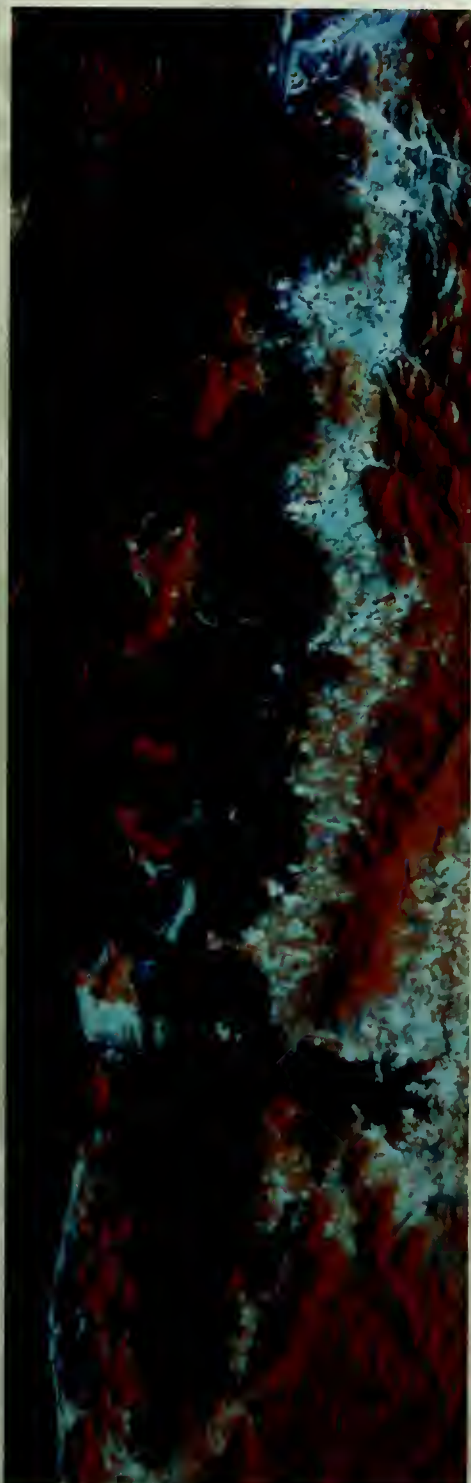
World MANGROVE ATLAS



Editors:
Mark Spalding, François Blasco and Colin Field

World Mangrove Atlas

The *World Mangrove Atlas* is the first significant attempt to provide an overview of the distribution of mangroves worldwide. Mapped data have been gathered from a wide range of sources and have been synthesised into a series of twenty-five regional maps. Related texts describe the species, areal extent and other summary information on the currently known status of mangroves in each country. This is the first time that such data have been gathered into a single volume. All data are referenced back to an original source. For people interested in the extent and dynamics of mangroves, this atlas provides a well documented foundation from which to start their explorations.

A number of case studies demonstrate what can be achieved using greater resolution and much more detailed investigation. The case studies show mangroves growing in very different conditions such as estuaries, deltas, lagoons, wet tropical coasts and arid coasts. They illustrate a range of different mapping techniques and provide detail on some of the issues threatening mangroves worldwide. Together with introductory chapters covering mapping techniques and mangrove phytogeography, the result is a wide-ranging but highly informative reference work.

Mangrove ecosystems are of great environmental and economic importance. However, mangrove forests in many countries are threatened and vast areas have already disappeared. The *World Mangrove Atlas* presents a baseline inventory of mangroves at the end of the twentieth century. It is intended for use by scientists, politicians, planners, conservationists and others, who have an interest in the current status and future of mangroves.

The *World Mangrove Atlas* is part of a trilogy being produced by the International Society for Mangrove Ecosystems and the International Tropical Timber Organization to promote awareness of the importance of mangroves. The other two parts of the trilogy are: *Journey Amongst Mangroves* and *Restoration of Mangrove Ecosystems.*

About the Editors

Mark Spalding has a degree in Natural Sciences from the University of Cambridge. He is currently the Marine Research Officer at the World Conservation Monitoring Centre, working largely on biodiversity mapping of both mangrove forests and coral reefs. In parallel with these activities he is undertaking a Ph.D. in biodiversity mapping in the Department of Geography, University of Cambridge.

François Blasco has a doctorate in tropical ecology from the Paul Sabatier University in Toulouse. He has a considerable experience of mangrove ecosystems and on the digital processing and analysis of satellite data. He is currently Director of the Laboratory for Terrestrial Ecology in Toulouse and Research Director at the National Council for Scientific Research (CNRS), Paris.

Colin Field has a degree in physics from the University of Reading and a Ph.D. in biophysics and physiology from the University of the West Indies. He is currently Emeritus Professor at the University of Technology in Sydney. He is overall coordinator of the ISME-ITTO mangrove project of which the atlas is one part.

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The International Society for Mangrove Ecosystems
The World Conservation Monitoring Centre
The International Tropical Timber Organization

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WORLD CONSERVATION MONITORING CENTRE

ITTO

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Foreword

The underlying spirit and philosophy of the International Tropical Timber Organization (ITTO), as enshrined in the International Tropical Timber Agreement, is to strike a balance between utilisation and conservation of tropical forests through sustainable development. This is clearly stated in the objectives of the agreement "to encourage the development of national policies aimed at sustainable utilisation and conservation of tropical forests and their genetic resources, and at maintaining the ecological balance in the region concerned". As provided for in the Agreement, ITTO goes beyond the narrow commodity focus of tropical timber, to be involved in conservation and forest management. The aim is to ensure the continued production not only of timber but also of other vital goods and services from the forests. Careful analysis of the problems besetting tropical forests indicates that only such an approach will ensure their survival.

Tropical forests are vitally needed for their wealth of genetic diversity, conservation and environmental values. Moreover, large populations in developing countries are dependent upon the forest for timber, food and basic essentials. Viable forest industries based on sustainable supplies of tropical timber can generate social and economic benefits to many developing countries, thereby ensuring the survival of tropical forests. Therein lies the linkage between wise utilisation and sustainable management of tropical forest resources.

It is within this background that the ITTO supports projects on mangroves. The importance of mangrove forests is unquestionable. Mangroves contribute a rich genetic diversity, which acts as a buffer zone between terrestrial and marine ecosystems. Fringing many coastal areas in tropical and sub-tropical countries, the mangrove ecosystem is a treasure of valuable goods and services which sustain the needs of many coastal communities. The wonderful mangrove forests have demonstrated to us their vital strategic and ecological functions, particularly in sustaining the productivity of fish and marine resources. The work now being presented in collaboration with the International Society for Mangrove Ecosystems (ISME) will improve the understanding of the dynamics and distribution of mangrove species under a variety of conditions, many of which have been modified by human activities. This atlas will strengthen the case for remedial measures to be taken against the mismanagement and abuse of mangrove ecosystems.

I congratulate the Editors for their pioneering effort to produce such a comprehensive and detailed *World Mangrove Atlas*. This atlas will serve as a useful tool to the general public, educators and other interested groups, by enhancing their knowledge of the nature and extent of the mangrove ecosystems, in a worldwide context. In turn, it will promote efforts to save mangrove forests through their conservation and sustainable utilisation.

B.C.Y. Freezailah
Executive Director
International Tropical Timber Organization

Preface

The origins of this atlas lie in the vision of the International Society for Mangrove Ecosystems (ISME) and the International Tropical Timber Organization (ITTO) to present, to as wide an audience as possible, information relating to the distribution and current status of mangrove ecosystems in our increasingly threatened and changing natural environment. It forms part of a trilogy being produced as outputs from the ISME and ITTO project *Manual and World Natural Mangrove Atlas* No PD 6/93 Rev.2 (F). The other two parts are *Journey Amongst Mangroves* and *Restoration of Mangrove Ecosystems*. The atlas draws on the wealth of knowledge and experience concerning mangroves that has emerged in recent years and in particular it has drawn extensively on the expertise and technical capability of the World Conservation Monitoring Centre (WCMC) in Cambridge, UK and the Institut de la Carte Internationale de la Végétation (ICIV) which is supported by the Centre National de la Recherche Scientifique and the Université Paul Sabatier in Toulouse, France. It has also relied heavily on the assistance of a dedicated network of people and organisations from around the world, who have first hand understanding of the problems of mapping and describing mangroves.

Inevitably, this atlas will contain omissions of information and interpretations that not everyone will agree with. However, we hope that readers will find the information useful and that they will be encouraged to obtain new data that can be made available so that the atlas can be updated in the future.

This atlas has benefited from the wisdom of many people. It is a pleasure to acknowledge the invaluable assistance of Dr Chan Hung Tuck, Malaysia; Professor Kazuhiko Ogino, Japan and Mr Mohammed Tahir Qureshi, Pakistan. As a group they formed a consultative committee to assist with the editing and production of the atlas. In addition, there are a number of people who contributed freely with ideas, suggestions, criticism and photographs and without whom this book would be much the poorer.

Appreciation here goes particularly to Professor Sanit Aksornkoae, Thailand; Dr Barry Clough, Australia; Professor Phan Nguyen Hong, Vietnam; Mr Motohiko Kogo, Japan; Professor Peter Saenger, Australia; Dr N.A. Siddiqi, Bangladesh; Professor Sam Snedaker, USA; Dr Arvind Untawale, India; Dr Marta Vannucci, India; Dr Richard Luxmoore and Ms Clare Billington, WCMC, UK; Dr Fromard and Dr J Fontès of ICIV, Toulouse, France.

We are indebted to Professor Sanga Sabhasri, President of ISME; Professor Yoshihiro Kohda, Executive Secretary of ISME and Dr Shigeyuki Baba, Deputy Executive Secretary of ISME who have not only generously provided ideas and material for the atlas but have also given continuous logistic support to the project, together with Miss Nozomi Oshiro for her helpful contribution in the ISME secretariat. We should like to acknowledge the dedicated assistance of Ms Mary Edwards who did the GIS work and produced the final copies of all of the regional maps. Further work and support at WCMC was provided by Corinna Ravilious, Ivor Wheeldon and Alastair Grenfell. Likewise, thanks are owed to Mrs Marie Aizpuru and colleagues who undertook much of the work in preparing the maps for the case studies. We should also like to recognise the assistance of the University of Technology, Sydney, who made their facilities available to Colin Field. In a similar manner the Department of Geography, University of Cambridge provided financial support and other assistance to Mark Spalding. Thanks are also due to Mr R. Fairclough and the staff of the Cambridge University Library Map Room for all their help in gathering maps from their vast collection.

The funds that supported the production of this book came from a generous grant to the Internal Society for Mangrove Ecosystems from the International Tropical Timber Organization and we should like to acknowledge the sponsorship of the Japanese Government in this project.

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François Blasco
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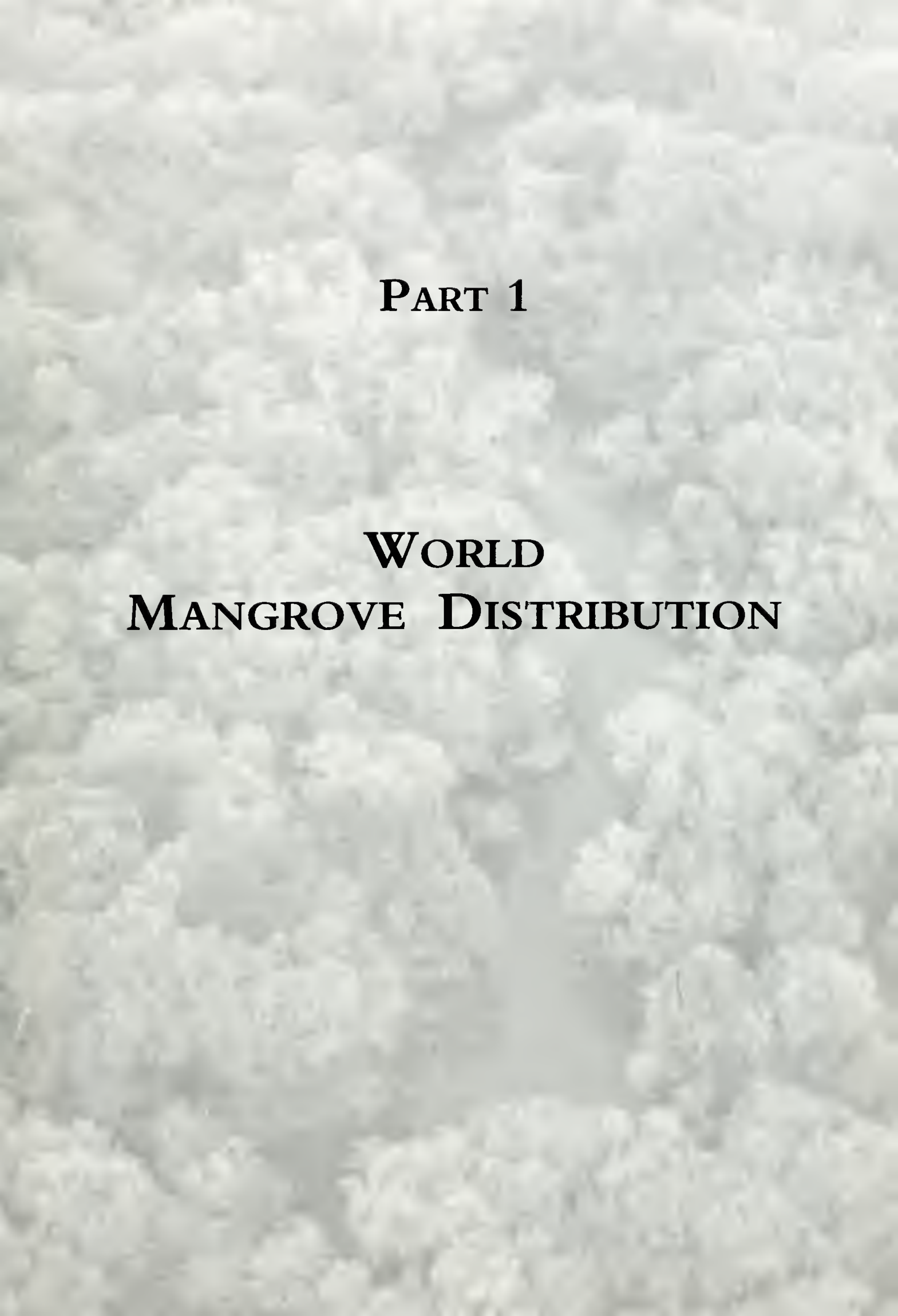

Part 1

World Mangrove Distribution

1

Introduction

As the twentieth century draws to a close there is increasing public and scientific concern about the future of biological systems on our planet. It is becoming recognised that uncontrolled population growth, increasing pollution and man-induced changes to our climate threaten the welfare of all people, not just those in underdeveloped countries. There is no agreement on the solutions. There is a fierce debate between scientists, economists, social planners, politicians, conservationists, developers and even theologians, as to the actions that need to be taken. There appears to be a lack of conviction and willingness on the part of most governments around the world to take any action. One of the difficulties that frequently arises is that scientific data relating to the environment, and particularly to environmental change, are often sparse or unconvincing and therefore open to challenge. This *World Mangrove Atlas* is an attempt to provide accurate data and, at least partially, to quantify the presence, extent and distribution of a distinctive and important coastal ecosystem.

