entire ecosystem.

With regard to wood production, sustainable use implies that the yield of wood products should never fall. In mangrove areas (as in other forests) which have previously not been subjected to management regimes, this concept is too rigid, as the forest may be very heterogenous or contain an abundance of overmature trees and thus far from the concept of a 'normal forest' often used as a goal to aim for. See **Box 9.5** below.

A *normal forest* is an ideally constituted forest with such volumes of trees of various ages so distributed and growing in such a way that they produce equal volume of produce, which can be removed continuously without detriment to future production and environment.

Box 9.5: Definition of a 'normal forest'

This ideal norm is seldom achieved in all parts of the forest due to ecological changes, varying market demands and other unforeseen factors such as pests and diseases.

In areas where wood production is the primary objective, a conversion phase will normally be required to transform irregular forests into managed, even-aged forests of higher productivity. During this phase, an idea of what is biologically, technically and economically feasible in restructuring of the growing stock is crystallized. The lack of management planning information on growth dynamics and other aspects, as well as the need to introduce forest management as soon as possible, may make it expedient to draw experiences from other sources or countries.

Tentative standards for achieving required final crop stocking are applied, and these are refined as the informational database improves. However, *blanket prescriptions for all forest types are not advisable because mangroves are dynamic ecosystems* and in spite of their broad structural similarities are nevertheless very site-specific.

To achieve sustainable development in the long term, some immature stands may have to be felled during the conversion phase so that age-classes are brought closer to the normal distribution, implying that sacrifices have to be made in order to achieve sustainable production in the future. Only the management planner can advise whether the sacrifice is too great or not, bearing in mind that unwanted trees today may become commercial lumber tomorrow.

As normality may not be achievable within a single rotation, annual removals should be kept reasonably flexible. Depending on demand, some over-cutting is permissible, provided periodic adjustments are made so that removals do not exceed the biological potential of the forest. Whereas individual stands may be cut too early or too late and the annual production may vary, a sustained production should be maintained within a working circle during the management plan period.

9.7 DIVISION OF AREA

The **regional management plan** is territorially divided into a number of forests or forest districts, which are self sustainable units under the responsibility of a District Forest Officer.

Forests are often legally constituted as Forest Reserves, which are dedicated to forest management for wood production and non-wood benefits. Reserves are subdivided into a number of compartments. A 'compartment' is *the smallest administrative unit of management, location and record that is territorial and permanently defined for purposes of description and record.* They are demarcated on the ground according to natural boundaries and defined by surveyed maps. The compartment size varies according to the intensity of work to be undertaken. The first step in organising forest management is to prepare a compartment map and a schedule of works for the survey, demarcation and identification of compartments on the ground. Only forest reserves which will be worked during the current plan period need to be demarcated as this is a costly and time-consuming activity.

A sub-compartment is a treatment unit. It may be defined as a *subdivision of a compartment, generally temporary in nature, differentiated for special description and treatment.* Sub-compartments function as silvicultural and production operational units, whereas compartments have administrative, managerial functions.

The forest estate is also silvicultural organized into a number of units as follows:

(a) Working Circle (W.C.): Sub-compartments are grouped under different 'working circles' (W.C.). A W.C. is defined as '*an area (forming the whole or part of a working plan area) organized with a particular object and under one silvicultural system and one set of working plan prescriptions*'.

Allotment of sub-compartments to W.C.s depends on site factors, forest types and silvicultural treatment needed according to objectives of management. Overlapping W.C.s may be necessary when, for example, the same compartments are endowed not only with molluscan resources but also productive stands requiring different types of treatment. Alternatively, W.C.s may be designated for recreation and wildlife or for coastal protection purposes.

For control and supervision purposes, W.C.s are subdivided into territorial ranges under the control of a range forester (forest supervisor). In large ranges, there are several beats, each of which is supervised by a forest guard.

(b) Felling Series: To administer harvesting and regeneration operations, and to provide stable employment, a working circle may be divided into two or more felling series. A 'felling series' is *an area of forest delimited for management purposes and forming either the whole or part of a working circle*. Its aims are, firstly to create a distribution of felling and regeneration areas attuned to local conditions, and secondly, to maintain or promote a balanced age-class distribution. Each felling series is a sustained yield unit.

(c) The Periodic Block: Felling operations may be organized according to periodic blocks for more or less even-aged forests. A Periodic block is defined as the part or parts of a forest set aside to be regenerated or otherwise treated during a specified period. Regeneration may be secured through one or more regeneration fellings or through artificial regeneration. If the rotation (R) is 25 years and the regeneration period (RP) is 5 years, the number of periodic blocks is five, with each block having one-fifth of the felling series. The area of the periodic block (A) for a felling series (FS) of 1 000 ha will be 200 ha. The formula to derive the periodic block area is $A = FS \times RP/R$.

Periodic blocks may be "permanent, revocable or single". In the first case the blocks are permanently selected and cannot be changed; in the revocable method stands may be reassigned to other blocks, and in the last method priority is always given to blocks based silvicultural regeneration, utilization and site factors. The last method may be considered to be a special case of the revocable periodic block method.

9.8 PREPARATION OF THE WORKING PLAN

The 'working plan' is the part of the Forest Management Plan which deals with the prescriptions of the work to be undertaken within the plan period and as an operational blue print comprises the silviculture and treatment plan, the felling plan, revenue collection arrangements and financial forecast, a basic description of the working plan area and its parts including a map together with guidelines and priorities for area management.

A working plan must contain a clear statement showing the average annual cut in for a fixed duration, say the next 10 years. Clear prescriptions are given to achieve the wood production targets and forest regeneration programmes and other silvicultural treatments planned. The major components of a working plan are discussed in the following sections.

10 MANGROVE SILVICULTURE

A system for managing the production side of forestry must be in place to support intended management objectives and operational goals. Producing goods and services on a continuing basis confers many social and economic advantages, which are beneficial to rural communities particularly for sustainable fuelwood supplies. A silvicultural plan is a means to gradually transform the forest stands into more manageable and efficient productive entities. An exception to this, are forests earmarked for preservation or for conversion to other non-wood uses.

10.1 CHOICE OF SILVICULTURAL SYSTEM

"*A silvicultural system may be defined as the process by which the crops constituting a forest are tended, removed, and replaced by new crops, resulting in the production of stands of distinctive form*" (Matthews, 1989). The silvicultural system to be applied depends on the ease with which the *desirable* species can regenerate themselves naturally in the disturbed environment caused by logging and/or the degree to which they lend themselves to artificial regeneration methods. There are few ready made systems which can be used directly without some adaptations to suit local situations. A silvicultural system comprises 3 main components as follows:

(1) the method of regeneration chosen suited to local ecologies, site potential and silvics of preferred species;

(2) the form of crop produced; and

(3) the systematic arrangement of the crops over the whole forest estate, with reference to silvicultural and protective considerations and efficient harvesting of produce.

A classification of silvicultural systems is shown in **Box 10.1**.

Some silviculture systems that may be applied to mangroves are briefly discussed and their main advantages and disadvantages summarized in the following:

10.1.1 Clear-felling systems

Clear-felling systems aim to establish an even-aged stand by removing the mature stands in a single operation. Where the principal species are light demanding and can regenerate naturally, and the sites are favourable, such systems may be very cost-effective. The Matang mangroves have been managed over three rotations using clear-felling systems in blocks without any major problems, except that large areas have to be artificially regenerated as more marginal sites are brought under intensive management, with *R. apiculata* as the main species.

The visual impact after logging can be very disconcerting to non-foresters and conservationists. It should not be practised in areas where ecotourism is contemplated and the felling coupes should not be too extensive. The pros and cons of such systems are listed in **Box 10.2**.

CLASSIFICATION OF SILVICULTURAL SYSTEMS

A1 **HIGH FOREST SYSTEMS** (usually from seedling origin)

B1 Felling/regeneration confined to only parts of forests

C1: Crop cleared by a single felling, resulting in even-aged crop: *Clear Cutting Systems*

C2: Crop cleared by successive regeneration fellings; resulting in more or less even-aged crops:

D1: Regeneration distributed compartment-wise

a. Canopy opening even; young crops more or less even-aged and uniform crop: *Uniform Systems*
b. Canopy opening in scattered gaps, young crops more or less even aged in gaps: *Group Systems*
c. Canopy opening irregular and gradual, resulting crop somewhat uneven-aged: *Irregular Shelterwood System*

D2: Regeneration confined to sub-compartments/strips:

a. Felling in strips: *Strip Felling Systems*
b. Felling in wedge pattern: *Wedge Felling Systems*

B2 Felling/regeneration distributed continuously over the whole area; crop completely irregular or uneven-aged: *Selection Systems*

Variant systems produced by:
a. introducing a young crop beneath an existing immature one: *Two-storied High Forest*
b. retaining certain old crop trees after regeneration is completed: *High Forest with Reserves*

A2 **COPPICE SYSTEMS** (mainly vegetative propagation)

1. Stands derived entirely from vegetative shoots:
Crop even-aged and clear felled: *Coppice System*
Crop uneven-aged and partially felled: *Coppice Selection System*

2. Stands comprise partly vegetative shoots and partly from trees of seedling origin: *Coppice with Standards Systems*

A3 **SHELTERWOOD SYSTEMS** a generic term describing systems of successive regeneration fellings and selections systems.

Note: *"Even-aged" is synonymous with "uniform" or "regular". The terms "uneven-aged" and "irregular" are also synonymous. Above classification adapted from "Silvicultural Systems" by J.D. Matthews, 1989.*

Box 10.1: Silvicultural systems

A "clear-felling in alternate strips" system, with and without retained standards (seed-bearers) is practised in several countries (Thailand, Venezuela, Cuba and Costa Rica). Felling strips are aesthetically more acceptable. The prospects of natural regeneration are enhanced due to the narrow width and the long borders relative to the size of the area felled and management control is simple to apply.

Clear-felling systems

Advantages:

(a) simple to implement and supervise;
(b) logging costs are generally lower, higher out-turn;
(c) over-mature stand removed in one operation;
(d) less skills needed than other reproduction methods;
(e) create even-aged regulated forests in one rotation;
(f) affords complete overhead light, required by light demanders.

Disadvantages:

(a) erosion and site deterioration risks may be higher;
(b) seedlings may be unevenly distributed;
(c) species must be able to withstand open conditions;
(d) high damage to advance growth if logging not well conducted;
(e) reduces the aesthetic and amenity values of stands;
(f) all trees, irrespective of species and merchantability are cut;
(g) it creates a large amount of logging slash and debris.

Box 10.2: Advantages and disadvantages of Clear-felling Systems

This system, due to its simplicity, is recommended where there is a shortage of trained personnel and/or skilled workers. It is also suitable for those countries where mangroves are newly brought under management.

10.1.2 Selection systems

Selection systems are characterised by two conditions: viz., the stands are uneven-aged, and the forest cover is never completely removed so as to deprive advance growth and seedlings of shelter and shade. Generally, such systems favour shade tolerant species but the degree of canopy opening may be manipulated to favour light demanders as well (e.g. Group Selection)

A selection system has been practised in the Sundarbans for a long time and also in the Ayeyarwady mangroves in Myanmar. This is an environment-friendly system in that the merchantable trees are harvested periodically and over all parts of the forests. In practice, however, unless the forests are adequately stocked, and the technical and subordinate staff are well trained coupled with responsible timber contractors, management can be very complex. The merits and demerits of selection systems are summarized in **Box 10.3**.

A variant of the Selection method is Group Selection. This system creates larger felling gaps, that favours the regeneration of light demanding species and promotes the formation of small groups of even-aged stands. Consequently, harvesting costs are lower and wood extraction is simpler.

Selection Systems

Advantages:

(a) only system capable of maintaining an uneven-aged stand;
(b) reproduction of tolerant species is easily obtained;
(c) site protection is excellent;
(d) stands can be readily adapted to meet fluctuating market demands;
(e) capital returns at short intervals.

Disadvantages:

(a) high level of technical skills and management control needed;
(b) extraction costs are higher and smaller removals/unit area;
(c) product dimensions more variable;
(d) crop trees are scattered throughout the stand;
(e) inventory data analysis and growth-yield forecasts are difficult;
(f) not favourable for growing intolerant species

Box 10.3: Advantages and disadvantages of Selection Systems

Shelterwood Systems

Advantages:

1. provides protection to species with sensitive juvenile stage;
2. excellent soil protection and reduces invasion by weeds;
3. less risk of multiplication of injurious insects that breed in clearings;
4. stands more wind-firm and better adapted to cyclonic areas;
5. aesthetically more pleasing than clear-felling systems;
6. selected trees can put on better increments through stand improvement treatments and gap openings.

Disadvantages:

1. requires more skill;
2. work dispersed, felling and extraction less profitable;
3. higher logging damage to young crops;
4. delayed regeneration response can be costly;
5. yield regulation and silviculture more complex.

Box 10.4: Advantages and disadvantages of Shelterwood Systems

In the Sierpe-Terraba mangroves in Costa Rica, a Selection system was suggested for areas with proven molluscan potential, as the commercial bivalve Piangua (*Anadara tuberculosa*, Sowerby), which appears to be associated with *Rhizophora* and *Pelliciera* roots, does not thrive under open conditions unlike their Asian varieties. Partial removal of the overwood reduces site disturbance and over-exposure.

10.1.3 Shelterwood systems

Shelterwood systems are those high forest systems in which the young crop is established under the shade or side-shelter of the old one, referred to as the "*overwood*". The overwood protects the site and sustains the forest micro-environment conducive to the regeneration and growth of the younger trees. The term is used to include some variants of the selection system using successive regeneration fellings. Pros and cons of such systems are described in **Box 10.4** on the previous page.

10.2 CHOICE OF SPECIES

A species preference list, based on silvicultural and marketing requirements, should be drawn up as a guide in prioritising treatment. The species, which are selected as ***desirables***, vary according to ecosystem type, location and market demand. In Costa Rica, *Rhizophora harrisonii* and *R. mangle* are the desirables, whereas in Sierra Leone, West Africa, *R. mangle* is a dwarf form and *R. racemosa* is the preferred species. In Malaysia, Thailand and the Mekong Delta in Vietnam *Rhizophora conjugata, R. apiculata* and *R. mucronata* are highly favoured. In the Bangladeshi Sundarbans, Sundri (*Heritiera fomes*) is the prime timber species, followed by Gewa (*Excoecaria agallocha*) a proven pulp species. In the Guanal mangroves in Cuba *Avicennia germinans* (mangle prieto) is the favoured species as the wood is suitable for railway ties and utility timber. An example of a species list for the Sierpe-Terraba mangroves, Costa Rica is shown in the box to the right.

Desirable	1. *Rhizophora harrisonii* 2. *Rhizophora mangle#*
Preferable	3. *Pelliciera rhizophorae* 4. *Avicennia germinans*
Acceptable	5. *Laguncularia racemosa*
Undesirable	6. *Other species*

\# *The dwarf-form of Rhizophora manglé, probably an ecotype should be avoided.*

10.3 NATURAL REGENERATION

Advocates of natural regeneration argue that such silvicultural systems are more in tune with the natural indigenous forest ecologies. The pros and cons of natural versus artificial regeneration are described in **Box 10.5** on the following page.

Natural Regeneration

Advantages:

1. cheaper to establish;
2. less labour and heavy equipment required;
3. origin of seed sources usually known;
4. better early root development by natural seedlings;
5. usually less soil disturbance

Disadvantages:

1. less control over spacing, initial stocking and distribution of seedlings;
2. risk of seed tree loss;
3. genetically improved stock not easily introduced;
4. regeneration delays and failures possible;
5. greater need for non-commercial thinning;
6. stands not suited to mechanised extraction;

Box 10.5: Advantages and disadvantages of Natural Regeneration

10.3.1 Seed sources for natural regeneration

In a "clear-felling in alternate strip" system, the natural sources of regeneration are as follows:

(a) existing advance growth of seedlings/saplings,
(b) seeding from perimeter trees around the felling strip,
(c) seeding from standards (mother-trees),
(d) water-borne propagules from adjacent stands,
(e) propagules from felled trees

10.3.2 Retention of standards (seed-bearers)

For *Rhizophora* stands the number of standards (seed-bearers) required is about 12 trees/ha. These should be well distributed and strategically retained in areas with insufficient or no regeneration. Generally, more standards are needed towards the swamp interior because of its inherent lower regeneration potential. When logging coincides with a heavy seeding year, the number of standards may be reduced.

The use of standards implies that the species can bear enough of propagules to reseed the site after logging and that the trees so retained can withstand exposure and isolation. In the drier north Pacific coast in Costa Rica, Jimenez has observed that only dominant stems of more than 15 cm DBH.ob bear propagules (per. com.). The number of propagules varies from 6-350 per tree. *Rhizophoras* are prone to sun-scorching and medium-sized stems apparently can withstand over-exposure better. Windthrow is always a risk on sites with very soft soils or exposed to strong winds.

Seed-bearers should be chosen and marked before logging. The criteria for the selection of standards or seed-bearers are as follows:

(a) medium-sized (>16cm DBH.ob), vigorous trees with healthy crowns, which are judged to be capable of surviving one rotation;

(b) trees bearing viable propagules or capable of producing viable propagules (healthy, unbroken crowns);

(c) avoid over-mature or very large trees because they:
- are prone to wind-throw and lightning; and can cause substantial damage to regrowth when they fall;
- may not produce viable propagules;
- contain substantial wood volumes, which, if not removed, will significantly reduce economic yields;
- are prone to termite attacks and bark scorching.

(d) a few malformed trees may be selected if they are healthy and bear viable propagules, but should be avoided if possible;

(e) standards that are damaged during logging should be not be accepted;

(f) in fluid or unstable substrates more standards are selected and these should be in groups of two-three trees to promote wind firmness;

(g) only desirable species are chosen as standards.

(h) more standards should be selected and retained in the backswamp areas.

Box 10.6: Criteria for the selection of seed-bearers (standards)

10.4 REGENERATION STOCKING

Artificial planting is required to restock blanks and sites with insufficient natural regeneration. However, natural regeneration is always preferred because it is cheaper. For this reason an assessment of the regeneration stocking *before* and *after* logging should be carried out. A linear regeneration sampling (LSM) will provide an overview of the site regeneration potential, in terms of seedling abundance, distribution, species and sizes. Some of the aspects to be considered are as follows:

10.4.1 Inadequate regeneration

Regeneration may be insufficient or absent due to the following:

(a) incomplete removal of overwood (*in the case of light demanders*);
(b) excessive damage during logging due to incomplete supervision and/or logging operation is too prolonged;
(c) excessive amount of logging debris and not properly stacked;
(d) unfavourable soil condition;
(e) absence of standards,
(f) excessive tidal wash (high energy sites) due to indiscriminate removal of the protective fringe trees;
(g) weed competition (e.g.*Acrostichum* ferns).

10.4.2 Regeneration classes

Seedlings above 30 cm high are often referred to as "*established regeneration*", and those below are noted as "*potential regeneration*". Regeneration classes, recognized and recorded during LSM regeneration sampling, are shown in **Box 10.7** below.

However, it should be noted that this classification system should be adapted to local conditions as *Rhizophora* propagules for instance may well exceed 30 cm in length without being considered "*established regeneration*".

Regeneration classes (RC)	Description
I	Seedlings of over 30 cm but less than 1.5 m in height;
II	Seedlings/saplings of 1.5 m or more in height but less than 3 m;
III	Saplings of 3 m or more in height but less than 5 cm DBH.ob.

Box 10.7: Regeneration classes

10.4.3 Regeneration stocking adequacy standards

For adequate natural regeneration a minimum of 2 500 well distributed seedlings per hectare (RC I), equivalent to a spacing of 4 m^2/seedling is required for multiple-use *Rhizophora* plantations. For bioenergy plantations, based on short rotations, 10 000 - 20 000 seedlings/ha may be required. The purpose here is to optimize above-ground biomass rather than to produce a mix of products like posts, poles and large size charcoal billets.

Applying mortality rates of 50, 30 and 10 percent for the 1-10, 11-20 and 21-30 year periods, the corresponding stand densities will be 1,250, 875 and 788 trees/ha at the end of 10, 20 and 30 years (**Table 10.1**). The overall mortality rate applied is -3.78% per annum compound.

Table 10.1: Average stand density and mortality rate for *Rhizophora apiculata*

Period (years)	Mortality % per period	Density stems/ha	Annual %
0 - 10	50	2 500 - 1 250	-6.70
11 - 20	30	1 250 - 875	-3.50
21 - 30	10	875 - 788	-1.04

Artificial planting must be initiated if less than 70 percent of the stand is regenerated with the desired species within 3 years. In *Acrostichum* fern infested areas, adequate regeneration should be secured at the end of two years.

The regeneration adequacy stocking standards for linear regeneration sampling (LSM) with different plot sizes are shown in **Table 10.2** below.

Table 10.2: Minimum seedling regeneration stocking for different sampling quadrat size (RC I)

LSM Quadrat sizes	Area in hectare	Quadrats per ha	Min. stocking per quadrat
2.5m x 2.5m	0.000625	1 600	2@
5 m x 5 m	0.002500	400	6
10m x 10m	0.010000	100	25

Note: seedlings: 30cm < =height < 1.5m; @ rounded.

10.4.4 Linear regeneration sampling

Linear regeneration surveys based on systematically laid out lines are used to assess regeneration status. Parameters used in the analysis and interpretation of results include the following:

(a) Stocking: This gives an indication of the completeness or distribution of the regeneration:

(b) Abundance: This refers to the number of individuals/quadrat for stocked quadrats. It gives an indication of crowding for larger regeneration classes and regeneration potential in the case of seedling regeneration.

(c) Regeneration size: The "regeneration size classes" of the advance growth is recorded. (Refer to the regeneration classification described above).

10.4.5 Effective stocking

To assess effective stocking the relative presence, abundance and sizes of all regeneration classes RC I-III are weighed. When larger sized seedlings/saplings (RC II/III) are present, their potential contribution to final crop stocking is considered, particularly when young seedlings (RC I) are found to be lacking or insufficient. The analysis and interpretation of regeneration sampling, therefore, will not be complete unless the role of larger regeneration classes is considered.

If the effective stocking is less than 70 percent, the cause should be determined by field inspection. If the void areas are plantable, artificial regeneration should be undertaken during the following planting season. All planting costs and silvicultural operations are recorded in the compartment history. On the other hand, if portions of the area are void because of deep flooding or other natural causes which make it impractical to replant, the affected portions (if large enough, say 2 ha) should be marked out in the compartment map and noted in the compartment history.

10.5 ARTIFICIAL REGENERATION

In planting of mangroves, plants belonging to the Rhizophoraceae are the most common species used and the following description applies mainly to *Rhizophora spp*. For information on artificial regeneration of other species the reader is referred to Das and Siddiqi (1985) and Siddiqi *et al*. (1993).

10.5.1 Phenology

The flowering and fruiting behaviour of the principal economic species should be studied to secure the timely collection of ripe propagules.

The selection of plus trees as potential bearers, and the setting up of "seed orchards" may be advantageous where there is a shortage of quality seeds and/or a large scale plantation programme is planned.

Rhizophoras produce propagules annually. In Costa Rica, *R. harrisonii* produces mature propagules mainly during June and July although there are some stragglers. *R. mangle* flowers more freely.

In Sierra Leone, West Africa, the main fruiting season of *Rhizophora racemosa* coincides with the beginning of the rainy season in May-July and the ripe propagules are easily recognized by the appearance of a 'collar' beneath the pericarp.

In Malaysia, the principal *Rhizophoras* fruit during June to December. Preliminary studies indicate that most species flower and bear fruits several months earlier in the drier and stressed sites in the Ayeyarwady delta area in Myanmar. For instance, *Aegiceras corniculatum* flowers and fruits during May to mid-July on the drier sites, but flowers and bears fruits only during July and mid-August in the lower intertidal zone. This general trend applies to most species that naturally occur over a wide range of sites.

Figure 10.1: Dense natural regeneration of *Rhizophora spp.*, Matang, Malaysia
Photo by M.L.Wilkie

Figure 10.2: Artificial regeneration of *Rhizophora apiculata*, Matang Malaysia
Photo by M.L.Wilkie

10.5.2 Collection of propagules

In Costa Rica, *Rhizophora mangle* and *R. harrisonii* propagules look rather similar, although the latter has a longer radical, more lenticellated and tapers more towards the shoot. Propagules are collected from mature *R. harrisonii/R. mangle* stands as there are varieties (ecotypes) that tend to produce multi-stemmed or dwarfed forms. The "mangleros" can easily distinguish between mangle caballero (*R. harrisonii*) and mangle gateador (*R. mangle*), and they are contracted for seed collection. In the Matang, *R. apiculata/R. mucronata* propagules are collected by tender during June to December. Contractors deliver the seedlings to the planting sites and these are culled by the Forest Ranger.

Two fruiting seasons are observed in the Ayeyarwady delta in Myanmar. In upper tidal zone ripe seeds are collected from mid-May to early June, before the monsoon starts. In the wetter zone, the collection season is from mid-July to early August. Ripe propagules are dark brown with a tinge of purple and are easily detached from the tree by shaking. Newly fallen propagules that float are also collected. As a guide, only ripe and healthy propagules of normal size and having well-formed radicals, that are unblemished by insect attack marks, are accepted.

10.5.3 Site preparation

After logging, the slash should be pruned, collected and stacked in neat rows perpendicular or 45° to the waterways. This is done to promote tidal flushing, dispersal of water-borne propagules and to reduce tidally induced slash movement that can cause damage to established seedlings and advance growth on the ground.

In *Acrostichum* infested areas, eradication measures should be carried out immediately. It is recommended that this be done manually as spraying with herbicides may adversely affect the marine environment.

10.5.4 Nursery operations

In most cases where *Rhizophora sp.* are planted, the propagules are transplanted to the field immediately and nursery operations are not necessary. However, in heavily crab infested areas or areas prone to deep flooding it may be advantageous to raise the seedlings in a nursery prior to planting in the field.

For other species such as *Sonneratia spp, Avicennia spp* and *Excoecaria agallocha*, which all have relatively small seeds, raising of seedlings in a nursery is advisable. For an excellent account of mangrove nursery practises developed for a variety of species in Bangladesh, please refer to Sidiqi *et al.* (1993).

10.5.5 Planting

In Matang, a reforestation plan is prepared before planting, listing the extent and areas to be planted, complete with an estimate of supporting resources needed.

Figure 10.3: *Rhizophora racemosa* propagules ready to be planted, Sierra Leone
Photo by M.L.Wilkie

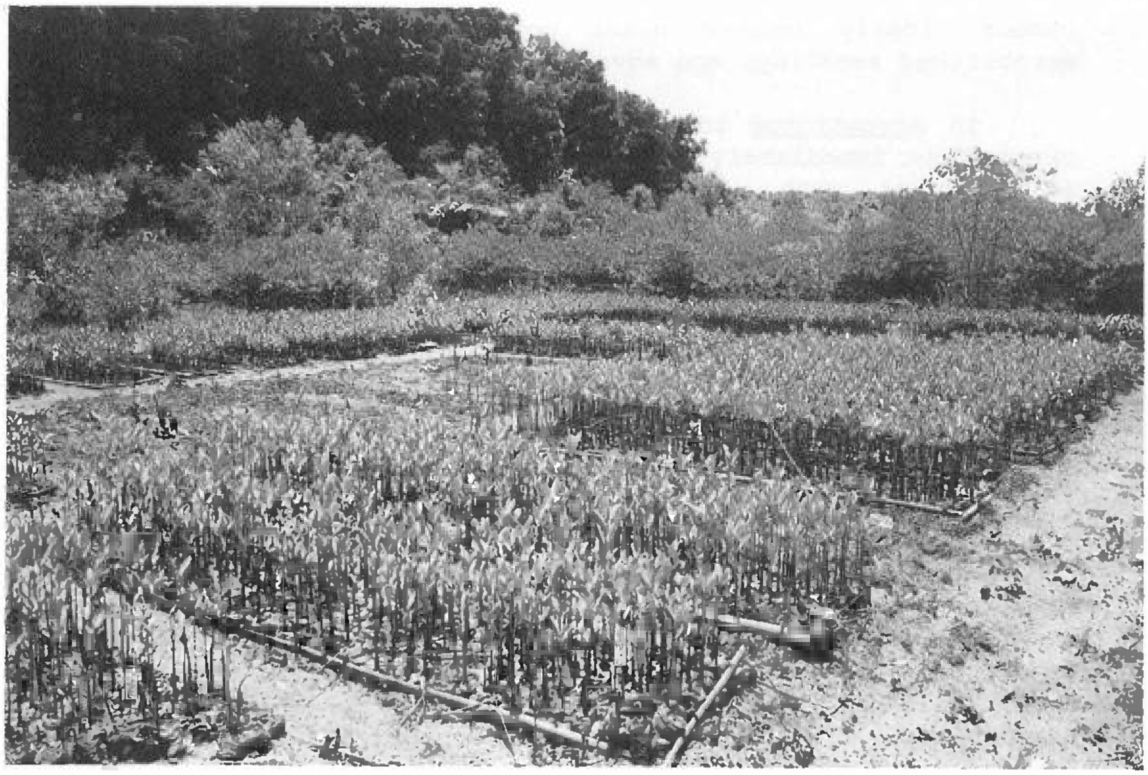


Figure 10.4: A mangrove nursery with *R. apiculata* and *B. gymnorrhiza*, Indonesia
Photo by M.L.Wilkie

The planting spacings are 1.5 x 1.5 m within the swamp for *Rhizophora apiculata* and 1.8 x 1.8 m beside the waterways for *Rhizophora mucronata*. Seedlings are planted by pushing the radicals gently into the soft mud up to about 5-7 cm deep.

Aerial sowing, on an experimental basis, was tried in the Indian Sundarbans mangroves with promising results as elaborated in **Box 10.8** below:

Aerial seeding of mangroves - an Indian experience

Reforesting mud-flats on Kakdwip island by means of aerial seeding with a helicopter was conducted for the first time in the Indian Sundarbans during August 1989. Treated tidal sites comprise regularly flooded, silty loam mud-flats, covered with Dhani ghas grass (*Porterasia coarctate*) and low bushes of Hargoja (*Acanthus ilicifolius*). Baen (*Avicennia officinalis, A. alba*) and Keora (*Sonneratia apetala*), the natural pioneering species, were used.

The seeding period is from mid August to early September after the full moon high tides. With a HILLER VI-EKB helicopter carrying 300 kg of seeds, 30 ha were seeded per day at a seeding rate of 6 ha/hour. A total area of 450 ha was treated in this way.

Survival surveys conducted in February the following year indicated establishment rates of 150 - 3,880 seedlings/ha. The seedlings were not uniformly distributed but with better seed hopper design and using a Beaver type of aircraft better results were obtained.

Source: Lahiri, A. K. 1991

Box 10.8: Aerial seeding of mangroves

In Sierra Leone, school children from the local primary schools assisted in planting mangroves in connection with the National Tree Planting Day. Please refer to **Figures 10.5 and 10.6** on the following page.

10.5.6 Afforestation of newly formed mudflats

Extensive afforestation has been implemented in the Bay of Bengal for many years to accelerate the reclamation of newly formed mudflats along the coast. *Sonneratia apetala* and *Avicennia officinalis* are the favoured species (Das and Sidiqqi, 1985). Other species, including non-mangroves such as *Acacia nilotica*, *Eucalyptus camaldulensis and Casuarina equisetifolia*, which can tolerate saline soils, can also be planted on the more consolidated sites. Natural soil subsidence in the newly accreted mud-flats can cause some of the plantations to disappear overnight. Overall, however, such reclamation efforts have accelerated silt entrapment, stabilized new accretions and protective embankments, while creating more land that is needed to accommodate an expanding rural population and for other agricultural uses.

Figure 10.5: **Planting of mangroves by school children**
Sierra Leone. Photo by M.L.Wilkie

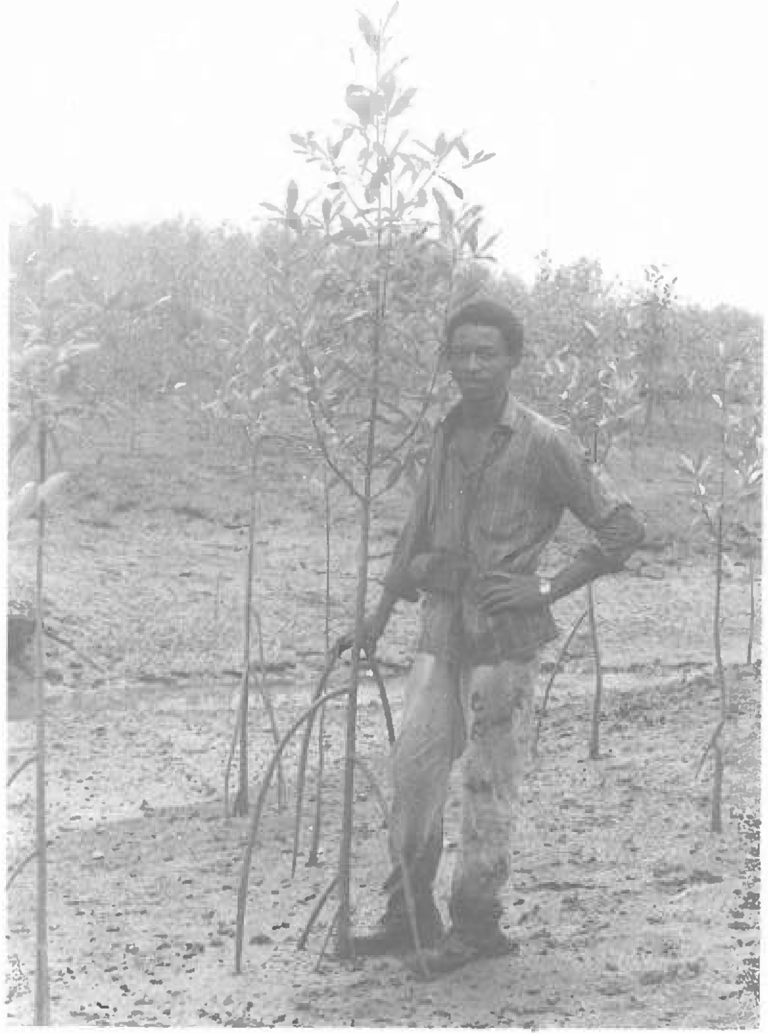


Figure 10.6: ***Rhizophora racemosa*** **2 years after planting**
Sierra Leone. Photo M.L.Wilkie

10.5.7 Reforestation of degraded areas

In 1988 a trial planting with *R. harrisonii* was initiated at Boca Chica, Sierpe-Terraba reserve in Costa Rica, where there were more than 5 000 ha of *Acrostichum* infested swampland. A significant proportion of the river-banks were denuded. The fern, about 2 m high, was manually cleared in rows perpendicular to the waterways. The planting spacing used was 1.5 m. x 1.5 m. Low survival rate (about 50%) was achieved because the site was rather dry and *R. harrisonii* might not be the suitable species. The seedlings were also attacked by borers.