Mangroves

Mangrove trees and shrubs (the term also includes ferns and palms) are a common sight on mudflats and banks of tropical and subtropical rivers and coastlines in many parts of the world. They stand with their roots in salt water and they are regularly subject to the influence of tides. As such they are a special form of vegetation existing at the boundary of two environments. They are predominantly found in the tropics. The species of plants known as mangroves belong to a wide variety of plant families. The common characteristic which they all possess is tolerance to salt and brackish waters. Mangroves have evolved a variety of survival and reproductive strategies to deal with their muddy, shifting, saline environment. Some seventy species of mangrove plants are recognised from various regions of the world, with the highest concentrations of species being found in Southeast Asia and Australia. More than forty percent of the estimated eighteen million hectares of mangrove forest in the world occur in Asia. Some of the largest mangrove forests are found in Indonesia, Brazil and the Sundarbans of India and Bangladesh.

Mangroves support a complex aquatic food web and provide a unique habitat for a variety of animals. They supply a number of natural resources, while the waters surrounding the mangroves are a rich source of fish and shellfish. The presence of mangroves in some places acts as a stabilising factor for the river banks and coastline. Mangroves can also play an important role in the functioning of adjacent ecosystems, including terrestrial wetlands, saltmarshes, seagrass beds and coral reefs.

Man and mangroves

In regions with continuous high temperatures, prolific rainfall and the appropriate terrain, mangroves have prospered. Productive mangrove forests have evolved and this rich resource has been widely used by coastal people of the tropics for thousands of years. Many human communities have a traditional dependence on mangroves for their survival and a wide range of natural products from the mangroves and their surrounding waters are utilised. Mangroves are used, among other things, to supply building material, firewood, charcoal, food and medicine.

A balance exists between the complex biological system, which the mangrove forests represent, and the local people who exploit the system without destroying it. Historically, human pressure on the mangroves was limited: all but a few subsistence populations saw mangrove areas as inhospitable, unhealthy and dangerous. They were not easy places to penetrate except by small boat and few communities of people actually lived within the mangrove forests.

In recent years, the pressures of increasing population, food production and industrial and urban development have led to a significant proportion of the world's mangrove resource being destroyed. As human populations have risen, the shortage of productive land in developing countries has led to the clearance of many areas for agricultural purposes or for the provision of fish and shrimp ponds for commercial production. Much of this reclaimed land has proved unsuitable for agriculture or aquaculture and today it lies derelict. Mangroves have also been logged for timber, fuelwood and charcoal production, chipped for paper production and destroyed to provide land for the construction of mines, ports, tourist resorts and housing. The exploitation of mangrove forests for short term gain has usually been irreversibly destructive.

The dilemma

Twenty years ago, mangroves were generally considered as waste lands with little intrinsic value and their destruction was encouraged by governments and planners. This attitude did little to ensure productive and sustainable use of the mangrove ecosystem. Such attitudes still exist today and mangroves are being cleared around the world without much thought being given as to whether this is the best way to manage a productive and economically valuable resource.

The dilemma is how to convince governments and developers that mangroves are a valuable resource and to persuade them to adopt best practices when deciding on the utilisation of mangrove land. Mangroves can be economically and ecologically important and common sense dictates that their use should be managed carefully. Short term schemes and attempts to produce quick profits all too often lead to long term disasters.

Towards a solution

In the early 1970s scientific interest in mangrove ecology began to shift from a long established academic investigation of these curious salt-adapted collections of plants and animals to include work relating to the more immediate problem of their rapidly increasing rates of disappearance. Rollet (1981) compiled a bibliography of mangrove literature that cited more than 6,000 references to research reports and journal articles for the period 1600-1975. A number of recent texts on mangroves are available which give an overview of mangrove ecology and mangrove management, such as Tomlinson (1986), Hutchings and Saenger (1987), Field and Dartnall (1987), Robertson and Alongi (1992), Field (1995 and 1996).

The wasteful destruction of vast areas of mangrove around the world persuaded a concerned scientific community to ask the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the United Nations Development Programme (UNDP) to mount a research and training programme on the biology and value of mangroves in Southeast Asia and the Pacific. The programme concentrated on training, field workshops and research. As a result of this activity, awareness of the importance of mangroves amongst governments, planners and the general public was enhanced and a group of people, drawn from all countries of the region, was created that could lobby for the proper management of mangroves. The first National Mangrove Committees were formed by governments in the region and consideration on how to manage mangroves properly began to permeate the thinking of planners.

A second programme was supported by UNESCO which created a model for evaluating and planning the utilisation of a mangrove system. This project involved many scientists and students from a wide range of countries working together in the field at Ranong in Thailand. Later, other mangrove projects were launched in Africa, Latin America and the Caribbean.

Following on from the UNDP-UNESCO mangrove projects, the International Society for Mangrove Ecosystems (ISME) was founded in 1990 as a non-governmental organisation based in Okinawa, Japan. The aim of the society is to promote research activities and the conservation, rational management and sustainable utilisation of mangroves. It also acts as an international data bank on mangrove ecosystems. ISME has recently adopted a Charter for Mangroves to complement the World Charter for Nature adopted by the United Nations in 1982.

In parallel with these developments, the Scientific Committee on Oceanic Research (SCOR) in collaboration with UNESCO's Division of Marine Science created a working group on mangrove ecology in 1979. This group undertook a biosphere inventory of mangrove lands and attempted to determine their current status. The Commission on Ecology (COE) of the World Conservation Union (IUCN) produced a report entitled *Global Status of Mangrove Ecosystems* (IUCN, 1983), which is widely cited in most reports on mangroves. The work of this group was supported by the United Nations Environment Programme (UNEP) and the World Wide Fund for Nature (WWF). IUCN, UNEP and WWF have continued their active involvement with mangroves up to the present day.

The Food and Agriculture Organization (FAO) of the United Nations has also pursued an interest in mangroves, particularly in forest management, and has published reports on mangroves (FAO, 1982 and 1994). In addition to these activities there has been involvement by aid agencies such as the World Bank, the Global Environment Fund, US-AID, and the European Community. There has also been support from many individual countries such as Japan, Australia, UK, France and the Scandinavian countries. A very recent initiative is a proposal by the International Geosphere-Biosphere Programme (IGBP) through its Land-Ocean Interactions in the Coastal Zone programme to study the economic and social impacts of global climate change on mangroves.

The global importance of mangrove ecosystems is clearly recognised in Agenda 21, the most recent and widely adopted international environmental resolution to date. This is described as a "blueprint for action" and, although primarily a voluntary code which is not legally binding, many of its principles are given legal effect through the Biodiversity Convention. Among the major themes running through this document is the need for international co-operation, integrated management, the preservation of vulnerable ecosystems (mangrove ecosystems are specifically mentioned), capacity building, and the collection and exchange of scientific data useful for management. The document deals specifically with the marine and coastal environment and singles out the protection of mangrove ecosystems as a priority.

The most tangible result of all this international activity over the past twenty-five years is that the ecological and economic importance of mangroves is now much better appreciated by all levels of society. There is also a well-informed, mutually supportive group of people able to argue for better management of the mangrove resource. However, there still remains an urgent need to translate this enhanced awareness of the importance of mangroves into the practice of better management of the mangrove resource.

A World Mangrove Atlas

The current work was initiated by the International Tropical Timber Organization (ITTO), which is an international organisation that aims to promote conservation and sustainable management of tropical forest resources, and ISME, with support from the World Conservation Monitoring Centre (WCMC), Cambridge, UK. ITTO has previously supported mangrove projects in Asia, Latin America and Africa (see, for example, Clough, 1993; Diop, 1993; Lacerda, 1993).

The compilation of a *World Mangrove Atlas* is a demanding enterprise and this version must be considered as a first attempt. We have used the best information that we could obtain from a wide range of sources, however, we are convinced that using a more intensive approach would yield improved data. The mapping process is described in more detail in the next chapter. The detailed case studies of mangroves presented in the regional accounts give a clear idea of what can be achieved, in terms of mangrove mapping at higher resolutions, given sufficient resources. These case studies also reveal more of the geomorphology, mangrove composition and socio-economic condition of the areas under study.

The area that mangroves occupy is of great interest in quantifying their global presence and changing status. There are significant difficulties in the calculation of such a figure, however, and this matter is discussed more fully in the next chapter. Problems arise in identifying, from satellite photographs, whether the vegetation is mangrove or not, in knowing whether the area includes open water surfaces or not, and in calculating the area from the GIS maps. Although area statistics for the mangrove coverage are provided in this work, such figures should be viewed with great caution.

If we are to be able to state whether the area of mangrove in the world has increased or diminished in twenty years time, due to the activities of people, natural disasters or changes in global climate, then we must establish a baseline from which to measure the change. This atlas is an attempt to summarise the available data and to construct such a baseline. It is far from perfect, but it is hoped that it will encourage governments and individual scientists to improve the data and to provide enough new information to revise the *World Mangrove Atlas* in the future.

There is no doubt that mangroves are important ecosystems biologically, socially and economically. It should not be beyond our capability to compile an accurate inventory of mangroves around the world and to be able to monitor any changes that may take place.

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2

The Mapping of Mangroves

Maps came into general use, particularly in Europe, in the 15th and 16th centuries. Many of even the very earliest of these maps (such as Ptolemy's *Cosmographia* of 1447) portrayed forests and other vegetation. However, the first true vegetation maps, drawn specifically to present vegetation, did not appear until the mid-nineteenth century. These included the 1858 *Florenreiche* of Brazil, produced by von Martius, which included mangroves.

In addition to their portrayal on terrestrial maps, mangroves also appear on many hydrographic charts, although here they are frequently presented as linear coastline features rather than actual areas. It is quite likely that the first regular occurrence of mangroves on maps was on hydrographic charts prepared by individuals and trading companies, and later by national hydrographic offices. The Portuguese were amongst the first to show mangroves on their charts. The first actual use of the term mangrove on a map dates back to the early sixteenth century where a chart of the coast of Brazil shows mangroves ('manguez') in the Golfo de los Reyes, just south of Rio de Janeiro. During the same period other charts, notably of the Moluccas, showed forest areas marked as 'alagados' ('inundated'), which were undoubtedly mangroves and were of military significance, as they were occasionally used by indigenous peoples as a base for hiding and attacking the foreign ships (Vannucci, 1989).

In recent years the mapping of mangroves has become more widespread and they feature not only on hydrographic charts, topographic surveys and vegetation maps, but also in natural resource inventories, coastal zone management plans, wetland maps and coastal sensitivity maps prepared at local, regional and national scales. A number of mapping projects have also focused entirely on mapping mangroves (see Thailand and Tanzania in this work). Data are still largely prepared and presented on paper maps, although they are increasingly being held in digital form (as in Belize, Florida, Philippines, Australia, Cambodia and Papua New Guinea, in this work).

Global syntheses on the distribution and status of mangrove forests are largely restricted to specialised books (Chapman, 1976; IUCN, 1983; Tomlinson, 1986). These works only contain very coarse scale maps and the current work thus represents the first attempt to prepare a detailed global synthesis of the distribution of mangroves.

This chapter considers the broader issues of mapping, with special reference to mangrove communities. It begins with an overview of mapping techniques, and some of the problems associated with these, before discussing the current mapping project in more detail.

The importance of maps

Recent years have witnessed an explosion in the levels of information in circulation throughout the globe, much of these data having at least some spatial attributes. The ability to handle and present data in a concise but informative manner is essential, and maps are one very powerful tool capable of achieving this.

Maps also have a strong visual impact and are frequently used to promote particular facts or concepts in a manner far more effective than text or tables. They are understood internationally, can show land-cover and land-use patterns and can link often quite disparate data, such as infrastructure, natural vegetation patterns or land tenure. Maps can further be used in monitoring, calculating changes in area of different features, or in modelling and planning processes. For these and many other reasons, maps are widely used by land-use planners, policy makers, scientists and the wider public.

Maps can convey important information on the distribution and status of natural resources, graphically illustrating the extent of natural and semi-natural vegetation and its spatial relationship with developed or agricultural areas. The importance of mangrove communities to man for coastal protection, fisheries production and supply of natural products, such as firewood, timber and charcoal, has been mentioned in the introduction. The location of mangroves in the coastal zone often places these communities in conflict with other human activities, but inappropriate development in the coastal zone can have disastrous consequences both for mangrove communities and for man. Where conflicts for space do exist, maps are an essential tool in providing location information for natural resources and in the coastal zone planning process.

The techniques used in the preparation of a map depend very much on the uses for which the map is required, the scale of the task and the availability of resources for the work, such as data, time and funding. The global coverage in this atlas is based on the compilation of a wide range of existing maps that are referenced in each country account. Each of the source maps might, itself, have been prepared using one or more of the techniques given below. The case studies in this atlas provide other examples of techniques for mapping mangroves.

Ground surveying

A variety of techniques may be used for ground surveying, from the very simple preparation of hand sketches and chain surveying to more sophisticated techniques of plane table surveying, surveying and contouring. It should be noted, however, that many of these are very difficult to apply in the complex structural environment of a mangrove forest. Theodolite mapping has been used in most national mapping and engineering surveys, but updates to these, and new maps, are now frequently based on aerial photography and other remote survey methods. More complex techniques of ground surveying include those developed for geodetic surveying and levelling. These allow for the more accurate positioning of the data on the globe, making allowances for such factors as the earth's curvature. The mapping of vegetation is often a part of the initial surveying exercise, and the survey methods used for levelling can also be used, for example, in the measurement of canopy height. In other cases, vegetation maps are often overlaid onto existing topographic maps which may have been prepared elsewhere. One of the great advantages of the more intensive ground survey methods is that they allow for the mapping of species distribution, ecological parameters and other features not visible from remote platforms.

Marine charts have often used land-based methods for the surveying of accessible coastlines, and they now make considerable use of air photos. They have also used boat-based surveys, particularly for less accessible shores. One problem in boat-based surveys has been the fixing of the boat's actual position. For this, it is possible to use existing maps and charts, astronomical methods and, more recently, it has become possible to achieve considerable positional accuracy with Global Positioning Systems (GPS). Distance to shore and elevation can then be measured using techniques similar to those used in land-based surveys. Definition of coastline type is largely based on visual identification and, because terrestrial features beyond the coast are not of major interest and are not easily gathered, vegetation, including mangrove forest, is rarely presented as an accurately defined area, but rather as a length of coast. Other key features of hydrographic surveying, such as the collection of depth data or the calculation and allowance for tidal variation and the establishment of a chart datum are of little relevance to this work and not given further consideration.

Remote sensing

Remote sensing is the term widely applied to the "acquisition of information about the land, sea and atmosphere by sensors located at some distance from the target of study" (Haines-Young, 1994). Typically, this means the gathering and analysis of images acquired from aircraft, satellites and even balloons. The use of such images was rapidly developed for military applications particularly during the First and Second World Wars.

In addition to conventional photography, other methods of image gathering are now widely used and, to better understand all of these, it is useful to consider some of the physical processes which lie behind them. Different objects show quite different reflectance patterns when exposed to electromagnetic radiation. This can be seen in the different colours that are reflected by different objects in the visible spectrum such as green trees and grey buildings, but the same phenomenon occurs across the wavelengths of the electromagnetic spectrum from x-rays and ultraviolet to infrared and microwaves. In addition, certain wavelengths are radiated from objects, particularly in the thermal infrared. These different patterns of reflectance and radiation from different objects are unique across a range of wavelengths, and are termed 'spectral signatures'. Figure 2.1 shows the reflectance patterns of some typical ground features, including water, sand and vegetation. Human sight and conventional photography are both sensitive to wavelengths in the visible spectrum, but it is now possible to build sensors that are capable of detecting wavelengths across the electromagnetic spectrum. Analysis of these patterns may enable the differentiation, for example, of mangrove forest from grassland, even from a remote location.

Certain objects may show considerably more variation in reflectance over some wavelengths than others. For example, vegetation generally shows highest reflectance in the near infrared and reflectance patterns vary considerably over relatively small changes in vegetation type. It is thus useful to single out these wavelengths when studying vegetation patterns with remote sensors (see Figure 2.1). Further complexity arises when selecting wavelengths for image preparation, as the atmosphere 'soaks up' considerable amounts of certain energy bands which effectively become invisible from a remote platform.

Any platform capable of picking up these radiating wavelengths can be termed a 'passive sensor'. At the research level, active sensors are also now frequently used which direct radiation, typically radar wavelengths or laser, towards the earth and then detect the reflected waves.

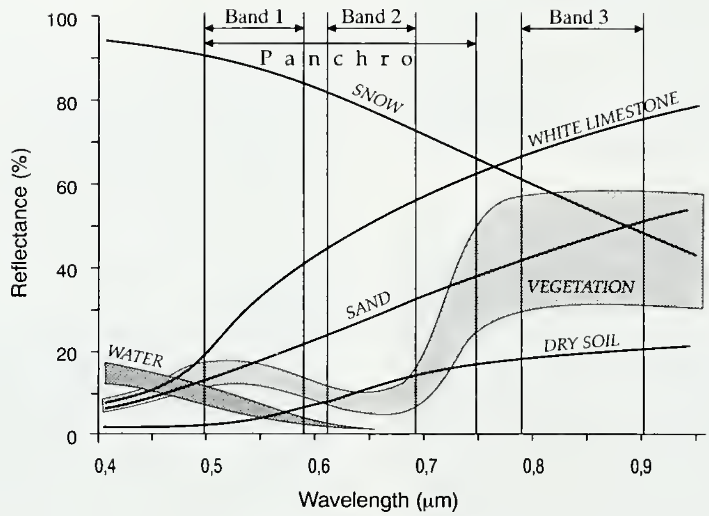

Figure 2.1 Some typical spectral responses of important ground features (spectral bands refer to SPOT 1, 2, 3 and the panchromatic channel)

The development of sensors for unmanned satellites necessitated the development of some means of transferring data back to earth without physical contact. For this purpose electronic scanners were developed. These operate with a lens which focuses an image onto an array of photoelectric cells which measure the amount of radiation being received. The information is converted into digital data and then transmitted to earth as radio waves.

Once an image has been obtained, either digitally or converted to a map, it must be interpreted. Reflectance is not the only tool available to the image interpreter, other characteristics, such as tone, texture, pattern, scale, relationship to other features, and surface relief may tell a great deal about a ground feature. The use of stereo imagery can enhance some of these characteristics. It is important to realise that image interpretation is a highly skilled process which, if undertaken with care and consideration, may improve the effective resolution of an image. It is possible, for example, that an area of dwarfed mangrove may have a very similar spectral signature to another vegetation type, but by looking at the patterns of surface drainage and relief it may be possible to distinguish one from the other. Such interpretation requires at least some knowledge of the distribution and ecology of mangroves.

Preparing maps from images

Remotely sensed images can be used to annotate or update existing maps or create entirely new maps. Traditional photographic images can be utilised directly, using analogue photogrammetric techniques that have been developed and widely used since the 1940s. Alternatively there are a number of methods of transferring the data to Geographical Information Systems (GIS) or other software systems where they can be manipulated with relative ease to correct geometric distortion and to undertake subsequent data analysis.

The simple visual interpretation of a satellite image can yield considerable information from a thematic viewpoint, however the conversion of such an image to a specified map projection usually requires geometric corrections, which are only possible with image processing software or, at least, a GIS. Digital image processing typically involves the enhancement of the contrasts between features, facilitating their interpretation. Although satellites already have their sensors tuned to specific wavelengths, further work can be undertaken to drop out or enhance particular wavebands in order to maximise differentiation of particular features. Known features on the ground can have their spectral signature analysed and software packages can be programmed to find all other areas with similar reflectance characteristics, producing a 'classified image'. This method is known as a supervised classification. Alternatively algorithms can be written to identify areas of similar reflectance automatically (unsupervised), and these can then be identified on the ground.

The development of GIS has closely paralleled that of image processing systems, and there is now a considerable overlap between the capabilities of the two. The former specialise in handling related, spatially referenced data, typically combining mapped information with a database and analytical tools. The notable advantages conferred by GIS include the ability to update information rapidly, to undertake comparative analytical work, to combine data from multiple sources, which may also be of differing age and scales and to link further data to maps in a variety of different ways. These and other mapping software tools are increasingly used by cartographers around the world.

Ground-truthing

With all remote sensing techniques it is necessary to undertake 'ground-truthing' in order to interpret and validate with certainty the features identified in images. Such work involves visiting a number of test sites, usually with a copy of the remote image in its raw form or partially processed. Detailed descriptions can then be gathered of the features of interest to the observer, together with other features which may interfere with these due to strong or conflicting spectral signatures. It may, for example, be necessary to note the features of soil or drainage as well as vegetation in order to produce a useful spectral classification for subsequent image analysis. Equally important is to ensure that data gathered in the field have accurate geographic locations. This is commonly done using Global Positioning Systems (GPS), but can be achieved equally well by linking to features on the ground which are clearly visible in the remote image. Also important is to take a large enough number of samples, and to ensure that individual samples are sufficiently large. Sample size will vary depending on the resolution or pixel size of the original image. Some surveys use ground-based remote sensing, employing cameras and radiometers, to get more accurate information relating to the spectral signatures of different ground features.

Scale and resolution

The scale of a map is a measure of the reduction of the size of features on that map. Resolution is a related term. It is a more direct measure of the detail shown on a map and refers to the minimum size of an object visible on a map or the minimum distance by which two objects must be apart for them to appear separate. The characteristics portrayed in the spatial representation of any natural system are strongly related to scale and resolution, and these need to be seriously considered by those responsible for the preparation of maps and by the users. A number of problems can arise, especially in the generation of statistics and the comparison of maps drawn at different scales.

This is illustrated by attempts to measure coastline length: the complexity, and hence the length, of any coastline shown on a map is a function of map resolution. In the Caribbean, for example, maps of individual islands frequently show great detail, including tiny offshore rocks and islets. Regional maps, by contrast, may summarise complex coastlines into a few simple lines, while world maps often leave out many Caribbean islands altogether. Measuring the length of coastline of any island from each of these maps would yield three very different results.

With traditional photography, the resolution or level of detail can be altered by varying the lens and photographic material, or by altering the height from which images are taken, although a balance must be struck between the area covered by the image and the detail or resolution to be found in the resulting image. Optical scanners gather light from a continuous grid of defined blocks, known as pixels. The sensor records, for each pixel, the reflectance levels of those wavelengths to which it is tuned. The resolution is largely a function of pixel size, which is dependent on the optics of the sensor and the height at which the images are taken. These parameters cannot easily be varied for satellites. A summary of the sensors in the most commonly used satellites is provided in Table 2.1. Data from all of these satellites have been used in the preparation of the source maps for this atlas.

The problems posed by scale are not simply those of statistics. Entire natural phenomena will be hidden or exposed depending on the scales of study. This is of particular relevance in the coastal zone where many narrow linear features are likely to be completely lost at low resolutions.

This atlas provides examples of some problems of scale. None of the 25 regional maps has a base scale much greater than 1:5 million. At this scale 1 centimetre on the map represents 50 kilometres on the ground, and it is very difficult to see features with a diameter of less than 2 kilometres. Extensive areas of the world's coasts have sparse mangrove communities, groups of just a few trees or fringe communities only a few metres wide. These communities may be important in terms of the geographical distribution of mangroves. They may also have local significance in providing propagules for the colonisation of mangrove areas, habitat for fauna and stabilisation of embankments. Few of these communities are clearly shown on the regional maps in this document. In contrast, some of the case studies in this atlas have been prepared at very high resolutions where it is possible to distinguish features measured in metres rather than kilometres and to differentiate areas within a mangrove community showing, for example, different species composition, or canopy height.

Comparison of methods

Traditional survey methods provide for extremely high-resolution mapping and can further allow for identification of many features invisible from remote locations, including species, and certain physicochemical parameters of the environment. They are, however, usually time-consuming, costly and not well adapted to mapping large areas.

Table 2.1 A summary of the main satellites used for vegetation mapping, together with their sensor specifications. Abbreviations used are defined below the table

Satellites and sensors	Band number and spectral coverage	Spatial resolution (pixel size)	Repetition rate and size of image	Altitude	Suitable mapping scale
NOAA-AVHRR (since 1978)	1 0.58-0.68 µm 2 0.725-1.1 µm 3 3.55-3.95 µm 4 10.5-11.3 µm 5 11.5-12.5 µm	HRPT, LAC 1 km GAC 4 km GVI 15 km	Daily 2,700 x 2,700 km	1,450 km	Global and regional from 1:1,000,000 to 1:10,000,000
Landsat MSS (since 1972)	4 0.45-0.6 µm 5 0.56-0.7 µm 6 0.67-0.8 µm 7 0.78-1.1 µm	79 x 79 m	16 days 180 x 180 km	915 km and 705 km	National from 1:200,000 to 1:1,000,000
Landsat TM (since 1982)	1 0.45-0.52 µm 2 0.53-0.61 µm 3 0.62-0.69 µm 4 0.78-0.91 µm 5 1.57-1.78 µm 7 2.10-2.35 µm (6 10.4-12.6 µm)	30 x 30 m or 120 x 120 m (Band 7)	16 days 180 x 180 km	705 km	Local from 1:50,000 to 1:200,000
SPOT HRV (since 1986)	1 0.50-0.59 µm 2 0.615-0.68 µm 3 0.79-0.89 µm (Panchromatic 0.51-0.73 µm)	20 x 20 m (10 x 10 m)	26 days 60 x 60 km	833 km	Local from 1:50,000 to 1:200,000
ERS-1 and 2 (since 1991)	SAR 5.3 GHz Band C 5-7 cm	30 x 30 m	Almost daily 100 km	785 km	Local from 1:50,000 to 1:100,000

NOAA-AVHRR	Advanced Very High-Resolution Radiometer	HRPT	High-Resolution Picture Transmission
Landsat MSS	Landsat Multi-Spectral Scanner	LAC	Local Area Coverage
Landsat TM	Landsat Thematic Mapper	GAC	Global Area Coverage
SPOT HRV	SPOT High-Resolution Visible	GVI	Global Vegetation Index
ERS-1 and 2	European Radar Satellite		

Aerial photography also allows for comparatively high-resolution mapping (scales of up to 1:2,000, enabling measurement of objects even just a metre or so across). It has a longer historical record than satellite imagery in many countries, allowing for the use of comparative data from as early as the 1940s. Photographs are also well adapted to stereo image preparation, although these are now also obtainable from SPOT images, and they can be relatively cheap to analyse, especially if only a small area is under survey. Aerial surveys can be tailored to the particular needs of specific users. The high-resolution and use of particular film have enabled the study of tree disease and pollution damage. The use of Side Looking Airborne Radar (SLAR) has a number of advantages, most notable is its ability to penetrate cloud or to survey at night. It generally produces images of slightly lower resolution than conventional aerial photography. SLAR images have been used for vegetation mapping, especially in areas prone to considerable cloud cover, and they can be used to differentiate mangrove communities. Radar images are now available from satellites (ERS-1, ERS-2, J.ERS). As with airborne radar, they are of considerable interest in enabling cloud penetration, but their use in mangrove mapping is still only at the research level.