Experimental plantings with 12 species were undertaken since 1990 in the Laputta and Bogalay townships of the Ayeyarwady delta in Myanmar. In the elevated and drier sites, *Excoecaria agallocha* was the most promising species. It coppices very well, starts slowly but picks up after having consolidated its rooting system. The primary roots grow deep into the mud and are therefore, less easily damaged by superficial soil cracking experienced during the hot and dry months. Some *Bruguieras* also fair well on similar sites but require better soil moisture conditions. The most difficult to re-establish was *Heritiera fomes* because it required a good supply of superficial freshwater. The network of *Heritiera* pneumatophores cannot develop properly when the surface soil hardens and cracks during the dry months. *Sonneratia apetala, S. caseolaris* and *Avicennia officinalis*, grow well in the wetter intertidal zone that is always moist and regularly inundated. Similarly, *Rhizophoras* grow well on the wetter but more consolidated mud-flats that are regularly flooded. *Ceriops decandra* and *C. tagal* regenerate well under *Phoenix paludosa* palm under varying degrees of shade in the drier soils. Overall, the planting trials indicated that the rehabilitation of ex-agricultural lands and denuded elevated sites was not easy. Appropriate species must be selected and planted at the right time and place, and care must be taken to ensure that sea water can reach the planted areas.

Site preparation may be needed to reforestate abandoned paddy lands located on marginal and drier sites, which can sometimes be strongly acidic. The first step is to restore and improve the natural soil condition by allowing the Spring tides and rains to saturate the soil. This can most easily be accomplished by breaching the man-made dikes/bunds that impede water movement. Shallow irrigation canals may also be constructed to guide sea water into the planting sites. Regular flushing removes toxic soil chemicals and recharges the soil with nutrients. Planting of such areas should be undertaken with nursery raised seedlings just before and during the monsoon rains.

Mangrove soils are rich in dissolved salts and pyrite sulphur (FeS_2). When the soil is drained and allowed to dry, oxidation occurs. Oxidation of pyrites, hastened by bacterial action (*Thiobacillus ferroxidans*), produces sulphuric acid that reduces soil pH. When the soil becomes strongly acidic, sulphate ions react with clay particles to release toxic amounts of aluminium ions that inhibit plant rooting and even cause fatality - one of the main causes for paddy land located in former mangrove areas to be abandoned.

10.5.8 Refilling

A year after planting, a survey is carried out to determine seedling survival. Areas with less than 70% survival should be refilled during the following planting season.

10.6 WEED CONTROL

In most mangrove areas there are practically no weeds. However, on drier sites and in more marginal areas there is one important exception: The *Acrostichum* fern, which in Matang in Malaysia seems to affect even the better sites. This fern is difficult to eradicate and in heavily infected areas it may be best to do only spot cleaning around newly planted seedlings - preferably seedlings raised in a nursery. Manual cutting is advocated though the herbicide Velpar is used in some countries. Its affect upon the marine environment has yet to be established.

10.7 DISEASE AND PEST CONTROL

Crabs may be a major problem in establishing mangroves, as they attack the succulent propagules. Various methods have been tried to protect the propagules from these attacks such as painting the hypocotyl with yellow paint, placing it inside a bamboo cylinder and planting seedlings instead of propagules. However, the most successful (and cheapest) method seems to be to let the propagules wither a bit by keeping them in storage for a couple of weeks before planting, as this makes them less attractive to the crabs.

Rhizophora seedlings are sometimes destroyed by stem borers. The frequency and severity of such attacks should be evaluated and may be related to site factors. In Cuba a large proportion of *Rhizophora mangle* propagules are also attacked by borers.

In Maswari, Sierra Leone, pristine stands of 35-40 m tall *R. racemosa* were completely defoliated in 1989 by a type of leaf caterpillar, but fortunately the trees managed to produce new leaves and survived the attack.

Herbivore attacks on mangroves in Thailand (mainly by species belonging to the Coleoptera, Lepidoptera and Diptera orders) are described by Murphy and Meepol (1990) and Rau and Murphy (1990).

Termites (*Nasutitermes termitaria*) are often found in the cankers that develop on the stems, branches and roots above the high-water marks. Infested stems become hollow and prone to wind throw. The incidence of termites and the fact that isolated trees suffer from bark-scorching, make it impractical to retain large stems as seed-bearers, with the aim of producing trees with bark of more than 75 mm in thickness.

In the Sundarbans in Bangladesh, a massive scale of top dying of one of the major species (*Heritiera fomes* or Sundri) has been reported (See for instance BARC, 1990). Whereas gall cankers are often found on affected trees, these infections seems to be of a secondary nature. Increased soil salinity has also been dismissed as the main cause and the general view is that a combination of abiotic and biotic factors may be involved.

Figure 10.7: ***Acrostichum* infested area, Matang, Malaysia**
Photo by M.L.Wilkie

Figure 10.8: **Defoliation of pristine *R. racemosa* stand, Sierra Leone**
Photo by M.L.Wilkie

10.8 THINNING

Depending on the growth rate, the length of rotation and the possibility for marketing smaller dimension products, thinnings of the stands may be conducted to increase the diameter growth of the remaining stock.

In Matang, Malaysia, two intermediate thinnings are carried out when the stands are 15 and 20 years old respectively. The method used is called stick thinning.

In the first thinning a 1.2 m long stick is used and a good, straight tree is selected. All other trees within a radius of 1.2 m are felled, a new tree selected and the procedure repeated. The first thinning thus results in a relative tree distance of 1.2 m with regard to the remaining stock, equivalent to an average 6 944 trees/ha. The second thinning results in a standing stock after thinning of 3 086 trees/ha. The wood obtained from the thinnings is sold as poles or firewood.

10.9 CHOICE OF ROTATION

There is an optimum size or age to which trees should be grown. *The period in years required to grow a stand to a desired condition of either economic or natural maturity* is known as a <u>rotation</u>. It is dependent on a number of factors, such as the objects of management, species or combination of species put under management, their growth rates, etc. Environmentally, the effects of rotation age on litter-fall should also be considered.

Rotations may be classified into four broad types as follows:

(i) The <u>physical rotation</u>: This rotation coincides with the natural life span of a species on a given site, which is an important consideration for amenity forests, gardens, parks or protection forests. In parks that are frequented by the public or in managing recreational forests for tourism, moribund or senile stems may have to be removed to reduce hazards due to falling branches and trees.

(ii) The <u>silvicultural rotation</u>: This is the rotation where, for a given species and site, its regeneration and growth potential remains satisfactory. Useful for amenity forests, where a wide range of tree sizes and the presence of large, mature individuals will enhance the forest landscape value.

(iii) The <u>technical rotation</u>: The rotation under which a species yields the most material of a specified size or specification for a special used. To produce fuelwood the rotation period may be 6-12 years but for charcoal billets varies from 12 - 30 years.

(iv) The <u>rotation of the greatest volume production</u>. This is the rotation that yields the greatest annual quantity of material. This type of rotation is commonly used to maximize production when growth increments data are available. The rotation of the greatest volume production is the point where the current annual increment (CAI) equals the mean annual increment (MAI).

Figure 10.9: *Rhizophora apiculata* **stand after first thinning, Matang, Malaysia**
Photo by M.L.Wilkie

Figure 10.10: **Mature *Rhizophora apiculata* stand ready for final felling, Matang, Malaysia**
Photo by ML.Wilkie

To the above should be mentioned the '<u>financial rotation</u>' which aims to optimize monetary returns on capital under the forest rent principle. Forest rent is similar to the culmination of MAI, except that the increment is measured in net money received instead of in volume units.

10.9.1 <u>Selection of rotation type</u>

Rotations may be classified into 3 broad groups to meet diverse purposes as follows:

(a) To control the supply of certain services, e.g. for amenity forests (Use silvicultural and physical rotations);
(b) To control the production of selected forest products (Use the technical and maximum volume rotations);
(c) To control financial returns (Use the rotation of highest financial return).

Technical rotations are appropriate when a sustained supply of timber is needed to meet priority industrial needs or social demands for wood. That of a financial rotation works best when the fund for silvicultural treatment is a constraint.

For Matang mangroves, Watson (1928) estimated that the MAI culminates at 10.6 m^3/ ha/year at 39-40 years. If the primary aim is to grow trees with bark over 75 mm thick, which will normally be found on trees of over 30 cm DBH, a rotation of more than 40 years is required. Such a long rotation may be economically difficult to justify, and even difficult to apply as in the case of the Terraba-Sierpe mangroves in Costa Rica due to the high incidence of termite and fungal attacks. For these reasons, (and due to the waste of wood) it is not practical to manage forests solely for bark production. Bark should thus be produced as a by-product of wood extraction.

The rotation length depends on the following factors:

- stand volume growth which varies with:
  - (a) species involved;
  - (b) site factor;
  - (c) thinning intensity and treatment.
- silvics of species such as age of seeding, timber quality, etc;
- soil erodibility or deterioration after frequent exposures;
- technical factors regarding equipment for felling/extraction
- economics.

Different lengths of rotation may obviously be selected for different species within the same forest, but also for the same species according to site conditions, end use, purpose of stand etc, i.e. one rotation for each working circle.

10.10 CONSERVATION AND PROTECTION AREAS

10.10.1 <u>Genetic biodiversity</u>

A sustained yield system based on a few desirable species or even monocultural plantations will reduce the genetic diversity of the ecosystem. To avoid this, areas should be set aside for maintaining biodiversity. See **Figure 10.11** for an example of a pristine mangrove area set aside for preservation in Malaysia.

10.10.2 Erosion control

The mangrove is a dynamic ecosystem in which tidal and hydrologic influences determine the pattern of sedimentation and erosion. The body of mud and silt stabilised and held by mangrove vegetation is the best form of natural protection. Accretion and erosion of river-banks are natural occurrences, and it is nature's way of building up the swamp with silt and enriching it with transported nutrients. This should be distinguished from man-induced erosion which can be most destructive and even irreversible. Destruction of riverine and fringe vegetation should be avoided through proper management and control.

10.10.3 Avifauna

Migrant shore birds breeding in Siberia, China and Japan use SE Asian coastal mangroves and mudflats as resting and refuelling sites on their annual migration to Australia.

The maintenance of Nature reserves where logging is prohibited is necessary for avifauna. Herons are commonly encountered at many sites of importance to migratory waders. Some build their nests among the *Acrostichum* ferns. Other species like the Milky Stork *Myceteria cinerea* and the Lesser Adjutant *Leptoptilos javanicus* seem to prefer tall, old trees for breeding (*B. gymnorhiza/R. apiculata*).

Their numbers are reduced due to (a) habitat change/loss (*old trees essential for nesting are lacking*), (b) hunting (*eggs and nestlings were collected for consumption*), and (c) human disturbance (*some sites are regularly disturbed by crab fishermen*). Bird counts in mangrove creeks in Matang revealed the importance of the creeks for a variety of bird species including the Little Green Heron (*Butorides striatus*), Common Sandpiper (*Actitis hypoleucos*, five species of kingfishers and the Masked Finfoot. Some species have feeding techniques adapted to foraging during high tide.

10.10.4 Other wildlife

Other wildlife such as for instance the Royal Bengal Tiger and the spotted deer found in the Sundarbans also require protected areas and/or no disturbance in selected areas during their breeding season.

10.10.5 Fisheries

As fish and other marine animals use the mangrove areas for spawning, feeding and shelter grounds, a belt of mangroves should be kept intact along all waterways except for landing and loading sites necessary for the felling operations.

10.10.6 Recreation and education

Sufficient sites should also be established and maintained to enhance the recreational and educational value of mangrove forests. **Figure 10.12** shows an example of the construction a walkway on stilts in a mangrove area designated for recreation.

All of the above areas may have particular silvicultural needs.

Figure 10.11: The 'Virgin Jungle Reserve', Matang, Malaysia
Photo by M.L.Wilkie

Figure 10.12: Walkway on stilts, Cilacap, Indonesia
Photo by M.L.Wilkie

11 YIELD AND ITS REGULATION

11.1 ESTIMATION OF YIELD

11.1.1 Rates of growth

Growth rates vary, *inter alia*, with species, site conditions, spatial position in the stand, competition status, vigour, and age. Notwithstanding, its inherent variability, mean increment per diameter size class (where age is not known) is normally used as a measure of growth and in stand projection. Growth data may not be locally available, but useful indications may be provided by using data available elsewhere. (Refer to **Table 11.1**, presenting data from the Matang Mangrove area in Malaysia.)

Table 11.1: Diameter growth rates of *R. apiculata* trees by diameter size classes (1920-81)

Diameter (cm)*	10 - 20	20 - 30	30 - 40	40 - 50	50 - 60
Period measured	1920-81	1920-81	1920-81	1946-81	1975-81
Weighted mean annual increment (cm/yr)	0.26	0.28	0.29	0.25	0.24

Source: Putz and Chan, 1986 [* Diameter overbark at breast height]

The spatial position of individuals in a stand, expressed in terms of crown domination, is useful in determining tree vigour. As expected, generally suppressed trees have lower increment rates than the dominants and codominants. (Refer to **Table 11.2**, Putz and Chan, 1986)

Table 11.2: Diameter increment of *R. apiculata* by crown classes in Pulau Kecil

Crown class	Diameter increment (cm/year)
Dominants	0.35
Codominants	0.25
Sub-dominants/Intermediate	0.15
Suppressed/Dominated	0.09

Source: Putz and Chan, 1986

Diameter increment data collected by Jimenez, J.A. (per.com.) for the North Pacific mangroves in the pure *Rhizophora* forests and the overlap zone between *Rhizophora sp* and *Avicennia germinans* are summarized in **Table 11.3**.

Table 11.3: DBH (overbark) increments for *Rhizophoras* in the pure and overlap zones along the North Pacific Coast, Costa Rica.

Diameter class (cm)	Rhizophora Zone Pure	Rhizophora Zone Overlap	Diameter class (cm)	Rhizophora Zone Pure	Rhizophora Zone Overlap
A. 1.7 - 2.9			F. 15.0-19.9		
mean	0.10	0.11	mean	0.08	0.15
std.dev.	0.50	0.10	std.dev.	0.07	0.13
number	50	47	number	24	30
B. 3.0 - 6.0			G. 20.0-24.9		
mean	0.11	0.14	mean	0.10	0.13
std.dev.	0.11	0.12	std.dev.	0.09	0.07
number	50	47	number	21	21
C. 3.5 - 5.9			H. 25.0-29.9		
mean	0.14	0.13	mean	0.16	0.14
std.dev.	0.10	0.09	std.dev.	0.14	0.07
number	35	36	number	13	12
D. 6.0 - 9.9			I. 30.0-34.9		
mean	0.19	0.13	mean	0.09	0.14
std.dev.	0.15	0.11	std.dev.	0.05	0.07
number	44	42	number	15	14
E. 10.0-14.9			J. >35		
mean	0.17	0.17	mean	0.09	0.17
std.dev.	0.15	0.14	std.dev.	0.07	0.08
number	30	40	number	10	15

Source: Jimenez, J.A. (unpublished, 1987)

11.1.2 Yield and production

Yield is the amount actually extracted, while **production** is the total accrued wood increment whether removed or not. The working plan should provide a forecast on revenue flows derived from an estimate of the commercial stem wood. For unevenaged stands and natural forests, where accurate data on growth rates are absent, the potential yield may be determined by an appraisal of the current standing volume.

For example, in Costa Rica an inventory of the Playa Garza forests gave plot volumes of 34.6 m³ - 373.2 m³/ha for stemwood over 10 cm (DBH.ob.). The average stand volume was 280.5 m³/ha, which was high as the forest had previously been exploited. The mean *Rhizophora* stand volume was 163 m³/ha. An indication of the spread of volumes/ha per diameter class is shown in **Table 11.4**.

Table 11.4: Volume in m3/ha per diameter class, Playa Garza, Costa Rica

Diameter classes (cm)	1 10<15	2 15<20	3 20<25	4 25<30	5 30<35	6 35<40	7 40<45	8 >45	Total per ha m3	Total per ha %
Rhizophoras	14.2	22.8	36.0	28.0	22.6	25.7	10.7	3.0	163.0	58.1
Pelliciera	17.6	27.5	32.7	17.9	8.4	8.5	4.8	0.0	117.5	41.9
Total	31.8	50.2	68.7	45.9	31.0	34.2	15.5	3.0	280.5	100.0

Source: Chong (1988a)

It was concluded that the final crop would produce at least 150 m³/ha of *Rhizophora* on a 25 year rotation, and an equal if not higher volume of other species.

In Matang, Malaysia, the average density and volume for 30 years old *R. apiculata* stands are 1 343 trees/ha and 153 m³/ha respectively. In Ranong, Thailand, an average stocking of 812 trees/ha and mean volume of 226 m³/ha have been reported.

The productivity of plantations in the Upper Gulf of Thailand, based on an inventory of privately owned plantations in Yeesarn by Wechkit (1987) is presented in **Table 11.5**. This is not a yield table because the data are compiled from diverse sites.

Table 11.5: Growth and Yield of *Rhizophora apiculata* plantations of different ages and sites in Yeesarn, Samut Songkram Province, Thailand

Age in yrs	Stand Density No of stems per hectare	Diameter (dbh) cm	Height m	Commercial Volume m3/ha	Annual Growth m3/ha/yr	Total Volume m3/ha
1	23,800	-	0.45	-	-	0.60
2	23,000	-	1.07	-	-	1.53
3	21,700	0.94	1.76	-	-	2.88
4	22,000	1.59	2.36	2.15	0.54	8.79
5	20,400	2.26	3.71	18.38	3.68	23.17
6	20,700	2.50	4.41	26.03	4.34	29.98
7	21,000	2.83	4.92	41.68	5.95	45.18
8	20,000	2.97	5.58	49.29	6.16	52.34
9	19,000	3.26	6.82	69.30	7.70	71.50
10	18,000	3.65	7.30	88.39	8.84	90.82
11	16,200	4.31	8.94	128.28	11.66	131.17
12	13,300	5.18	10.19	161.97	13.50	164.90
13	11,200	5.51	10.76	163.14	12.55	165.77
14	11,500	5.98	11.40	231.00	16.50	233.56
15	10,300	6.26	12.36	219.29	14.62	221.85

Source: Weechakit, 1987

The mean annual growth is derived by dividing total commercial volume with known age and whereas the table seems to indicate that MAI rises significantly after year 10, the data are heavily influenced by site factors.

11.1.3 Effective logging area

The effective logging area refers to the area actually worked after having excluded so-called unproductive areas such as rivers and canals, areas required for conservation, coastal protection, research, recreation or other purposes incompatible with the felling of trees as well as the naturally unproductive sites. The volume yield is then calculated by multiplying the effective area to be felled by the mean volume per ha.

11.1.4 Estimation of product-mix

The mix of forest products to be produced during a plan period should be estimated in the working plan, in the form of tonnes of charcoal billets, cubic metres/steres of firewood, number of posts and poles, etc,. An example of the estimation of product-mix from Costa Rica is described in Box 11.1 below.

The potential end products for *Pelliciera rhizophorae* dominated stands were determined by estimating the number of 1.5 m sectional lengths obtainable from merchantable-stem wood up to 10 cm underbark for different diameter size-classes.

The relationship between merchantable height (Hm) to 10 cm top diameter underbark and DBH.ob was given by the linear regression [Hm = - 6.564 +0.864(DBH)] with a correlation coefficient of 0.94 (std.error 2.194 and F-ratio 170.6). This regression was used to predict the merchantable height (i.e. merchantable bole) for different diameter size classes. Knowing this, the potential mix of end-products is determined based on the known product specifications and their market values for a given country, as for example shown for Costa Rica in **Tables 11.6 and 11.7** below.

Telegraph/transmission poles can also be used for construction purposes. In Costa Rica, the standards used for wooden poles are based on that for Western Red Cedar and Ponderosa Pine instead of local timber. Locally, concrete poles are also used and these are considerably more expensive than wooden ones.

Source: Chong (1988a)

Box 11.1: Estimation of product-mix in Costa Rica

Table 11.6: General specifications for selected mangrove-based products in Costa Rica

	Products	Diameter/tree(cm)	Length (m)
1.	Firewood	< 10	1 - 1.5
2.	Charcoal	10 - 25	1.5
3.	Fencing posts	10 - 21	2 - 2.5
4.	Telegraph poles	17 - 21	8.0
5.	Transmission poles	22 - 31	12.0
6.	Sawlog	> 30	4 - 8.0

Table 11.7: Estimated products range based on diameter classes and merchantable height (10 cm overbark)

Merchantable height (m)	DIAMETER CLASSES (cm) I (10<15)	II (16<21)	III (22<31)	IV = > 31
3 - 7	Firewood	Billets Posts	Billets Posts	Sawnwood Post
8 - 12		Billets Telegraph	Billets Posts	Sawnwood
3 - 15			Posts Transmission	Sawnwood
16+			Sawnwood	Sawnwood

Source: Chong (1988a)

11.2 Forest Yield Regulation

A regulated forest is *one in which sustained yield condition operates over all parts of the managed property*. This is seldom possible in practice. It is determined by, (a) the rotation period, and (b) the annual cut.

11.2.1 Determination of the annual cut

All silvicultural operations culminate in the removal of forest products, such as fuelwood, poles, posts and timber, etc. The final felling has the most decisive influence on the forests and is in itself a silvicultural operation. The determination of the type, location and amount of the cut is crucial, therefore, for the future shape and development of the forests.

A cutting policy determines the following, viz., how much to cut, the kind, quality and dimension of produce to be harvested and where to cut and in which sequence? It is guided by following considerations:

(a) achieve management objectives;
(b) market situation for different products;
(c) silvicultural needs and constraints;
(d) harvesting constraints;
(e) environmental impact on non-wood values, e.g., fishery, mollusca, apiculture, wildlife and ecotourism potential which may be disrupted by extensive clear-felling;
(f) social aspects such as sustained employment, off-season employment opportunities, etc.

There are two possible approaches to determine the cut; viz., (a) by means of area control, and (b) through volume control.

Neither approach, can by itself, be completely satisfactory because a volume to be cut is meaningful only if it is location-specific, otherwise is difficult to apply and supervise. Thus, area and volume approaches are complementary and often combined.

Area Control

The principle of area control is that *annually a certain area of forest is available for final felling*. Where the site is very variable and/or the area is large, it is usually not possible to stabilize volume production based on cutting an equal area of forest annually. Fluctuations in yearly volume yields can be mitigated by the device of using equiproductive or 'reduced' areas, which take into account site productive capacity.

Example: If a uniform forest is managed under a 30 years rotation, then each year 1/30 of the total forest area reaches the rotation age and will be harvested and regenerated. This can be expressed by the following formula:

$AC = A/R$ where AC = Annual Cut in ha/year;
A = Total productive forest area in ha.
R = Rotation in years

Note: The Annual Cut in this example is the area annually available for final felling. An equal size area is available for each of the prescribed intermediate thinnings.

Volume Control

In this method, the cut is determined by the volume and distribution of the growing stock and/or the increment. The required data are derived from forest inventory results. Von Mantel's formula which is entirely based on the growing stock may be used as a guide. The formula may be expressed as follows:

$AC = 2(Gs/R)$ where AC = Annual cut (m^3);
Gs = Growing (standing) stock (m^3);
R = Rotation (years).

Example: Given a total forest area of 3 000 ha with a standing stock of 360,000 m^3 and a rotation of 30 years, the annual cut in m^3 will be determined as follows:

$$AC = 2 \times (360\,000/30)$$

$$= 24\,000 \text{ m}^3\text{/year}$$

$$= 8 \text{ m}^3\text{/ha/year.}$$

Note: This estimate of the allowable annual cut in m^3/ha is inclusive of the volume removed through intermediate thinnings.

The value of Von Mantel's formula lies in its simplicity, the small amount of data required for its use, and its usually rather conservative results.

However, it can only serve as a quick and rough approximation, and its application is restricted to forests of even-aged stands with a balanced distribution of age classes, i.e. a 'normal forest'. In practice, this is seldom the case.

More precise control methods incorporate the annual increments and combine the area and the volume control methods, as these two methods are complementary. For this combined approach the data requirement is more demanding and may be difficult to fulfil.

As a general rule for plantations with comparatively short rotations, the area control method will provide acceptable results, whereas in natural forests with uneven-aged stands the volume control method will lead to better results.

Detailed coverage of the more sophisticated control methods is beyond the scope of these guideline. Reference should be made to standard forest management texts. (e.g., Davis, K. 1966; Osmaston, F.C. 1968, Clutter, J.L. *et al*, 1983)

11.2.2 Regulation in even-aged stands

Stands in which *the dominant and co-dominant trees are about the same age* are defined as "even-aged". Even-aged stands may be established as follows:

- Afforestation or reforestation after clear-felling;
- Coppicing system;
- Seed tree method and natural regeneration (shelterwood system)

However, by relying completely on natural regeneration it may be difficult to achieve even-aged status, unless steps are taken to intervene either by spot, enrichment or even block planting when the regeneration stocking is judged to be inadequate in numbers or unevenly distributed.

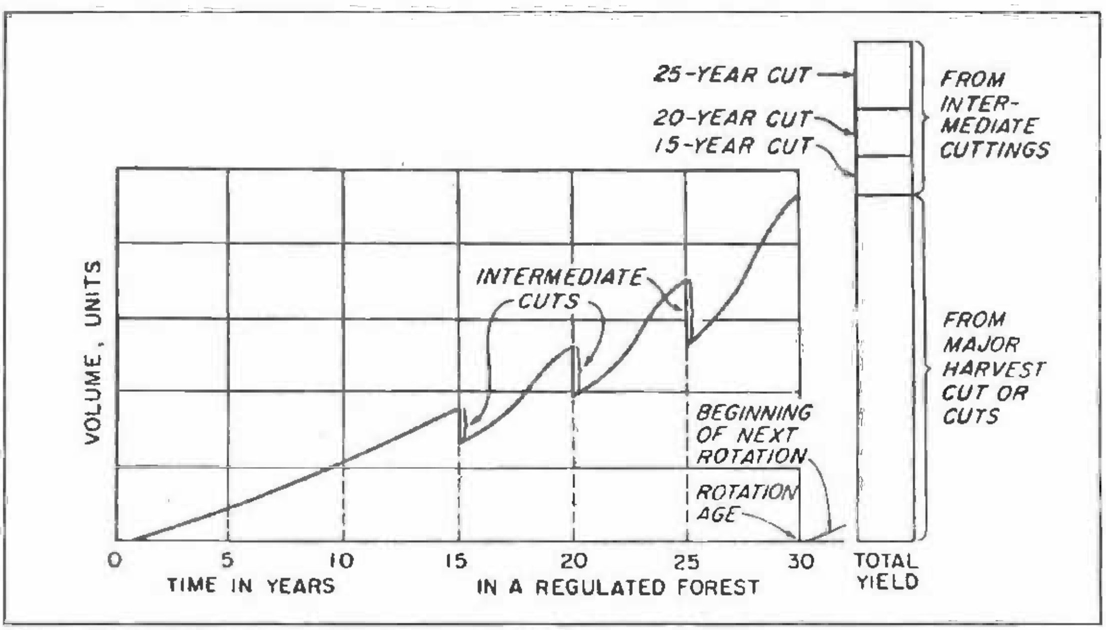


Figure 11.1 Life-pattern of an even-aged stand

The management of even-aged stands is characterised by the application of clearly defined rotation periods and silvicultural measures aimed at achieving an even age-class distribution. **Figure 11.1**, adapted from Davis (1966), graphically depicts the life-pattern of an even-aged stand over a rotation of 30 years.

11.2.3 Regulation of uneven-aged stands

The Society of American Foresters defines an uneven-aged stand as one in which *there is considerable difference in age of trees and in which three or more age-classes are represented.*

The management of uneven-aged stands is directly related to a certain cutting cycle which starts with a certain reserve of standing stock.

The cutting cycle is the planned interval between major felling operations in the same stand, and is determined by the stand volume increment. Felling begins once the growing stock has attained the desired volume or the desired dimensions. A number of marked or selected stems are removed the volume of which in aggregate equal the volume of the total increment of the stand within the cutting cycle.

The general objective is to harvest before the increment of the stand volume decreases significantly and to maintain a defined reserve of growing stock. **Figure 11.2** illustrates the effects of the cutting cycle on the growing stock of an uneven-aged stand.

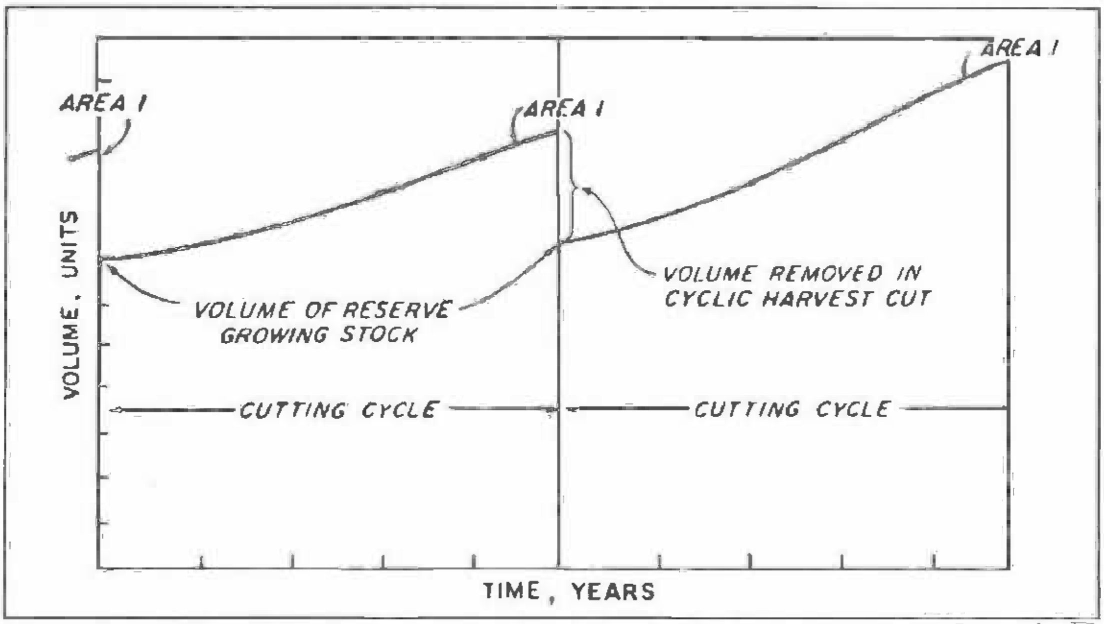


Figure 11.2 Life-pattern of an uneven-aged stand

11.2.4 Control of removals

Due to the variability between stands, it is impossible to extract equal volumes every year, therefore, a 5-10% variation in annual yield can be expected. In order to control the yield, the planned cut is compared to the actual cut through periodic inventories. The purpose is to maintain a sustained yield of forest products.

It is clear that only in ideal situations will the actual annual cut corresponds to the one which was determined at the beginning of the inventory period. In principle, however, the total actual cut or removal in volumetric terms within the planning period should correspond to the planned one, i.e., the total cut divided by the number of years of the planning period should result in the planned annual cut. This can be controlled by using the following formula:

$$I = \frac{(V_{t+n} - V_t) + Hn}{n} \quad (m^3/ha/year)$$

Where:

I	=	mean annual increment during the period in m³/ha/year;
V_{t+n}	=	stand volume in m³/ha at the end of the planning period;
V_t	=	stand volume in m³/ha at the beginning of the planning period;
Hn	=	sum of the intermediate removals in m³/ha within the planning period;
n	=	planning period in years.

Sustained yield management would be judged to be prevailing if the total actual cut during a plan period does not exceed the accumulated annual increment during the same period.

Example:

V_{t+n}	=	180 m³/ha;
V_t	=	120 m³/ha;
Hn	=	30 m³/ha (in the form of pole thinnings);
n	=	10 years (working plan period);

Substituting, therefore:

$$I = \frac{(180 - 120) + 30}{10} = 9 \text{ m}^3/\text{ha/a}$$

In this example, the mean annual increment of 9 m³/ha/year is slightly higher than the average annual cut of 8 m³/ha/year as shown in the earlier example. The growing stock has increased and sustainable yield is achieved.

12 HARVESTING AND EXTRACTION OF MANGROVE WOOD

12.1 THE FELLING PLAN

The felling plan sets out the sequence of logging operations over space and time, complete with felling prescriptions to guide the area forest manager.

Preparation of a felling plan begins from the design of inventories which should ask basic questions such as: Where, when and how the cutting/logging operations take place? (See **Table 12.1**). A felling plan must contain a clear statement showing the average annual cut in for a fixed duration, say the next 10 years. Clear prescriptions are given to achieve the production targets and forest renewal programmes planned.

Table 12.2: Example of detailed objectives for a Felling Plan Inventory

Part of the General Objective	Detailed Objective	Data specification
Where?	1. Mapping of stands. compts, and sub-compartments (treatment units)	Aerial photography Photo-interpretation Field survey - maps
	2. Description of stands and compts. with regard to terrain, stand and tree factors	Field work. Integrate data from strategic inventories (data processing)
When and how should the cutting\logging operations take place?	3. Operative and relevant classification of stands and compts. from management system point of view, priorities with the 10 - years period and the cutting/logging system to be applied.	Problem-oriented classification Accessibility studies

Source: N.E. Nilsson, 1978.

12.1.1 Felling strips

Dimensions

The width of the felling strip is often set to 50 m which is about 1.6 - 2 times the height of the predominant trees. It can be varied.

Orientation of felling strips

Felling strips are normally oriented perpendicular or 45° to the out-going tide to facilitate tidal flushing, promote seed dispersal, reduce insolation and provide shelter from prevailing strong winds. Generally strips should not be inclined towards the direction of river flow near the river mouth because of the danger of excessive silt deposition during peak flows. Further way from the coasts into the more sheltered estuarine areas, the orientation of the strips becomes less important. Here the main concern is to facilitate efficient wood extraction without impairing the environment.

12.2 CHOICE OF HARVESTING SYSTEM

A harvesting system is the coordinated package of activities and methods used to fell trees, snig and haul logs and transport them to market. The main constraints in choosing a harvesting system may be the climate, soil, terrain, equipment available as well as the need to protect the site and residual trees. Ideally, the chosen system should yield the lowest cost per unit volume at the forest gate or of timber delivered to the market place without impairing the site and growing stock.

Planning a tidal swamp harvesting system is a complex undertaking, as the available options are limited. Until recently, the difficult ground condition has always precluded wood extraction by any but primitive manual methods. The low unit value of the produce also limits the use of cost intensive systems, while the need to reduce surface disturbance implies that precautionary measures and related costs must also be included. There is, therefore, a gulf between what is silviculturally desirable and what is economically and technically feasible.

Each silvicultural system produces a distinctive form of crop which generates particular problems in felling and extraction. A uniform system may be more cost effective as larger amount of wood is extracted per unit area. At the same time, the products are usually more uniform in size and amenable to handling. A system which retains a significant number of seed-bearers will not be suitable for high-lead cable extraction for instance.

In Asia, generally, forest operations are very labour intensive. Increasingly, the extraction industry is facing difficulty in hiring skilled manpower. In West Africa, wood extraction is usually not properly organized as the supporting processing industries are often not in place. In Central America, until recently, the emphasis has been on bark collection rather than charcoal billets and other products. In Venezuela, a barge equipped with an A-frame cable system was used to extract *Avicennia sp* for mining props, railway ties, and telegraph/transmission poles. Such operations are feasible only in mangroves with deep waterways. Removals must also be large enough to justify the capital outlay required in such mechanised operations. In Cuba, where there is a shortage of railway ties for the sugar-cane industry, *Avicennia germinans* logs are extracted through a system of artificial canals.

At the initial management and silvicultural conversion phase, the forest may contain many over-mature residuals, which must nevertheless be felled, removed and used, if the chosen silvicultural system is to succeed. This first crop may thus pose special problems whereas in the succeeding crop the dimension of the forest produce will be more uniform and manageable.

A capital intensive system should be avoided in countries where, generally, a policy of import substitution and conserving foreign exchange prevails. Instead, simple but cost-effective systems should be adopted, which can be progressively upgraded as local servicing support facilities are in place. Along the coastal zone, the general shortage of mechanical support services and the high cost of transporting replacement parts to the mangroves are additional constraints to be considered. Furthermore, due to the corrosive saline environment and tidal nature of the mangroves, mechanical equipment requires close maintenance.

The main methods used for extracting mangrove wood products are: (a) wheelbarrow, (b) tramway, (c) canals, (d) high-lead cable, (e) portable cable winch and (f) manual. A brief review of these methods is given below.

12.2.1 Wheelbarrow method

This method is still used in Matang. It is labour intensive. Wooden planks (1" thick x 9" wide) about 5 m in length are laid across the felling coupe. Billet or firewood loads of about 300 kg are manually pushed to the boat landings, using locally made wheelbarrows over an average distance of 150 m. A shoulder strap is often used to help lift and balance the wheelbarrow. The planks are replaced about every six months. Both the wheel and axle of the wheelbarrow are made of wood to resist salt corrosion. This method is suitable for the removal of billets (1.6 m long) and is not used for the removal of pole thinnings. This is a simple, practical and low cost method. It may not be suitable for frequently flooded areas because the planks may be washed away by the retreating tides. (See **Figures 12.1 and 12.2**)

The billets are loaded manually on to the boats. Two or more boats are towed by a diesel powered boat of 25-35 hp. Each boat can carry about 3 t. In Thailand as many as 12 boats are towed by a single tug boat.

12.2.2 Tramway

Unlike the *Rhizophora* dominated stands, which are situated in the lower intertidal zone and are encumbered with tangled stilt roots, forests in the elevated inter-terrestrial zone are dominated by species which, generally, do not have prominent aerial roots, such as *Bruguiera gymnorhiza* and *B. caryophylloides*. These trees can grow to large sizes and, as they are situated in less frequently inundated areas, they can usually be accessed by light trolleys or small-wheeled carts on wooden rails or tramways.

12.2.3 Canals

Extraction canals are used in many parts of the world, notably Malaysia, Vietnam and Cuba. In Cuba, the early Spaniard settlers dug canals to extract Yana (*Conocarpus erectus*) for making charcoal. Though there are reservations that its use may be environmentally undesirable because local micro-relief and ecology may be significantly altered, no quantifiable adverse results have been reported. Canals aligned parallel to the felling strip (50 m x 200 m) facilitate the rapid and orderly removals, thereby reducing disturbance to advance growth. During logging damage to seedlings and saplings is normally high. Most of the younger and less lignified *Rhizophora* regeneration will coppice, and can also straighten themselves into an upright position if pushed over and held down by debris. Logs, posts and billets are loaded onto the boats usually at high-tide.

Canals are constructed *manually, mechanically, or with explosives.* In Matang canals are dug by hand. Billets are manually carried and/or wheelbarrowed to the stacking and loading sites. Felling is carried out by a combination of chainsaw and handsaw/axe.

Figure 12.1: Extraction of wood by wheelbarrow, Matang, Malaysia
Photo by M.L.Wilkie

Figure 12.2: Loading of billets unto the boat, Matang, Malaysia
Photo by M.L.Wilkie

Small boats are guided up the canal during high tide and loaded manually, then taken out of the canal and normally rowed or sailed to the market at collection points. Motorized boats are now used. It is very labour intensive and well suited to rural settings where labour is plentiful but jobs are limited.

In the Ca Mau peninsula in Southern Vietnam, the main connecting canals were made by dredges and some of the Forest Enterprise still operate such dredges. Most of the minor extraction canals were constructed manually. These may be temporarily adapted for shrimp-farming in certain cases without disturbing the environment.

In Guanal, Cuba, extraction canals are constructed with explosives (Amonita GJB, Amonal, Roca amonita y Nitromiel). It is very rapid, labour extensive and cost effective. Canals are made under the supervision of explosive experts provided by the local militia. Unless properly planned and implemented, this method can be ecologically disruptive, particularly to wildlife during their breeding seasons. Similarly unless open-ended canals are made connecting two bodies of water, a localised increase in the salinity may be induced during the summer months. It should be noted that mechanical methods are no less disruptive and are capital intensive. See **Figure 12.3 below.**

Some guidelines on canalization based on the Guanal area are summarized in **Box 12.1** on the following page as an example of what precautions should be taken to avoid negative environmental impacts.

Figure 12.3: **Man-made canal in Guanal, Cuba**
Photo by P.W.Chong

- The existing network of primary and secondary canals, including their navigable width and operating depth should be surveyed and mapped;

- Before construction, the canal should first be surveyed. It should be aligned towards the predominating winds to promote better surface water flow and oxygenation.

- The principal canals should be interlinked at both ends to waterways;

- The middle section will be exploded first with both ends of the canal intact and closed to reduce site disturbance and adverse environmental impacts;

- When the water in the exploded section has cleared, the ends can be breached preferably during low tide, so that acids may be flushed out seawards.

- Canal depth should not exceed 1.5 m deep to minimize the quantity of overburden. Excessive soil removal increases the risks of acid-sulphation, impedes water movement, covers up too much of fertile surface soils and damages advance growth.

- Explosives should not be used close to wildlife nesting or resting sites, particularly during their nesting/hatching periods (February-April and April-June are the respective nesting seasons for the Cuban and American crocodiles;

- An environmental impact assessment in selected areas should be conducted. In particular, the impact of canalization on local site factors (soils/salinity/pH), water movement, flora and fauna should be determined.

Source: Chong (1989b)

Box 2.1: Guidelines for canalization with explosives in Guanal, Cuba

12.2.4 <u>High-lead cable system</u>

In the San Juan-Guarapiche area, in Venezuela, harvesting of *Avicennia* stems and poles is organized into clear-felling strips perpendicular to the river bank. The strips average 50 m in width and up to about 300 m in length. A high-lead cable system mounted on to a barge towed by a tug-boat is used to haul the timber to the stacking/loading sites along the river bank. Within each clearcut strip two cable settings are typically used so that the maximum lateral reach of the cable system is limited to 25 m or less. This reduces the damage to the soil.

The wood is used for telegraphic/telephone posts, mining pit-props and general utility timber. Logs and poles are transferred onto barges and transported to the jetty.

Small boats are also used to transfer the timber to the barges, especially when the stacking sites are situated along shallow creeks. The barge has a capacity of 400-450 pieces of poles or 18,000-24 000 kg of billets. In Venezuela, long-distance transport to the processing mills is carried out by floating platforms hauled by tug boats.

The high-lead cable system is a capital intensive system and therefore can be used economically only in areas with high volume of commercial timber and/or where the wood has to be transported over long distances. Additionally, it can only be used for clearcutting as the action of the high-lead cables will destroy any remaining trees within the area. Furthermore, the rivers and creeks have to be deep enough to permit the use of shallow draught barges.

12.2.5 Portable cable winch

In Costa Rica, a portable winch powered by a small chainsaw motor has proved to be a useful alternative in timber harvesting. Stems, poles, firewood and charcoal billets are hauled with minimum disturbance to advance growth. It was first tested in the Sierpe-Terraba mangrove reserve along the Pacific south coast. A strip clear-felling method was used. The ultimate goal was to transform the irregular *Rhizophora* dominated forests into a series of even-aged equi-productive stands. During the conversion phase, the existing forest, which has been selectively logged, has a high proportion of over-mature residuals, which must nevertheless be felled, removed and utilized, if the chosen even-aged silvicultural system is to succeed.

Manual removal of large sized individuals was difficult as the soil was soft. The diameter ranges from 10 cm to over 45 cm. Because of its portability, a light winch could easily be moved from place to place. It was found to be very practical, low costs and easy to apply. A load of billets attached to a skidding sleigh of 1/2 t can be hauled without difficulty over a distance of 200-250 m. Training was simple because most of the locals knew how to operate a chainsaw.

With this method it was found possible to remove the large sized trees which were often left by the bark collectors, who only exploited the bark and not the wood.

Under Cuban conditions, working in the *Avicennia germinans* dominated forests, it was estimated that the average snigging distance using an experimental portable winch was about 60 to 80 m, and 20 - 30 m with manual methods. With a larger winch and longer cables, it may be possible to reduce the intervals between extraction canals very significantly. On this basis a cost comparison between manual and winch methods was made and shown in **Table 12.2** below:

Table 12.2: Comparative snigging costs using manual and winch methods

Snigging method	Manual	Winch Cable
Density of canals (m/ha)	200	62
Cost of canals (pesos/ha)	414	128

Source: Chong, 1988/ Eugenio Poussin Molinet, 1989

12.2.6 Manual extraction

In Sierra Leone, the trees are cut using a local type of axe. The smaller firewood billets are normally bundled and carried manually to the dug-outs.

Extensive tests carried out in Mali show that a labourer is able to transport one stere of firewood over a distance of 100 m in about 1.2 hours. (Atlanta, 1986). With regard to the bigger billets, most workers will not carry a load of over 150 lbs, and then only over short distances.

Directional felling is possible with proper axes, handsaws and wedges. Removal of billets may be facilitated by the deliberate felling of convenient trees in such a manner that the topped trunks lie end to end forming a rough track across the swamp.

12.3 LOGGING DAMAGE

In the following the main causes of logging damage in relation to the choice of harvesting system are described together with mitigating measures to be taken based on Hamilton and Snedaker (1984). The environmental impacts of mangrove management *per se* is the subject of **Chapter 14** to which the reader is referred for further details.

The harvesting and extraction of wood products always causes some adverse effect on the forest soil unless the logs are extracted by high-lead cable without touching the ground.

Dragging of trees and logs result in removal of the top soil, damage to natural regeneration and remaining seed-bearers and compaction of the soil. The latter is also causes by using tramways and wooden rails. The skid rails may later be prone to deep flooding and thus have a negative effect on natural regeneration.

Construction and widening of canals alter tidal influence and draining patterns.

As is evident from the above, all of the harvesting systems described have advantages and disadvantages and none of them can be universally applied due to the differences in working conditions between countries. In order to minimize logging damage, the following should be kept in mind when choosing and implementing a particular harvesting system:

- Select the most appropriate harvesting system keeping in mind the environmental impacts of each system as well as their technical and economical feasibility under the local conditions;

- Design extraction methods to minimize damage to seed trees and advance growth. Such measures include directional felling, proper lay-out of loading site and skid rails, the use of two barge settings in each felling strip when the high-lead cable system is used etc.;

- Adjust strip width in clearfelling to ensure supplementary regeneration from adjacent uncut areas;

- Retain buffer strips along rivers and waterways to stabilize banks and as a habitat for birds and marine life;

- Attempt to reduce slash size and volume. A large amount of slash represents not only an under-utilized wood resource, but a damaging agent to natural regeneration until it has decomposed.

13 PLAN IMPLEMENTATION, MONITORING AND EVALUATION

13.1 THE OPERATIONAL PLAN

The operational plan can either be a working plan covering all the aspects of forest management implementation within a forest district or a range limited in time to 2-3 years or it can consist of specialised plans for each of the major operations such as a silvicultural plan and a felling plan often prepared for the full plan period (10 years) with more detailed plans developed for each year.

Such plans specify the location and the operations to take place in details and include information on organisation of work, man hours and equipment needed, costs and yearly targets. The operational plans are used to guide the day to day implementation of the overall forest district management plan.

13.2 PLAN MONITORING

13.2.1 Records to be kept

In order to ascertain that the objectives of the management plan are met a set of records are kept where the actual achievements are registered together with the annual targets.

For silvicultural operations such records contain information on size of area planted, number of seedlings/propagules per ha, manhours, costs, survival rate 1-2 years after planting etc. For felling operations the records show the size of the area to be felled, expected and actual yield, manhours, costs and revenues, natural regeneration status etc.

13.2.2 Supervision and control

Supervision of activities is carried out by rangers, forest guards and other forestry staff. However, some aspects may be cover by contractors.

Felling activities

In the clear-felling in alternate strip method with or without the retention of standards, the contractor should carry out the following before logging begins:

- after the forest ranger has shown the logging area (coupe) and its boundaries to the contractor, he must demarcate the boundaries satisfactorily before logging can begin;
- all seed-bearers are identified and marked on the instruction of the area forester;
- he should furnish a list of his subcontractors or workers engaged to work in the licence/permit area;
- the felling coupe is subdivided into two more felling blocks and it is the contractor's responsibility to be fully aware of the layout of the blocks.

The range forester should prepare a felling plan map at 1:5 000 or 1:10 000 scales, noting the following:

- storage and loading points;
- gaps with good regeneration where directional felling is needed;
- excluded areas such as research plots, etc.
- progress of felling blocks.

Control between felling strips

Felling should be conducted in an orderly and sequential manner. Normally, the contractor is not permitted to extract timber in the second and subsequent felling strips, unless at least 80% of the preceding felling strip has been properly worked. No more than two felling strips may be worked simultaneously.

Control within felling strips

The effective area of each felling strip is subdivided lengthwise into felling blocks at about 100 m intervals. Felling is permitted in the first two blocks, but may not be permitted in the third and subsequent blocks unless one of the preceding block has been "closed". A "closing report" is prepared by the range officer based on field inspection.

Marked standards should not be damaged or felled and logging slash to be properly disposed. If such standards are accidentally damaged, an alternative tree should be substituted. Over-mature or moribund stems are felled and removed.

Control of removals

To regulate removals, the movement of the produce has to be supervised and controlled.

In Matang only boats registered with the Forest Department are allowed within the Forest Reserve and permitted to operate and carry forest products. The same is true for the Sundarbans in Bangladesh, where the Forestry Department also is in charge of issuing licenses for fishing and honey collection within the area and thus has control posts situated at all the waterway entry points to the Reserve.

<u>Silvicultural activities</u>

Most silvicultural measures in mangroves, such as planting, weeding and pest control, are carried out by forest staff under the supervision of the forest ranger.

13.2.3 Costs and revenues

An essential objective during the plan period is to quantify costs of forest establishment, harvesting and administration. Each forest range should be treated as a cost centre.

Cost records are similar to those kept for inland forests and vary according to countries and will thus not be described in detail.

Revenue collection

There are three methods for revenue/royalty collection, viz., (a) collection at stump, (b) at wood processing sites, and (c) in transit by means of checking stations.

The first method is recommended because it requires few staff and it encourages the contractors to be more efficient in wood harvesting and extraction. However, this method requires quite intensive inventories of the stands prior to felling.

In Matang, Malaysia, the premium for wood for charcoal is paid prior to the commencement of the felling operations based on a inventory of the area to be felled. The royalty on the other hand, is collected once the charcoal has been produced at designated processing sites. Royalties for firewood, post and poles are collected at source in the form of prepaid licences or through the issuance of removal passes validated at approved checking points.

13.3 PLAN EVALUATION AND REVISION

Ideally the forest management plan should be evaluated at least once during the plan period and revisions incorporated where necessary. However, due to the amount of work involved in such an exercise, plan evaluation is often only undertaken in connection with the preparation of the next management plan.

Such an evaluation should *inter alia* encompass an assessment of the following:

- standing stock and growth rate compared with the estimated production and the actual yield;
- the environmental impacts of the current harvesting system and an examination of mitigation measures which could be undertaken;
- plan objectives;
- the need for changes in current silvicultural operations and
- further research needed in order to refine the present management prescriptions.

14 ENVIRONMENTAL IMPACTS OF MANGROVE MANAGEMENT

14.1 ENVIRONMENTAL CONCERNS

There are several environmental concerns regarding the use and management of the mangrove ecosystems. The level of concerns, however, vary from country to country and from region to region in the terms of severity and areas of impacts. The concerns are most severe at the local level where remedial measures are much needed.

The most common concerns worldwide are:

(i) Deforestation of mangrove forests;

(ii) Depletion of fisheries and other mangrove dependent living resources;

(iii) Loss of protective function of mangroves, in particular in coastal areas subject to severe storms and wave actions;

(iv) Serious degradation or destruction of critical habitats;

(v) Loss of bio-diversity/genetic resources.

At the local level, the concerns are directed at more specific losses of production and production potentials and services (see Part II).

14.2 MANAGEMENT ACTIVITIES AND THEIR ENVIRONMENTAL IMPACTS

The questions to be asked are whether mangrove forests can in fact be managed on a sustained basis and if so, does the management have any significant detrimental effect on the environment. To the first question we have to rely on the experience from two areas that has been under management for a long time, the Matang Mangrove Forest Reserve in Perak, Malaysia, and the Sundarban mangrove forests in the Bay of Bengal.

The Matang Mangrove Forest Reserve has been under intensive management since the beginning of the century. The forest is regulated in the appropriate even-aged classes and harvested stands are immediately replanted and, to a limited extent regenerated naturally; afforestation of marginal areas incorporated into the reserve is generated exclusively by means of plantation. The preferred species is *Rhizophora apiculata* although other species are also utilized.

With regard to the 5 concerns listed above, it is relevant to ask if this form for intensive management of mangrove forests, which has been widely regarded as an ideal model and in fact copied or adapted to local conditions in Thailand and elsewhere, has been sustainable; and whether it has any negative effect on

- fisheries and other mangrove dependent living resources;
- critical habitats;
- bio-diversity.

Monitoring of the permanent sample plots installed in the reserve has not shown any decline in yields over the last 3 rotations (Haron 1981). The incorporation of marginal areas by canalization and plantation has increased the size of the management area over the years. It must, therefore, be concluded that **sustained yield forest management** is feasible at least for 3 rotation periods of 30 years.

With complete crown cover and immediate regeneration of harvested areas, the production of litterfall from the managed forest has been found to be superior to that of natural untouched stands (Ong *et al.*, 1982). Litterfall is an important source of energy for the food web that affects fisheries and other living mangrove dependent organisms. There has not been any significant decline of commercial **catches of fish, mollusc and shellfish** in the coastal waters adjacent to the Matang Reserve reported during the management period.

It can not be ruled out that **critical habitats** have been modified or radically changed in Matang, although no reports in this respect are available. Marginal areas for wood production have been provided with canals in order to lower the salinity levels to those appropriate for *Rhizophora apiculata* and *Rhizophora mucronata* and other desirable tree species, and in this process it is possible that critical habitats have been disturbed.

It would seem most likely that the original **bio-diversity** of the original mangrove has been affected in the regulated parts of Matang since only a few preferred species have been used to regenerate harvested areas. Consequently, with this type of management, areas should be set aside in the initial planning stage (or at the Integrated Coastal Area Management planning exercise) as reserves managed for there genetic resources rather than for commercial wood production.

In the Sundarban mangroves, management has been practiced for a much longer time and developed along different lines than those of the Matang reserve. The fundamental differences are, that the total area under management is almost 10 times as large; many more species are utilized - sawn wood being a major project; and the shelterwood system is applied to promote natural regeneration.

Although the regeneration system should maintain **bio-diversity**, the inherent complexity of the system also makes it difficult to assess, if this has in fact happened. However, one would assume that it has. But the most important advantage of the forest management of these mangroves is, that they have been retained at all. As has been the case elsewhere in the tropics, the Sundarban mangroves have been under heavy pressure to be converted to food production, i.e., fishponds, shrimpfarming and agriculture. The fact that there are such an extension of mangroves still in existence today, in two countries with some of the highest population pressures in the world, is largely due to the fact that a significant part of them were reserved at an early stage for forest management.

Nowhere in the world are mangroves more important for protection of human lives and activities than in the Bay of Bengal, which is periodically affected by dangerous typhoons. Consequently, it can be safely stated that the **forest management** of these mangroves has had a positive impact on the environment.

Natural waterborne feed is also still available for fish and shrimp farmers in the Sundarban contrary to some parts of the world, where heavy deforestation of mangroves, not subject to management, has made it necessary for the shrimp farmers to resort to artificial feed in recent years (Ecuador).

The use of inappropriate management techniques can, however, have a detrimental effect on mangroves resulting in deforestation, losses of critical habitats and bio-diversity. The harvesting of mangroves for chip production using large and costly machines, has made it economically necessary to clearcut large areas (Indonesia, Sabah and Sarawak). The regeneration of these areas have either failed or proven to be very difficult and this type of operations have, at least in part, been stopped. For more details on logging damage in relation to various harvesting systems please refer to **Chapter 12**.

Canalization of mangroves to facilitate wood extraction and allow sea water to enter into non productive salt flats are beneficial if properly done. However, cases have been observed where canals constructed with explosives were banked in a way that did not permit water to flow freely in the affected area. This in turn led to localized high salt concentration patches with stunted tree growth.

In conclusion, it would seem that forest management of mangroves, if properly carried out, has a largely beneficial effect on the environment. However, integrated management planning should ensure that all goods, services and values are catered for. In order to ensure that is in fact done, it is recommended that the management planning includes an Environmental Impact Assessment, and that actual management is monitored periodically by Environmental Auditing.

15 CONCLUSIONS AND RECOMMENDATIONS

These conclusions, aimed at achieving sustainable mangrove management, are drawn from regional and selected country experiences. Accordingly, they are general in nature. Similarly, the guidelines on "recommended practices" highlighted in italics should also be adapted to suit local requirements.

15.1 FOREST POLICY AND LEGISLATION

15.1.1 Land use policy

To achieve the desired management goals, an important precondition is to redefine and/or prepare a land use policy so that mangroves are recognized as a legitimate form of priority land use rather than a residual use.

A national land use policy to ensure the sustainable use of mangrove resources, and providing for the establishment of a permanent resource base, should be redefined and/or formulated and implemented.

(a) *Proposals for converting mangroves to non-wood uses should be supported by favourable environmental impact assessment reports.*

(b) *Solar salt should be produced only in the semi-arid or seasonally dry zones*, and be located on natural salt-flats with restricted or sparse natural vegetation cover.

(c) *Potential acid sulphate and acid sulphate mangrove soils should not be cultivated under rice or other crops*, without an adequate source of rain-fed or irrigated freshwater.

(d) *Tin-mining activities should be avoided along the coast* and the mining discharge should be confined to sedimentation ponds and not discharged directly into the river system;

(e) *Aerial spraying of pesticides and chemical fertilizers adjacent to the mangroves should be avoided.*

15.1.2 Multiple-use concept

Single-use management should be avoided as this forecloses the many direct and indirect benefits and services that the natural ecosystem can offer on a continuing basis.

A policy statement on the multiple-use management of mangrove resources, particularly for forestry, fishery and wildlife conservation should be formulated and politically supported at the highest level of government.

To ensure an integrated approach to planning and management of mangroves, the forest management plan should conform to an approved Integrated Coastal Area Management programme.

(a) NATCOM: In support for the above policy, coordination among concerned agencies and land users is required. *To coordinate and promote environmentally sound development of mangrove resources, a National Mangrove Coordination Committee should be established.* Membership of the NATCOM comprises concerned Ministries and Departments, Research and Education institutions and NGOs.

(b) Consensus: *To achieve a national consensus, seminars and workshops to discuss mangrove management policy and land use should be organized by NATCOM.*

(c) Development strategy: *A strategy for the sustainable management and use of land and aquatic resources, including conservation of wildlife and biodiversity, should be prepared and implemented.*

(e) Coordination: *Close liaison should be fostered between the Services of Forestry, Fishery, Environment and Agriculture, related departments and NGOs,* who have an interest in the management, utilization, regulation or research in mangroves.

(d) Social forestry: In forestry, there is an *economic* and a *welfare* sub-sector. Meeting the basic needs of the poor is mainly the responsibility of the public sector. *Sufficient mangrove forests should be designated for the local supply of goods and services needed by the rural communities.*

15.1.3 Legislation

Generally, the coastal zone is covered by several overlapping maritime, fishery, forestry and other laws. It is important that the agreed policy should enjoy the force of law, which does not conflict with the existing laws of the country.

Legislation on conservation of mangroves should be framed, revised or amended to reflect the agreed forest policy. Such a law should harmonize with the general body of legislations in the country.

15.2 RESOURCE INVENTORY

The nature, form, and extent of mangroves should be determined through national inventories:

The mangrove resources (i.e. terrestrial and aquatic), regardless of ownership status, should be inventoried to assess their relative economic and ecological importance and management requirements at national and local levels.

15.3 ESTABLISHMENT OF PERMANENT MANGROVE RESERVES

A permanent resource base forms the basis for sustainable management and use, in order to optimize their contribution to national development.

To ensure protection and conservation, mangroves, regardless of their ownership, should be constituted as mangrove reserves, and sufficient areas be reserved for production purposes.

15.3.1 Classification of forest use categories

The economic potential of the mangroves stems from three main sources: viz., forest products, marine products and ecotourism (*production function*). In addition, mangroves have *protection functions*. There are also marginal mangroves in the inter-terrestrial that are more suitable for permanent agriculture or other non-wood uses. (*conversion forests*).

Mangroves should be classified into three functional categories as follows: (a) Production; (b) Protection, and (c) Conversion forests. The last category may be converted to other uses subject to 15.1.1 (a).

15.3.2 Land tenure and usufruct

The customary and usufructuary rights of indigenous people and rural communities over forest produce should be clarified as part of the enabling mechanism devised to promote broad-based participatory forestry programmes.

To augment the resource base, community-based mangrove plantations and private woodlots should be promoted, particularly in fuelwood deficit areas. Concomitant measures to clarify the usufructuary rights and land tenure arrangements for rural communities should be made.

15.4 FOREST SERVICE

Establishing a mangrove management unit within the Forest Service, that is responsible for management planning, harvesting, reforestation and protection is highly desirable in countries endowed with abundant mangrove resources.

15.4.1 International technical assistance

In countries where the management, protection and integrated use of mangrove resources have not been institutionalized, assistance in strengthening the technical and managerial capacity and capability of the concerned Forest Services is required.

International assistance may comprise the following:

- *Fellowships and study tours;*
- *Build up a working library on mangrove ecosystems, management, utilization, wildlife conservation and protection;*
- *Organization of seminars, workshops and training courses in academic, research institutions and NGOs;*
- *Pilot demonstrations.*
- *Provide international expertise in preparing model management plans for selected pilot areas and to provide on-hand experience;*
- *Provide technical assistance to formulate and implement appropriate research programmes.*

Adequate funding and vehicles and boats, equipment, materials and tools to undertake sustainable mangrove management should be provided. Back-up research support is also needed.

15.5 MANAGEMENT, SILVICULTURE AND UTILIZATION

The continued production of wood and non-wood benefits is greatly dependent upon the effectiveness of forest management measures.

(a) Management objectives: *Management objectives, which meet the socioeconomic, technical and environmental requirements of the forests should be framed as a basis for action.* (See **Chapter 9.**)

(b) Management planning: The first vital requirement for forest management *per se* is *the preparation of long-term management plans, integrating the production of selected wood and non-wood resources, needs of rural population, recreation, conservation of genetic resources and soils/water protection.*

(c) Growth and yield plots: Scientific management depends on, *inter alia*, growth and yield data, and information on the regeneration and phenological characteristics of desirable species. Accordingly, *growth/ yield and silvicultural plots should be established to provide growth and biological data for forest yield prediction, regulation and management.*

(d) Silvicultural concept: The silvicultural concept should aim at the cost-effective sustained yield of desired products without impairing the environment. The choice of silvicultural systems should take into account the requirements of the multiple-use concept elaborated under 15.1.2.

A clear-felling system with the retention of standards using the alternate felling strip method has been successively used in many countries. The rotation age may be 9-12 years for firewood or stands managed under the Coppice-with-Standards system or 25-35 years for vigourous *Rhizophora* stands. (Refer to **Chapter 10.**)

A selection felling system based on a minimum cutting diameter (say, 15-18 cm overbark) should be applied where the overriding management objective is to optimize non-wood production or conservation (e.g. mollusca culture, breeding or feeding of commercial shrimp and fish species, or wildlife).

(e) Annual Allowable Cut: *The annual allowable cut for wood products, permissible fishery catch, and use levels for services (ecotourism) should be set flexibly, conservatively and harmonized to ensure sustainable management.* (Refer to **Chapter 11.**)

(f) Harvesting Plan: Harvesting must be regulated by a harvesting plan. *The harvesting system used must be compatible with ecological and environmental site requirements apart from being cost-effective. It should also not impair the production of other non-wood resources.*
Post harvest surveys are necessary to assess logging damage, regeneration sufficiency, and to plan follow-up treatment measures required.

15.6 SOCIOECONOMIC AND FINANCIAL ASPECTS

Equitable distribution of forest management incentives, costs and benefits between the forest authority, forest owners, rural communities and private entrepreneurs is a vital requirement.

15.7 SOCIAL FORESTRY, EXTENSION AND DEMONSTRATION

(a) "Voice of the people": Management plans, no matter how well articulated, cannot succeed without regard to the requirements and aspirations of indigenous and local populations. Success depends, *inter alia*, on being able to *match management objects with the interests of local populations* and through extension, secure their support and commitment.

(b) Local participation: *Participation of rural communities in mangrove-based small-scale industrial activities should be given priority.* It is also most desirable to encourage a degree of "*self-management*" amongst the various users of the mangrove environment, such as shrimp-farmers, farmers, fishermen, charcoalers so that they may be involved in protecting their own resources.

(c) Sensitization: The potential of mangroves for rural development is not perceived. The principal issue, therefore, is to ensure that planners and decision makers have access to factual information on the role and potential of mangroves. *Seminars, talks, workshops, film shows and exhibitions on mangrove products and services targeted for various audiences should be conducted to create public awareness.*

(d) Providing economic alternatives: Over-exploitation occurs due less to a lack of awareness of the problems, than to a lack of economic alternatives. *To win public acceptance and support for forestry programmes, in situ pilot projects are required* to demonstrate the economic viability, sustainability and manageability of planting mangroves, proper carbonization and sound forest management practices, as well as ecotourism;

(e) Staff training: *Professional forest officers should attend short courses on mangrove ecology*, conducted by the local universities wherever possible, to widen their knowledge and appreciation of the technical basis needed for successful integrated forest management;

15.8 APPLIED RESEARCH

Rational management is based on an in-depth understanding of the forest and its environment that can only be obtained through a series of planned observations and measurements relating to its composition, structure and ecology.