Satellite imagery has been available since the launch of the first Landsat platform in 1972. Although resolution is improving it is still limited, at best, to pixels of side 10 or 20 m. The advantages, however, are numerous. Very large areas can be covered relatively cheaply, a wide variety of spectral bands can be covered, and data can be collected frequently and regularly. The data are available in digital format, which is useful for processing and incorporating into a GIS. In general, for vegetation mapping the higher resolution 'earth resources satellites' (e.g. Landsat and SPOT) are more useful than the 'environmental satellite systems' (e.g. NOAA-AVHRR), whose data are primarily used in meteorology. Although satellite data are regularly collected, the satellites have a fixed path and cannot be directed: it is thus not possible to get data from different times of day with the sun-synchronous satellites (Landsat and SPOT), nor is it possible to guarantee data from cloud-free days. Even after 20 years of Landsat imagery there are still some areas that have not been viewed under cloud-free conditions.

Further comparisons of remote sensing methods are provided in the case studies included in this atlas, and mention of this is made later in this chapter.

The portrayal of mangroves

Man-made or man-modified features such as roads, buildings and fields are relatively easy to portray on a map, as they can usually be clearly defined with sharp lines. Natural features are generally far less easily delimited and, even with strict definitions, are somewhat subjectively defined by systems that require points, lines and polygons to set limits on features that may, more realistically, be gradients and patchworks and, in turn, may be transitional or seasonal. In most cases the process of transferring information to maps requires a considerable amount of data aggregation for the sake of clarity and integrity. Even the coastline proves a feature of some difficulty to cartographers due to problems of tidal fluctuations. There has traditionally been very little overlap between the charts for marine navigation and maps for terrestrial features. The former often measure depths below sea level from a different point (datum) in the tidal cycle than the latter measure heights above sea level.

The term 'mangrove' has been used variously to define a constituent group of plants and the communities in which these occur. Other terms for these communities include coastal woodland, intertidal forest, tidal forest, mangrove forest, mangrove swamp and mangal. To define the mangrove community it is necessary firstly to define the constituent mangrove plants: these are shrubs or trees (and including ferns and palms) which inhabit the intertidal zone. They are a polyphyletic group from a wide range of families, which makes the development of a strict definition difficult. The total number of mangrove species varies from author to author, although most would agree on a minimum list which would include the dominant species in most situations. The definition of a mangrove community would be that of a habitat dominated by one or more of these species. The text and tables in this work use a list of some 70 mangrove species, adapted from Duke (1992). It should be noted, however, that the maps themselves are drawn from sources which rarely define the mangrove communities that they map. The only case where this is likely to cause concern is with *Nypa* dominated forests. *Nypa*, which is related to the palms, is probably omitted from the mangrove areas on some maps. This is unlikely to be noted, even in map keys, and is thus difficult or impossible to correct.

Further difficulties arise in the preparation of maps from defining areas which could be seen as integral to the mangrove ecosystem, such as salt pans (tannes or blanks), creeks, mudflats, or areas with dwarfed or sparsely distributed trees. Some workers may include these areas as part of the ecosystem, others will not. Their approach is likely to be further influenced by the problems of scale noted above. The landward margin of a mangrove forest may be delimited by any one of a number of different systems, but where the forest grades into another forest system, such as swamp forest or lowland rainforest the change may be gradual and virtually imperceptible, presenting yet further problems for the cartographer.

Despite these apparent differences of definition it is relatively easy in most areas to describe and map mangrove communities. The commonest mangrove species are agreed upon by most authors (with the possible exception of *Nypa*), and where these form dense communities they can usually be defined clearly. Frequently they can be seen from the air or surveyed from the land or sea and have clear boundaries where the trees stop.

Existing mangrove mapping

Mangroves make up a significant part of many tropical and near-tropical coasts, lagoons, estuaries and deltas. As such they are portrayed on a wide range of maps. Many countries mark mangroves on general topographic surveys, and they are often marked, at least as linear features, on marine charts to aid navigation. In both of these cases mangroves are rarely defined. In the latter case they are rarely shown as polygons and may not be shown if they are in lagoons and so not visible from the sea. Typically, national topographic maps have developed over many years and the source material is a complex patchwork of different surveys made from the ground, the air and space. The most reliable maps are vegetation maps, which are increasingly available at both national and regional levels. In all of these cases, the maps may have been prepared from one or more of the survey methods described.

Despite all of these comments it remains relatively unusual to find a recent map showing mangroves at a useful scale. Revision of national topographic map surveys is currently at about 1% per year, and this figure is much lower for regions in Africa and South America (Howard, 1991).

The present approach to global mangrove mapping

This work represents the first attempt at the preparation of a global map of mangrove forests. Gathering global mapped data has been undertaken by the World Conservation Monitoring Centre (WCMC) in the past for a number of other publications. Of greatest relevance for the current work has been the preparation of *The Conservation Atlas of Tropical Forests*, a three-volume series (Collins *et al.*, 1991; Sayer *et al.*, 1992; Harcourt and Sayer, 1996). This very large undertaking led to the development of forest maps, including mangroves, for all of the major wet-tropical forest countries. For *The Conservation Atlas of Tropical Forests*, original data were gathered by a major search process which involved correspondence and discussion with mapping agencies, government authorities, non-government organisations interested in conservation, international agencies and scientists. Data requests led to the gathering of data in numerous forms, ranging from detailed digital data sets to sketch maps. These data were incorporated into the GIS system at WCMC where they were harmonised and prepared for publication. Using the same GIS it has been possible to extract the mangrove coverage from these maps to act as a starting point for the current atlas.

The primary aim of the current work has been to build on the existing data set for mangrove forests by identifying gaps, which include the coasts of dry countries and small island nations, updating obsolete data, improving low resolution data and seeking new data sets. Data gathering was undertaken along similar lines to those used for the production of *The Conservation Atlas of Tropical Forests*, through correspondence and discussion with mapping agencies, government authorities, non-governmental organisations, international agencies and individual scientists. In particular, the search effort has been more focused on mangrove experts in many countries. Help and advice was sought from members of the International Society for Mangrove Ecosystems (ISME), the staff of the Laboratoire d'Ecologie Terrestre, Toulouse, France and many other centres of mangrove expertise. As well, extensive searches of the literature were carried out.

Much new data were obtained, including detailed digital data sets for a number of countries, printouts from other GIS systems, unpublished reports and published maps. In some cases confirmation was given that the data already held at WCMC were sufficiently accurate. Elsewhere, WCMC provided base maps to country experts for annotation which were then returned for digitising.

The twenty-five regional maps in this atlas represent the first map summary of the distribution of mangroves at the global level. Mangroves are thought to occur in some 112 countries and territories (including many small island nations where the total mangrove area is very small). Between them, the maps show the distribution of mangroves in one hundred countries and thus provide a detailed picture of overall distribution patterns at the global and regional level. The remaining countries, for which data were not found, are all known to have only a small area of mangroves, unlikely to influence the general appearance of the regional distribution maps.

The information presented may not always be the best available, and it is not necessarily strictly comparable across country boundaries. This will depend on the source data, and the age of the data. With more time and a larger budget, it would have been possible to develop a more consistent approach, yielding more recent and accurate data for many countries.

Case studies

The regional mangrove maps in this atlas have been supplemented by a number of case studies. These have examined a few selected mangrove areas in much greater detail. There are very few published papers specifically relating to mangrove studies using remotely sensed data, despite the relatively large number of studies dealing with other tropical forest systems. Remote sensing is a tool which cannot be used alone in the mangrove environment. It must be used with appropriate 'ground-truthing', and the importance of this is shown in the various case studies provided. As a general rule, the data extracted from satellite sensors are directly related to the density of the ecosystem, its main floristic components, its phenological stage or physiological status. It is not yet possible to use satellite imagery to derive accurate and reliable data on canopy height, forest stratification, species identification, timber volume or standing biomass. However, it is possible to discriminate mangroves from neighbouring ecosystems, to delineate mangrove areas, to provide information on their density and degradation, and to monitor changes due to natural and man-induced hazards, such as cyclones, surges and floods. Such information may be achieved using high-resolution data such as Landsat TM, SPOT HRV, combined, or not, with ERS data. Some of the most recent satellite image interpretation has looked at photosynthetic activity and primary productivity of forests, but, so far, mangrove areas have not been studied. It should further be noted that in some cases mangrove inventories require higher accuracy than is currently achievable from satellite imagery and in these cases (1:20,000-1:50,000) aerial photography remains a more powerful tool.

The case studies presented in this atlas have been selected to illustrate at least a part of the range of mangrove ecosystems, based on:

- biogeography
- coastal environment (bioclimate, geomorphology)
- structural properties (size and density of the trees)
- human usage and exploitation

In addition to this, the data presented have used information from all of the most commonly used satellites such as NOAA-AVHRR, Landsat, SPOT and ERS-1. In these terms, a summary of what the different case studies show is outlined overleaf.

Bay of Bengal, India and Bangladesh

The two studies provide a composite of the full range of scales from low resolution data (NOAA-AVHRR), to high (SPOT and aerial photography):

- Ganges-Brahmaputra - a huge area of deltaic mangroves, including both natural systems and plantations, showing cyclone damage and conversion to agriculture.
- Cauvery Delta (Pichavaram) - a small area of coastal lagoon mangroves on a dry coast, showing forest clearance.

Ranong, Thailand

High-resolution Landsat TM imagery is shown. The site consists of estuarine mangroves in a relatively natural system.

Balochistan, Pakistan

High-resolution imagery showing the mangroves of Sonmiani Bay is provided. The coastal region is highly arid and saline. The mangroves are sparse with stunted tree growth.

French Guiana

This shows the use of radar data from ERS-1 combined with SPOT. The country has both estuarine and coastal mangroves, showing zonation and natural degradation.

Sine-Saloum, Senegal

Two types of high-resolution satellite imagery, Landsat MSS and SPOT, are shown. These are sahelian mangroves, arid and degraded.

Gabon

This study illustrates the use of aerial photography. The sites shown are relatively natural estuarine systems, with dwarfed trees away from the river banks.

Gambia

High-resolution SPOT imagery has been used. Riverine mangroves are shown. The trees are well developed with a high density and a high canopy.

Spatial accuracy

Some mention has already been made of the problems of scale. Data prepared at high-resolution will show even very small areas of mangrove, while at low resolutions such areas may be omitted, or their size may be exaggerated. Exaggeration of size at low resolutions may occur when, for example, a number of smaller areas are coalesced into a single polygon which actually includes areas of non-mangrove, or when areas of bays or rivers are simply infilled with mangrove. Low resolution satellite imagery may exaggerate or reduce an actual mangrove area, depending on the techniques that are applied and the spatial distribution of a given mangrove area. To be detected within a one square kilometre pixel, mangroves must occur over an area large enough to produce a sufficient reflectance for detection. Small patches are likely to be omitted, as are larger areas if these are linear and quite narrow. In some circumstances, however, the actual area may be exaggerated by the same imagery. It is possible for individual pixels to be recorded as mangrove even when the total area of mangrove is much less than one square kilometre, depending on such factors as the reflectance of surrounding features and the wave-bands being used in the analysis.

Areal estimates

Knowledge of the mangrove area in any country or region is important for policy-making, planning and resource management. With the increasing concern over the loss of mangrove areas in many countries there is also an urgent need to assess the scale and rate of this loss. To undertake such work, accurate calculations of areas are necessary, and these must be repeatable over time.

In this atlas, the total area of mangrove, as shown in the regional maps, is provided in the country tables and was generated from the GIS. There is reason to treat some of these figures with caution. In part, this is because of the issues of scale and spatial accuracy but problems of definition and interpretation also affect the calculation. A one square kilometre pixel resolution, especially in a small country, will be of little or no value in the calculation of the total mangrove area for that country. For larger countries the same errors arise, although the percentage error is likely to be less.

It is rare for map sources to provide a detailed definition of what they have called 'mangrove' so it is possible that, for some maps, 'mangrove' may include areas of swamp forest, saltmarsh or mudflat; or may exclude areas of *Nypa*. In some areas there may be further problems of misidentification. Thus, for example, in Venezuela it has been suggested that estimates of mangrove area may have been consistently overestimated by over 100% as they have included the non-mangrove species *Symphonia globulifera* which is a swamp-forest species, difficult to distinguish from mangroves in remote images. If this is indeed the case, it may have further ramifications for a number of other countries in the region as *S. globulifera* is a relatively widespread species. It is difficult to estimate the magnitude of these problems but, in the opinion of the editors, they are probably not widespread.

The uncertainty in areal calculation has resulted in the provision of a second figure for mangrove area in the country tables, described as the 'alternative estimate of mangrove area'. This figure is taken from a recent, reliable source (referenced). In many cases this figure may be more accurate than the figure generated from the maps. Where either figure is considered to be very unreliable it is placed in parentheses. When citing areas, it is also important to include the date of the source information as mangrove areas in some countries may have changed considerably since the data were originally prepared. Readers are strongly encouraged to refer to the source material which is referenced for each country. It is possible, using this information, to assess the age, quality and scale of each country coverage and to use the data accordingly. Of the two areal figures provided that which is considered to be the most reliable, in the opinion of the editors, is marked with a '#'. These figures have been used in the generation of regional and global statistics in the next chapter.

Despite these problems, the area estimates presented here, derived from the maps or alternative sources, represent a summary of the best available areal estimates for most countries in the world. Furthermore, the maps themselves provide an important record of the spatial distribution of mangroves around the world. This has never been available until now, and the maps and related data thus represent a unique and valuable baseline on which future work can build.

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3

The Global Distribution of Mangroves

Mangroves are largely confined to the regions between 30° north and south of the equator, with notable extensions beyond this to the north in Bermuda (32°20'N) and Japan (31°22'N), and to the south in Australia (38°45'S), New Zealand (38°03'S) and the east coast of South Africa (32°59'S). Within these confines they are widely distributed, although their latitudinal development is restricted along the western coasts of the Americas and Africa, as compared to the equivalent eastern coasts. In the Pacific Ocean natural mangrove communities are limited to western areas, and they are absent from many Pacific islands.