15.8.1 Environmental Impact research

Multidisciplinary studies to determine the biological, physical and socioeconomic effects of the major users of mangrove areas is required. The objectives are to determine:

- *the inter-relationship between mariculture, current forestry practices and other human activities and their resources;*
- *the costs and benefits, both social and economic, of different alternative uses;*
- *alternative aquaculture systems consistent with local ecologies;*
- *criteria for site selection of mangrove areas for aquaculture development.*

15.8.2 Socioeconomic studies

The objectives are to analyze:

- *the social and economic setting of the mangrove dependent population;*
- *income levels, income sources, income distribution in such coastal communities;*
- *alternative economic activities and investments;*
- *market structure for mangrove products; and*
- *practices/techniques used in collection of mangrove products.*

15.8.3 Demand for mangrove products

Objectives are:

- *to estimate the local, regional and/or national demand for mangrove products, including their export potential;*
- *to analyze current and future supply and demand trends;*
- *to determine price trends; and*
- *to analyze factors affecting the demand for such products.*

15.8.4 Evaluation of mangrove management policies/programmes

The objectives are:

- *to review and formulate policies on the utilization, management, conservation and wildlife and research;*
- *to determine the extent of implementation of such policies and programmes; and*
- *to analyze the impact of such policies and programmes on the mangrove-dependent population.*

15.8.5 Ecological and silvicultural studies

Studies on plant succession, structural development, phenology, effects of treatment and other related aspects should be initiated as the findings are highly relevant to the formulation of appropriate silvicultural systems and management prescriptions.

15.8.6 Zonation and site classification

A Study on the relationship between vegetational zonation, tidal influences, salinity and soil conditions is required to determine the most appropriate silvicultural treatment to apply, species to be used in reforestation or afforestation, site potential and also integrated land use planning.

15.9 CONSERVATION, WILDLIFE AND TOURISM

(a) Contamination: Mangroves are influenced by tidal as well as terrestrial influences, in terms of their hydric, biochemical and ecological impacts. Aquatic animals and terrestrial plants are affected by water quality and sedimentation. *Monitoring of industrial and man-made pollutants that may adversely impact on the mangrove ecosystem should be conducted and regulatory measures taken to minimize estuarine and coastal contamination.*

(b) Upland land practices: *Unregulated river flows and heavy siltation due to land mismanagement in the watersheds and the extensive use of pesticides are producing negative impacts* in the mangroves.

(c) Wildlife management: Mangroves provide habitats for a variety of wildlife and avifauna. *Surveys on populations, feeding and migration of major wildlife species should be conducted. These data could be used to formulate a plan for the interactive management and control of these species.* Through proper planning and management, the wildlife potential can not only be preserved but also commercially exploited and the recreational potential of the area enhanced.

(e) Crocodile farming: *The economic and technical feasibility of crocodile framing should be explored,* where there are sufficient wild populations and the supporting facilities are adequate, including feedstock. (Refer to **Chapter 3**.)

(f) Apiculture: Most mangroves have the potential to support a thriving honeybee-keeping industry which is environmentally compatible. *A survey should be initiated to determine the extent of melliferous plants (honey and pollen resource) with the view towards improving or introducing local apiculture as an in-situ income source to coastal mangrove dwellers.* (See **Chapter 3**)

(g) Ecotourism: If properly implemented ecotourism can provide people with a viable alternative to destroying their environment.

The mangroves have many natural scenic, vegetational features, fishery, wildlife and birds which are attractive to ecotourists. *The potential for ecotourism as a viable economic alternative to rural people and to conserve the environment and its natural resources should be fully explored.* (See **Chapter 3**)

CASE STUDIES

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CASE STUDY 1

AN EXAMPLE OF A CARTOGRAPHIC SURVEY OF MANGROVES IN THAILAND

(Source: Ratanasernmong, 1986)

1.1 OBJECTIVES

One of the objectives of this survey was to compile information on mangrove distribution and classification and to produce thematic maps. On a few test sites, both visual photo-interpretation and digital analysis of Landsat data were conducted to enable a comparison of the two methods.

1.2 AERIAL PHOTO-INTERPRETATION

Black and white photos at a scale of 1:15 000 scale taken in 1975 and infra-red photos in the scale of 1:20 000 from 1985, were interpreted for the purpose of identifying and assigning "training areas" for satellite data analysis. Photo-interpretation permitted the differentiation between the following nine classes:

1. Mangrove forest class I: Located near the sea shore, on a soft and wet soil. The forest is dominantly composed by *Rhizophora mucronata* and *Bruguiera gymnorrhiza*. In other areas, the dominant species include *Rhizophora apiculata, Bruguiera gymnorrhiza, Avicennia sp.* and *Xylocarpus moluccensis*;

2. Mangrove forest class II: Located on lower land than class I. This zone remains submerged after the high tide. It is mainly composed by pure stands of *Ceriops tagal*. In the transition area between class I and class II, *Acrosticum aureum* and *Xylocarpus sp.* are present;

3. Mangrove forest class III: This class is located in higher land, on hard soil, which is flooded only occasionally. The main species are *Lumnitzera littorea, Lumnitzera racemosa, Phoenix paludosa, Intsia bijuga* and *Melaleuca sp.*;

4. Mangrove plantations;

5. Mangrove clearings (for shrimp farms);

6. Paddy land;

7. Shrimp farms;

8. Orchards and other solitary standing trees;

9. Water.

1.3 ANALYSIS OF LANDSAT DIGITAL DATA

Images from Landsat bands 4, 5 and 7 were used in the analysis. Image enhancement was also carried out by using a band ratio of difference over sum of bands 5 and 7 (5-7/5+7).

The classification was based on the training areas derived from the results of photo-interpretation. The maximum likelihood approach was applied in the image classification. A filtering process was further applied in order to reduce the patchy appearance of the classified features. **Diagram 1.1** illustrates the sequence of the image analysis process.

1.4 RESULTS

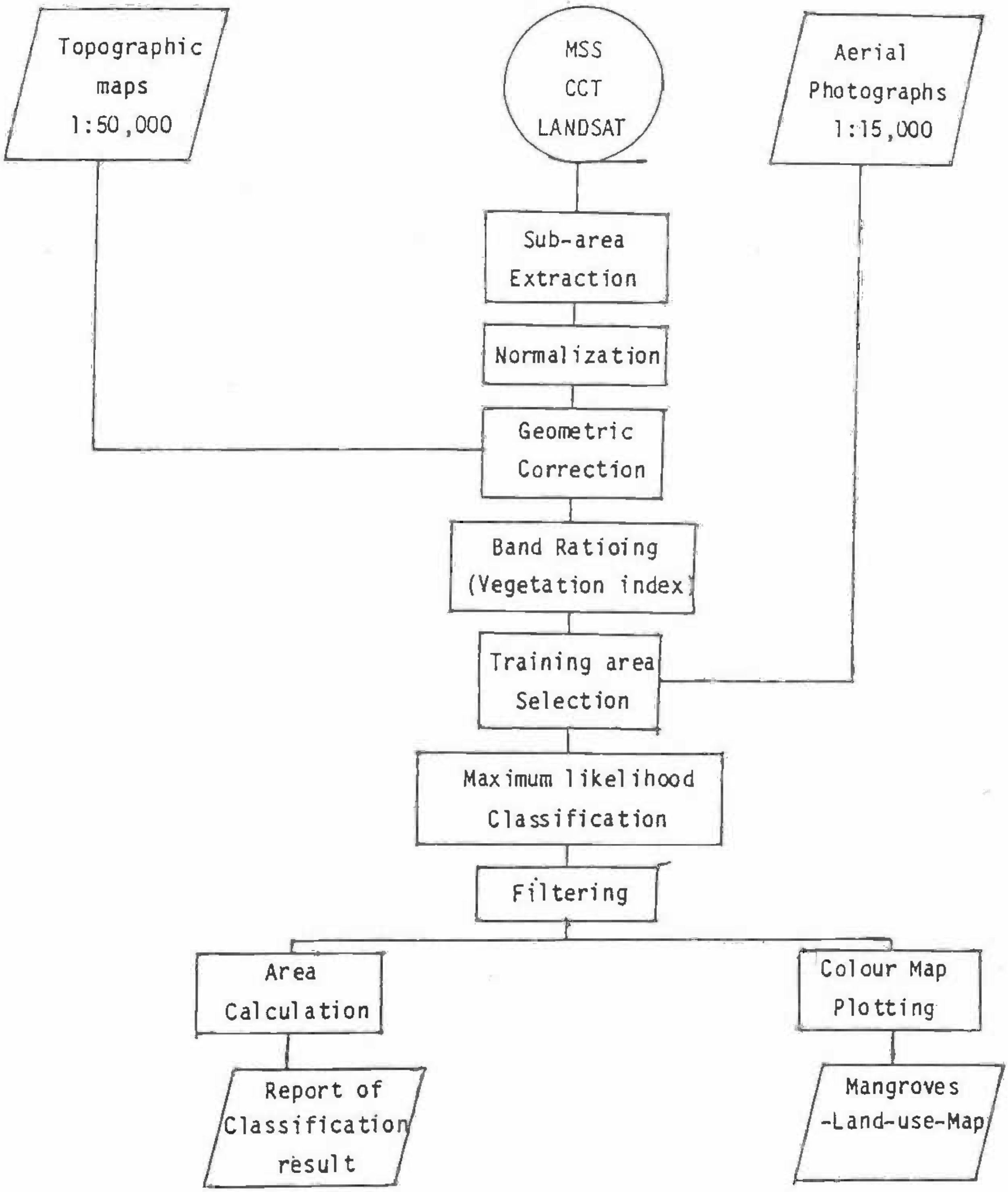
Figures 1.1 and 1.2 are the outputs obtained from photo-interpretation and digital analysis of the Landsat image respectively. A summary of area statistics is presented in **Table 1.1** below.

Table 1.1: Comparison of classification results in Khlung District, Thailand, in the 10 year period 1975-1986.

Class	Air photos 1975 km2	Landsat Nov. 1975 km2	IR photos Oct. 1985 km2	Landsat Jan. 1986 Km2
Mangrove class I	22.75	12.60	18.04	11.25
Mangrove class II	8.92	17.90	2.43	11.50
Mangrove class II (flooded)	-	6.30	-	-
Mangrove class III	13.12	7.90	13.94	14.50
Mangrove plantation	1.30	2.50	-	-
Clearing area	1.38	3.60	6.84	9.70
Shrimp farms	0.92	1.30	4.20	3.40
Paddy fields	10.01	5.35	15.45	11.00
Standing trees	6.75	5.90	4.27	3.50
Mudflats	-	1.90	-	-
Water	24.85	22.95	24.85	24.85
Unclassified	-	2.00	-	1.30
Total	90.00	90.00	90.00	90.00

As can be seen from the table above, it was found that the confusion between the 3 mangrove classes is rather high, suggesting that these 3 classes should be grouped as one.

The accuracy of the classification could likewise be improved considerably if classes 5 and 7 (Mangrove clearings for shrimp farms, and Shrimp farms) were to be grouped together.



(Source: Report on Remote Sensing and Mangrove Project, Thailand, 1985)

Diagram 1.1: A flowchart of the digital image analysis.

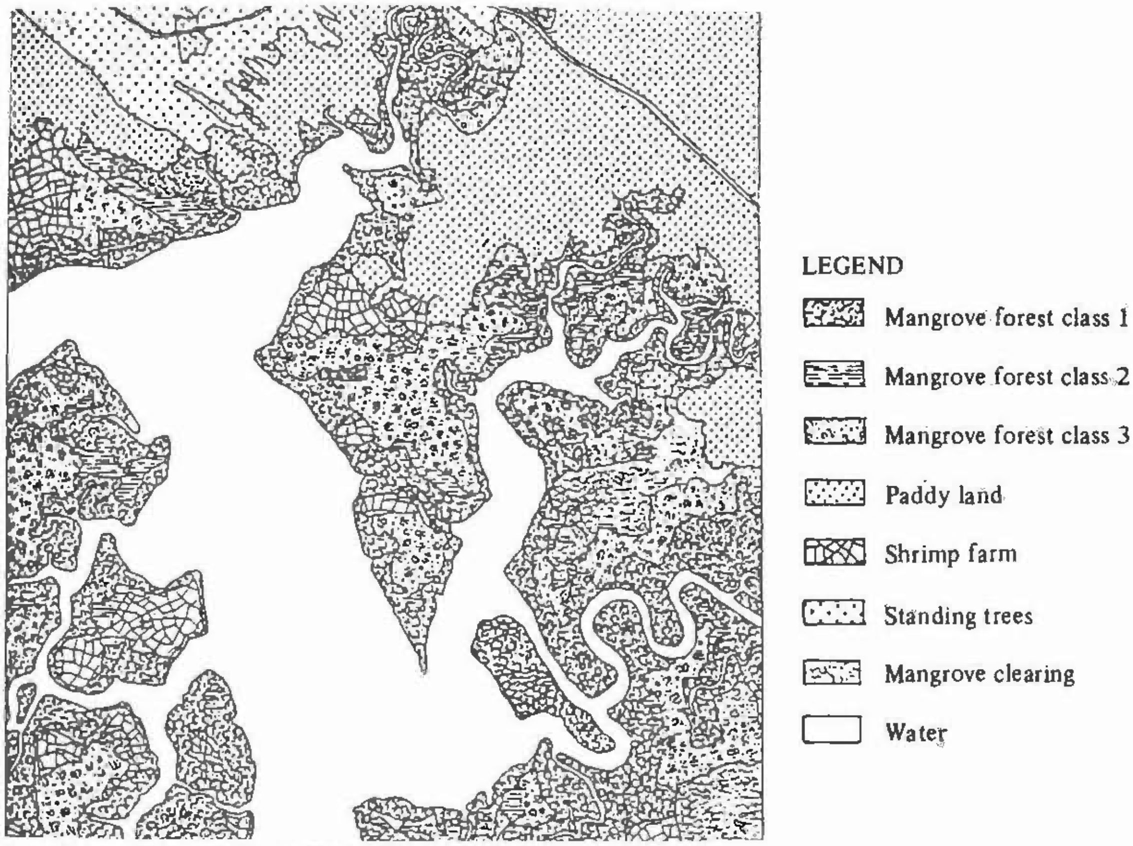


Fig. 1.1: Map based on photo-interpretation of IR aerial photography
Khlung District, Chantaburi, Thailand

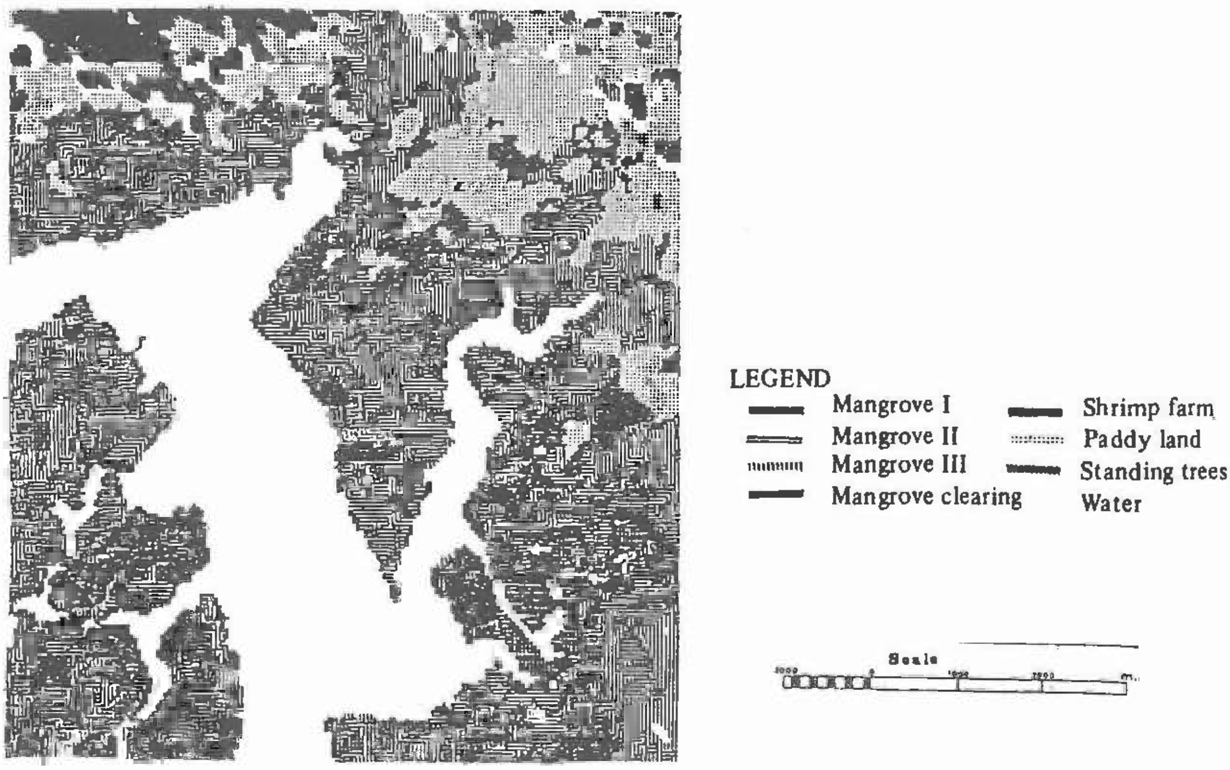


Fig. 1.2: Map based on digital analysis of Landsat image
MSS bands 4, 5 and 7 used. Same area as above.

CASE STUDY 2

AN EXAMPLE OF A MANGROVE MANAGEMENT SURVEY AND INVENTORY IN VENEZUELA

(Source: Luna Lugo, 1976)

The total area concerned by the study encompasses about 20,000 ha, including water and mangroves without commercial value.

2.1 FOREST TYPE CLASSIFICATION

On 1:25 000 scale panchromatic aerial photographs, three mangrove genera were distinguished, based on tone, relative height and crown diameter as it is presented in the following table.

Genus	Crown diameter	Crown tone	Tree height
Rhizophora	small	dark	shorter
Laguncularia	medium	grey	intermediate
Avicennia	large	white	taller

A further subdivision was achieved using tree height and canopy density. Height and density classes adopted are listed in the two tables below.

Height classes:

Code	Total height	Type
1	> 30 m	High
2	20-30 m	Medium
3	10-20 m	Low
4	< 10 m	Very low

Density classes:

Code	Density (%)	Canopy cover
a	85	Very dense
b	75	Dense
c	65	Normal
d	55	Light
e	45	Clear
f	35	Sparse
g	25	Scarce

The height was occasionally measured with a parallax bar, and density was estimated using a transparent grid.

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 the distinction between the three species of *Rhizophora* present in the area, namely *R. mangle*, *R. racemosa* and *R. harrisonii*.

2.2 FOREST INVENTORY

A forest inventory was carried out using a systematic sampling design with 1% intensity. Strips, 20m wide and 300m long were laid out perpendicularly to rivers and channels. The distance between strips was 2 000m.

In the strips, all trees with dbh larger than 8cm were measured and their species identified. Also, for the regeneration assessment, seedlings were counted in 2mx2m plots located along the strips.

With regard to timber volume calculation, tables for volume, bark and form factor were constructed for each diameter class. Moreover, from interpreted aeriSw photos (of which an example is presented in **Figure 2.1**) a forest type map was produced. **Figure 2.2** is an example of such a map.

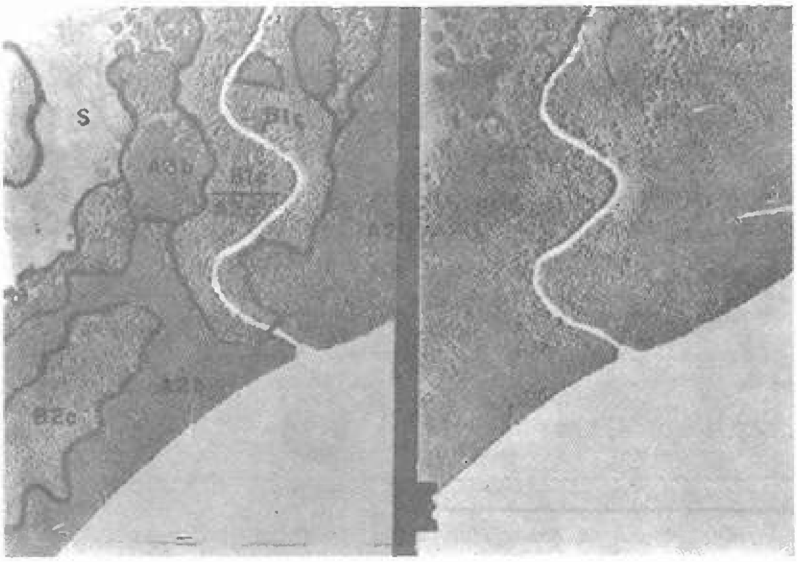


Fig. 2.1: **Forest type mapping on stereo aerial photography** Venezuela. (Source: Luna Lugo, 1976.)

Fig. 2.2: **A mangrove forest type map based on interpretation of aerial photos,** Venezuela. (Source: Luna Lugo, 1976)

CASE STUDY 3

A LARGE SCALE FOREST INVENTORY OF THE SUNDARBANS IN BANGLADESH.

(Source: ODA, 1985).

The Sundarbans forest is the largest single-tract mangrove forest in the world (4 200 km^2 in Bangladesh alone) and has been managed for more than a century. Currently, it is a major source of timber, fuel-wood, pulp wood and various other products. The main objectives of the inventory which was carried out in 1983 and 1984, were to produce forest type maps and to assess the growing stock.

3.1 STRATIFICATION

The area was divided in nine blocks. The demarcation of the blocks was intended to reflect broad differences in forest types. In each block, preliminary air photo-interpretation was carried out on panchromatic prints of the scale 1:30 000.

3.2 FOREST TYPE CLASSIFICATION

Forest types were subdivided into canopy density classes. Moreover, the main species, namely *Heritiera fomes* and *Excoecaria agallocha* were subdivided into height classes by inspection of the height data collected during enumeration. Density and height classes were as follows:

Code	Stand density	Code	Height (h)
a	> 70 %	1	h >15 m
b	30 - 70 %	2	15 m > h > 10 m
c	10 - 30 %	3	10 m > h > 5 m
		4	h < 5 m

3.3 SAMPLING DESIGN AND FIELD MEASUREMENTS

Each sampling block was sampled individually. In those blocks containing the most important species, the sampling design was based on forest type and compartment. Approximately ten sample plots per compartment were randomly located in each type accounting for more than 10% or more of a compartment area. In the case of forest types not occupying as much as 10% of any compartment area but occupying 5% or more of the total block area, sample plots were randomly located through the block as a whole. **Table 3.1** illustrates the various sampling units used in each block.

In each plot, dbh measurements were taken on all trees with a diameter equal to or larger than 5 cm. The height of the tallest trees in the vicinity were also measured.

Regeneration was assessed by counting the number of small trees having a dbh less than 5 cm and those below 1.30 m. Other data on the soil and on the top dying of *Heritiera fomes* were collected in field sample plots.

For growth determination of the main species, ring counts were made on disks collected from felled trees, but information obtained from periodic measurements from existing permanent plots was also used.

3.4 VOLUME DETERMINATION

Volume regression equations were established for the main species mentioned above, based on measurements taken on felled trees used in increment studies.

3.5 RESULTS

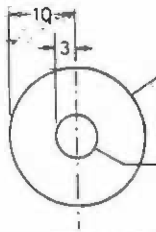
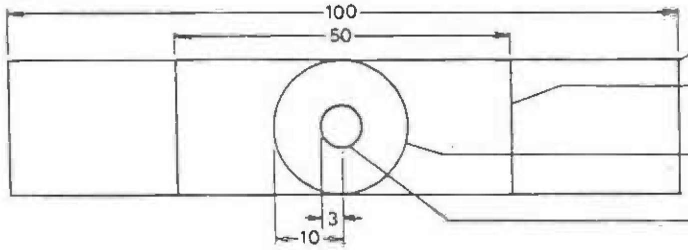
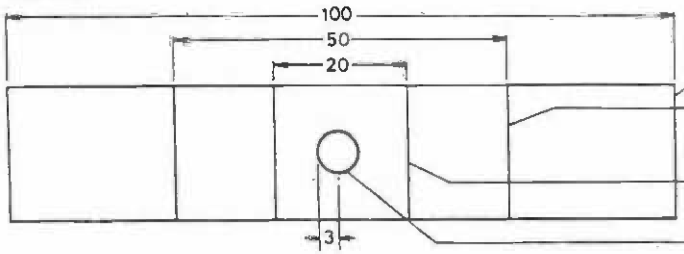
The results of the inventory include among other things:

- Areas of forest types, by canopy cover and height;
- Areas by compartment for all forest and non forest categories;
- Volume tables and regressions for all the main mangrove species with both stem volume and crownwood volume;
- Volume of the growing stock and bark for each commercial timber species, by forest type and block;
- Diameter increment by height classes for the main species.

Some of these results can be found in **Case Study 6**. Examples of the volume regressions obtained are presented in **Appendix 5**.

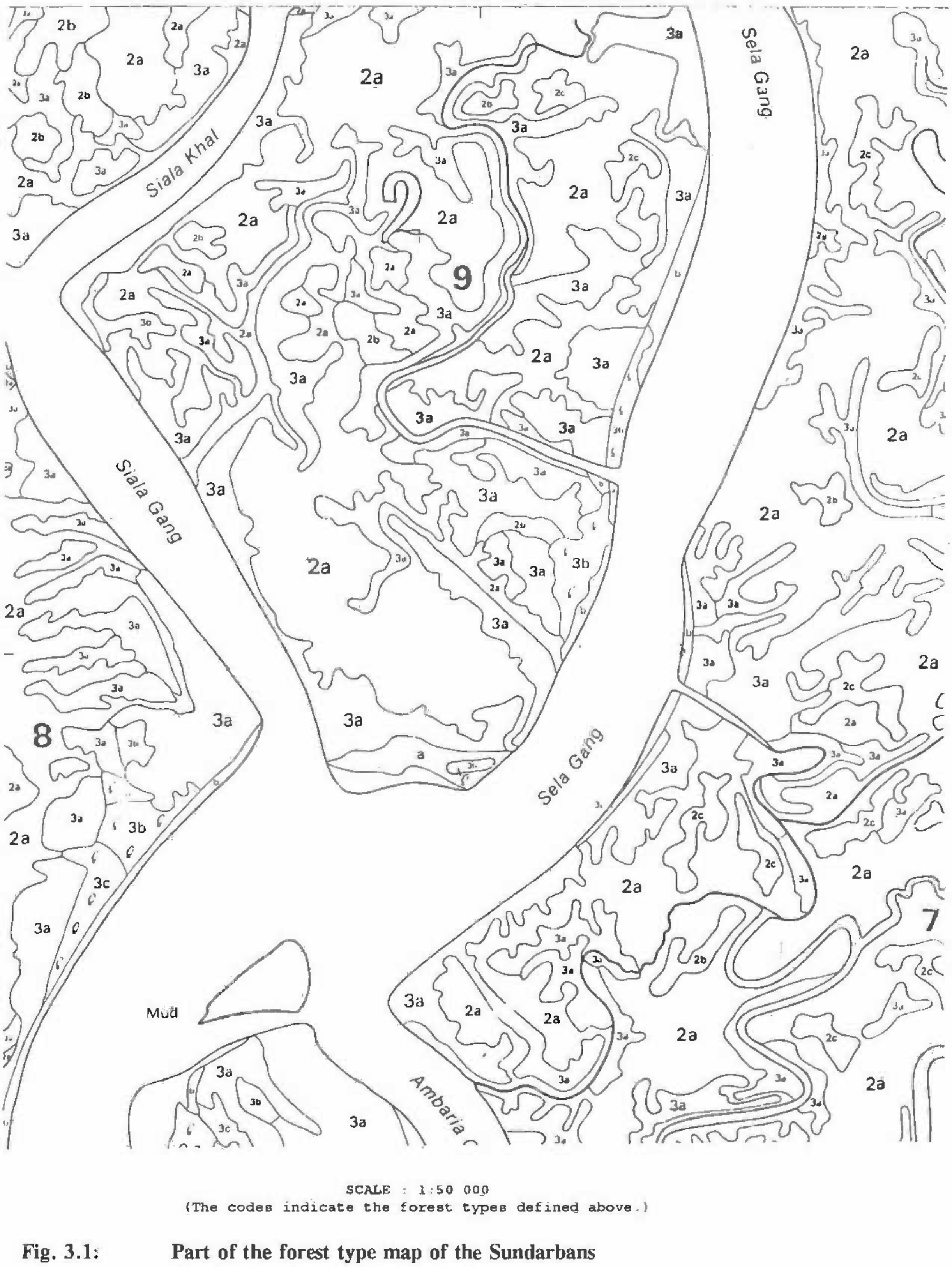
Type maps were also produced. An example is shown in **Figure 3.1**.

Table 3.1: Types of samples units, stems recorded and blocks in which used. Survey of the Sunderbans.

Sample unit types		Dimensions, m	Area, ha	Stems recorded: species	Stems recorded: dbh, cm	Blocks in which used
Type 1 	Main sample	Radius 10	0.031	All	≥5.0	1 (part) 4 (part)
	Regeneration subsample	Radius 3*	0.003	All	<5.0	
Type 2a 	Main sample	100 x 20	0.200	All	≥15.0	3 6
	Gewa subsample	50 x 20	0.100	Gewa	≥10.0	
	Regeneration subsample	Radius 10	0.031	All	≥5.0	
	Regeneration subsample	Radius 3	0.003	All	<5.0	
Type 2b 	Main sample	100 x 20	0.200	All	≥15.0	1 (part), 2, 4 (part), 5A, 5B, 7, 8
	Gewa subsample	50 x 20	0.100	Gewa	≥10.0	
	Fuelwood and regeneration subsample	20 x 20	0.040	Fuelwood species** All	≥2.5 ≥5.0	
	Regeneration subsample	Radius 3	0.003	All	<5.0	

* Initially 5 but reduced to 3 after first few plots ** Fuelwood species: goran, kalshi, kirpa and singra

Gewa : Escoecaria agallocha



SCALE : 1:50 000
(The codes indicate the forest types defined above.)

Fig. 3.1: **Part of the forest type map of the Sundarbans** Bangladesh. (Source: ODA, 1985)

CASE STUDY 4

A SMALL SCALE INVENTORY OF THE MA-SWAR MANGORVE AREA SIERRA LEONE

(Source: B.Birkenhager, 1988)

4.1 INTRODUCTION

Under the FAO/UNDP Fuelwood Project in Sierra Leone (SIL/83/003 and SIL/88/008), a pilot area of 270 ha was selected for demonstrating improved mangrove management techniques.

The area, on three sides enclosed by a U-shaped curve in the Ribi River, is inundated by normal high tides and consists of an almost intact natural mangrove forest. The main species encountered were *Rhizophora racemosa*, which formed the highest stands - especially along the river; *Rhizophora harrisonii* and *Avicennia africana*.

The forest inventory was undertaken in 1987/88.

4.2 METHODS AND MATERIALS

The systematic line plot sampling design was employed with 100 m between the lines and 40 m between each circular plot along the line. The radius of the plots was 5 m giving a plot size of 79 m^2 and a sampling intensity of 2 %.

Since initial reconnaissance and the study of aerial photographs (1975/76 Infrared False Colour; scale 1:70 000) indicated the occurrence of strongly divergent vegetation types within the area, the vegetation type of each plot was noted based on the following stratification:

(a) High Forest (Pure *Rhizophora spp.*)
(b) High Forest (*Rhizophora/Avicennia*)
(c) Semi-high Forest (*Rhizophora*)
(d) High Bush (Pure *Rhizophora spp.*)
(e) High Bush (*Rhizophora/Avicennia*)
(f) Low Bush (Pure *Rhizophora spp.*)
(g) Low Bush (*Rhizophora/Avicennia*)

Within each plot the species and the dbh for all trees with a dbh ≥ 7 cm were recorded. (In the case of trees with stilt roots originating above 1 m up the stem, the diameter 30 cm above the stilt root was used.) The height of trees was measured on all trees in every fifth plot.

A total of 655 plots were laid out. With 8 plots falling in the Ma-swar River, the assessment was based on an inventory of 647 plots.

4.3 RESULTS

Based on the classification of plots into vegetation types and with additional information obtained from infra-red aerial photographs at a scale of 1:70 000, a vegetation map was produced. The map clearly shows that the high forest is found along the river banks and that towards the interior of the swamp a decrease in height occurs via semi-high forest and high bush to low bush.

Matching plot data and plot stratification led to the following characteristics for the vegetation types discerned in this study:

Table 4.1: Inventory results, Ma-swar, Sierra Leone

Vegetation type	No. of plots	Tree height (m)	Maximum DBH (cm)	Estimated volume (m^3/ha) Mean volume Rhizophora	Avicennia	90% confidence limits Rhizophora	Avicennia
High Forest (Rhizophora)	180	20-30	>25	231.1	0	209.9-252.3	0
High Forest (mixed)	21	20-30	>25	156.6	39.6	112.2-200.9	12.6-66.5
Semi-high Forest	104	15-20	15-25	59.9	0	52.1-67.9	0
High Bush (Rhizophora)	73	12-15	10-15	17.3	0	14.2-20.3	0
High Bush (mixed)	35	12-15	10-15	22.0	8.0	16.1-28.0	1.7-14.4
Low Bush (Rhizophora)	62	<12	<10	1.2	0	0.5-1.1	0
Low Bush (mixed)	172	<12	<10	0.8	5.9	0.5-1.1	4.3-7.4

The volume in the above table is the stem volume above 7 cm and is estimated using a volume table from Matang, Malaysia with entry for dbh.

The total standing volume of the area was estimated to be 23 000 m^3. With a suggested rotation of 15 years, a maximum of 1 500 m^3 can thus be harvested annually during the first rotation if a clearfelling system is to be employed.

4.4 DISCUSSION

The systematic line plot sampling design and the sampling intensity employed yielded adequate results. However, the actual plot size was deemed to be too small as only 2 plots contained 10 trees or more. This accounts for some of the variance of the estimates - especially with regard to plots found in the mixed *Rhizophora/Avicennia* vegetation types, as the actual plots often contained either *Rhizophora* or *Avicennia* trees rather than a mixture of the two.

For natural stands such as these, comprising mainly *Rhizophora spp.*, where in many cases the stands are far from being homogenous and the density of trees is small due to wide spreading stilt roots, it is thus recommended that a plot radius of 8 or 10 m be used.

The volume table used was the only one available at the time, but is based on other species (*Rhizophora apiculata* and *Rhizophora mucronata*) grown as even-aged plantations, not natural stands. It was thus decided that a local volume should be constructed to test the validity of the Malaysian table and, if necessary, to adjust the above estimates. See **Case Study 5**.

CASE STUDY 5

THE CONSTRUCTION OF A LOCAL VOLUME TABLE IN SIERRA LEONE

(Source: M.Løyche and C.L.Amadou, 1989)

5.1 INTRODUCTION

As a follow-up to the inventory carried out as described in the previous case study, a local volume table was constructed due to the following reasons:

- No volume table was available for the mangrove species of West Africa;

- The volume table from Matang, Malaysia used for the preliminary assessment of wood volume in the Ma-swar area in Sierra Leone is based on *Rhizophora apiculata* and *Rhizophora mucronata* grown as even aged plantations and only gives the big wood volume i.e. stem volume above 7 cm in diameter with the entry for dbh;

- In Sierra Leone, the mangroves are mainly natural and mature climax stands, which along major rivers reach a height of up to 40 metres. The dominant species is *Rhizophora racemosa*, which often have stilt roots originating 4-6 m up the stem and dbh is thus not a valid parameter;

- Near urban centres, in particular close to the capital Freetown, over exploitation by unregulated cutting for firewood and charcoal has reduced former mangrove forests to thickets seldom reaching above 5-6 m in height and 10 cm dbh. The main species here are *R. racemosa, R. harrisonii, R. mangle* and *Avicennia africana*. Fuelwood is still being extracted here utilizing wood down to approximately 3 cm in diameter.

The volume table should thus take into account not only the big wood volume, but also indicate the wood available from the above over exploited thickets.

5.2 METHODS AND MATERIALS

The area chosen for felling and measuring trees was the Ma-swar mangrove area, where the inventory described in Case Study 4 had taken place.

The preparation of a volume table normally entails the felling of a great number of trees. However, due to limited skilled manpower, equipment and funds, it was decided to measure approximately 100 trees equally spread over the area to avoid 'neighbouring effects' and in order to have all the vegetation types represented. At the same time it was decided to obtain a maximum of 20 measurements for trees with a dbh less than 10 cm and 15 trees in each of the following 10 cm diameter classes.

The outline of the inventory plots (the line plot sampling design) was followed and it was decided to fell one tree in every fifth plot. Thus the distance between the plots along the line was 200 m with 100 m between each line of plots.

The tree to be felled in each plot was chosen at random. An attempt was made to chose a tree with a diameter close to the average diameter in the plot. Abnormal trees with broken stems, dead tops etc. were avoided, as were trees directly bordering the main river. Plots only containing trees with diameters falling within a diameter class, where the maximum number of trees had already been reached, were disregarded.

After choosing the tree, the diameter was measured with a diameter tape. This was in most cases the 'diameter above stilt roots' (D_{as}), taken 30 cm above the highest stiltroot, as recommended by FAO (1980). Only stilt roots resulting in a deformation of the stem were taken into account.

The stem was marked with lumber crayon at the measuring point and the height above ground level of this point recorded and the tree was then felled with a chainsaw.

Starting from the point of the D_{as}, the stem was then marked for each one meter following the form of the tree, and the diameter at the end of each section recorded in cm with one decimal, until a diameter just above 7 cm was reached. The exact point where the diamter was 7.0 cm was found and marked, and the distance to the last recorded diamter measured. The point where the diameter was exactly 5.0 cm was likewise marked and the distance to the 7 cm mark recorded.

The length of the tree from the D_{as} mark to the top most leaf bud following a straight line was recorded and added to the height at which the D_{as} was measured to obtain the total height of the tree.

All branches and stilt roots down to 5 cm in diameter were weighed. As the branches often were very crooked and the stilt roots oddly shaped, this was found to be the best method of obtaining an estimate of the amount of this wood, which in many cases would be used as firewood.

For trees with a dbh less than 10 cm, a slightly different method was employed, as these trees are often felled for firewood by the local villagers using cutlasses, and wood down to 3 cm in diameter is extracted.

The diameter and the total height were recorded as previously, but instead of measuring the volume, the tree with branches and stilt roots down to 3 cm in diameter was weighed.

Establishment of the green weight and volume of samples from some of these trees and of some of the branches and stilt roots of the bigger trees was undertaken in order to determine a conversion factor from weight to volume. The volume of the wood samples was found by submerging them in water and measuring the weight and thus the volume of the water displaced.

A total of 85 trees were felled and measured. Three wood samples taken from each of 10 trees with a diameter below 10 cm dbh; 30 samples of branch wood and 30 samples of wood from stilt roots were weighed and their volume measured to obtain the green density.

Please refer to **Figures 5.1 - 5.4** for an illustration of the difficult working conditions found in mangrove areas.

Figure 5.1: **Mature natural mangrove forest, Ma-swar, Sierra Leone**
Photo by M.L.Wilkie

Figure 5.2: **Measuring the felled tree, Ma-swar, Sierra Leone**
Photo by M.L.Wilkie

Figure 5.3: **Weighing the stiltroots of a felled tree, Ma-swar, Sierra Leone**
Photo by M.L.Wilkie

Figure 5.4: **Measuring the green density of wood samples, Ma-swar, Sierra Leone**
Photo by M.L.Wilkie

5.3 RESULTS

For the volume calculations the Smalian formula

$$V = \frac{D_1^2 + D_2^2}{2} \times \frac{\pi}{4} \times L$$

was used to determine the volume for each section of the stem above D_{as}.

Due to the shape of the stem below the stilt roots, this part was regarded as part of the stilt root system.

For the trees with a diameter above 10 cm, the stem volume above stilt roots and above 7 cm in diameter was calculated, as was the stem volume down to 5 cm. The results from the determination of the green density of branch wood and stilt roots were used to convert the measurements of weight into volume and the total wood volume above ground down to 5 cm in diameter was determined.

For trees less than 10 cm in dbh, the green density obtained was used to convert the weight into volume and the total volume down to 3 cm in diameter was calculated.

The results of the determination of the green density are shown in **Table 5.1** below:

Table 5.1: Results of the determination of the green density

Type of wood	No. of samples	Average green density (g/cm³)	Standard deviation (sd)	95% confidence limits (g/cm³)
Branches	30	1.1754	0.2118	1.1610-1.1898
Stilt roots	30	1.1613	0.0400	1.1586-1.1640
Small trees	30	1.2022	0.0538	1.1986-1.2059

As the wood from the small trees was slightly heavier than the branch wood and significantly heavier than the wood from the stilt roots, the individual means were used for the conversion rather than an overall average.

Plotting of the diameter against the height of the trees measured showed a very good correlation in spite of localised variation in site factors and the use of D_{as} for most of the bigger trees. The correlation between diameter and height was analysed and curve fitting with four different regressions (Logarithmic curve, Straight line, Exponential curve and Power curve) was undertaken. The heighest correlation coefficient (0.9960) was obtained for the power curve derived from the following formula:

$$H = 1.123 \times D^{0.8592}$$

where H is the total tree height in metres and D is the diameter in cm measured at breast height (1.30m above ground level) or - especially on the bigger trees - 30 cm above stilt roots.

Due to the good correlation between diameter and height, it was decided that a one entry tariff for the volume table would be sufficient. An analysis of the relation between the diameter and the volume was thus undertaken in the same manner as above. For the relation between diameter and stem volume above 7 cm, the best correlation coefficient (0.9986) was obtained for the following regression:

$$V_{stem} = 0.0001 \times D^{2.5478}$$

where V_{stem} is the stem volume in m^3 above the point of the dbh/D_{as} and down to 7 cm in diameter and D is measured as above. Based on the above formula a volume table for the *Rhizophora* species in Sierra Leone has been constructed. This table was found to vary considerably from the Malaysian volume table previously employed (See **Appendix 5**).

The correlation between diameter and the total tree volume was, as could be expected, less good. However, a correlation coefficient of 0.9942 was found for the following regression:

$$V_{total} = 0.004 \times D^{2.2128}$$

where V_{total} is the total tree volume in m^3 down to 5 cm in diameter.

For trees less than 10 cm in dbh, the total tree volume down to 3 cm in diameter was found to average 0.0199 m^3.

A summary of the findings with regard to trees above 10 cm in dbh is presented in **Table 5.2** below:

Table 5.2: Summary of findings according to diameter classes

Diameter class (cm)	No. of trees felled	Mid diameter (cm)	Average height (m)	Average V_{stem} above 7 cm Actual (m^3)	Regression (m^3)	Diff. (%)	Average V_{total} above 5 cm Actual (m^3)	Regression (m^3)	Diff. (%)
10-20	14	15	11.98	0.0805	0.0749	- 7.5	0.1888	0.1682	- 12.2
20-30	16	25	18.69	0.2498	0.2753	9.3	0.4632	0.5209	11.1
30-40	13	35	24.74	0.6200	0.6489	4.5	0.9505	1.0968	13.3
40-50	13	45	30.13	1.2561	1.2310	- 2.0	1.9843	1.9127	- 3.7
≥50	5	55	32.15	2.1597	2.0526	- 5.2	3.0150	2.9819	- 1.1

5.4 DISCUSSION

As the number of trees measured is relatively small, the above volume regressions are only tentative in nature, but serve as a good starting point. More data should be collected from a variety of sites within the country to further refine the above table(s).

CASE STUDY 6

MULTIPLE-USE MANAGEMENT OF THE SUNDARBANS FOREST IN BANGLADESH

(Source: M.Z. Hussain, 1992)

6.1 INTRODUCTION

The Bangladesh portion of the Sundarbans mangrove forest is located in the Southern most extremity of the Gangetic delta, bordering the Indian State of West Bengal in the west and the Bay of Bengal in the south. The forest occupies a flat mud swamp which is submerged by high spring tides most of the year and by almost all high tides during the rainy season.

This portion of the Sundarbans covers an area of 577 285.6 hectares. The forest extends into the State of West Bengal where it covers an additional area of 416 000 hectares. Within Bangladesh, the Sundarbans forest extends over three administrative districts in the Southwestern part of the country and lies between 89°E and 90°E longitudes and 21°0N and 22°31N latitudes extending about 80 kilometers inland from the Bay of Bengal. Please refer to **Figure 1**.

The total land area of the Bangladesh portion of the Sundarbans is about 401 600 hectares. The rest is under water in the form of rivers, channels and creeks varying in width from a few feet to several miles. The larger of these rivers are the remains of former beds of the Ganges, which have gradually shifted eastward, and are no longer directly connected to the Ganges river. Baleswar, which passes along the eastern boundary of the forest, is the only river which is still connected with the Ganges and receives direct fresh water effluence from this river. A large number of channels and creeks flow into larger rivers in the Sundarbans. These, in addition to flooding the forest floor, make most of the forest accessible by country boats during high tides and make forest extraction activities relatively easy. Some of these creeks or channels flow between two major water ways and play important roles in navigation within the forest.

Tides also play an important role in the Sundarbans since the scouring action during the ebb tides remove silt that may have been deposited and keep the rivers, channels and creeks open. The high tides on the other hand ensure the inundation of the forest floor - a necessity for the proper growth and sustenance of the vegetation.

The Sundarbans has a humid tropical climate with a mean annual rainfall ranging between 1 640 and 2 000 mm. The quantity of annual rainfall recedes from east to west. Most of the rainfall occur between May and September. There is very little rainfall between November and April. The temperature ranges between 20.4°C and 31.5°C. The highest temperatures are recorded during May and June and the lowest during December and January.

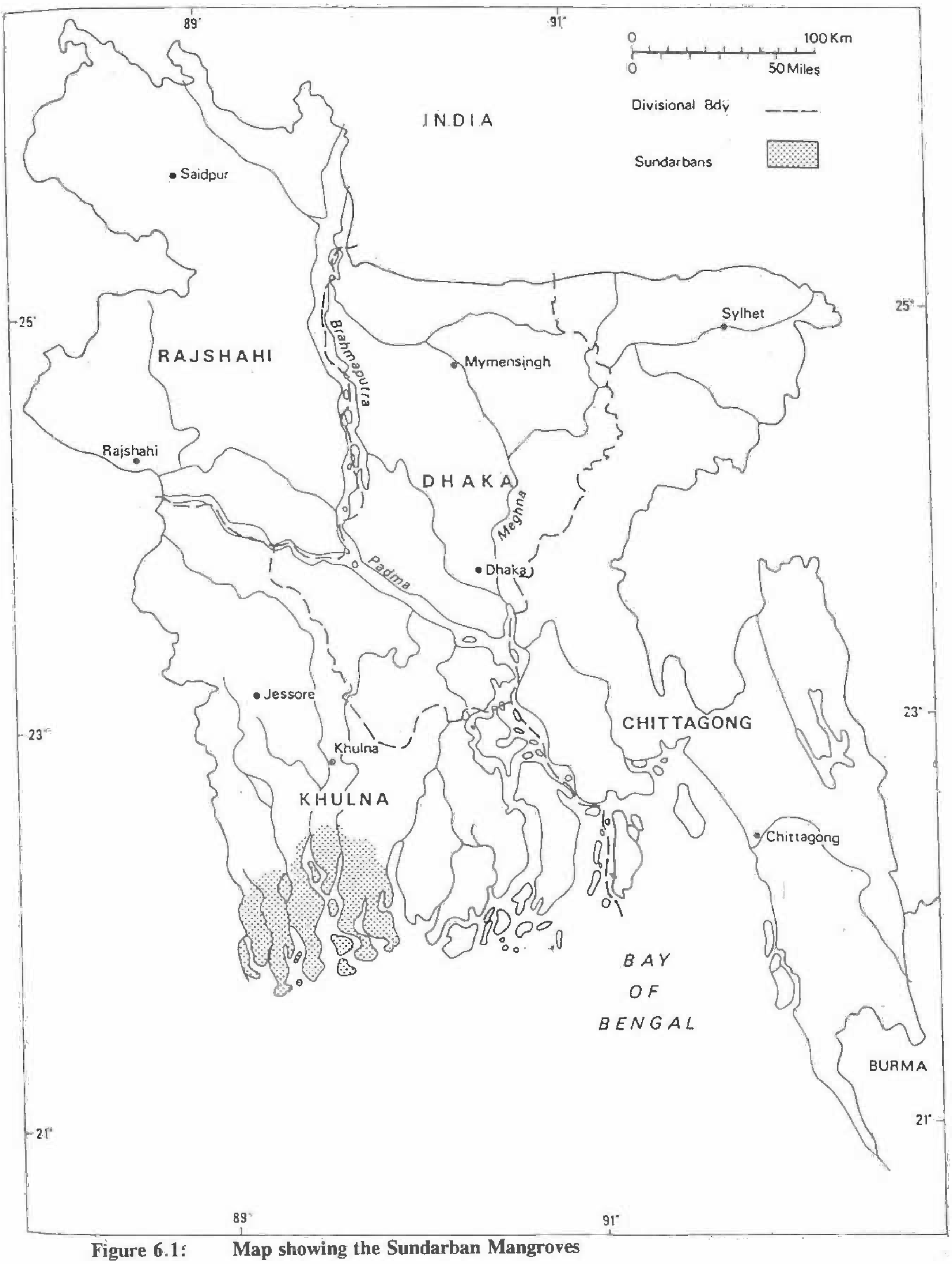


Figure 6.1: **Map showing the Sundarban Mangroves**

The forest grows on soil which is of recent geological origin and consists of alluvium deposit which has been washed down from the Himalayas. The soil is a silty clay loam and the sub-soil consists of alternate layers of clay and sand which at greater depths are compacted with shale and sandstone. No rock formation occurs in the area. The surface soil of the forest area consists mainly of clay. Sandy patches are absent, except near the sea. The grey colored soil is neutral to mildly alkaline in reaction. However, in some areas the dried up sub-soil is more acidic in reaction. The soil is slightly saline in the East/Northeast and moderately saline in the West/Southwest. A seasonal gradient of salinity fluctuation in soil and water exists in the Sundarbans. The salinity gradient reaches a peak in April - May before the rains but falls off abruptly with the monsoon rains in May - June.

6.2 THE FLORA OF THE SUNDARBANS

Heritiera fomes (Sundri) and *Excoecaria agallocha* (Gewa) are the two principal mangrove tree species in the Sundarbans. According to a recent inventory report (Chaffey *et.al.*, 1985), Sundri and Gewa occur over more than 70% of the Sundarbans in either pure patches or mixtures. One of the two species occurs in mixture with other species in over another 25.8% of the forest. *Ceriops candelleana* (Goran) is the third most frequent species occurring in the Sundarbans. Other important tree species in the Sundarbans are *Sonneratia apetala* (Keora), *Xylocarpus mekongensis* (Passur), *Bruguiera gymnorrhiza* (Kankra), *Avicennia officinalis* (Baen), *Cynometra ramiflora* (Singra), *Amoora Cucullata* (Amur), *Hibiscus tiliaceus* (Bhola) and *Nypa fruticans* (Golpata). A complete list of the Sundarban flora can be found in Chaffey *et al.* (1985) and is also included in Das and Siddiqi (1985).

The Eastern portion of the forest receives much more fresh water than the Western portion and the quality of crop is better in this region due to the fresh supply of silt each year, which result in a soft and fertile top soil. The quality of crops gradually deteriorates towards the West, where, in the absence of silt, the top soil has become hard and less suitable for tree growth (Das and Siddiqi, 1985).

Heritiera fomes prefers relatively fresh water area and is thus more abundant in the Eastern portion. *Excoecaria agallocha* occurs throughout the forest but is relatively more abundant in areas which receive less freshwater. *Ceriops candelleana* occurs mostly in mixture with *Heritiera* and *Excoecaria*. However, pure patches of *Ceriops* are not uncommon. *Sonneratia apetala* occurs mostly in pure patches along water courses and is a colonizing tree species growing on newly accreted land. *Xylocarpus mekongensis* occurs in association with *Bruguiera gymnorrhiza* in damper places throughout the forest. Common understorey species, particularly in moist soils, are *Cynometra ramiflora* (Singra) and *Amoora cucullata* (Amur). *Nypa* palms occur on the edge of water courses and are more abundant along small creeks than big rivers. The more saline western portion of the forest has a greater abundance of *Ceriops* and *Phoenix paludosa* together with some *Excoecaria*.

Heritiera fomes is economically the most important tree species in the Sundarbans. The timber is extensively used in construction, piling, and boat building. *Heritiera* poles are also being used as transmission poles. *Heritiera* fuelwood is of a high quality and is used in domestic cooking, small scale industries and brick manufacture. A hardboard mill in Khulna exclusively uses *Heritiera* fuelwood as raw material.

Excoecaria, on the other hand, produces a high quality pulpwood and is exclusively used as raw material in the only newsprint paper mill in the country. The species is also used extensively in the match industry.

Ceriops candelleana is a high quality fuelwood and is also used as fencing and house posts. *Xylocarpus mekongensis* and *Bruguiera gymnorrhiza* are used in construction and furniture manufacture. *Cynometra ramiflora, Amoora cucullata* and *Hibiscus tiliaceus* all produce good quality fuelwood. *Nypa* leaves are used for thatching in rural areas.

6.3 ASSESSMENT OF THE WOOD RESOURCES

The first effort at generating quantitative information on the growing stock in the Sundarbans was made by Curtis during the formulation of his working plan in the lata 1920s and early 1930s. Data collected from a number of sample plots of *H. fomes*, which were established between 1893 and 1911, were analyzed and the volume and diameter growths were assessed. Sample plots for measurement of growth of other species were also established during the preparation of the plan. Rough estimates of growth of *Excoecaria agallocha, Sonneratia apetala* and *Avicennia officinalis* were carried out through counting of annual growth rings. Volume tables were prepared for all commercially important species. The forest was divided into four quality classes.

A detailed inventory of the Sundarbans was carried out in the late 1950s by the Forestal Forestry and the Engineering International Ltd. This inventory used aerial photographs and applied photogrammetric techniques combined with statistically controlled ground sampling. The forest was divided into four quality classes of 50+, 35-49, 20-35 and below 20 feet mean heights. Class 3, corresponding to heights of 20-35 feet, was divided into two subclasses of 25-35 and 20-25 feet mean heights. The 20-24 feet mean height sub-class was created because large areas in the Western and Southwestern part of the forest fall in this mean height category. The density of the forest was divided into four classes as foolows:

A	90 - 100%	crown	closure
B	75 - 90%	"	"
C	50 - 75%	"	"
D	less than 50%	"	"

Volume tables for commercially important species were constructed and a summary of the merchantable volume of different species was tabulated as shown in **Table 1.**

ODA carried out an inventory of the Sundarbans in the early 1980s and published the results in 1985. Important information generated by the inventory is shown in **Tables 2 and 3.**

Even though *Ceriops* is the third most frequently occurring species in the Sundarbans, the volume of the growing stock of the species has not been calculated during either of these inventories.

According to the ODA study 65% of the forest had a crown closure of more than 70% while the Forestal inventory (1960) classified 78% of the forest as having a canopy closure of more than 75%.

Table 6.1: **Summary of net merchantable volumes in the 1950s**
Utilization standard : To 4 inch top D(o.b.)

Volume	Total Volume (ft^3)			Volume per acre (f^3)		
DHB class	5" and over	6" and over	9" and over	5" a.o.	6" a.o.	9" a.o.
Species :						
Gewa	111 726 530	67 184 730	9 211 850	119	72	10
Sundri	520 735 640	449 229 180	204 999 970	556	480	219
Passur	28 074 710	25 950 260	14 512 060	30	28	15
Kankra	17 677 170	15 515 960	7 224 940	19	16	8
Baen	15 284 290	15 152 870	14 498 850	16	16	15
Keora	19 471 200	19 389 150	18 764 460	21	21	20
Other Species	4 246 820	2 827 420	1 479 200	5	3	2
Total	717 216 360	595 249 570	270 691 330	766	636	289

Source : Forestal Inventory Report of the Sundarbans

Table 6.2: **Area of major forest types**

Forest types	Area miles^2	Area Km^2
Heritiera	324.61	831.0
Heritiera-Excoecaria	455.08	1165.0
Heritiera-Xylocarpus	8.59	22.0
Heritiera-Xylocarpus-Bruguiera	25.39	65.0
Excoecaria	76.56	196.0
Excoecaria-Heritiera	228.52	585.0
Excoecaria-Ceriops	141.41	362.0
Ceriops-Excoecaria	223.40	572.0
Ceriops	36.33	93.0
Sonneratia	12.87	33.0
Others	12.50	32.0
Total	545.30	3956.0

Source : ODA Inventory Report, 1985

Table 6.3: Merchantable volume of different species in the 1980s

Species	Volume f^3	Volume m^3
H. fomes	240 071 000	6 798 000
E. agallocha	63 320 000	1 793 000
S. apetala	16 810 000	476 000
Others*	55 763 000	1 579 000
Total	375 964 000	10 646 000

* Others include A. officinalis, X. mekongensis, B. gymnorrhiza and X. granatum.

Source : ODA Inventory Report, 1985

It is difficult to correctly compare the growing stock in the forest from the two inventories, as trees of different sizes were considered as merchantable trees during the two inventories. However, using the ODA inventory data, Balmforth (1985) has calculated the decline in the volume of *H. fomes* and *E. agallocha* between the two inventories, which stands in the order of 40% for each species.

6.4 FAUNA OF THE SUNDARBANS

The Sundarbans supports a very rich and diverse fauna which includes at least 43 species of mammals, 52 species of reptiles and amphibians (Hendrichs, 1985; Mukherjee 1975) and over 186 species of birds (Salter, 1984). The Sundarbans is the last remaining natural habitat of the famous Royal Bengal Tiger, 350-450 of which are still reported to be present in the Bangladesh portion of the forest.

The mammals of the Sundarbans include the Royal Bengal Tiger (*Panthera tigris*), civets (*Paradoxurus hemaphroditus* and *Viverra zibetha*), three species of wild cat (*Felis spp.*), mongoose (*Herpestes spp.*), the Smooth otter (*Lutra perspillata*), Spotted deer (*Axis axis*), Barking deer (*Muntiacus muntjak*), Wild boar (*Sus scrofa*), Rhesus monkey (*Macaca mulatta*), Gangetic dolphin (*Platanista gangetica*), porcupine (*Hystrix spp.*), squirrels, rats and bats.

The reptiles and amphibians of the Sundarbans include the Estuarine crocodile (*Crocodilus porusus*), the Bengal monitor and the Yellow monitor (*Varanus bengalensis* and *V. salvator*), various lizards and geckoes, the Rock python (*Python molurus*), King cobra (*Naja naja*), several species of marine and freshwater turtles including the Green turtle and Ridley turtle (*Cheonia mydas* and *Lepidochelys olivaca*, the River or Estuarine terrapin (*Batagur baska*), frogs and toads.

The bird population of the Sundarbans includes at least eight species of kingfishers, including the large Brown-winged and Stork-billed kingfishers (*Pelargopsis amauroptera* and *P. capensis*), the magnificent White-bellied Sea Eagle (*Haliacetus leucogaster*), which is quite common, the very rare Grey-headed Fishing Eagle (*Ichtyophaga ichtyaetus*) and Pallas' Fishing Eagle (*H. leucoryphus*). Brahminy kites (*Haliastur indus*) are also a very common sight. Herons, egrets, adjutant storks, plovers, sandpipers and other waders are to be seen along mudflats and sandbanks. Doves, pigeons, sea gulls and terns are likewise numerous. Other birds include the Red jungle fowl (*Gallus gallus*), several woodpeckers, the Red-ringed parakeet(*Psittacula krameri*) and mynas (*Acridotheres spp.*).

Compiled lists of all the mammals, reptiles, amphibians and most of the birds occurring in the Sundarbans can be found in Das and Siddiqi (1985).

The rivers, channels and creeks within the forest are rich in fish, crustaceans and molluscs, which are tapped regularly on a commercial basis and thus generate employment for a large number of people. 120 species of fish are reported to be commonly caught by commercial fishermen from the Sundarbans waters (Seidensticker and Hai, 1985).

6.5 THE SOCIO-ECONOMIC IMPORTANCE OF THE SUNDARBANS

The Sundarbans plays a very important role in the economy of the region. A large number of people in the neighboring districts are directly or indirectly dependent on the forest for their livelihood. In addition, the forest makes a substantial contribution to the economy of the country. The forest now comprises about 45% of the nation's productive forest and naturally constitutes the single largest source of wood in the country. The forest also supplies raw materials for a number of industries including a large newsprint paper mill and a hardboard mill.

The forest has, so far, been managed primarily for timber, fuelwood poles and industrial wood (raw material). However, the current management practice, which has been developed over a long time, allows entrepreneurs both large and small, to participate in income generative activities. Before a temporary moratorium was imposed on forest harvest in the Sundarbans in 1989, the average annual harvest of various products was as follows:

Table 6.4: Annual production from the Sundarbans

Item	Quantity
Timber (m3)	68 000
Industrial wood (m3)	182 900
Transmission Poles (no.)	15 900
Fuelwood (tons)	106 450
Nypa leaves (tons)	68 400
Phoenix leaves (tons)	7 350
Grasses (tons)	11 830

Source: Bangladesh Forest Department

It may be mentioned here that *Nypa* palm leaves and grasses are used for thatching, *Phoenix* leaves are used for making house walls on which mud is plastered, and are used extensively by the poorer sections of the rural population. Fuelwood, *Phoenix* leaves and grasses are sold in small boat loads of 2-8 tons capacities for which permits are issued to individuals for each boat load. This allows a large number of people with small capital to involve themselves in income generating activities. The timber and *Nypa* coupes are also divided into a large number of small lots of different values thus allowing a large number of entrepreneurs to engage themselves.

The Sundarbans is not just a conglomeration of trees like most other forests, it is an ecosystem which is also very rich in a number of other resources. The Sundarbans has a rich fishery resource and it provides vital breeding and nursery grounds for the fish, crustaceans and molluscs that make up the fishery in the head of the Bay of Bengal. It is estimated that some 35% of the total marine fish catch in the Bay of Bengal is of species dependent upon this forest for some period of their life.

The rivers, channels and creeks in the Sundarbans are also very rich in fishery resources. As has already been mentioned, a total of at least 120 species of fish are reported to be regularly caught by commercial fishermen in the Sundarbans. The fishing within the forest takes place year round while fishing along the outer coast is seasonal and takes place between October and February when at least 10 000 fishermen establish temporary camps in the forest and fish along the coast. The fish are mostly dried and shipped to the market. A large number of fishermen are also involved in year round fishing in the Sundarbans. According to a recent report by AWB (1991), about 150 000 metric tons of fish are caught from the Sundarbans and adjacent waters each year.

Mollusc shells are extensively collected from the forest and converted into lime by heating at high temperatures. According to the Forest Department Records, on an average, 3 150 metric tons of shells are collected annually.

Flowers of mangrove trees in the Sundarbans produce high quality honey and on an average about 200 metric tons of honey and 50 tons of bee-wax are collected by individual honey gatherers annually.

It is therefore obvious that the Sundarbans plays a very vital role in the economy of the region and generates a lot of diverse economic activities and provides a livelihood to a very large number of people in the region.

An estimate of the number of people directly dependent on the forest for their livelihood is not known. However, an estimate in the late 1970s puts the number of people present within the forest on any day during the peak working season at 45 000. This figure has most probably increased since. The cumulative number of people entering the forest is much higher. In fact, according to Forest Department Statistics, about 300 000 people enter the forest each year but unofficial estimates suggest that the figure is likely to be much higher. According to a report by ESCAP (1987), the actual figure for direct employment by the Sundarbans is likely to be in the range of 500 000 - 600 000 people for at least half of the year.

These figures do not provide any indication of the number of people involved in Sundarbans products related income generating activities outside.

In activities such as wood processing in mills and factories, transportation, retail and wholesale trade, no assessment of the number of people involved has ever been made. However, the number is expected to be high. The aggregate of people who are dependent on the Sundarbans is high. This, together with the quantum of economic activity that the forest generates, makes it very important for the economy of the country. The revenue earned by the Forest Department from the forest is also very high compared to expenditure. Between the fiscal years 1984-85 and 1988-89 the average annual income from the forest was Bangladesh Taka 264.38 million (US$ 7.0 million) and the average annual expenditure was Bangladesh Taka 21.6 million (US$ 576 000).

The forest has a huge potential for tourism and provides excellent opportunities for outdoor recreation and is a paradise for nature lovers. The potentials for tourism, research and nature and conservation education have not been exploited. These activities have potentials for generating additional economic activities.

Bangladesh is often battered by cyclones and sea storms which result in colossal damage to human lives and properties. The Sundarbans act as a buffer between the densely populated agricultural land and the sea, and protects the hinterland from major damages. The cyclones and sea storms have wrought destruction in the coastal regions time and again during the last thirty years or so. However, because of the presence of the Sundarbans between the sea and the habitation, no noticeable damage has ever taken place in the large area behind the forest.

6.6 MANAGEMENT OF THE FOREST - PAST AND PRESENT

The present-day management practices in the Sundarbans were evolved locally over time and were not introduced from outside. The actual evolutionary process, which started at the beginning of the current century, was developed during the early and middle part of the century and is reflected in the management plans/schemes executed during this period. The evolution of the process makes interesting reading and has therefore been included in this document.

The exploitation of the tree resources of the Sundarbans on a commercial basis dates back to the middle of the 16th century when a local king imposed a levy on the export of wood from the forest and used this as a regular source of income. Since then, local landlords realized tolls from the export of wood. In the early days of the British Indian Government, leases were granted to both locals and Europeans who were allowed to clear forests and convert them into agricultural land or human settlement.

The value of the Sundarbans as a forest resource base was first realized in the 1860s, and in 1879 a Forest Division was created for the management of the Sundarbans. The first management prescription was developed after two reports on status of the *Heritiera*, the only tree species thought to be of commercial value and extensively exploited at that time, were made by A.L. Home (1872-73) and Dr. Schlich and Sir Richard Temple (1873-74). A minimum exploitable girth for Sundri was fixed in 1874. Toll Collection Stations were also established on the recommendation of Dr. Schlich on the main routes of timber export. In the early days revenues were realized on the basis of the weight of the wood exported.

The first management plan for the Sundarbans, which came into operation in 1893-94, was developed by R.L. Heinig who formulated management prescriptions for the exploitation of Heritiera trees in Bagerhut and Khulna forests where the forests were divided into 10 annual coupes for management purposes. The minimum exploitable diameter limit was refixed for *Heritiera* only which was thought to be the only commercially valuable species. However, regulated felling of trees continued in the rest of the forest. The main objective of the plan was to increase revenue and little attention was given to the silvicultural requirements or the conservation of *Heritiera*. This, as expected, resulted in substantial depletion of the forest.

Luckily, the value of preservation of the forest took precedence over revenue generation at this stage and the follow-up actions which were taken laid the foundation for the evolution of a sustainable forest management regime, which today is still in practice, in a modified form. The adverse effect of over-exploitation was recognized before irreparable damage was caused to the forest and steps aimed at better regulation of felling of trees were taken. In the working scheme written by Lloyd for the period from 1903-04 to 1908-09, the sizes of annual coupes were reduced to a quarter of the original size and the felling cycle was increased from 10 years to 40 years. This resulted in the exploitation of a much lesser area annually and the gap between two fellings in any area was increased to 40 years. Simple silvicultural treatments were also prescribed.

During this plan period all felling operations, including those of species other than *Heritiera*, were confined to annual coupes and unregulated scattered felling was discontinued. Proper supervision of coupes was introduced and necessary measures were taken to control pilferage of wood.

Trafford's working plan which was written for the period 1912-13 to 1931-32, divided the entire forest into two working circles: the Sundri (*Heritiera*) or Eastern Working Circle, covering relatively freshwater areas with good quality crop, and the Western Working Circle, covering more saline area where the crop was poorer.