Figure 3.1 shows the global distribution of mangrove communities. This represents a global synthesis of the data gathered for, and presented in, this atlas. To enhance the visibility of the smallest sites, which would otherwise not show at this scale, the boundaries of all sites have been enlarged and thus should not be regarded as indicative of actual mangrove area at any one site.

There are two main centres of diversity for mangrove communities which have been termed the western and eastern groups (Tomlinson, 1986). The eastern group broadly corresponds with the Indo-Pacific and is bound to the east by the limits to natural mangrove occurrence in the west and central Pacific, and to the west by the southern tip of Africa. The western group fringes the African and American coasts of the Atlantic Ocean, the Caribbean Sea and the Gulf of Mexico, and also includes the western (Pacific) coast of the Americas. These two regions have quite different floristic inventories, and the eastern region has approximately five times the number of species that are found in the western region.

The distribution patterns of mangroves are the result of a wide range of historical and contemporary factors. Perhaps the most obvious distribution patterns, the latitudinal limits, are largely set by low temperatures, both sea surface temperatures and air temperatures, and particularly by extremes of temperature. Rainfall also has a strong influence over mangrove distribution, largely through the reduction of salinity in an otherwise highly saline environment. Although mangroves are adapted to saline or brackish environments the high salinity of seawater, and the sometimes higher salinities associated with intertidal areas, particularly in arid countries, frequently restrict growth. In areas with low, irregular or limited seasonal rainfall the number of mangrove species which can survive is limited. This is clearly one of the major factors leading to sparse mangrove development over wide areas of coast, such as around the Arabian Peninsula. Historical and tectonic factors are probably responsible for the easterly limit to mangrove development in the Pacific, although exact mechanisms for these limits are unclear. It may be that mangroves were once more widely distributed in this ocean and have undergone range constrictions, alternatively the current distributions could represent the eastern limits to dispersal from a western centre of origin. At the national and local level, many other factors influence the distribution of mangroves, including soils, tides, geomorphology, mineral availability, soil aeration, winds, currents and wave action. The influence of man is now considerable and is affecting mangrove distribution patterns at all scales.

The total global area of mangroves

Mention has been made previously of the difficulties of calculating the area of mangroves for different countries. This atlas includes a comprehensive assessment of the total mangrove area statistics for every country in the world. In most cases, two estimates are presented, one calculated from the map, the other an alternative best estimate from a given source. In order to derive summary statistics the editors have, as objectively as possible, selected from these two figures that which, in their opinion, is likely to be the more accurate. These figures (marked with a '#') have been used in the calculation of the regional statistics presented below.

According to these data (Table 3.1), the total area of mangroves in the world is some 181,000 square kilometres (sq km). This figure, and the regional totals, compare favourably with estimates prepared by Fisher and Spalding (1993), but considerably less well with the figures provided in IUCN (1983). The latter document is older and does not cover all countries, notably in the Red Sea and Arabian Gulf areas and parts of the Americas: Florida, Bahamas and Lesser Antilles. The overlap in the material used in each of these references is minimal, so the figures can be taken as being effectively independent. Approximately half of

Table 3.1 Estimates of mangrove areas, together with percentage figures of global totals

Region	Mangrove Area (sq km) (this atlas)	Mangrove Area (sq km) IUCN (1983)	Mangrove Area (sq km) Fisher and Spalding (1993)
South and Southeast Asia	75,173 (41.5%)	51,766 (30.7%)	76,226 (38.3%)
Australasia	18,789 (10.4%)	16,980 (10.0%)	15,145 (7.6%)
The Americas	49,096 (27.1%)	67,446 (40.0%)	51,286 (25.8%)
West Africa	27,995 (15.5%)	27,110 (16.0%)	49,500 (24.9%)
East Africa and the Middle East	10,024 (5.5%)	5,508 (3.3%)	6,661 (3.4%)
Total Area	181,077	168,810	198,818

the figures used for the current assessment have been calculated from the mapped data, while most of the remainder are from very recent references.

Changes in mangrove area

The areal statistics in Table 3.1 give a reasonable assessment of the total area of mangroves in the world but there are likely to be considerable margins of error. These can be related to the problems of areal calculation described in the previous chapter. Due to differences in definition, age, scale and accuracy of different national sources, the use of global composite statistics as a baseline for monitoring changes in global mangrove area should be employed with extreme caution. Any future composite figures derived in a similar way will probably be subject to similar errors. There is an urgent need in most places for more accurate mapping of mangrove areas at much higher levels of resolution. A compilation of data from more accurate maps would lead to a more reliable baseline for measuring change. The case studies included in this atlas give an indication of what can be achieved but such information is, unfortunately, all too rare at the present time.

An effort was made by the editors to present, within the text, figures showing mangrove loss in those countries where these exist (see regional accounts). Such figures are not available for most countries, but where these do exist there is an indication that significant decreases in the global mangrove area have already occurred. In Southeast Asia, for example, the loss figures for four countries are: Malaysia - 12% from 1980 to 1990; the Philippines - 4,000 sq km originally to 1,600 sq km, today; Thailand - 5,500 sq km in 1961 to 2,470 sq km in 1986; and Vietnam - 4,000 sq km originally to 2,525 sq km, today. These figures suggest a total of some 7,445 sq km of mangrove loss, representing over 4% of the current global total. The four countries concerned have suffered significant mangrove loss but they are not alone. Ong (1995) considers that the 1% loss of mangrove area per year in Malaysia is a conservative estimate of destruction of mangroves in the Asia-Pacific region. Indeed, there are very few national accounts in this atlas which do not list considerable threats to the mangrove environments.

In counter to this, the increasing area of mangrove plantations in some areas is worthy of note. Plantations in Bangladesh, Vietnam and Pakistan now cover over 1,700 sq km, while Cuba is reported to have planted some 257 sq km of mangroves. A companion volume to this atlas, *Restoration of Mangrove Ecosystems* (Field, 1996), considers in detail the planting of new mangrove areas.

One further comment concerns the dominance of the areal statistics by a few countries. Notable among these are Indonesia (42,550 sq km), Australia (11,500 sq km), Brazil (13,400 sq km) and Nigeria (10,515 sq km). In total, these countries have some 43% of the world's mangroves and each has between 25% and 50% of the mangroves in their respective regions. Indonesia alone has 23% of the world's mangroves. Aside from the general geographical interest of this situation, it is clear that these four countries have a considerable heritage. Political and management decisions relating to mangroves in each of these countries will have a significant effect on the global status of mangrove ecosystems into the future.

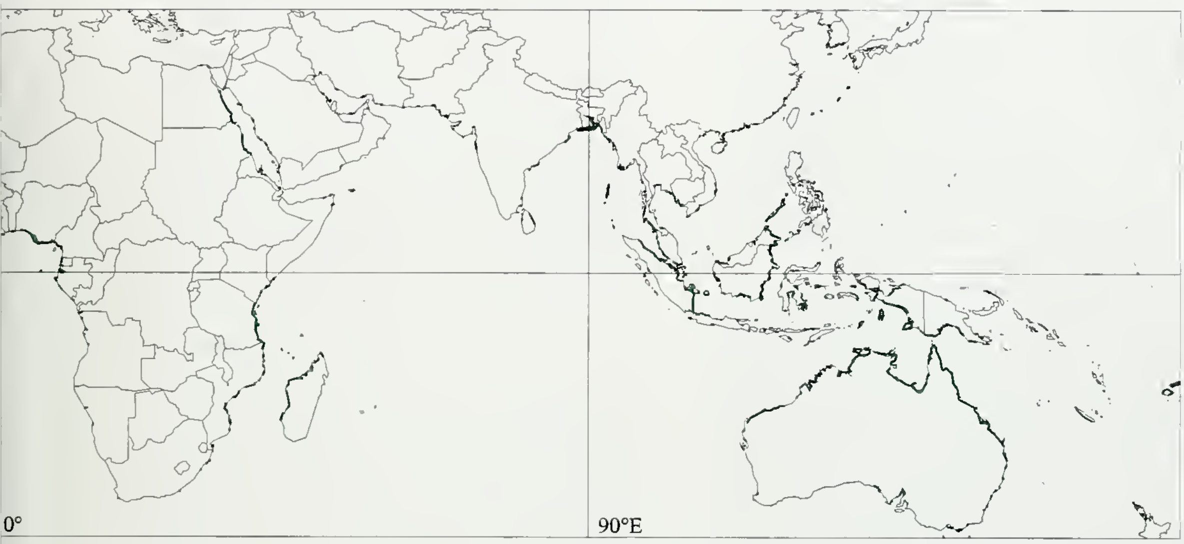
Protected areas

One of the most widely used tools in mangrove conservation is that of legal protection through the designation of protected areas (national parks, nature reserves and other categories). Figure 3.2 shows the global distribution of protected areas with mangrove habitat. There are some 685 protected areas containing mangroves globally, distributed between some 73 countries and territories. Statistics are rarely available which show the area of mangrove habitat within these sites, and such figures cannot be calculated from the total areas of these sites. It is possible, however, to get a very general picture of the distribution of mangrove protection at the global level, and more particularly to draw attention to the obvious holes in the protected area network. Most of the countries with very large areas of mangroves have a significant number of protected areas, notably Australia (180), Indonesia (64) and Brazil (63). Conversely there are some, such as

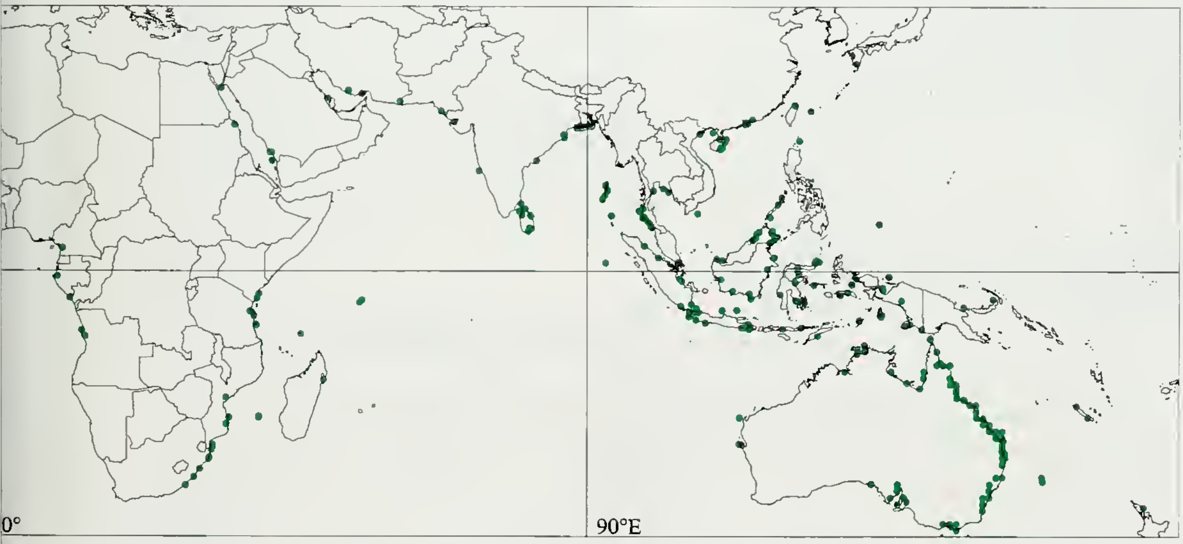
Figure 3.1 The global distribution of mangroves

In order to make the mangrove areas more visible, generalised outlines have been pr
For more detailed information on actual mangrove area and distribution see the map

Figure 3.2 The global distribution of protected areas incorporating mangrove ecosystems. (Dat



ared. These greatly exaggerate the actual mangrove area.
n the regional chapters.



erived from WCMC Protected Areas Database.)

Nigeria, with very large areas of mangroves, which are notable in not having any of these within legally gazetted areas.

Legal protection is, of course, only one tool for the conservation and sustainable use of mangroves. Furthermore, there are many cases where there is a lack of adequate management or insufficient resources to offer real 'on-the-ground' protection to these sites. Many other legal, industrial or traditional management regimes exist which are also used with considerable effect for the conservation and sustainable use of mangroves around the world. The regional tables and texts in this document provide a further, more detailed, overview of the management regimes operating in many of the world's mangrove areas.

The regional accounts

Part 2 of this atlas takes five different regions of the world and presents a variety of data relating to those regions. Twenty-five regional maps are presented giving a detailed global map coverage of mangroves. Text and statistics accompany these maps. Each regional account begins with an introduction describing the region in general terms. This is followed by a table showing the species of mangrove recorded from each country, together with references for this information. The text and tables consist mainly of individual country accounts. Finally, there are detailed case studies relating to the mapping of mangroves at a higher resolution. These cover eight sites in three different regions and provide an important insight into the techniques used for mapping mangroves. An understanding of these techniques is useful in understanding and correctly interpreting the regional maps. The case studies represent what can be achieved with the latest technology, given appropriate funding and a commitment to secure the best possible information.

Regional maps

Regional maps have been compiled on a country-by-country basis and a map reference is given for each country giving the details of the source material, together with further details where appropriate. The areas of mangrove have been calculated from the maps, although some caution is necessary in the interpretation of these figures. As already mentioned, a second figure entitled 'alternative estimate of mangrove area' is also given for most countries. Where, in the judgement of the editors, data from either source are considered to be of dubious value they are placed in parentheses. Such figures should not be quoted without the reservations being noted.

The representation of very small mangrove areas is somewhat problematic, particularly in the coastal zone where the presentation of the coastline and rivers may further obscure the map. In areas where this has been deemed a problem, the overall area of mangrove has been slightly exaggerated by means of surrounding the mangrove 'polygons' with a thick line of the same coloration, even if the polygon is too small to show at the scale of printing, this surrounding line should be sufficient to indicate the location. Where possible this technique has been kept to a minimum so that all mangrove areas are visible, but the total area of mangrove is still representative of the actual area of mangrove cover. Inset boxes are provided for some of the most important areas, showing certain mangrove communities at greater resolutions.