This plan fixed the exploitable girth for the other commercial species and introduced an intermediate type felling called the main thinning in order to relieve the congestion among middle aged crop. This prescription was designed to make improvement on felling and thinning on a 20-year cycle in more rapidly growing forests in the Eastern circle and 40-year cycle in the other areas. Provisions were also made for subsidiary thinning among congested saplings.

The working plan written by Curtis for the period 1931 to 1951 was a very comprehensive document which incorporated a number of modern management concepts, synthesized the experience from the past management practices and developed a management regime for perpetual supply of timber, fuel and thatching material. The prescriptions formulated by Curtis are still in practice and almost in the same form. Detailed enumeration, stock mapping, site classification, etc., were done and exploitable diameters for all commercial species were fixed for all site classes.

Detailed rules and procedures for calculation of yield, laying out of coupes, marking and felling of trees including *Nypa* palms were made in the plan. These prescriptions are still followed. However, the plan was thought to be too intensive at the time and was simplified by S. Choudhury in 1937.

Curtis also decentralized the forest management by creating six forest ranges. The forest was worked on a 20, 30 and 40-year cycle in good, moderate and poor quality forests. The yield was regulated by area even though provisions for a detailed yield calculation were made in the plan. Separate sets of rules were developed for the management of minor forest produces including *Nypa* palm leaves, honey, wax, grass and shells.

A.M. Choudhury revised the plan for the then East Pakistan portion of the forest in the early 1960s after a detailed inventory was carried out and a lot of quantitative information was generated. Since a newsprint paper mill was then established in Khulna, and was designed to utilize *Excoecaria* (Gewa) as the pulping raw material, emphasis was laid upon the management of this species for the first time. A cutting cycle of 20 years was fixed for the entire forest and an annual allowable cut was calculated by using information generated from the inventory. Yield had, however, been regulated by area and while prescribing annual coupes the areas had been fixed so as to equalize the volume yield as far as possible in the case of the *Heritiera* (Sundri) forests. The rules laid down by Curtis were also fine tuned by Choudhury.

Choudhury's plan expired in 1980 and an inventory of the forest resources was carried out and a report was published in 1985. A revised plan is reported to be under preparation and meanwhile, the forest is being managed on prescriptions formulated on an annual basis.

There has been a strong awareness in the recent years about the depletion of the growing stock of the two major species in the Sundarbans. Efforts are being made to restrict the annual *Excoecaria* harvest to 3.8 million ft^3. A complete ban was imposed in 1989 on the harvest of *Heritiera*. This order has since been modified and top-dying *H. fomes* trees are being harvested from 1990. This annual harvest is located to one location in the forest and is undertaken by the forest department. So, the process of harvest of *H.fomes* timber and fuelwood, as described in the preceding paragraphs, has temporarily been suspended. Harvest of other fuelwood, palm leaves and other minor produces continues as before.

6.7 PRESENT MANAGEMENT ADMINISTRATION

Administratively, the Sundarbans is under the control of one Divisional Forest Officer who is based in Khulna and is assisted in the discharge of his duties by an additional Divisional Forest Officer. The forest is divided into four ranges - Sarankhola, Chandpai, Khulna and Satkhira Ranges. The area and location of range headquarters are furnished below.

Table 6.5: Ranges in the Sundarbans

Range	Headquarters	Area (Ha)
Sarankhola	Sarankhola	130 998.0
Chandpai	Chandpai	100 021.0
Khulna	Nalianala	161 345.0
Satkhira	Burigoalini	184 992.0

Each range is under the management of a Range Officer who is a Professional Forester. The Range Officer is assisted by a Sub-Professional Assistant. There is a Game Warden who is in charge of the game sanctuaries. In addition to the above mentioned offices, a Forest Check Station has been established on the bank of each river and channel at the point where they enter the forest. There are 16 such stations in the Sundarbans. These stations primarily perform protective functions by checking the produce and ensuring that no unauthorized produce is brought out of the forest. These stations also regulate the flow of boats into the forest for collection of fuelwood which will be discussed later in the paper. There is no other permanent establishment inside the forest. Temporary coupe offices are constructed for supervision of activities near the coupes or the felling areas. These are so constructed that activities of 2 to 3 years coupes can be supervised from each office. A Sub-Professional Forest Ranger is normally in-charge of a coupe and is responsible for pre-felling marking of the coupes as well as the entire wood harvest operation. The Coupe Officers are assisted by a number of staff members in the discharge of their duties. These staff members include Deputy Rangers, Foresters and Forest Guards. An office is established in Dubla Island for revenue collection and supervision of fishing activities in the coastal waters in the winter months. This operation is headed by a Forest Ranger.

6.8 SUSTAINABLE MANAGEMENT OF THE WOOD RESOURCES

The gradual fine tuning of management prescriptions initiated by Lloyd early this century has resulted in the development of a management regime which, if followed strictly, will ensure sustainable management of tree resources.

The management practice currently followed was developed taking into consideration primarily the silvicultural requirements of the species and the need to maintain the crop in a steady and unchanged condition. The decision on the size of the coupe or the degree or intensity of felling was based on a sample set of rules where the density, size and overall condition of the crop were the decisive factors in controlling the level of harvest. These easy-to-follow rules ensure that the felling practice does not cause any depletion of the forest. Even though two very detailed inventories have been carried out in the Sundarbans, very little information is as yet available on the rate of growth and yield from the forest. Such information is a basic pre-requisite for formulating sustainable management regimes based on quantitative information.

The management practices in the Sundarbans involve a one-time harvest and improvement felling of tree resources in any portion of the productive forest, once in each 20-year cycle. This operation normally lasts for about a year to a year and a half and after that the area is left undisturbed till it is time for another harvest in the next cycle. This allows the forest to grow undisturbed without any outside interference and causes minimum possible disturbance to the wildlife. Since an annual coupe is scattered over the entire forest, the size of the area under exploitation in one center at any one time is also very small. The rules which are followed in timber harvest operation are described in **Box 1**:

(1) Removal of all trees above minimum exploitable girth trees as long as such removals do not create a large gap in the canopy, except in places where regeneration has already been established.

(2) Removal of one arm of a forked tree is to be avoided as the retained arm will ultimately become unsound.

(3) Removal of diseased and large spreading, misshaped trees, even if this creates gaps.

(4) The improvement felling consists of

(i) felling of some trees in younger crop for the removal of congestion in the crop and

(ii) removal of diseased, dead and dying trees for the improvement of the hygienic condition of the forest.

Box 1 : General timber harvesting rules

These rules apply to both *Heritiera* and *Excoecaria* except that in the case of *Excoecaria* no improvement felling is undertaken.

In the case of *Ceriops*, the felling in a given year is confined to an annual coupe area and the felling process involves three steps:

(i) selective felling of *Ceriops* poles

(ii) removal of other exploitable *Ceriops* trees

(iii) thinning of congested crop.

These rules are simple and easy to follow even though they require some subjective judgement in the selection of trees. This regime does not follow the basic principle of sustainable management where removal is equal to the increment of the forest during the period between the previous and the current fellings. However, what it does do is to disturb the forest to the minimum and to allow the removal of only those trees which have reached maturity and whose removal results in the occupation of the vacated space by new recruitments. Such fellings, together with improvement fellings, create better conditions for the enhanced growth of the remaining trees.

In the absence of detailed information on growth and yield, the management practice is ideal for maintaining the forest in its original condition. It also ensures a sustainable production when coupes are laid in such a way that annual coupes provide more or less equal output. This is quite possible because of the detailed information which is now available on the sizes and distribution of trees of different species in different areas within the forest.

Different methods are employed for the disposal of different produces. Based on the management prescriptions, annual coupes are laid out at different locations in different ranges in the forest.

Normally coupes are laid out in one or two locations in each range. The area at each site is divided into small lots of 10-20 acres (4-8 ha) by clearing vegetation in lines along a North-South and East-West direction. The trees are then measured and marked following the prescription described in **Section 6**. A list showing the species, diameter and height is made for each lot. Any deformities in the trees are also mentioned. A consolidated list of all lots is then published and a date for the sale of the lots fixed and announced both in local and national newspapers as well as the government gazette. Lots are sold in open auction to the highest bidder. The purchaser then enters into an agreement which details the payment schedule and other terms and conditions. The purchasers are allowed about 9 months to complete the harvest.

After the timber extraction has been completed, the Coupe Officer makes an assessment of fuelwood that will be available from thinning and improvement felling in each lot and informs the Range Officer. Normally, the Coupe Officer sends a consolidated statement of how much fuelwood is available from the officer's jurisdiction each fortnight.

Fuelwood sales follow an altogether different mechanism. *Heritiera* fuelwood is sold in small lots of 1.5 to 6 metric tons by boat loads to individual wood collectors. Individual woodcutters commonly known as '*bawalis*' register their boats at any Forest Check Station along the boundary of the forest. The registration is a two step process. The first step involves the registration of the Boat and procurement of a Boat Licensing Certificate (BLC). This certificate provides the name and address of the owner together with the dimensions and load carrying capacity. The load carrying capacity of a boat is calculated using the following formula.

Load carrying capacity* = L x B x D x 0.356

where L = Total length of the boat
B = Breadth at the widest point
D = Depth at the deepest point
0.356 = a constant

* Load carrying capacity in maunds
(1 maund = 37 kg.)

Once the BLC has been procured, the woodcutters register their boats with the station for fuelwood collection and are given serial numbers. They then wait their turn for permission to proceed to a coupe for fuelwood collection.

Once the Range Officers receive the fortnightly return of fuelwood available in the coupes, they allocate them to different Forest Stations where the station officer issues permission to waiting woodcutters serially from the waiting list.

Woodcutters then proceed to coupes, pay the royalty and are assigned lots for collection of wood. Separate permits are issued for dry lops and tops left behind after the timber harvest operation and green fuelwood from the thinning and improvement felling.

Separate coupes are laid out for the extraction of *Ceriops* poles and fuelwood. Coupe Officers issue permits on a first-come-first-served basis, allocate areas for harvests and supervise the operations.

While extracting trees, care should be taken to ensure that at least one *Ceriops* shoot, preferably more, should be left on each root or bunch. Except where absolutely unavoidable, woodcutters should not be allowed to cut young withes merely to facilitate felling, and not for actual utilization. Solitary stems of under 2 inches in diameter at 3 feet from the base, should be left to produce either a larger pole or a larger root and more shoots.

The Newsprint Mill carries out its own operation for the extraction of the *Excoecaria* pulp wood. The Forest Department allocates the area and normally supervises the operation. The Mill has developed an elaborate set-up for the operation as described in **Box 2** below.

(i) Felling plans covering the geographical and chronological distribution of the Newsprint cutting operation is prepared by the Forestry Section of Khulna Newsprint Mill. These felling plans cover periods of 5 years.

(ii) Where it is considered necessary, in the estimation of the Divisional Forest Officer, sufficient sound, healthy and well shaped *Excoecaria* trees above 4.6" dbh will be marked with paint for retention as seed bearers.

(iii) Felling of a group of trees in any one place and thereby enlarging an existing gap is to be avoided, except where regeneration is established. This rule does not place an embargo on felling of individual large and spreading trees or any diseased tree which will eventually cause a gap when felled.

(iv) All *Excoecaria* trees of 4.6" dbh and above and not covered by the restrictions in rule (ii) or (iii) are felled.

Box 2: Timber harvesting rules used by the Newsprint Mill

Excoecaria is also used in the matchwood industry. A separate set of felling and marking rules applies in this case. These are described in **Box 3**.

Inspite of the above practices, there has been a major depletion in the merchantable growing stock between 1960 and 1985 when two inventory reports were published. Even though the causes of the depletion are not documented or identified, the system of management cannot be faulted for this depletion, since, if followed strictly, the system offers no scope for depletion.

The depletion of *Heritiera* may have resulted from over-exploitation particularly during improvement felling which accounts for up to 85% of all the removals (Balmforth, 1985). This operation is carried out with very little supervision, if any, and is left to low level forest staff who may not have the knowledge or concept of how this operation should be carried out.

(i) The annual coupes prescribed have been listed in the management plan. Each coupe is divided into sections of approximately 40 acres each by making North-South and East-West lines 20 chains apart. With the aid of these lines, the coupe will be mapped on a scale 4 inches to 1 mile. The course of the small creeks will be shown on this map.

(ii) All unsound and badly shaped or otherwise defective trees are marked, provided their removal does not create a permanent gap. Diseased trees are removed under any circumstances.

(iii) All trees 6" diameter and above at breast height are marked for felling.

(iv) Marking of a group of trees in one place and the enlargement of an existing blank area is to be avoided, except where regeneration has been established.

(v) Felling of one arm of a forked tree is to be avoided as the remaining arm generally becomes unsound.

(vi) All trees should be hammer-marked at a height of 4" - 6" and at the base. The base mark should be as low down as possible to avoid waste.

(vii) List of trees marked should be prepared according to 1" diameter classes.

(viii) Utilization will be to 4" top diameter and all attempts should be made to avoid any waste.

Box 3: Timber harvesting rules used by the Match Factories

Frequent cyclone and death of trees because of a die back disease (the reason of which is still unknown - refer to BARC, 1990), account for some depletion of *Heritiera*. Pilferage of *Heritiera* is also becoming a matter of serious concern.

The cause of depletion of *Excoecaria* stock is, however, clearer. Over-exploitation of the growing stock has continued from the time of the establishment of a newsprint paper mill in the late 1950s. This public sector undertaking had been enjoying the privilege of harvesting the entire pulping raw material requirement from the forest without due consideration to the sustainability of such actions.

The mill carries out its own wood harvest operation with very little, if any, on the ground supervision from the Forest Department. The Forest Department allocates the felling area and fixes the annual quota. The ODA inventory has recommended an annual harvest of 2.5 million cubic feet while records show that 8.9 million cubic feet have been harvested in 1984-85. Even though the harvest had fallen to 4.7 million cubic feet in 1989-90, it is far above the ODA recommended quantity.

The Forest Department has been trying to limit current felling of *Excoecaria* to 3.8 million cubic feet, but this is also well in excess of the quantity recommended. However, despite this over-exploitation, regeneration, which has occurred in these local areas, remains satisfactory.

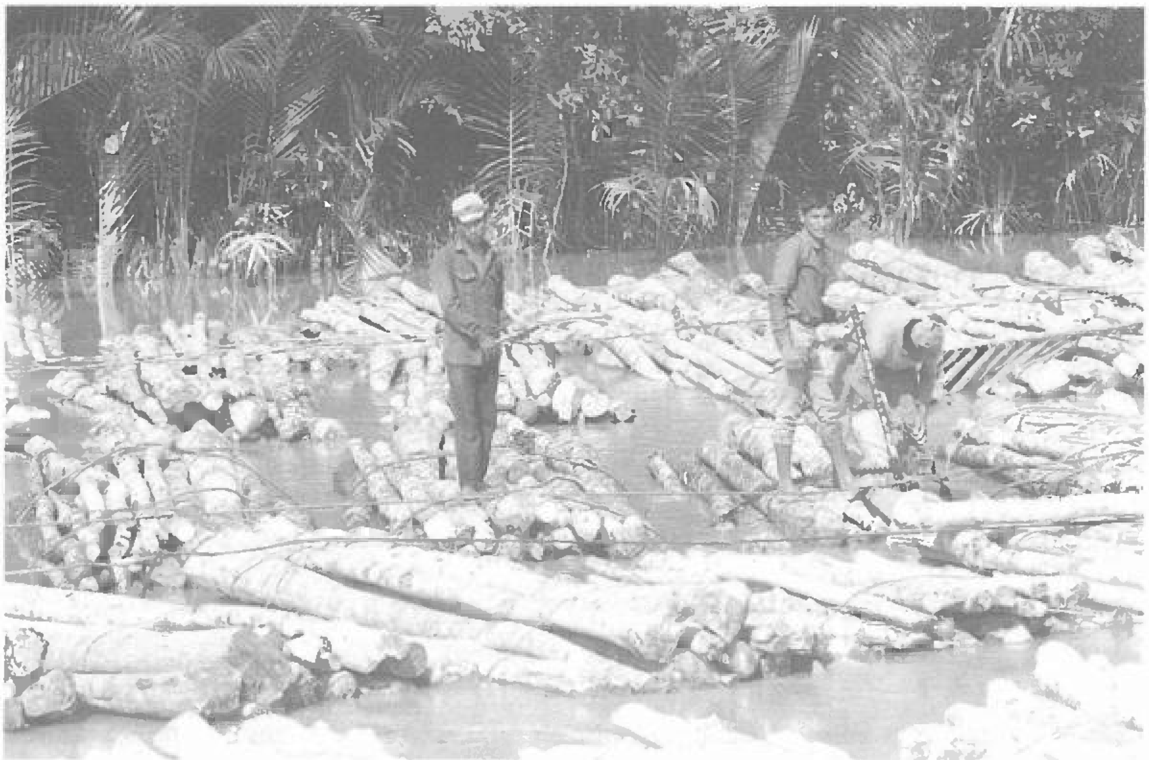


Figure 6.2: **Bundling of *Excoecaria* wood**
Photo by M.L. Wilkie

Figure 6.3: ***Excoecaria* wood ready to be transported to the Newsprint Mill**
Photo by M.L. Wilkie

6.9 MANAGEMENT OF MINOR WOOD AND NON-WOOD PRODUCTS

Permits are issued from check stations on a first-come-first-served basis for the extraction of *Amoora, Cynometra* and *Hibiscus* fuelwood.

Nypa leaves, or Golpatta as it is commonly known, is an extensively used thatching material in Southeastern Bangladesh. The permissions to harvest the leaves are sold in open auction and the purchasers divide these permissions up and sell them to actual collectors by small boat loads. For the purpose of management, each year's working area is divided into a number of coupes (usually seven) and each is sold separately. The *Nypa* extraction is now regulated completely by the Forest Department through Coupe Officers who issue permits for collection and supervise the operation. The extraction is carried out in winter months.

The rules outlined below in **Box 4**, which were originally formulated by Curtis are still followed.

(i) No area should be exploited more than once a year.

(ii) New fronds, or so-called "central leaves" should not be cut; also purchasers must not be allowed to cut leaves which they do not intend to utilize, but to leave on the ground to rot. Young plants with only one utilizable leaf should not be cut.

(iii) The main work of Coupe Officers of Golpatta coupes will be to see that rules (1) and (2) are obeyed, and that no Golpatta in the interior of the forests is left unworked before the coupe moves on. Each purchaser should be allotted a small khal, or a part of a large khal to work in, and should not be given a fresh area until the area already allotted is finished. Areas near the sea-face should be worked during the calm season.

(iv) As they travel through the forests, Coupe Officers will prepare stock maps on a 4-inch scale of the Golpatta in each compartment. One copy should be sent to the Divisional Forest Office for record, and one copy kept on the coupe to facilitate the next year's work.

Box 4: Harvesting rules for *Nypa* (Golpatta) fronds

Grasses and Hantal (*Phoenix paludosa*) leaves are also sold by permits to individual collectors and are regulated by Station Officers at the entrance of the forest.

Some of the mangrove trees produce excellent quality honey and permits for honey and wax collection are issued to individuals between 1 April and 15 June.

The major non-forestry products of the Sundarbans are different varieties of fish, prawn and molluscs. The harvest of these items are controlled from Forest Stations. Permits are issued for a specified period of time and collection or harvesting is carried out by permit holders.

Figure 6.4: **A boat loaded with *Nypa* leaves**
Photo by M.L. Wilkie

Figure 6.5; **A fishing boat and crew**
Photo by M.L. Wilkie

A fishing camp is operated on Dubla Island, just in-shore from the Bay of Bengal, from November to February each year. Fishermen establish temporary camps on the island under the supervision of the Forest Department, catch fish from the Bay of Bengal and mostly dry them for export. Some fresh fish are also marketed. The Forest Department collects tolls from the fishermen.

Except for *Nypa* leaves, no management practice is in place for the sustainable management of other minor and non-forestry products. The number of permits to be issued for any one item is also not regulated. But it is interesting to note that there is no trend of decline in annual catch or collection.

6.10 WILDLIFE MANAGEMENT

The management of wildlife is confined to their protection against poaching. Hunting is strictly prohibited in the forest except in cases where it becomes necessary to kill a man-eater (tiger).

Three wildlife sanctuaries have been established in the Sundarbans. Additional protection is provided to wildlife in these forests. No census of wildlife in the Sundarbans has ever been carried out. However, inspite of the very low level of management, the fauna of the Sundarbans has remained pretty much intact during the current century.

6.11 CONCLUSION

The Sundarbans is not just a conglomerate of trees stretching over a large area. It is a unique ecosystem, the components of which are very diverse. It is the habitat of the largest remaining population of the famous Royal Bengal Tiger (*Panthera tigris*). In addition, it is the home of a diverse fauna which includes other endangered species such as the Lesser Adjutant Stork (*Leptoptilus javanicus*),the Estuarine crocodile (*Crocodilus porosus*), the Rock Python (*Python molurus*) and the Estuarine terrapin (*Batagur baska*).

The Sundarbans plays a very important role in the economy of the region and according to an ESCAP (1987) estimate, about half a million people may be entering the Sundarbans each year for income generating activities. There is also a large number of people in primary and secondary processing, retail and wholesale trade, who are dependent on the Sundarbans for their livelihood. It is, therefore, very important that the conservation of this forest in its original condition is ensured at all costs.

In the future management of the Sundarbans, the conservation of the forest should be considered as the primary factor in formulating management regimes. Production from the forest should be of secondary consideration and limited only to the quantum which will not cause any depletion of the resource. The Sundarbans is a unique gift of nature, not only to Bangladesh, but to the whole world, and it is our solemn duty to conserve and maintain it properly.

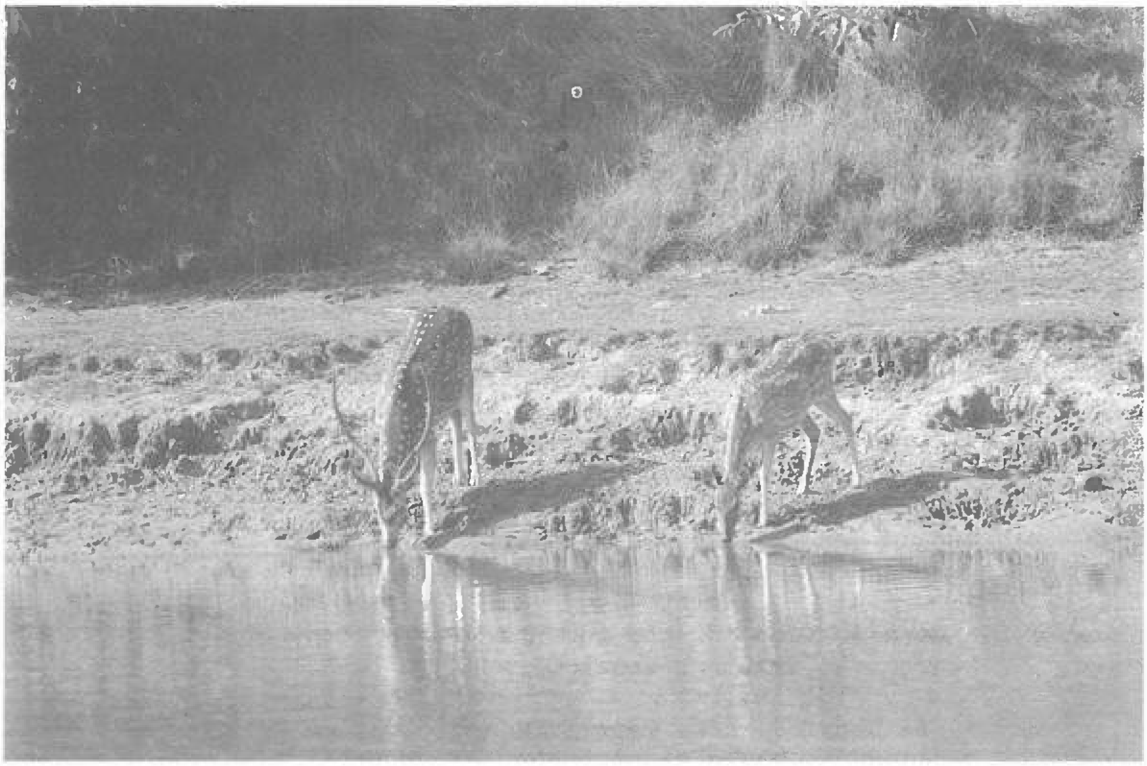


Figure 6.6: **Spotted deer coming down to drink at a man made water hole**
Photo by M.L. Wilkie

Figure 6.7: **The Sundarbans - a mangrove forest with great biodiversity**
Photo by M.L. Wilkie

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A.1 TECHNICAL CHARACTERISTICS OF REMOTE SENSING SOURCES

A.1.1 AERIAL PHOTOGRAPHY

Aerial photography has applications in many forestry related activities including forest type mapping, tree species identification, drainage and land-use classification, forest inventory and forest management plans, road site locations, fire and disease damage assessment, erosion studies etc.

Depending on the information needed and the ground resolution required - which is directly related to the classification precision - characteristics of aerial photography should be specified. These characteristics concern the photographic system, the type of film, the scale and the atmospheric conditions.

A.1.1.1 General characteristics of aerial photography

Scale

The choice of a photo scale depends on the area to be covered, the required ground resolution and the coverage cost. For forest inventory operations, different scales also depend on the purpose of the survey. **Table A.1.1** below gives a simplified classification of scales used in forestry.

Table A.1.1: Classification of scales used in forestry

SCALE		APPLICATION
Very large scale	> 1:5 000	Tree enumeration - damage assessment
Large scale	1:5 000 - 1:10 000	Stand measurement for inventory
Medium scale	1:10 000 - 1:30 000	Forest type mapping - management planning
Small scale	1:30 000 - 1:60 000	Topomaps - Reconnaissance surveys
Very small scale	1:60 000 and smaller	National forest inventory

Source: Remeijin (1981).

In the extensive tropical forests, including mangroves, small scales, down to 1:60 000, might be used for broad type mapping. As aerial photography of about 1:50 000, designed for topographic maps, is generally available, it can also be used for broad forest type delineation and for planning forest inventories.

Format

Together with the photo scale, the format is an important element to consider during a photographic coverage. The most common format available is 23x23 cm (9x9 in) but photos of 18x18 cm are also used occasionally. Small format photography, obtained from 70 mm and 35 mm cameras (57x57 mm and 24x36 mm respectively), are also increasingly used in forestry applications. These particular systems are presented in a later section.

In relatively flat areas such as mangroves, large formats are to be preferred since no important relief displacement occurs on the photo image. In combination with the format, one should also consider the camera focal length to be used.

With a 23x23 cm format for example, a camera focal length of 152 mm will provide a wide angle photograph usually used for mapping over flat terrain. Wide angle photography, however, causes difficulties in seeing the details on the edges of the prints. **Table A.2.2** below gives examples of lateral and areal format coverage at several scales.

Table A.1.2: Example of lateral and areal format coverage

Format	Scale	Lateral coverage (m)	Areal coverage (Ha)
35 mm (24x36 mm)	1 : 2 500	86x60	0.52
70 mm (57x57 mm)	1 : 2 500 1 : 5 000	143 285	2.04 8.12
9x9 in. (23x23 cm)	1 : 12 000 1 : 30 000 1 : 60 000 1 :120 000	2743 6860 13720 27439	752 4706 18823 75289

Source: SAF Forestry handbook (2nd edition).

To secure complete photo coverage, necessary for mapping and for stereoscopic observation, end-lap (overlap between successive photos within a flight line) and side-lap (overlap between flight lines) must be about 60±5% and 30±15% respectively. It should also be recalled that crab and drift, due to bad navigation, may cause insufficient end- and side-lap, which results in gaps between flight lines.

Type of film

The most commonly used types of films are panchromatic, infrared black and white, colour and colour infrared. Their constitution and spectral sensitivity range are described in various text books and documents. It should be noted however that species identification and detection of diseased trees are much easier on colour and infrared colour films photography than on panchromatic emulsions, in spite of their higher cost.

Various other photo characteristics must be carefully considered when a photo survey is being planned. They concern film processing, paper type, timing, storage, etc.

A.1.1.2 Oblique and panoramic photography

The interest of oblique photographs resides in their use for reconnaissance survey and illustrative purposes. Compared to vertical photographs, they cover a much larger area. However, they present the disadvantage of not having the geometric accuracy required for mapping and measurements.

Panoramic photographs are also used in reconnaissance surveys. They are characterized by a wide angle field of view and high resolution. Like oblique photographs, they are not suitable for mapping because of the geometrical distortion of the image.

A.1.1.3 <u>Small format photography</u>

The most commonly applied systems utilize a motor driven 35 mm or 70 mm camera which can be mounted on a light aircraft or a helicopter. The system can operate with different film/lens combinations.

The quality of contemporary 35 or 70 mm cameras and films is such that prints enlarged from negatives can provide acceptable detail. The low cost of such systems and the simplicity of the equipment has drawn the attention of many researchers and inventory groups. Small format photography has been used in many applications in forestry such as detection and evaluation of forest disease, monitoring land management activities and in forest and range inventories - especially in areas of difficult access.

Gains from small format photography systems might be expected in:

- Rapid data acquisition, i.e. a short period of time is required to assure up-to-date photo coverage;
- Timing, i.e. the simplicity of the system allows for rapid preparation of flight planning and execution and requires relatively simple film processing arrangements;
- Small format photography is an excellent sampling tool. It requires relatively inexpensive photographic and photo-interpretation equipment, and provides fine resolution at low cost.

However, the system presents a major disadvantage of having a limited areal coverage per frame and it is subsequently not suitable for complete coverage of large areas unless the photo scale is small. Moreover, for precise flying height determination special devices (laser or radar altimeter) are required.

A.1.2 AIRBORNE VIDEO SYSTEMS

Recent attempts have shown the advantages of video systems in vegetation assessments. The system is usually loaded on a light aircraft in the same manner as small format photography using a camera mount. The viewing system is mostly composed of a camera, a monitor and a video-cassette recorder and can operate in an autonomous manner if a battery pack is incorporated in the configuration.

Black and white, colour or even colour infra red imagery can be produced, allowing for a large spectrum of applications. Due to fast developments in the techniques of recording and the improvement on the resolution, this relatively recent technique is gaining much interest among researchers concerned with vegetation studies. When applied to forest mapping, the system has been found to facilitate the distinction between forest types based on colour combined with crown contour and size (Vlcek, 1983).

Advantages of the video system reside in:

- The relatively low cost of imagery when compared with photographic systems such as a 35 mm camera setting;
- The system may be quickly set up for operation and for a quick evaluation after coverage;
- It also presents the ability of yielding a real time imagery during the flight which allows the operator to interactively adjust the camera and the tape recorder settings;
- Due to the digital format of video data, the system can potentially be used in computer image processing;
- The incorporation of an audio track allows for oral comments to complement vegetation description during the flight.

Considering the image sharpness and definition and the quality of the product, major actual disadvantages of video imagery is its poor resolution and difficulties in establishing the scale of the images. In spite of these drawbacks, such a system can be useful in reconnaissance surveys and broad forest type classifications.

A.1.3 SATELLITE IMAGERY

The application of satellite imagery to vegetation studies - particularly in mangrove areas - has mainly been, and still is, using Landsat data and more recently SPOT imagery. The latter is increasingly being introduced in survey operations. Its major advantage resides in a higher ground resolution.

In the following sections, some basic technical aspects of major sensors on board satellites are presented. The indications outlined are those mostly related to vegetation mapping. More details on system configuration, orbit characteristics and image processing can be found in various textbooks and documents (ASP, 1983; Baltaxe, 1980 and many others).

A.1.3.1 <u>The Landsat system</u>

The characteristics of the Landsat satellite system has undergone continuous changes due to progressive modifications of different elements of the system and particularly the sensors on board since the launching of the first satellite of the series in 1972.

The Multi Spectral Scanner (MSS)

The MSS records the solar radiation reflected by the earth's surface in four spectral bands. These bands are called band 4, green (0.5 - 0.6μm), band 5, red (0.6 - 0.7μm), band 6 and band 7, reflected infra-red (0.7 - 0.8μm and 0.8 - 1.1μm) respectively.

On board Landsat 3, Launched in March 1978, major changes were introduced, namely the addition of a thermal channel which operates in the range 10.4 to 12.6 μm.

Shortly after the launch of this satellite, the fifth channel was de-activated due to problems encountered with the quality of the data. The remaining four spectral channels continued to function normally until the retirement of the satellite in September 1983. In Landsat 4 and 5, the spectral wave lengths covered by MSS data are the same as those in Landsat 1,2 and 3, and the ground resolution has also been kept at about 80 m.

The Return Beam Vidicon (RBV)

The images from the RBV have greater inherent cartographic fidelity than the Landsat MSS and contains a reseau grid which is inscribed on the photo conductive surface of the RBV tube. This reseau pattern facilitates the geometric correction of the imagery during the image recording process. Due to problems with the tape recorder on Landsat 1 and 2, the RBV was shut off and little RBV data are available.

On Landsat 3, only two cameras were mounted compared to three on Landsat 1 and 2. The new system provides broad band imagery (0.505 - 0.750μm, from green to near IR) with an improvement in ground resolution compared to the previous RBV. This arrangement makes two successive scene pairs (4 images) coincide with one MSS scene. These cameras have a 40 m spatial resolution or about twice that of the MSS system.

The Thematic Mapper (TM)

The Thematic Mapper is a seven-channel scanner which is designed to improve vegetation analysis capabilities. It operates with a spatial resolution of approximately 30 m which corresponds to about 2.6 times the resolution of the MSS. Due to the great number of spectral bands, the TM is characterized by a greater radiometric sensitivity. **Table A.1.3** gives a summary of sensor characteristics in Landsat satellites launched so far.

A.1.3.2 <u>The SPOT system</u>

This system operates in the spectral bands (the visible and the near IR portion of the spectrum) with a ground resolution in the order of 20 m in the MSS mode and 10 m in the panchromatic mode. **Table A.1.4** indicates spectral sensitivity and ground resolution of the system.