Species lists

Species lists have been compiled from a wide variety of sources and a single taxonomy of mangroves has been adopted from Duke (1992). Reference was also made to Tomlinson (1986) for queries relating to taxonomy and synonymy. Only three symbols have been used in the species tables:

- • Present
- I Introduced
- Ex Extinct (at the national level)

In all cases the sources for the species list are provided. These source lists were reviewed by an international team of experts following their initial compilation.

Table 3.2 A key to the sources and explanation of the figures provided in the country tables

Land area	WRI (1994)
Total forest extent	WRI (1994)
Population	WRI (1994)
GNP	WRI (1994)
Mean annual temperature or temperature range	Same sources as text or Hunter (1994)
Mean annual rainfall or average rainfall range	Same sources as text or Hunter (1994)
Spring tidal range	Typically taken from same sources as text
Alternative estimate of mangrove area	Specified reference #
Area of mangrove on map	Calculated from GIS system at the World Conservation Monitoring Centre (WCMC) #
Number of protected areas with mangrove	Derived from the WCMC Protected Areas Database (legally gazetted sites in IUCN Management Categories I–V)
#	Marked next to the total mangrove area considered, by the editors, to be the most reliable

Country texts and tables

Country texts and tables give an indication of the key features and issues relating to mangroves in each country. Where appropriate, or of particular interest, these may include information relating to key sites and features, forest structure, climate, salinity, tides, human uses (aquaculture, salt extraction, fisheries, forestry), threats, and conservation measures. The references used in the compilation of the text and statistics are provided at the end of each account. The tables contain standard information drawn from the sources shown in Table 3.2.

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4

Some Phytogeographical Considerations

The widespread occurrence of mangrove vegetation and the floristic divergence between the 'old' and the 'new' world mangroves, can only be explained by geological events, in that the composition of the modern mangrove flora at any one location, while subject to present-day climatic and geographical conditions, is largely relict (Tomlinson, 1986; Duke, 1995). The present distribution of individual mangrove species must be seen against this background of plate tectonics and continental drift. Although several interpretations have been offered to relate mangrove distributions to past events (van Steenis, 1962; McCoy and Heck, 1976; Specht, 1981; Mepham, 1983; Duke, 1995), none has been universally accepted.

Each of these various interpretations is based on the existence, during the early Cretaceous, of an extensive tropical sea, the Tethys Sea, separating the northern supercontinent of Laurasia from the southern Gondwanaland. Mangroves evolved within the Tethys Sea and dispersed outwards. Around 18 million years ago (mya), the western Tethys Sea became more or less enclosed, as the Mediterranean, by the collision of Africa and Asia Minor. At that time, the pantropical mangrove flora became disjunct and developed as two isolated floras (assuming that the southerly extensions of Africa and South America formed impassable barriers to mangrove dispersal). Around 3 mya, the Panama gap closed due to the collision of North and South America. Thus, today, there are three disjunct mangrove floras. However, the eastern Pacific flora is too recent in origin to differ from its Atlantic progenitor.

The prime areas of dispute concerning the phytogeography of mangroves are the exact centre(s) of origin for mangroves and their subsequent dispersal routes around the various continents. Three broad views have been suggested:

1. An eastern Tethys Sea origin with dispersal across the Pacific and via the Panama gap into the Atlantic eastwards.
2. An eastern Tethys Sea origin with dispersal north and westwards into the Atlantic and then via the Panama gap into the eastern Pacific.
3. A western Tethys Sea origin with dispersal south via southern Africa to the eastern Tethys Sea.

Each of these various interpretations is possible, although mangrove fossil records (Table 4.1), while somewhat ambiguous, generally support an eastern Tethys Sea origin and a westward dispersal via the Mediterranean route which, until about 18 mya, contained extensive *Avicennia* communities with Indo-Pacific affinity (Bessedik, 1981; 1985).

Table 4.1 Significant geological events and mangrove fossil records

Era	Period	mya	Fossil record
Cainozoic	Pliocene	3	Panama route closed
	Miocene	18	Tethys Sea route closed; *Avicennia* still present in Mediterranean
		10	*Avicennia* and *Sonneratia* pollen in Borneo; *Avicennia* pollen in Nigeria
		24	*Rhizophora* in Nigeria and South America
	Oligocene	36	*Rhizophora* pollen in Asia and Papua New Guinea
	Eocene	40	*Rhizophora*, *Avicennia* and *Sonneratia* in southwest Australia; first *Rhizophora* and *Pelliciera* in Panama
		45	Fossils of *Nypa*, *Ceriops*, *Palaeobruguiera* and *Acrostichum*-like ferns in London Clay Flora
		54	*Nypa* pollen in Europe, Asia and Australia
Palaeocene		63	*Nypa* pollen in Nigeria
		69	*Nypa* pollen in Brazil
Mesozoic	Cretaceous	110	First flowering plants

On the other hand, during the Palaeocene (63-55 mya) when the proto-Atlantic was a narrow waterway and western Africa was experiencing a 'wet' phase, there was no mangrove vegetation *per se* in the Niger Delta but extensive estuarine swamp communities dominated by *Nypa*. The earliest *Nypa* pollen is recorded from Brazil and this genus apparently evolved in, and spread throughout, the proto-Atlantic at this time. This *Nypa* dominated swamp community remained in West Africa during the entire Eocene (Sowunmi, 1981; 1986) and may have extended as far north as Europe (Wilkinson, 1981).

Towards the end of the Eocene when seasonally dry conditions were widespread in West Africa, *Nypa* declined in abundance and finally disappeared altogether in the early Miocene (24 mya). At the same time *Nypa* disappeared from the fossil record of Venezuela. These disappearances coincided with the sudden and predominating appearance of *Rhizophora* throughout the region. Thus, at least one mangrove apparently evolved in the western Tethys Sea (the proto-Atlantic) and dispersed out of the region while selected members of the eastern Tethys Sea (Indo-Pacific) mangrove flora were able to enter and survive in the proto-Atlantic before the Tethys Sea (Mediterranean) became unavailable as a migration route.

Whatever the exact origin(s) and dispersal routes of mangroves, the present distributions of mangroves show many interesting features and can be used to illustrate a number of biogeographic processes. The remainder of this section considers a number of these features and processes in more detail.

Discontinuities and endemism

Most mangroves (e.g. Maps 4.5 - 4.13 and 4.26 - 4.32) have a more or less continuous distribution but there are exceptions.

Sonneratia alba appears to have several disjunct populations respectively centred on East Africa/ Madagascar, India/Sri Lanka and Australasia (Map 4.7). Even the northern Australian distribution appears to be separated by a significant discontinuity in the Gulf of Carpentaria.

Sonneratia ovata has a major disjunction between the Thai-Indonesian and the Papua New Guinea occurrences (Map 4.16). Similarly, *Sonneratia lanceolata* appears to have three discontinuous distributions (Map 4.15).

Avicennia rumphiana appears to be the only species of *Avicennia* with three disjunct distributional ranges (Map 4.14).

Bruguiera hainesii is discontinuous between western Malaysia and New Guinea (Tomlinson, 1986).

Rhizophora apiculata also appears to be discontinuous in that the Indian-Sri Lankan distribution is separated from the Southeast Asian distribution by the extensive gap comprising the entire Gulf of Bengal (Map 4.9). The 'new world' species of *Rhizophora* also show disjunct distributions with West African, Atlantic American and Pacific American occurrences (Maps 4.28, 4.30 and 4.31). In the case of *Rhizophora mangle* (Map 4.28), even the West African distribution appears to be disjunct with a Senegal to Liberia and a Nigeria to Angola distribution (Saenger and Bellan, 1995).

Pelliciera rhizophorae is of very limited distribution and endemic to the tropical Pacific coast of America (Map 4.24). While fossil records of this species have a much wider Caribbean distribution, this species is endemic over a very limited range. Its presence on the Caribbean coasts, first noted in the early 1980s, is of uncertain origin (see below).

Other locally restricted species include *Heritiera fomes* (Map 4.17), *Aegialitis rotundifolia* (Map 4.1), *Avicennia integra* (Map 4.22), *Avicennia bicolor* (Map 4.23), *Avicennia schaueriana* (Map 4.25), *Excoecaria ovalis* (Map 4.21), *Excoecaria indica* (Map 4.20), *Sonneratia griffithii* (Map 4.18) and *Sonneratia apetala* (Map 4.19).

The explanations for many of these disjunctions are undoubtedly to be found in the ecological requirements of the individual species but, in a broad biogeographical sense, temperature and rainfall are probably the main determinants. Nevertheless, the high endemicity of the south Asian and northern Australian areas may reflect their proximity to one of the centres of mangrove origin and subsequent dispersal routes.

Vicariants

Being seawater dispersed, there are few examples of divergent species of one genus with non-overlapping ranges. However, such vicariant species are found in *Aegialitis* and *Camptostemon* (Tomlinson, 1986). *Aegialitis annulata* (Map 4.2) is distributed from northern Australia to Papua New Guinea while *Aegialitis rotundifolia* (Map 4.1) is restricted to shorelines of the Bay of Bengal and the Andaman Sea. Similarly, *Camptostemon schultzii* occurs in northern Australia, Papua New Guinea and, possibly, as far north as Borneo while *Camptostemon philippinense* occurs in the Philippines, Borneo and Sulawesi. Whether there is any overlap between these species in Borneo is not known.

By way of contrast, the genus *Aegiceras* contains one species (*Aegiceras corniculatum*) with a wide Australasian distribution which totally includes the more restricted Philippine distribution of *Aegiceras floridum* (Maps 4.3 and 4.4).

Hybridisations

Hybrids are known between several species of mangroves including *Sonneratia*, *Rhizophora*, *Xylocarpus* and *Lumnitzera* (Duke and Bunt, 1979; Duke, 1984; Tomlinson, 1986) which suggests that the genetic isolation between species of some genera is not complete.

Plant introductions

As with other plant groups, mangroves have been deliberately introduced into areas beyond their natural distributional ranges to meet human needs. While some of these introductions are well documented, other are not and are likely to affect apparent distributional ranges.

Thus, the present West African populations of *Nypa fruticans* were introduced to Calabar in 1906 and Oron in 1912 (Wilcox, 1985) from the Singapore Botanic Gardens even though this species had occurred throughout the Niger Delta until 25 mya (Sowunmi, 1986). To date, this species has spread into the Niger, Imo, Bonny and Cross Rivers and its rate of spread is perceived to be accelerating over recent years. It has now reached the Wouri Estuary in Cameroon where its dispersal is facilitated by local villagers who value its thatching properties (Din, 1991). Introduced stands of *Nypa fruticans* have also recently been recorded from the Atlantic coast of Panama, where a similar spread is predicted (Duke, 1991).

Even though *Pelliciera* fossils indicate their presence in the Caribbean during the Eocene, the present populations of *Pelliciera rhizophorae* on the Caribbean coasts of Panama and Colombia have a questionable origin. This species has been introduced from the Pacific to the Atlantic coast of Colombia, around the Canal del Dique y Covenas, in the last twenty years (Paez, 1994) although apparently ancient stands occur on the Atlantic coast of Panama (Duke, pers. comm.).

An extreme example of the extension of the distribution of species is the introduction and establishment of *Rhizophora mangle, Rhizophora mucronata, Bruguiera parviflora* and *Bruguiera sexangula* on Oahu, Hawaii around the turn of this century.

Floristic decline

Superimposed onto historical events are present constraints of climatic, geographical and socio-economic conditions. These constraints are manifested by a reduction of species with increasing latitude or aridity on the one hand, and selective removal or loss of species by human activity on the other.

Latitudinal limits

The latitudinal limits of mangroves on each of the major land masses (Table 4.2) show these limits to be quite variable and broadly related to temperature and aridity.

In addition, these latitudinal limits are preceded by a gradual attenuation of species with increasing latitudes. For example, Saenger and Moverley (1985) have suggested that in the presence of an adequate rainfall (as on the eastern coast of Australia), temperature is the major factor in reducing species abundance with latitude, and good correlations between the temperature optima of species and their geographical distributions were found.

Table 4.2 Latitudinal limits of mangroves on major land masses

Continental land mass	Northern limit	Southern limit
Atlantic America	32°20'	28°56'
Pacific America	30°15'	5°32'
Atlantic Africa	19°50'	12°20'
Eastern Africa/Red Sea	27°40'	32°59'
Western Australia	-	33°16'
Eastern Australia	-	38°45'
Pacific Asia	31°22'	-

Aridity

The latitudinal limits of mangroves on the West African and South American Pacific coasts, as shown in Table 4.2, coincide with the limits of arid regions (UNESCO, 1979) (defined as: summer rainfall and winter drought, 12 months/year with <30 mm rainfall, and a precipitation to potential evapotranspiration ratio (P/PEt) <0.03). This suggests that, as found on other western coasts of continents (e.g. Australia), mangrove distribution on these coasts is more limited by aridity than by temperature. Similar considerations would also be relevant to parts of West Asia and the Middle East. This influence is clearly seen in the broader latitudinal ranges of species on the eastern coasts of the Americas than those on the western coasts (Maps 4.27-4.32).

Human-induced distributional changes

Human activity (such as pollution, water diversion and selective clearing) can significantly change mangrove distributional ranges. Thus, the northernmost stands of *Rhizophora racemosa* in West Africa, reported by Adam (1965) from the île de Thiong (16°03'N), Mauritania, have been cleared by the local inhabitants in the last two decades (Gowthorpe and Lamarche, 1993). Similarly, significant stands of *Bruguiera gymnorrhiza* have been selectively felled for boat building in Yemen while *Rhizophora mucronata* has virtually disappeared from the Gulf for similar reasons in historical time. Elsewhere, the construction of dams and barrages has shifted prevailing salinity regimes to the exclusion of one species over another.

Conclusion

In conclusion, there are a number of poorly understood historical as well as current factors implicated in the biogeography of mangrove communities and species. Most importantly, the maps of present day mangrove distributions are based on incomplete data for considerable areas of the world. This is a situation that must be addressed urgently if the information is not to be lost.

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Authorship

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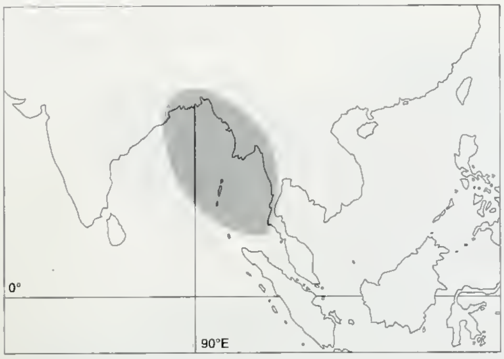
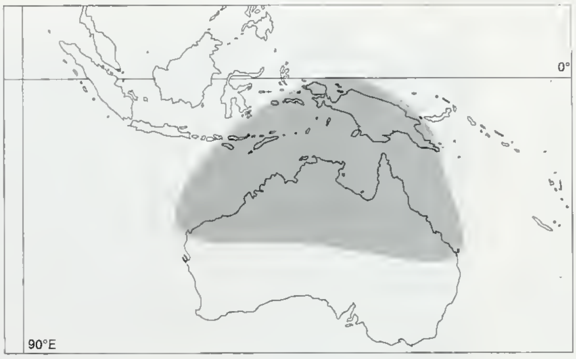
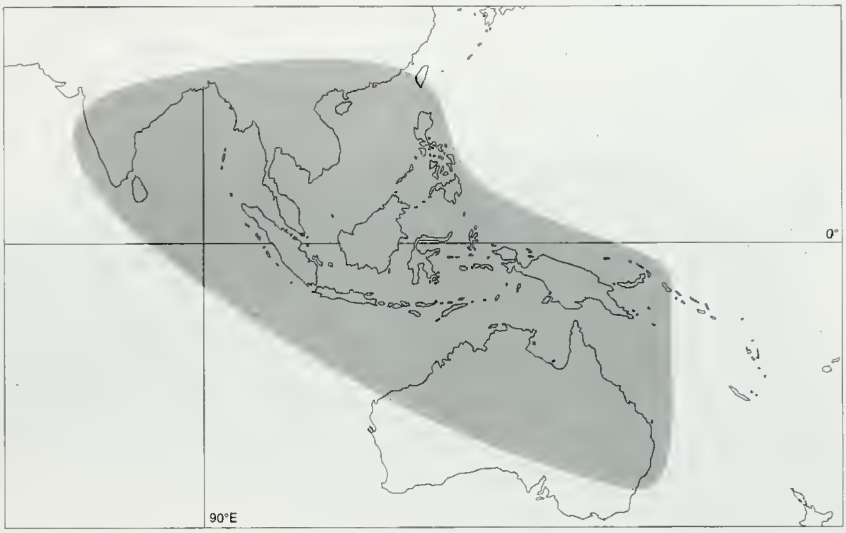