During the flight, a steerable mirror views the ground surface with a swath width of 60 to 80 km. With such a steerable device, two different viewing systems - vertical and lateral - are possible. The lateral viewing confers to the system a distinctive advantage of being able to increase the revisit frequency of a given scene on the earth's surface. This is significant as it provides the possibility of stereoscopic viewing of the image.

Table A.1.3 provides a summary of major sensors used on board satellites for vegetation studies.

Table A.1.3: Spectral sensitivity and resolution of Landsat sensors

Sensing System	Band	Spectral sensitivity μm	IFOV m	Landsat no.
MSS	4	0.5 - 0.6 (green)	80	1,2,3,4,5
	5	0.5 - 0.7 (red)	80	1,2,3,4,5
	6	0.7 - 0.8 (IR)	80	1,2,3,4,5
	7	0.8 - 1.1	80	1,2,3,4,5
	8*	10.4 - 12.6	240	3
RBV	I	.475 - .575	30	1*,2*,3
	II	.580 - .680	30	1*,2*,3
	III	.690 - .830	30	1*,2*,3
TM	1	.45 - .52	30	4,5
	2	.52 - .60	30	4,5
	3	.63 - .69	30	4,5
	4	.76 - .90	30	4,5
	5	1.55 - 1.75	30	4,5
	6	2.08 - 2.35	30	4,5
	7	0.40 -12.50	120	4,5

*: non operational

Table A.1.4: Characteristics of Spot sensors

Characteristics	MSS mode	Panchromatic mode
Spectral bands	.50 - .59μm .61 - .68μm .79 - .89μm	.51 - .73μm
Ground sampling interval	20m x 20m	10m x 10m
Number of pixels per line	3000	6000
Ground swath	60 km	60 km

Source: Borel,1985.

Table A.1.5: Comparative table of different sensors in terms of wavelength and resolution

WAVELENGTH (μm)				
DEADALUS SCANNER	LANDSAT TM	LANDSAT MSS	SPOT HRV	
.38-.42 .42-.45			MSS MODE	PANCHROM MODE
.45-.50	TM1 .45-.52			
.50-.55				.51
.55-.60	TM2 .52-.60	MSS4 .5-.6	S1 .50-.59	
.60-.65				
.65-.69	TM3 .63-.69	MSS5 .6-.7	S2 .61-.69	
.70-.79		MSS6 .7-.8		.73
.80-.89	TM4 .76-.90	MSS7 .8-1.1	S3 .79-.90	
.92-1.1				
	TM5 1.55-1.75			
	TM6 2.06-2.35			
	TM7 10.4-12.5			
GROUND RESOLUTION (m)				
16x16	30x30	57x79	20x20	10x10

Source: Borel,1985.

A.1.4 RADAR SYSTEM

Side Looking Airborne Radar (SLAR) is the most common sensor operating in the microwave portion of the electromagnetic spectrum, which has been used for vegetation studies. SLAR has been more widely used in tropical forests because of its great ability of penetrating clouds and rains. This property makes radar system the best time independent sensor available (Morain, 1976).

Normally, resolution with radar is poorer than with sensors operating in the optical and IR regions. With the inclusion of radar in the pay load of space platforms, this system will play an increasingly important role in natural resources studies. The ground resolution of SLAR depends on the pulse rate and the antenna beam width.

A.2 PHOTO-INTERPRETATION PROCEDURES

A.2.1 AERIAL PHOTOGRAPHS

A.2.1.1 Pictorial characteristics

The ability to identify terrestrial objects depends on various image characteristics but also on the objects to be interpreted. Stratification criteria used in mangrove studies are usually based upon the physiognomic appearance of the vegetation and on physiographic features such as landforms. Qualitative and quantitative pictorial elements which are used in the photo-interpretation process are extensively discussed in most photo-interpretation manuals. In short they include:

Tone and colour

The difference in tone or colour between an object and its environment on an image help identify the object. The contrast in grey tones and colours are determined by the intensity of the radiation reflected by the objects, the atmospheric conditions, and the processing of the film. For forest classification, tones may depend on the sun angle during the time of exposure, the age of the trees, the moisture conditions and the stand density. That is why photo-interpretation should not be based on this single pictorial element alone. Moreover, differences of colour hues on colour prints should be carefully interpreted as perceived differences might not correspond to different vegetation types or trees.

Size and shape

The size of an object on an image depends upon the photo scale, the object's size on the ground and the resolving power of the imaging system used. It is often the combination of size and shape which is responsible for the recognition. For forestry applications, the size and shape of tree crowns are useful in tree species identification.

Texture and pattern

The texture can be smooth, fine, coarse or rough and is very much dependent on the scale of the image. The pattern is the spatial arrangement of objects and their repetition on the image. The pattern can be natural or man made. Natural pattern usually results from local topography, drainage pattern etc., while a man made pattern is found in plantations, shifting cultivations, cutting regimes etc.

Location and association

Location and association are not object characteristics, but are related to the surroundings of the objects. The knowledge of the ecological conditions and environment in which an object is located, can be helpful in identifying the object. Also, a given object can be recognized simply from another neighbouring known object.

The Nipa palm for example can be easily recognized because it is associated with mangrove forests and does not occur on dry sites (Boonchana, 1983).

Quantitative elements

Criteria of this type include all measurements which can be performed on aerial photographs. Recorded information is expressed quantitatively and is used to emphasize qualitative photographic information and improve classification accuracy. Such measurements are usually crown density, crown diameter and tree height. The accuracy of photo measurements depends on the photo scale, the size of the object and the instruments used.

A.2.1.2 Photo-interpretation keys

Aerial photo-interpretation is best carried out if interpretation keys are available. They are "reference material designed to facilitate rapid and accurate identification and determination of the significance of objects by the photo-interpreter" (ASP, 1960). The purpose of interpretation keys is to provide the analyst with reference sources providing background information. These sources may consist of vertical and oblique aerial photography, ground photographs, and could be single or mounted in stereogramme form.

Photo-interpretation keys can be selective or dichotomous. Selective keys are arranged in such a way that the interpreter selects from a set of examples which corresponds to the image he/she is trying to identify. This type of key is easy to construct and easy to use. In dichotomous keys (also called elimination keys) the interpreter follows a prescribed step-by-step process that leads to the elimination of all items but the one to be identified. The construction of dichotomous keys is rather difficult, especially when many classes are to be distinguished. Moreover this kind of key requires a precise standard description of the tree shape on aerial photographs which, in the case of mangrove forests, is not available at the present time. If established, dichotomous keys could however, be a valuable tool to be used to achieve a higher classification accuracy.

A.2.1.3 Photo-interpretation aids

Various enhancement techniques exist, which may aide in the analog (visual) interpretaion of aerial photographs, such as density slicing and the additive colour viewer. For details of these techniques please refer to **Box A.2.1** on page 271.

The generation of digital data from a film transparency using a densitometer or an image digitizer can also be performed. However, this type of digital image data is generally considered of inferior quality. Analyses of digital data can best be made on multi-spectral imagery which is designed for such applications.

A.2.2 AIRBORNE VIDEO SYSTEMS

From colour infrared video images, one can generate false colour composites, similar to those produced from satellite MSS imagery (Meisner and Lindstrom, 1985). The analysis of video imagery is currently based on viewing the tape on a monitor screen using the still-image capability of the system, or simply on a hard copy photographed from the CRT. The image from the CRT may also be transferred to a map through simple instruments such as a Zoom Transfer Scope. The option of manually digitizing and interpreting the image is also possible by means of an image analyzer. No application of such a system to mangrove areas is known to the author.

A.2.3 SATELLITE IMAGERY

Satellite data are presented either in the form of images or in a computer compatible tape format. Information is extracted from images by analog (visual) interpretation while digital data analyses - called numeric interpretation - require the utilization of an appropriate device called the image analysis system.

Satellite imagery offers the possibility to provide a quick and relatively cheap coverage over extensive areas. Because of the urgency of information needs, this kind of remote sensing is receiving much interest in vegetation study applications. In conducting surveys of mangrove vegetation, satellite remote sensing techniques (mostly Landsat) have been found to be highly effective. For mapping purposes satellite images can provide sufficient information for an overall planning at national and regional levels.

A.2.3.1 Analog interpretation of satellite images

Analog interpretation is concerned with a direct visual analysis of satellite images produced on paper prints or transparencies. Analog analysis has the major advantage of producing results (maps) which can be readily usable in the field. Moreover, a visual interpretation of satellite images can be achieved with a small input of personnel and materials. In order to achieve reliable results, visual interpretation requires:

- Skillful interpreters:

The quality of the interpretation depends on the interpreter who must be able to differentiate between colours and tones. He or she is also required to have a solid field experience for a rapid and efficient interpretation.

- Good quality images:

Visual interpretation is usually made on paper prints or transparencies. The detail and accuracy with which vegetation cover can be identified depends to a large extent on the quality of the image, characterized by the degree of contrast and sharpness and the range of grey levels or colours. If the interpretation involves several scenes, tonal and spectral characteristics should be uniform.

Techniques used for aerial photographs and satellite imagery

Density slicing

In this process, which is used to enhance the contrast among image tones, different colours are assigned to various density levels allowing tonal differencies to be more apparent. A typical density slicing includes a light table, a video camera and a colour monitor.

Additive colour viewing

The reproduction of images on transparencies (diapositives) usually produces sharper images and a better definition than on paper prints. More details are discernable when transparencies are seen on a light table. In this form, black and white image transparencies can furthermore be observed with devices such as a colour additive viewer. The manipulation of various combinations of filters built into the device allows the analyst to determine - by trial and error - the best output suitable for feature separation.

Techniques used solely for satellite imagery

False colour composite generation

In order to produce false colour composites, MSS bands are superimposed and a colour hue is assigned to each band. False colour composition can also be generated directly from the standard computer compatible tapes using a film recorder of the colour VIZIR type. The interpretation of such colour composite is similar to that of infra red images (Borel, 1983). The author also pointed out that colour composites produced better results when the two first spectral bands are de-correlated.

Diazo colour film

Another alternative which can be used to produce image enhancements is diazo colour film. The process of obtaining diazo colour films has been discussed by several authors (Moore, 1979; Skaley et al., 1977). With this procedure, a wide range of colours can be obtained at a relatively low cost by various combinations of positives and negatives of single bands.

Photographic contrast enhancement

This technique is performed to increase image interpretability by increasing density differences between scene features. It consists mainly in stretching the density range of the image over the whole density range of the film. One may also generate enhanced colour composites if single black and white band transparencies are contrast-enhanced before compositing them.

Box A.2.1: Enhancement techniques for analog photo-interpretation

In tropical areas, clouds can be a major problem as it may not be possible to obtain cloud free coverage of large areas at the same time. Images from different satellite passes can be acquired but one should be aware of the variation in spectral characteristics which may result in differences in tonal values and colour hues.

To achieve an effective interpretation of images, it is necessary to pay much attention to the image characteristics of the different images. Some of the points to be considered are: the cloud cover, the spectral bands, the season of the year, and the scale of the image.

Interpretation techniques

Satellite images can be viewed in the form of single spectral bands but combinations of them can also be advantageously analyzed under a mirror stereoscope for a more detailed distinction (Baltaxe, 1980). Additional improvements in image interpretation can also be achieved using various procedures including density slicing, additive colour viewing, false colour composite generation, diazo colour film and photographic contrast enhancement. For further information on these techniques refer to **Box A.2.1**.

Auxiliary data

During the process of image analysis, base maps - if available - are of utmost importance because they may provide accurate information on the location and identification of land features. Their incorporation is made easier when their scale is similar to that of the images used in the interpretation.

In vegetation studies, the introduction of auxiliary data contained in topographic or thematic maps was found to be very valuable for detail recognition and delineation. The procedure consists of superimposing the maps and positive transparencies on satellite imagery of the same scale. Planimetric details from a topographic map for instance can be transferred to a plastic overlay. This overlay is then superimposed to the image and land-use pattern and boundaries of each type are simply delineated by tracing over the transparency. The inclusion of auxiliary information may ensure a decrease in costs incurred in ground surveys (checking the classification) and may result in an overall reduction in interpretation time.

In the process of image analysis, the addition of secondary data from maps is not limited to visual interpretation. It can equally be used in studies where small format photography or digital data analysis is applied.

Equipment needed

Visual interpretation of satellite imagery does not require more than what is needed for conventional aerial photography interpretation.

Basic equipment includes:

- Light table (with uniform illumination to ease the strain on the eyes);
- Transparent paper. In order not to damage the image, delineation is best carried out on paper which is super-imposed;
- Magnifying glass; large low power lens;
- Dot grid for area assessment;
- Drawing pencils and pens;
- Tape;
- An additive colour viewer and a mirror stereoscope are also essential instruments which can be of great value to the interpreter.

A.2.3.2 Computer-aided classification

Digital data which is recorded on computer compatible tapes (CCT) must be processed on an image analysis system. The physical aspects of such systems are out of the scope of the present paper but it might be indicated that a typical system is composed of a computer, a terminal, a colour display monitor and other peripherals such as a printer, a plotter and a digitizing table. To successfully operate an image analysis system, some experience in computer utilization and familiarity with digital classification are required.

The process of digital data analysis passes through three phases: preprocessing, enhancement and classification. Digital data preprocessing and enhancement are generally conducted to improve the interpretability of images. They can be applied to virtually all kinds of MSS data. The interpretation which follows preprocessing and enhancement can then be automatic (computer classification) or visual from a screen or a photographic image.

Preprocessing

Before any classification begins, radiometric and geometric corrections of the MSS data should be undertaken in order to eliminate the various anomalies and defects which may have occurred during the process of data recording. Anomalies are caused by transmission losses or sensor saturation, and may result in missing scanning lines and/or in lines of contrasting brightness across the scene. Such defects can be eliminated by a radiometric correction. In the case of a missing line, pixel values are usually replaced by the average of the pixels immediately above and below them. This correction should only be applied in cases where no more than a few missing lines are encountered.

Atmospheric scattering of short wave lengths can also cause a reduction in contrast. In this case, it is suggested to apply a subtraction of a constant value from all spectral radiance quantities.

Image distortion is another problem. This is caused by the earth's rotation, sensor delays and orbit altitude variations. Therefore, it is necessary to apply a geometric correction to adjust the spatial position of each pixel in the scene.

Enhancement techniques

In the same manner as analog image enhancement, there are also digital enhancement techniques which can be employed to facilitate image interpretation. The main procedures involve contrast enhancement and data transformations. Please refer to **Box A.2.2** for details.

Image classification

The primary goal of digital data processing is to extract useful information from the image. Having this in mind, the analyst must select the procedures or techniques which allow him or her to bring out the image features judged to be most important.

Through one or all of the enhancement techniques described above, the computer is used to make it easier to interpret certain features of interest in a more detailed and accurate way, but the interpretation can also be performed by visual means.

Prior to the classification itself, it is always useful to conduct some sampling analyses in order to obtain insight into the interpretability of the data relevant to the categories to be differentiated. One may examine the frequency distribution of spectral values in each band and/or analyse feature space plots which can be generated by plotting radiance values in a given spectral band against those of other bands.

The two basic approaches which are employed in digital classification are supervised and unsupervised classifications. The **supervised classification** utilizes "training" information obtained from sample sets of spectral clusters which correspond to land-use or land cover classes that the interpreter wishes to distinguish. The sample sets should encompass the spectral diversity in the class. They must therefore be spread throughout the image. The choice of spectral classes and their number are key elements for the success of the classification. Furthermore, they must be distinct enough to assure a reasonable accuracy. Once the spectral classes have been defined, the second step in supervised classification is to classify all the image pixels according to the spectral characteristics obtained from the training areas. Based on this information the classifier places unknown features in the most likely group. Among all classifiers in use, numerous studies have shown that the maximum likelihood discriminant analysis provides the most accurate classification.

Contrast enhancement

The objective of contrast enhancement is to permit features of interest to be separated using tonal values. For this purpose, the frequency distribution histogram of spectral radiance values is modified (histogram stretching) by expanding the range of the pixel values of a given area of interest over the entire range of the display device. Histogram equalization can also be performed in order to ensure that the image levels fit the distribution of digital values. It consists of assigning equal numbers of pixels to each tone level.

Edge enhancement is another technique which is applied to increase tonal separability between features which exhibit small variations in tonal values along their edges. With regard to mangroves, this technique may be useful in drainage network delineation.

Data transformations

Modifications of digital data are frequently made through various transformations of spectral values. These transformations include band ratioing, canonical and principal components, band de-correlation and image smoothing.

Band ratioing:

This technique is commonly applied to MSS data. It consists of dividing the spectral values in one band by the values in another band on a pixel by pixel basis all over the scene. Ratios of the difference to the sum of bands and ratios of each band to the sum of all the bands are commonly applied to produce derived data sets. For vegetation studies, the ratio of band 7/band 5 of Landsat, termed vegetation index (as it correlates with green vegetation), has been frequently used as an index of green biomass. Mulder and Hempenius (1974) indicated that the application of ratioing techniques reduces the variation in brightness on multi-temporal scenes.

Principal components:

With principal component techniques, the spectral values from all bands are compressed in the form of a set of un-correlated axis in order to maximize the variance between classes (categories to be identified) and minimize it within each class. This procedure is valuable in digital data analysis when the interpreter is dealing with a large number of spectral bands and its application is effective without significant loss of information (Baltaxe, 1980).

Image smoothing (spatial filtering):

Image smoothing is a data transformation in which blocks of 3x3 or 5x5 pixels are passed through a spatial filter in order to remove some of the high spectral variation in the data. In the process, the digital value of the central pixel of each block (window) of the scene, is replaced by the average of the pixel values (9 or 25) constituting the block. Sometimes, the median is used instead of the mean. The application of this technique to Landsat data has been shown to be efficient for enhancing forest type boundaries (Fox, 1983).

De-correlation:

MSS blue and green bands either from Landsat or SPOT are highly correlated. This correlation has a reducing contrast effect when colour composites are made. Practically two colour pictures are obtained with a dominance of blue and cyan. To overcome this problem, a de-correlation procedure can be applied to improve the image interpretability by producing more colour hues in the blue and the green spectra. In order to achieve a band de-correlation without causing much loss in spectral values, new spectral bands can be generated by finding a linear combination of the original ones.

Box A.2.2: Enhancement techniques for computer aided interpretation

Conversely, the **unsupervised classification** uses only the statistics of the data on which the classification is based. In this way, pixels from samples areas are examined in order to determine natural groups of data based only on their spectral properties. It is then up to the analyst to assign meaningful classes to the clusters. The unsupervised approach is practical when the number of classes is high which, would make the process of using training areas very tedious.

The combination of both supervised and unsupervised strategies has however been found to produce the best results.

A.2.4 RADAR IMAGERY

The Synthetic Aperture Radar (SAR) sensor follows the same basic principles whether it is mounted on board an aircraft or a satellite. This sensor, operating in the microwave portion of the electromagnetic spectrum, has been used for vegetation studies in many tropical forest areas. Most of them were based on aircraft mounted SAR.

Radar sensors do not generate images according to the human eye. One should be aware that some forest types are different in tone on SAR images compared to aerial photographs. Moreover, differences in tone on SAR do not always correspond to differences in vegetation, and important differences in forest types are not always reflected in differences in tones on SAR. Because of this, a pre-established legend has no significant value in Radar image interpretation. It is therefore suggested to:

- Separate roughly between forest and non-forest areas;
- Use physiographic features to delineate broad forest types;
- Use additional data from reconnaissance surveys to finalize vegetation classification.

SAR imagery is not as well known as photographic or MSS imagery, mainly because it only recently became available to civilian use. In fact, with a few exceptions, its applications to earth resources is still at a research phase. But, future plans to include SAR in the pay load of orbiting satellites such as ERS-1 (European satellite), JERS-1 (Japanese satellite) and others, will open up new perspectives of more frequent applications of this system. Like MSS data, the new developments in image data processing can also be applied to SAR imagery which can be produced either optically or digitally.

In addition, since SAR senses micro-relief on surface configuration and dielectric properties of vegetation, its combination with MSS satellite imagery can increase discrimination and identification of vegetation boundaries (Gelnet et al., 1978).

The results obtained from different vegetation studies where SAR data been used, indicate that research has only just begun to explore the techniques of interpreting Radar imagery. However, because of its complexity, the interpretation and analysis of SAR images necessitates well trained image analysts, who are acquainted with preprocessing, postprocessing and enhancement procedures, specific to the system.

A.3 MAPS AND MOSAIC COMPILATION

Maps play an important role in forest activities. The information to be contained on a map depends on the objectives for which the map will be used, and the scale of the map, which is determined by the level of application. This application can be national, regional, provincial or even a district or a smaller unit level.

A.3.1 MAPPING PROCEDURES

A.3.1.1 Maps from aerial photography

Map compilation consists of producing a document - based on photo-interpretation - from which the final map can be prepared for printing. Before the procedure starts, care should be taken that no doubtful lines are drawn and the photographs are free of superfluous information. Moreover, it is important to check that the class delineations from one photo to the next are matching. This provision facilitates the transfer of cover classes to the base map and prevents editing errors.

If delineation is carried out on transparent sheets, these must carry fiducial marks and pass points to facilitate their orientation. It may also be useful to match photocopies of delineated transparent sheets to obtain a rough map which can be used to check the photo-interpretation (Remeijn, 1985).

Base map

Details of each land-use class, forest type and other strata which have been identified and interpreted on aerial photography must be transferred onto a base map. The function of a base map is to indicate the geographical location and distribution of the terrestrial features plotted on it, therefore, it should contain some topographical information.

A topographic map is usually adopted as a base map. If used as it is, however, the addition of more information might produce a map with too many superfluous details, which may hamper readability. It is therefore suggested to simplify it to an extent that it still gives sufficient information to allow the map user to locate in the field the features drawn on the map. Items that could usefully be included are roads, rivers, urban areas, etc. Contour lines are generally not necessary. Over relatively flat areas, such as mangroves, their density is in any case not very high.

Aerial photographs can be used to provide topographical information for the base map if no topographic maps are available, or existing maps are of too small a scale to provide reliable feature location. Aerial photos can also be employed if terrain features identifiable both on the map and on the ground are lacking, or existing maps are outdated. The photos should in this case include a number of control points to ensure mapping accuracy. For that purpose, a radial triangulation is carried out.

This gives the coordinates (x,y) of control points which have been identified in the field or from geodetic sources. Slotted template and graphical methods are simple to use and can provide a satisfactory network or supplement an existing network of control points.

For nearly flat terrains, it may be possible - and economical too - to use every second photograph both for interpretation and control point determinations.

Transfer instruments

The transfer of photo delineation onto base maps can be performed by means of various transfer devices. The transfer can be achieved by either stereo or mono instruments with varying capabilities of adjustments for image distortion and scale differences between photographs and the map.

The instruments which are generally used for transferring details from interpreted aerial photographs to a map vary in performance, precision, handiness and cost. For some cartographic tasks, including mapping for forest surveys, the accuracy requirements do not justify the use of sophisticated and therefore expensive devices. In mangrove areas, characterized by relatively flat terrain, simple methods and equipment may be adopted to produce satisfactory results. Most advantages of simple devices reside in their low cost, easy transportation, simple construction and operation, and - more relevant - their simple maintenance. A few of the simple instruments are presented in **Table A.3.1**.

Table A.3.1: Examples of simple transfer instruments

Instrument	Mode
Sketchmaster	mono
Stereosketch	stereo
OMI Stereo facet plotter	stereo
Reflecting projector (optical pantograph)	mono
Bausch and Lomb ZTS	mono-stereo
Stereopret	stereo

Technical characteristics, construction principles and performances of these instruments can be found in various documents and textbooks (Weir, 1981, 1983). The instruments presented above are suitable for the transfer of details of photographs of flat terrain, where displacement errors do not occur or are negligible, and where the main source of error is the camera tilt at the moment of exposure.

In spite of their advantages in terms of cost and handling, it is important to note that simple instruments provide only a partial elimination of geometric errors inherent to the aerial photograph.

Where high planimetric accuracy is required, one has to resort to stereoplotting instruments. These devices are also capable of producing planimetric details and contours directly from stereoscopic models. In addition, modern stereoplotters are equipped with coordinate readouts which are more convenient to use with data in digital form.

A.3.1.2 Maps from satellite imagery

At a small scale, which characterizes satellite images, the objective of image interpretation is primarily to produce maps showing mangrove forests along the coast and rivers. The information which can be obtained from the images (although it is only at reconnaissance level), is very useful for a forester or land manager in areas where basic information is lacking. The map and other data obtained from the image will give an overall indication of the actual land-use pattern, which is sufficient for planning at a national or regional level.

Maps can be directly drawn either from photographic prints or from computer-aided interpretation outputs.

Mapping from photographic images

Mapping from Landsat imagery, which has been commonly applied, is usually carried out with black and white prints of single spectral bands 5 and 7, at a scale of 1:1 000 000. For a more detailed interpretation, colour and colour prints or transparencies and enlargements to scales of 1:500 000 and 1:250 000 are also frequently used. At these larger scales, the observation of details and their delineation is made easier although no increase in resolution is obtained. From images produced by other more recently launched satellites, such as Landsat 5 and SPOT, equipped with high resolution sensors, enlargements to 1:100 000 and 1:50 000 can be obtained without much loss of definition.

On satellite images, the position of ground points is subjected to geometric errors due to various factors such as the satellite altitude, the orbit variation and earth's rotation. A correction of these geometric errors can be achieved using a number of ground control points. But, unlike aerial photographs, which contain geometric distortions requiring adequate transfer devices, satellite images exhibit only small geometric discrepancies when compared to topographic maps of the same scale (Wong, 1975). For this reason, standard satellite images are generally considered to have sufficient accuracy required for forest survey applications (Baltaxe, 1980).

The simplest procedure of mapping from satellite images consists of delineating boundaries of vegetation cover and other land uses directly on the image. Image interpretation can be transferred simply by tracing photo details onto the map, the latter being prepared on transparent material. On the image, the interpretation may alternatively be carried out under a stereoscope, and feature delineation can simultaneously be drawn on a transparent sheet placed on one of the scenes. Later on, each transparent sheet, associated with each scene, can be adjusted according to the base map, on which ground control points and other topographic features have been plotted.

Mapping from automatic interpretation

When computer facilities are available, and image data are used in digital form, classification results are often produced by a line printer. The output is thus a digital map where each single pixel is represented by a symbol, a letter or a digit, chosen by the image analyst. Also, various grey levels during printing can be obtained so as to facilitate the map readability. This is in fact just a matter of software.

This kind of output can also be produced in colours, providing multi-colour printers are available. Due to printer sizes, and since each image pixel is represented by a printer character, it is usually necessary to assemble many computer outputs to cover a whole scene. Compressed outputs may be produced to accommodate large area coverage and reduce the number of sheets which in practice pose some handling difficulties. Nevertheless, for a provisional analysis, this type of maps may be useful. More condensed versions of computer maps can also be produced on dot matrix and ink-jet printers, which are able to generate a wide range of grey levels and colours.

Photographs, taken directly from the monitor screen, on which the classification is displayed, have also been used as map products. Obviously, image distortions caused by the curvature of the screen do not allow correct measurements to be made on the photos, but areas can still be determined based on pixel counts.

Higher quality products are obtained by means of appropriate devices which convert computer processed classification into a hard copy image, generally on photographic material. Due to the high cost of equipment, computer processed data can be recorded on tapes and sent to specialized centers for their conversion to photographic films either in black and white or as colour products.

A.3.1.3 Map accuracy

When a map is produced, it should be evaluated for its accuracy. Two kinds of accuracy can be distinguished: geometric and thematic accuracy.

Geometric accuracy

Geometric accuracy concerns planimetric and altimetric accuracy. It is generally expressed in terms of the precision in the geographic position of map features, given a certain range of tolerance. Geometric accuracy is a function of the base map construction, the procedure used to determine the coordinates of ground control points, and the method and instruments used in the transfer of photographic details unto the base map.

For forest surveys, photographs and the maps derived from them constitute the base for measurements and planning operations. In order to achieve reliable inventory results, reasonable planimetric accuracy should be present in forest maps, particularly those used on the forest management and operational level.

Boundaries must be properly defined, and vegetation types correctly indicated. This is of utmost importance when property and concession boundaries are considered. Planimetric accuracy affects to a large extent the area measurement which, together with the volume per unit area, determine the total timber volume of a tract, a concession, a stand or a larger unit.

Planimetric accuracy can be determined by means of measurements of a number of distances on the map and the ground or other reliable data support (topographical maps for instance). It may be pointed out in this respect that planimetric accuracy of a map is also dependent on the stability of the material on which the map is produced. In tropical conditions, characterized by high temperatures and humidity, this is an important criterion to be taken into account in the choice of map supporting material.

Altimetric accuracy is of little importance in mangrove areas due to the flat terrain.

Thematic accuracy

In recent years, the development of new techniques for collection and processing of remotely sensed data has progressed rapidly, allowing for mapping at low cost and with different output formats. Given the cost advantages, the question posed is whether accuracy is sufficient when remote sensing imagery is the principal data source.

Thematic accuracy, which is the accuracy of interpretation, is associated with the ability of the interpreter to correctly identify terrestrial features from the images. Thematic accuracy is thus a function of image characteristics such as print quality and scale but is also dependent on the skill and experience of the interpreter.

When producing maps to be used at the forest management and operational level, the accuracy of the photo delineation is associated with the ability of the interpreter to distinguish between different types of vegetation, different species, different stand age and stand site quality. The reliability of photo based classification has been addressed in many studies. Ground verification seems to be a logical answer but due to time and cost constraints, a valid sampling procedure is required. Several techniques have been used - both qualitative and quantitative approaches.

The accuracy of image interpretation can be assessed from a sample of points on which cover classification is confronted with the ground truth. Misclassification affects area determination, which must be adjusted after such field checks.

It should be noted however, that misinterpretation can be reduced in many instances by careful selection and good training of interpreters and continuous checking of results together with limiting the stratification to a reasonable number of easily determined strata.

For extensive areas, where the interpretation involves small scale satellite data, aerial photography at medium and large scale can be used to complement field checks. Small format camera systems mounted on a light aircraft may in this respect turn out to be a suitable solution as conventional aerial photographs may be outdated or not available. At low altitudes, sample strips can be taken to complement the costly ground checks, especially in remote areas of difficult access.

The sampling problem is one of determining the optimum number of map sampling points to be compared with ground points and the sampling design to be used. A random selection of points based on the binomial distribution was suggested by Hord and Bruner (1976). In order to satisfactorily represent the smaller areas in the sample, stratified random sampling is recommended. Rosenfield et al. (1982) and Hay (1979) also indicated that stratified sampling should be applied with at least 50 observations per map category. The procedure consists of sampling each category, either separately or in combination with the others. In the latter case, a sample is drawn randomly over the whole area of interest and the number of points falling in each stratum is cumulated until each one of the strata has a sufficient sample size. During the process of sampling, samples which fall in a category which is already filled are rejected, whereas those falling in other categories are retained until all strata are completely sampled.

Samples can as well be systematically distributed over the whole area using a regular grid. With a regular distribution of sample points, the number of samples in each category will be proportional to the stratum size. Care should however be taken that small strata are sufficiently represented in the sample. This may cause some problems if the grid has a low density and/or map categories are broken up into small patches.

Whatever the sampling design used, the actual classification is compared to the 'correct' classification and the accuracy is expressed in terms of the percentage of sample points correctly classified.

Digital classification of aerial photography and satellite produced imagery has also been investigated for its accuracy. When compared to the manual selection of sample points on the map, a computer based sampling procedure provides more adequate samples of all categories and results in easier analysis (Fitzpatrick-Lins, 1981). For digital classification, the discrete multivariate analysis technique is usually applied to assess accuracy. The method consists of constructing an error matrix, also called a confusion matrix, where row and column elements correspond to the number of cells or pixels classified on imagery and on the ground (or other ground truth source) respectively.

Table A.3.2 below is an illustration of such a confusion matrix.

Table A.3.2: An example of an error matrix

	REFERENCE DATA					
	CLASSES	1	2	. . . .	r	Totals
IMAGE DATA	1	x_{11}	x_{12}		x_{1r}	x_{1+}
	2	x_{21}				x_{2+}
	3	.				
	.	.				
	.	.				
	.	.				
	r	x_{r1}			x_{rr}	x_{r+}
	Totals	x_{+1}	x_{+2}		x_{+r}	N

In this matrix, diagonal elements represent the number of units correctly classified. The method, which has been commonly applied to the accuracy assessment of satellite data classification, is based on a measure of agreement of square matrices presented by Bishop et al (1975), and which was extensively discussed by Cohen (1960, 1968), and Fleiss et al (1969).

For a multi-nominal sampling model where the total number of elements is fixed, an estimate of the agreement coefficient is given by:

$$K = \frac{N \sum^{r} x_{ii} - \sum^{r} x_{i+}x_{+i}}{N^2 - \sum^{r} x_{i+}x_{+i}}$$

where

k = coefficient of agreement
Σx_{ii} = sum of all diagonal elements
x_{i+} = marginal total of row i
x_{+i} = marginal total of column i
N = total number of units in the sample
r = number of categories (strata)

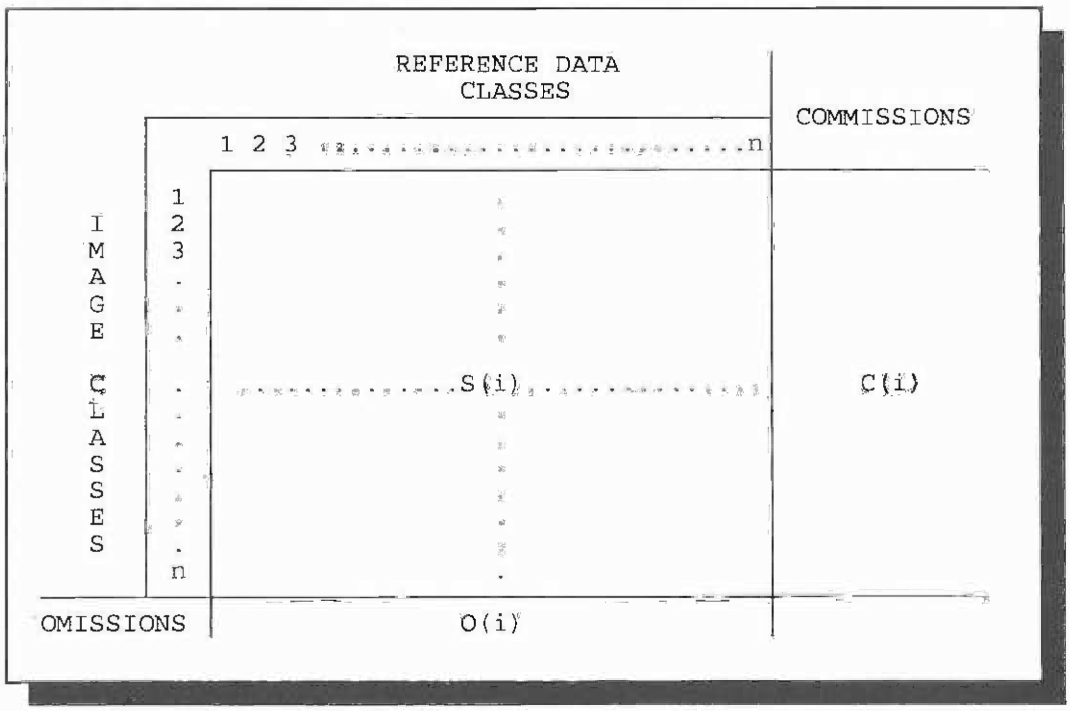
The classification accuracy of a given class i is obtained by dividing the marginal total in row i by the marginal total of column i (xi+/x+i), and the overall accuracy is simply computed by dividing the sum of diagonal elements by the total number of points classified.

The coefficient of agreement can also be employed to assess the photo classification accuracy for each cover type or all cover types simultaneously.

Congalton et al. (1982) found this procedure to be useful in evaluating photo-interpretation accuracy and in comparing photo-interpreters performances. The comparison is based on a statistic test which can be developed to determine if there is a significant difference between two independent K's. This test is achieved by evaluating the normal curve deviate, since K is asymptotically normal (Bishop et al, 1975).

Instead of point counts, the error matrix may be filled with areas determined from the image classification and from a reference data source. Then, one may compute correctly classified areas, omission and commission errors and overall accuracy (see **Table A.3.3**). Lantieri (1986) suggested that the computation of classification accuracy should take into account the commission and the omission errors in each class, as it is defined below.

Table A.3.3: An example of an error matrix with area values instead of point counts



S(i): Area correctly classified
C(i): Commission error on class i: Area classified in i on image but is not class i in the terrain
O(i): Omission error on class i: Area in class i on the terrain but not classified as i on the image
S(i)+O(i): Total area of class i on the terrain
PC(i): Mapping precision of class i (in %): [S(i)/S(i)+O(i)+C(i)]100
PS(i): Statistical evaluation of class i (in %): [S(i)+C(i)]/[S(i)+O(i)]100
Pd(i): Weight of class i among n classes : [S(i)+O(i)]/d[S(i)+O(i)]
PCT: Total mapping precision (n classes): d Pd(i) PC(i)

(Source: Lantieri, 1986)

A.3.2 MOSAIC COMPILATION

In some instances, where no adequate maps are available or their compilation is lengthy, photo mosaics can be used as substitutes. In a photo mosaic, images are assembled and fitted together to form a document which gives an overall view of the area being covered by aerial photography or satellite images.

The simplest form of a mosaic is a photo lay-out, where prints are mounted together to obtain the best fit of image detail. In this form, the mosaic - named **uncontrolled mosaic** - will have appreciable planimetric errors caused by camera tilt, scale variation and relief displacement distortions contained in the original prints. For field survey operations and navigation, uncontrolled mosaics are however useful. Errors can be reduced by using the central part (the effective area) of each photograph.

If measurements are to be taken on the photo mosaic, the latter should have a reasonably consistent planimetric accuracy. One should therefore resort to a **controlled mosaic**. For its construction, photographs should be brought to a common scale and the effect of camera tilt removed. In mangrove areas, where relief displacement is negligible, photo distortion due to camera tilt can be eliminated by means of optical rectification. The construction of a controlled mosaic requires the determination of a number of ground control points which can be obtained from an aerial triangulation. The result is a photomap where terrain features are represented by their photographic image in their true planimetric location. It is worth noting that the cost of mosaic compilation can be reduced if small scale aerial photographs are used both for triangulation and rectification before they are assembled.

For a more effective use of the data, strata delineation on aerial photography can be transferred onto the photomap, by means of adequate instruments (generally, a pocket stereoscope is sufficient in case of homogeneous scale). On the photomap lineal and area measurements can directly be made for planning management operations, timber sales etc.

Satellite images can also be employed for mosaic construction, and where no aerial photography is available, such mosaics are extremely useful. Good quality images should however be selected in order to ensure a uniform appearance in terms of brightness and tonal values. Complementary photographic treatments might be required to obtain more homogeneous tones on images of different passes. Moreover, marginal information must be used to obtain a good detail fit and correct position of scenes with respect to each other.

A.4 SAMPLING DESIGNS FOR SURVEYS, RESOURCE ASSESSMENT AND FOREST INVENTORIES

The objective of sampling is to gather reliable information at low cost. In view of the problems posed by accessibility and working conditions in mangroves, it is strongly recommended, in designing a survey, to incorporate any element that may contribute to increasing the accuracy of forest classification while at the same time making the field enumeration less time consuming. Low altitude aerial reconnaissance, stratification and other sampling procedures such as multi-phase and cluster sampling are some approaches which deserve consideration. The description of these designs and the associated statistical formulas are extensively discussed elsewhere (Lanly, 1973 and others), and are thus only briefly summarized below.

A.4.1 STRATIFIED SAMPLING

Stratified sampling designs are frequently applied in surveys and forest inventories. The object of stratification is to subdivide the forest into more homogeneous parts, in order to reduce the variability of the parameter to be estimated.

The allocation of sampling units to strata can be proportional to the strata area or to the variance of the strata. These approaches are discussed in various forest inventory documents. The optimum allocation approach requires advance estimates of the variation in each stratum, which can be provided from pilot surveys or, if available, from past surveys and inventories in similar areas.

A.4.2 MULTI-PHASE SAMPLING

Basically, the procedure involves the selection of large units in the first phase, named primary sampling units. Within each primary, a number of smaller units - secondary units - is drawn. The procedure can have more than two phases and can use varying methods of selection in each phase.

Its disadvantage however, is that the concentration of the ultimate sampling units results in a larger variance of the estimate compared with a one phase design of the same sampling intensity.

A.4.2.1 Double-phase sampling

The application of **double-phase sampling for stratification** in a forest survey results in an improvement in the stand characteristic estimate through a better estimate of strata areas.

In this method, a large number n of photo plots are drawn in the first phase, and a subsample n' of the first sample is selected in the second phase to be used in the field. The main objective of the survey is to provide an estimate of strata proportions in the first phase, based on some stratification rule allowing the first phase sampling units to be classified into land-use classes, vegetation cover classes or other classification criteria. The second phase plots are used to check the photo classification and collect data on forest and tree characteristics.

Advantages of this technique have been found to be substantial in surveys of large areas. The design is more complex than a single stage random sampling but it is more efficient.

The application of this design usually involves aerial photography in the first phase. Satellite imagery can also be used but, because of its low resolution, it might be very tedious or even impossible to correctly locate the subsample units on the ground.

In non-forest classes and areas where the forest has been so severely disturbed, that no commercially valuable trees exist or the forest is poorly stocked, data collection may be restricted to simple observations on vegetation status.

Areas are estimated from the first large sample of photo plots. The proportion of each stratum is estimated by :

$$P_h = \frac{n_h}{n}$$

Where

n_h is the number of photo plots falling in stratum h and
n is the total number of photo plots in the first large sample.

The area A_h of stratum h is estimated by:

$$A_h = P_h * A$$

Where A is the total area concerned by the survey, assumed to be known.

The information collected from the ground plots is used to correct biases in area estimates caused by various sources of misinterpretation. The adjustment is applied to strata proportion in the following manner:

The adjusted stratum proportion P_H is obtained by:

$$\text{Adjusted } P_h = \sum^{M} P_h * p_{hj}$$

Where

M is the number of strata and

$$p_{hj} = \frac{n_{hj}}{n_h}$$

with n_{hj} being the number of ground plots actually falling in stratum j, but classified h on photos and

n_h being the number of photo plots classified in h.

The variance of the adjusted stratum area proportion is computed by the expression:

$$V(Adj.\ P_{hj}) = \sum^{M} \frac{P_h^2 p_{hj}(1-p_{hj})}{n_h} + \frac{1}{n} \left[\sum^{M} P_h p_{hj}^2 - \left(\sum^{M} P_h p_{hj}\right)^2\right]$$

which is a simplified formula for double sampling for stratification with a discrete random variable having attribute 1 or 0, and where the term P_h/n has been dropped being considered negligible.

Data obtained from ground sampling units can also be used to estimate mean values of stand characteristics such as timber volume, stocking, etc. The estimate of the mean value per unit over the whole area concerned by the survey, is given by the expression (Lanly, 1973):

$$\bar{y}_{st} = \sum^{M} \sum^{M} P_h p_{hj} \bar{y}_{hj}$$

where $\bar{y}_{hj}$ is the mean value per sampling unit of the characteristic y in the part of plots actually in stratum j, classified in stratum h by photo-interpretation.

The mean value per unit in stratum j is estimated by:

$$\bar{y}_j = \frac{\sum P_h p_{hj} y_{hj}}{\sum^{M} P_h p_{hj}}$$

The estimate of the total Y over the whole area inventoried is obtained by multiplying the estimate of the overall mean y_{st} by the total area A, and the total in stratum j is computed by multiplying the mean of stratum j by the term $A(\Sigma P_h p_{hj})$ which is the corrected area for stratum j.

Double-phase sampling for regression is another technique which involves two variables, the main (y) and the auxiliary (x). It is a powerful procedure which is frequently used in forest inventory sampling. It is particularly useful when the cost of enumeration of the main character is much higher than the cost of the auxiliary variable, the latter being correlated to the first one. The approach is recommended when the inventory can make use of both aerial photographs and field enumeration.

In the first phase, a large sample n of photo plots is drawn from the population N. The stand characteristic of interest (represented by the auxiliary variable x) is first measured on photo plots. This can be a gross volume estimate for example, based on measurements of the stand height or the crown density on the photos. In the second phase, a subsample n' of the first phase large sample is taken and measurements are made on both x and y. y may well in this case be the volume per plot, which is determined in the field through conventional techniques, while x is ground measurements of either stand height or crown density.

Double sampling for regression is also used in inventories on successive occasions. It may involve completely independent samples, or, in case of permanent (CFI) plots, it uses subsamples of the original sample or samples which are partly independent and partly subsamples. The latter case is termed sampling with partial replacement. In either case, change evaluation is determined through regression analysis between measurements made on successive occasions. The technique involves rather complex computations. Relevant estimators are presented in various forest inventory and statistical textbooks.

A.4.2.2 <u>Three-phase sampling</u>

The design is similar to that of double-phase sampling for stratification except that more phases are considered. In the first phase a simple random or systematic sample n of large size is drawn from the population concerned by the forest survey or inventory, and sampling units are classified into predefined strata. From this first phase stratification, n1, n2, ...n_h, sampling units are obtained where n_h in the number of units in stratum h. (h= 1, ...L).

The second phase consists of selecting a subsample m_h from n_h. The selected m_h units of phase one are further stratified into the same or different strata as in the first phase one, and m_{hj} second phase sampling units are obtained for each stratum j of second phase in each stratum h of phase one.

In the third phase a subsample in each second phase stratum is drawn. The units selected in the third phase noted b_{hj} are then used for measurements of the characteristics of interest. Observations are noted y_{hjk}, where k= 1, ...b_{hj}.

A typical three-phase sampling design incorporates satellite imagery (phase one), aerial photography (phase two) and ground sampling (phase three). A four phase design can as well be employed if both small and large scale aerial photography are used in the second and the third phases respectively.

One question which may be posed concerns the sample sizes in each phase. Theoretically, sample sizes in each level should be determined in such a way that the total survey cost is minimized. The problem becomes one of optimization which is out of the scope of the present discussion. For more details on the question and the computation of the variance of estimates, the papers of Frayer (1979) and Jeyaratnam *et al.* (1984) are recommended. More simply, sample sizes associated with each phase, can be defined arbitrarily before the first phase selection. It is, however, not recommended to use less than two sampling units per stratum.

In the three-phase sampling case, the estimate of the total value of the population parameter is obtained by:

$$\hat{Y} = \frac{N}{n} \sum_{h=1}^{L} \frac{n_h}{m_h} \sum_{j=1}^{J_h} \frac{m_{hj}}{b_{hj}} \sum_{k=1}^{b_{hj}} y_{hjk}$$

The application of a three-phase sampling and the above formula to mangrove forests can be illustrated by the following example: Let N be the total number of sampling units contained in a given area to be inventoried. Let each sampling unit be associated with a pixel from Landsat imagery (say of 1:250 000 scale), used in the survey as the first level of sampling. We consider further that medium scale (1:30 000) aerial photography of the same area is available and could be used in the second phase. The third phase is the sampling in the field where stand characteristic measurements are taken. The sequence of the method is described as follows:

- Step 1.

From the total number N of sampling units, say 262 144, a sample n is drawn at random or systematically on satellite images. Out of a total of N units, n = 13 107 (5 % sampling intensity) units are then classified according to defined land-use classes on satellite images. The number of different classes (L) will be a function of the sensor and classification procedure used. The latter can be computer-aided or visual. For sake of simplicity, let us assume that three classes (strata) are defined in this first phase: Forests, non-forest and water.

The results in this first phase may be:

Stratum number	Land cover	sample size
h=1	forest	n_1= 9 830
h=2	non-forest	n_2= 1 966
h=L=3	water	n_3= 1 311
		Σn =13 107

- Step 2.

In the second phase, samples are drawn from the first phase samples. Using some predefined sampling fraction (1% for instance), these phase two samples which are noted m_1=983, m_2=197 and m_3=131 are located on aerial photographs and stratified according to a more detailed interpretation using photo variables such as crown density, tree height, etc, and other criteria on non-forest areas such as agricultural lands, salt ponds, fish ponds and shrimp farms. We assume in the example that the first phase stratum "forest' is refined into three strata in phase two, namely "dense", "open" and "degraded". The second stratum of phase one is split into three strata also. They are "agriculture", "aquaculture" and "other".

Finally, we consider that the third stratum of phase one which is "water" remained unchanged in the second phase. According to this scheme, the results of classification are:

Stratum number		Land cover	sample size	
Forest	j=1	dense	m_{11}=464	
	j=2	open	m_{12}=197	m_1= 983
	j=3	degraded	m_{13}=322	
Non forest	j=1	agriculture	m_{21}=100	
	j=2	aquaculture	m_{22}=59	m_2= 197
	j=3	other	m_{23}=38	
Water	j=1	water	m_{31}=131	m_3= 131
				Σm =1 311

■ Step 3:

In the third phase, samples are selected from phase two samples to be located in the field. Assuming again a sampling fraction of 1%, the final number of sampling units to be measured in the field will be:

Stratum number	Land cover	sample size	$\sum_{k=1}^{b_{hj}} y_{hjk}$
j=1	dense	b_{11}=46	2 760
j=2	open	b_{12}=20	1 930
j=3	degraded	b_{13}=32	530
j=1	agriculture	b_{21}=10	0
j=2	aquaculture	b_{22}=6	0
j=3	other	b_{23}=4	0
j=1	water	b_{31}=13	0

- b_{hj} is the number of third phase samples drawn from the second phase samples m_{hj}.
- y_{hjk} is volume measured on the ground plots.

The values in the last column are assumed to be the total values of timber volume in each third phase stratum expressed in m^3. In non-forest classes and areas where the forest has been so severely disturbed, that no commercially valuable tree exists or the forest is poorly stocked, data collection in the field may be restricted to simple observations on vegetation status.

The estimate of the total timber in the whole area concerned by the survey is given by the formula presented above, which yields the following result:

$$\hat{Y} = \frac{262\,144}{13\,107}\left[\frac{9\,830}{983}\left[\frac{464}{46}(2\,760) + \frac{197}{20}(1\,930) + \frac{322}{32}(530)\right] + \frac{1\,966}{197}\left[\frac{100}{10}(0) + \frac{59}{6}(0)\right] + \frac{1311}{131}\left[\frac{131}{13}(0)\right]\right]$$

$$= 10\,436\,884.25 \text{ m}^3$$

Other parameters such as the total forest area may also be estimated using multi-phase sampling techniques. In that case, the variable y_{hjk} takes on the value 1 when the sampling unit falls in the stratum forest and zero otherwise.

In a two-phase sampling design, following the same pattern as above, the estimate of the population total is given by:

$$\hat{Y} = \frac{N}{n} \sum_{h=1}^{L} \frac{n_h}{m_h} \sum_{j=1}^{m_h} y_{hj}$$

A.4.3 CLUSTER SAMPLING

Cluster sampling is also a commonly applied techniques, which has often been used in extensive forest surveys, resource assessments and inventories, particularly in the tropics. With cluster sampling, the elementary units, on which the observations are to be made, are grouped in clusters of pre-assigned size. When all elementary units of the cluster are included in the sample we have a single phase sampling design. Clusters can be also of unequal sizes. The cluster size refers to the number of elementary units that compose the cluster.

Like in double-phase sampling, plots which are grouped in clusters, reduce the overall travel distance. However, a cluster sampling design - when compared to simple random sampling - is efficient only if the variance within clusters is large relative to the variable observed. With cluster sampling the variance of estimate is generally larger than that obtained by a simple random sampling of the same intensity. This increase in variance is due to the correlation between units within clusters.

A.5 EXAMPLES OF VOLUME REGRESSIONS FOR SELECTED MANGROVE SPECIES

The following examples of volume regresasions for selected mangrove species are listed in geographical order, starting with Latin America and ending with Asia and the Pacific. The list is by no means complete and some of the regressions are based on limited measurements and should therefore be treated with caution. However, it is hoped that it may be of use for preliminary assessments in areas where no volume tables are available.

A.5.1 LATIN AMERICA

Cuba

Avicennia germinans : Equation: Log(V) = - 9.06038 + 2.39559 x Log(D)

Correlation coefficient	=	0.995
Standard error of estimate	=	0.149
F - ratio	=	4473.063
Degree of freedom	=	49

Laguncularia racemosa: Equation: Log(V) = - 8.72393 + 2.36491 x Log(D)

Correlation coefficient	=	0.989
Standard error of estimate	=	0.197
F - ratio	=	1545.063
Degree of freedom	=	28

Rhizophora mangle : Equation: Log(V) = - 8.92114 + 2.38992 x Log(D)

Correlation coefficient	=	0.986
Standard error of estimate	=	0.193
F - ratio	=	962.163
Degree of freedom	=	28

Costa Rica

Pelliciera rhizophorae: Equation: V = - 0.37714 + 0.03200 x D

Correlation coefficient	=	0.994
Standard error of estimate	=	0.038
F - ratio	=	316.146
Degree of freedom	=	21

Rhizophora harrisonii: Equation: V = - 0.50857 + 0.04116 x D

Correlation coefficient	=	0.993
Standard error of estimate	=	0.058
F - ratio	=	294.946
Degree of freedom	=	25

Note: The volume calculated in Costa Rica is Volume under bark.

Source: Chong (1988b and 1989b)

A.5.2 AFRICA

Sierra Leone

Rhizophora racemosa/harrisonii : $V = 0.0001 \times D^{2.5478}$, or in tabular form:

Diameter (dbh/das) (cm)	Stem volume >7 cm (m^3)	Diameter (dbh/das) (cm)	Stem volume >7cm (m^3)
7	0.01	37	0.75
8	0.02	38	0.80
9	0.02	39	0.85
10	0.03	40	0.91
11	0.03	41	0.97
12	0.04	42	1.03
13	0.05	43	1.10
14	0.06	44	1.16
15	0.07	45	1.23
16	0.09	46	1.30
17	0.10	47	1.38
18	0.12	48	1.45
19	0.14	49	1.53
20	0.16	50	1.61
21	0.18	51	1.69
22	0.20	52	1.78
23	0.22	53	1.87
24	0.25	54	1.96
25	0.28	55	2.05
26	0.30	56	2.15
27	0.34	57	2.25
28	0.37	58	2.35
29	0.40	59	2.45
30	0.44	60	2.56
31	0.48	61	2.67
32	0.52	62	2.79
33	0.56	63	2.90
34	0.60	64	3.02
35	0.65	65	3.14
36	0.70		

Source: Løyche and Amadou (1989) (See also **Case Study 5**)

A.5.3 ASIA

Bangladesh

The following three volume regressions, shown graphically, are based on the inventory of the Sundarbans carried out by ODA in 1984 and described in **Case Study 3**. The equivalent regressions used in an earlier inventory by Forestal in 1960 are also shown. The volume equations and tables giving the volume for each 5 cm diameter class can be found in the report by Chaffey *et al.* (1985).

For each of the species the height classes are as follows:

1	H ≥ 15.2m
2	10.7m ≤ H < 15.2m
3	6.1m ≤ H < 10.7m

The diamter is dbh (in cm) and the volume is volume under bark (in m^3) to a 10 cm top diameter.

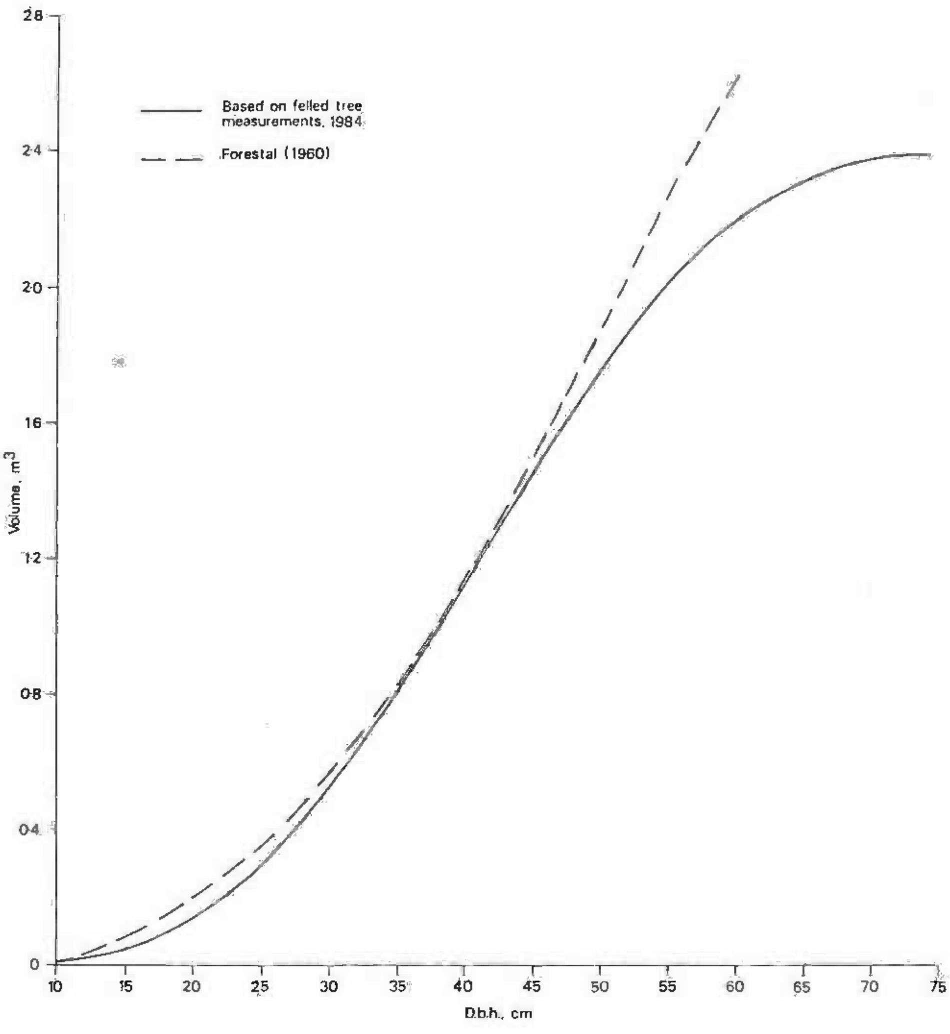


Figure A.5.1: Volume regressions for Keora (*Sonneratia apetala*)

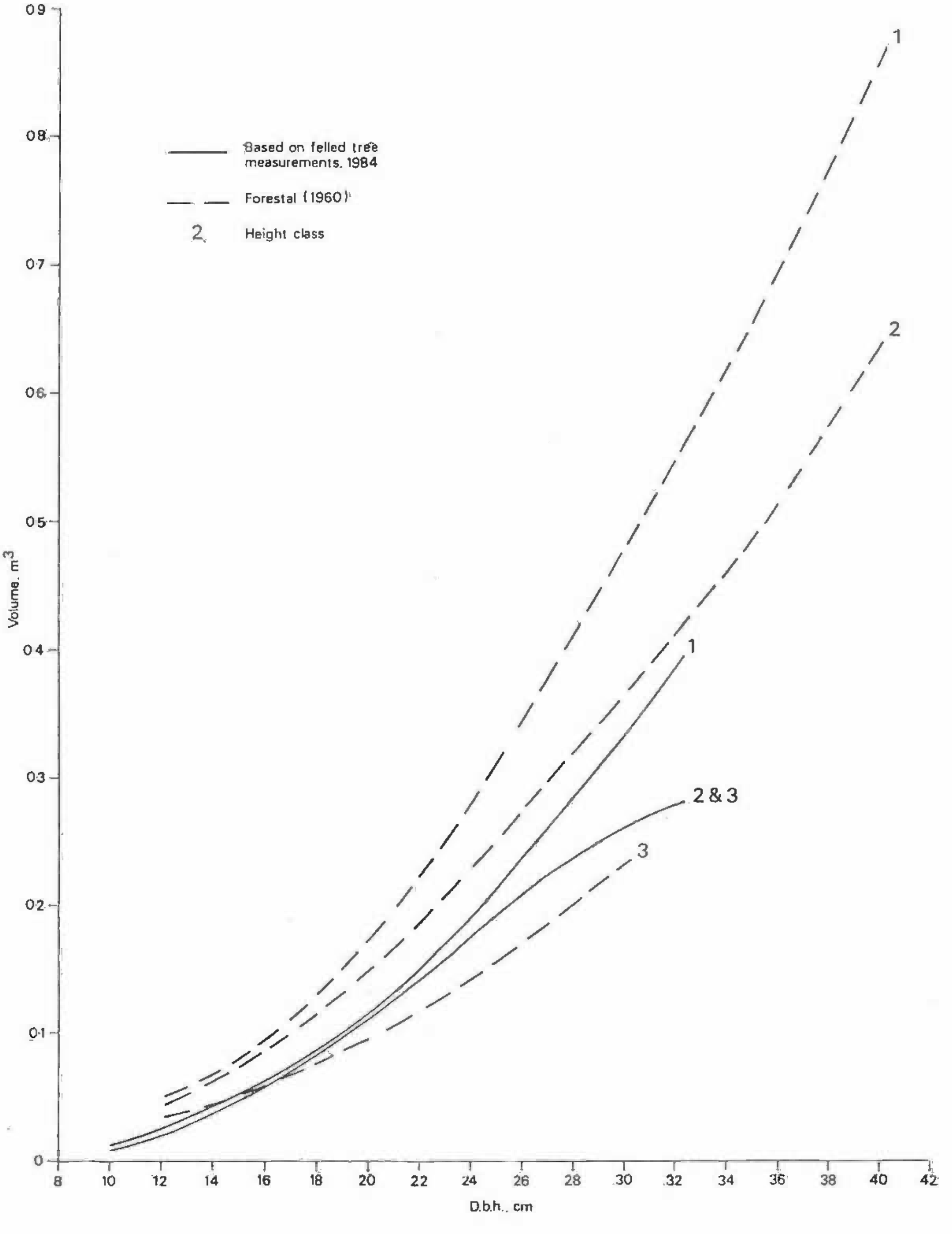


Figure A.5.2: Volume regressions for Gewa (*Excoecaria agallocha*)

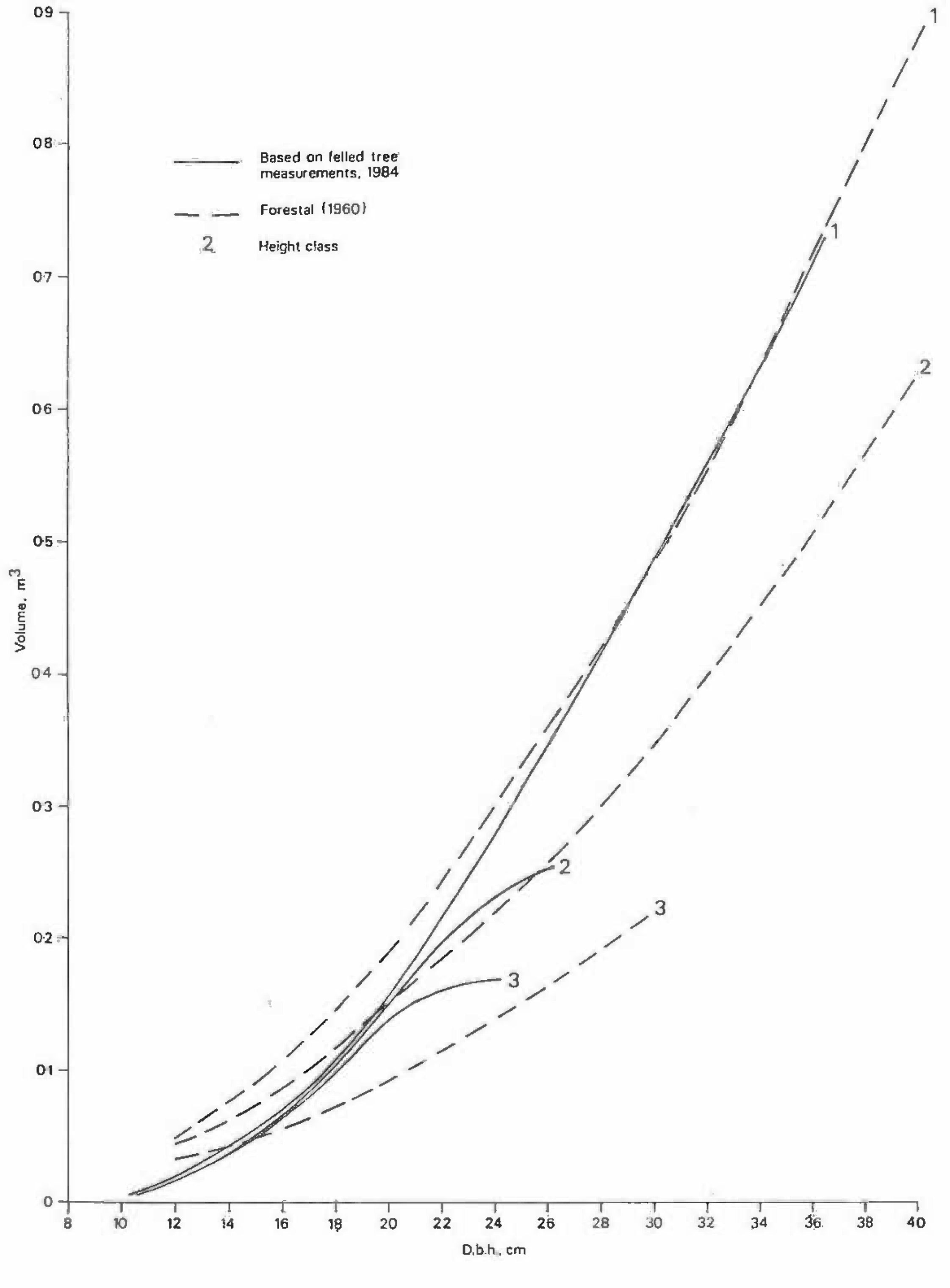


Figure A.5.3: Volume regressions for Sundri (*Heritiera fomes*)

Malaysia

Rhizophora apiculata/mucronata:

Diameter (dbh) (cm)	Stem volume >7 cm (m^3)	Diameter (dbh) (cm)	Stem volume >7 cm (m^3)
7	0.01	34	1.19
8	0.02	35	1.26
9	0.03	36	1.35
10	0.04	37	1.41
11	0.06	38	1.50
12	0.08	39	1.59
13	0.10	40	1.68
14	0.13	41	1.77
15	0.16	42	1.86
16	0.19	43	1.95
17	0.22	44	2.03
18	0.26	45	2.10
19	0.29	46	2.16
20	0.34	47	2.21
21	0.38	48	2.27
22	0.43	49	2.32
23	0.48	50	2.38
24	0.52	51	2.44
25	0.57	52	2.49
26	0.62	53	2.55
27	0.70	54	2.60
28	0.76	55	2.66
29	0.83	56	2.72
30	0.90	57	2.77
31	0.97	58	2.83
32	1.04	59	2.88
33	1.11	60	2.94

Note: Diameter class 8 cm = 7.5-8.4 cm
Diameter class 9 cm = 8.5-9.4 cm

The Philippines

Volume tables for *Rhizophora apiculata*, *R. mucronata*, *Bruguiera cylindrica*, *B. gymnorrhiza*, *Xylocarpus granatum*, *Lumnitzera littorea* and *Scyphiphora hydrophyllacea* can be found in PCARRD (1991).

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