Map 4.1 *Aegialitis rotundifolia*



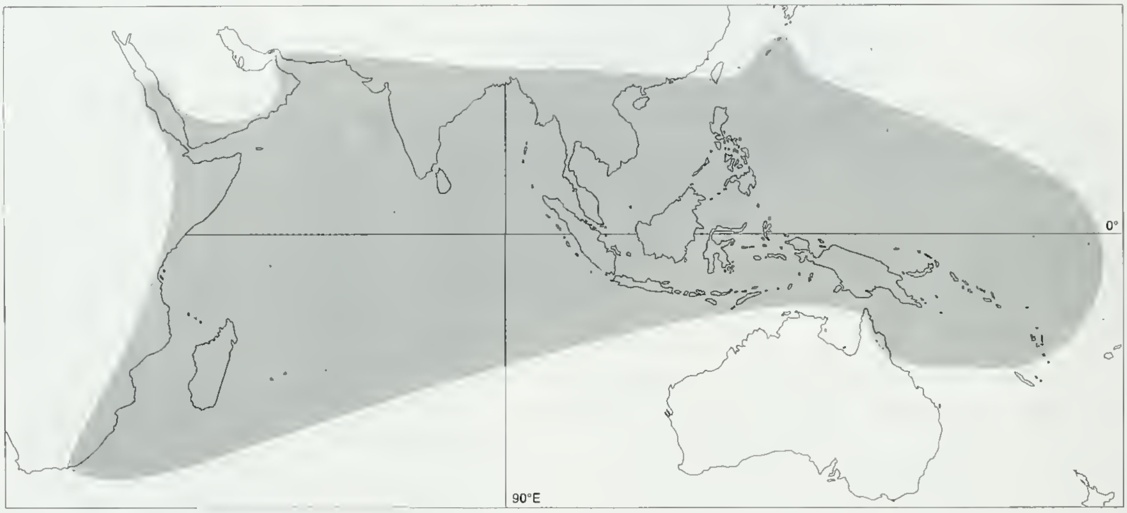
Map 4.2 *Aegialitis annulata*



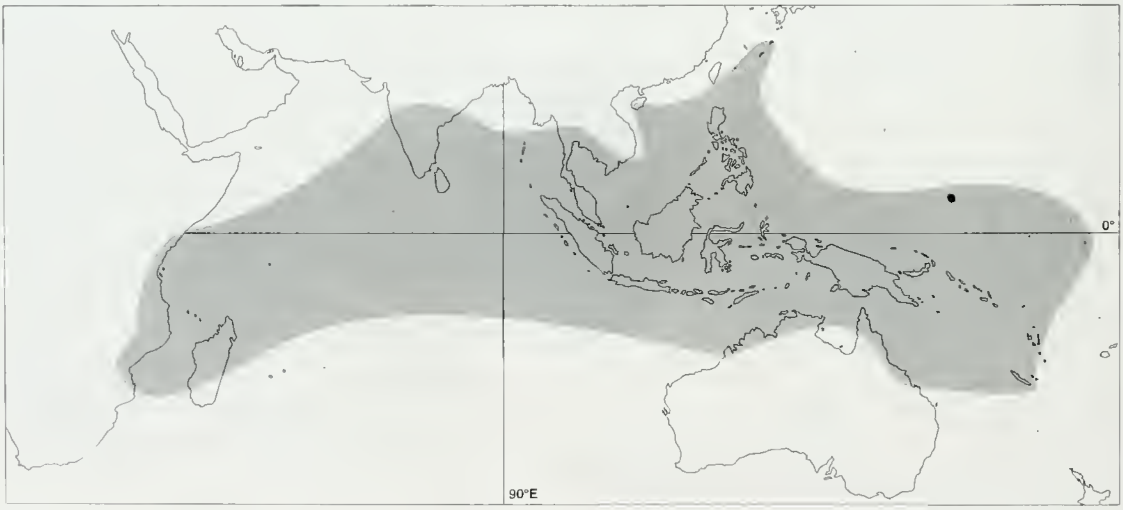
Map 4.3 *Aegiceras corniculatum*

Map 4.4 *Aegiceras floridum*

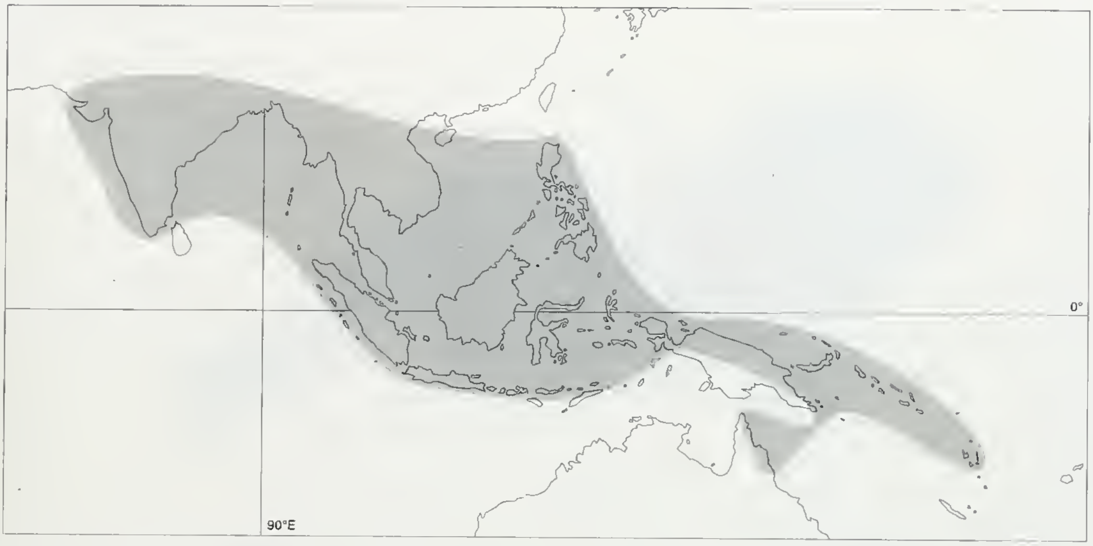
Map 4.5 *Avicennia marina*



Map 4.6 *Rhizophora mucronata*

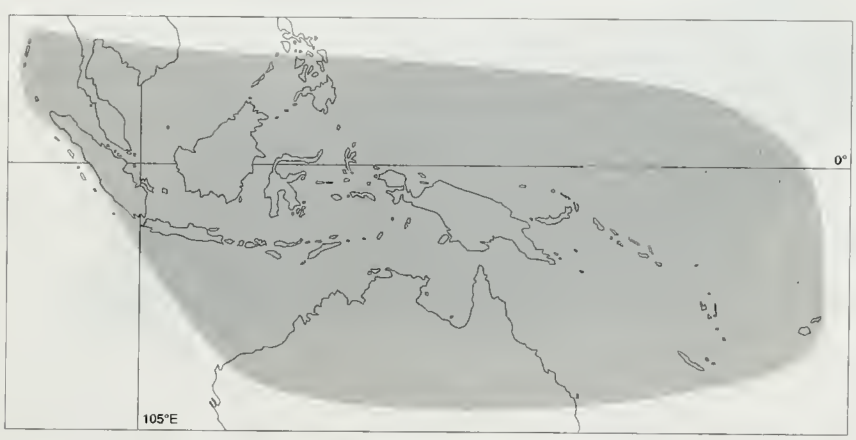


Map 4.7 *Sonneratia alba*

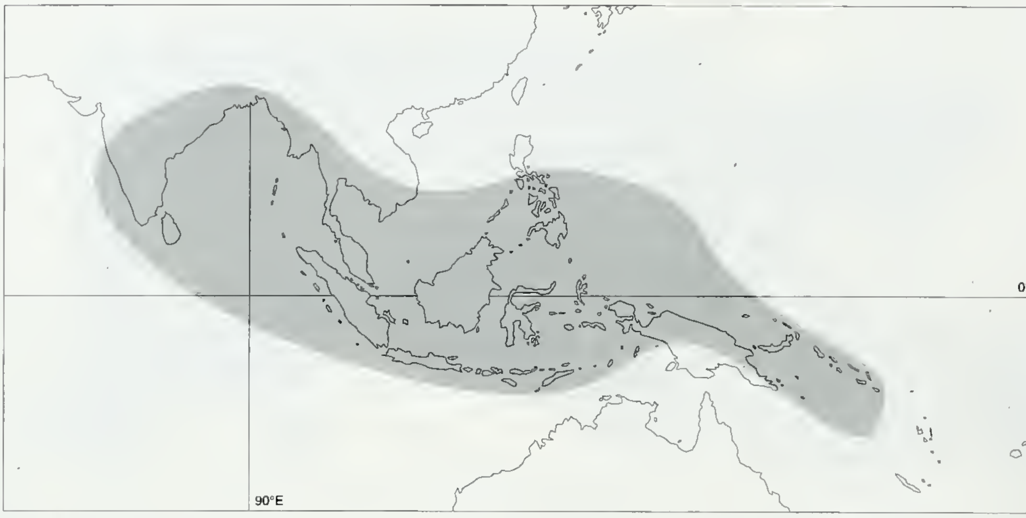


Map 4.8 *Sonneratia caseolaris*

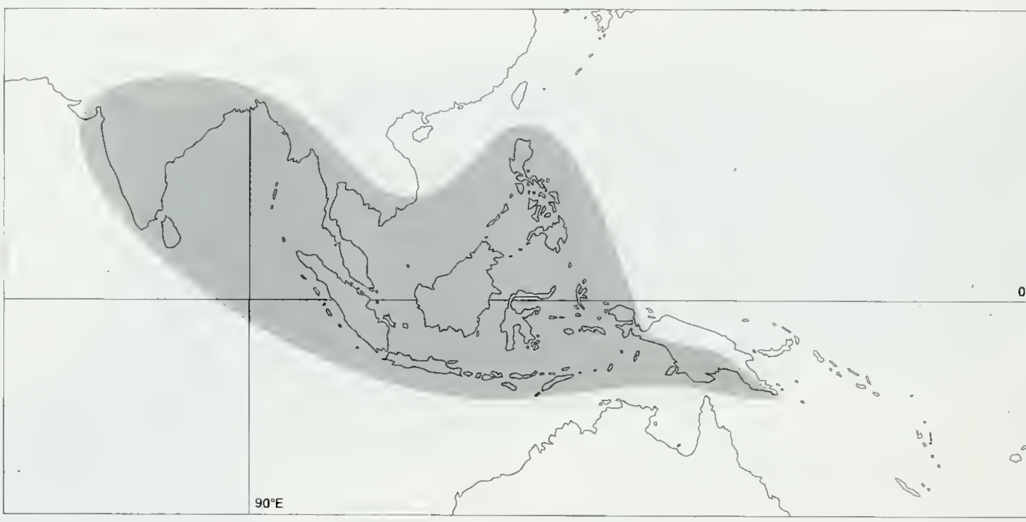
Map 4.9 *Rhizophora apiculata*



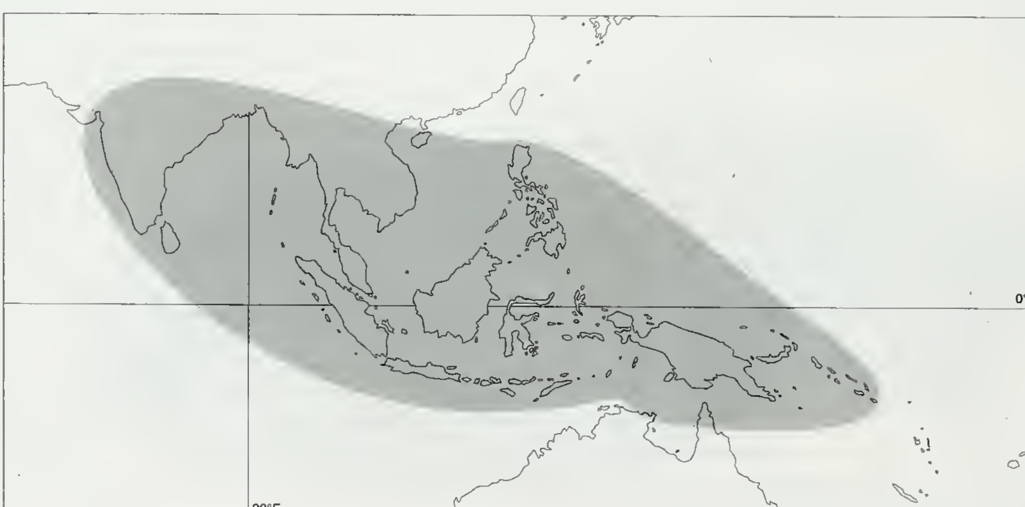
Map 4.10 *Rhizophora stylosa*



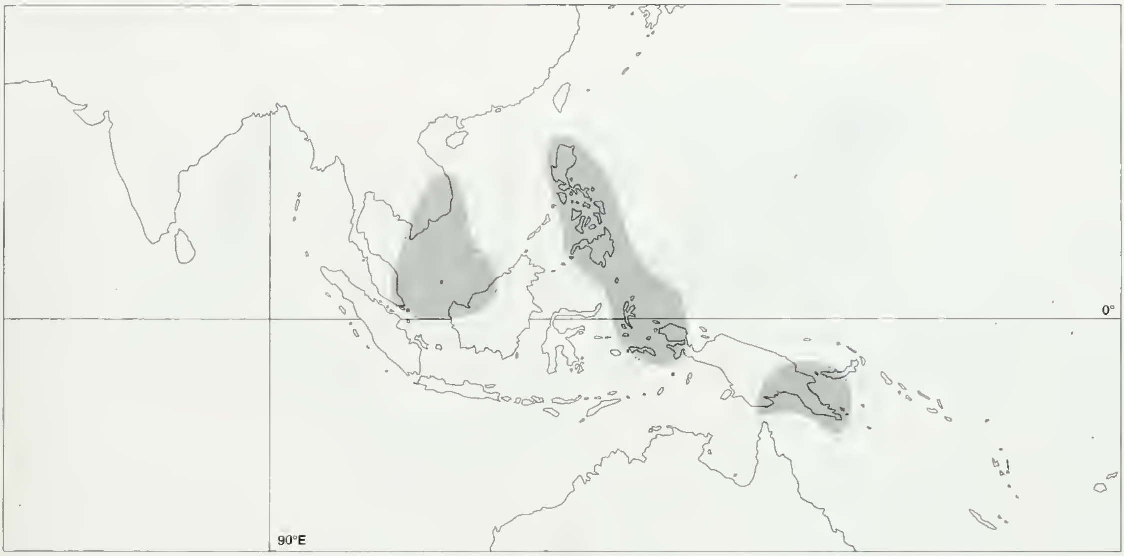
Map 4.11 *Avicennia alba*



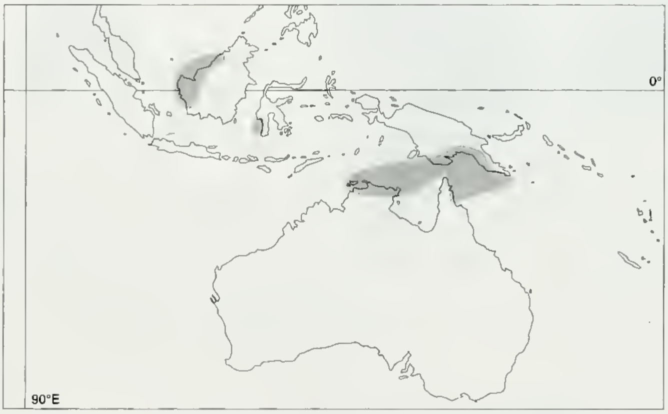
Map 4.12 *Avicennia officinalis*



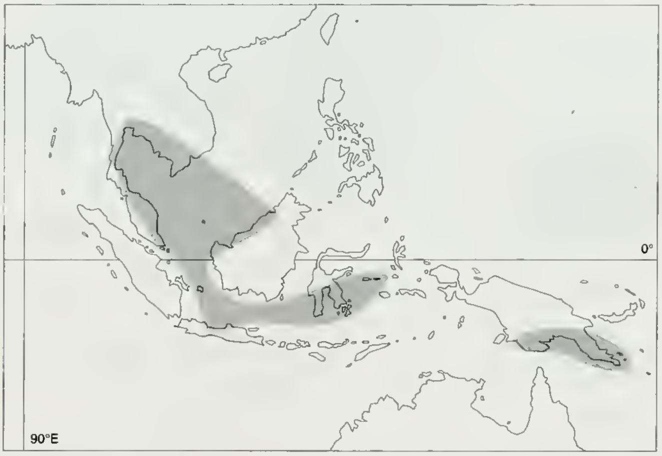
Map 4.13 *Bruguiera sexangula*



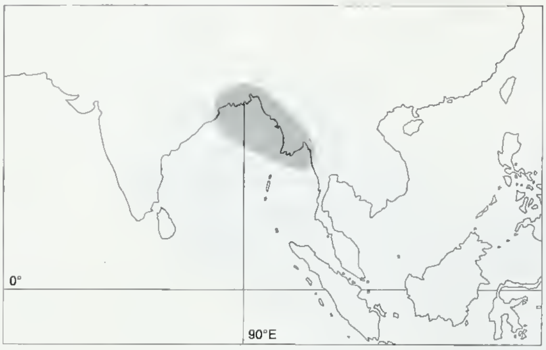
Map 4.14 *Avicennia rumphiana*



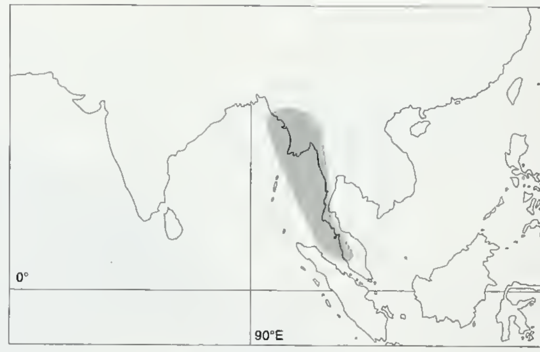
Map 4.15 *Sonneratia lanceolata*



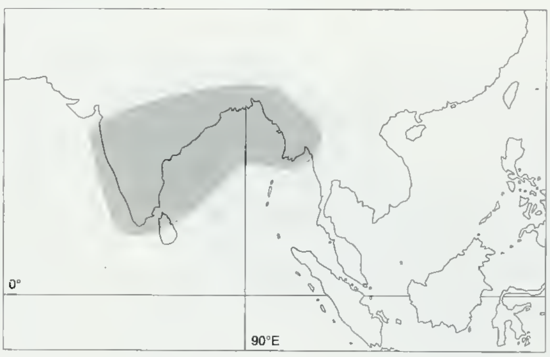
Map 4.16 *Sonneratia ovata*



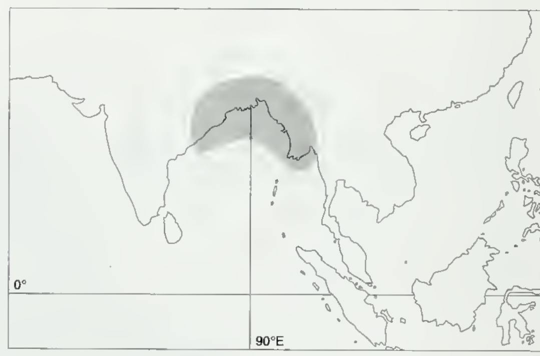
Map 4.17 *Heritiera fomes*



Map 4.18 *Sonneratia griffithii*

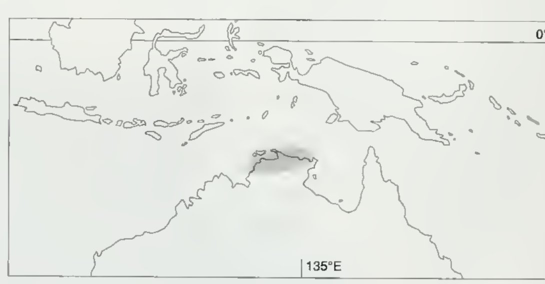


Map 4.19 *Sonneratia apetala*



Map 4.20 *Excoecaria indica*

Map 4.21 *Excoecaria ovalis*

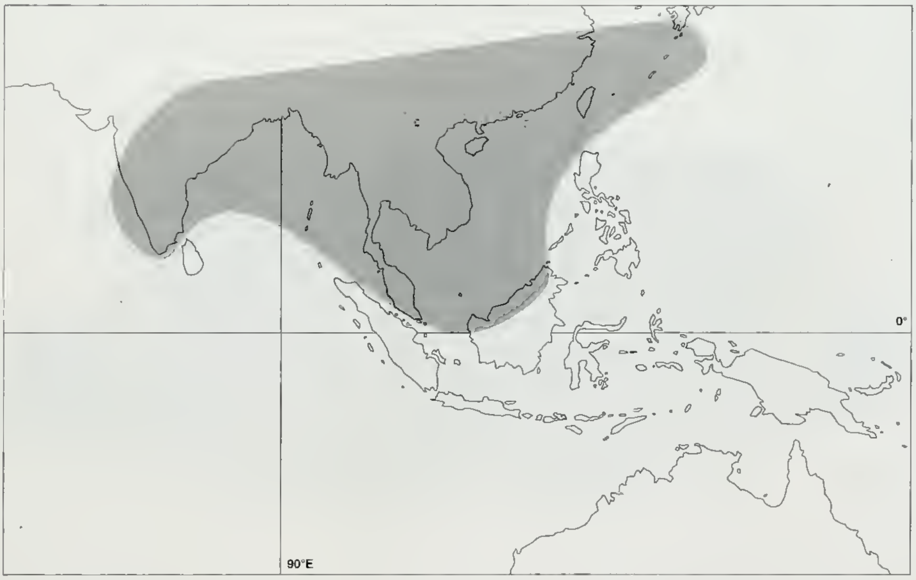


Map 4.22 *Avicennia integra*

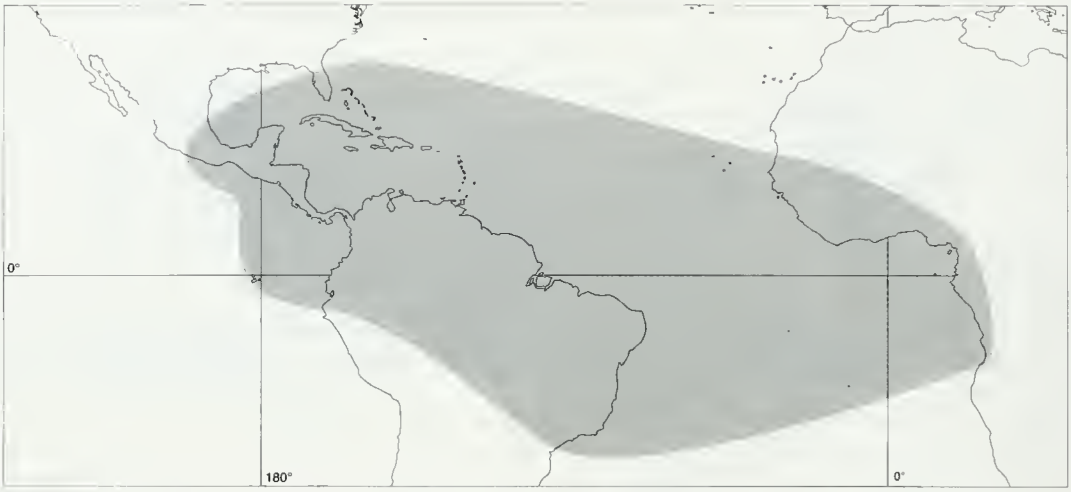
Map 4.23 *Avicennia bicolor*

Map 4.24 *Pelliciera rhizophorae*

Map 4.25 *Avicennia schaueriana*

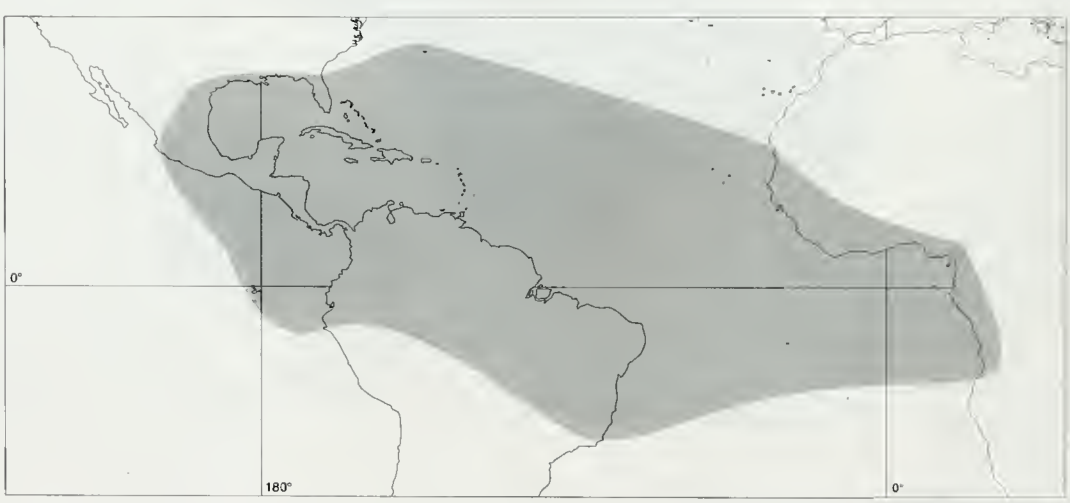


Map 4.26 *Kandelia candel*

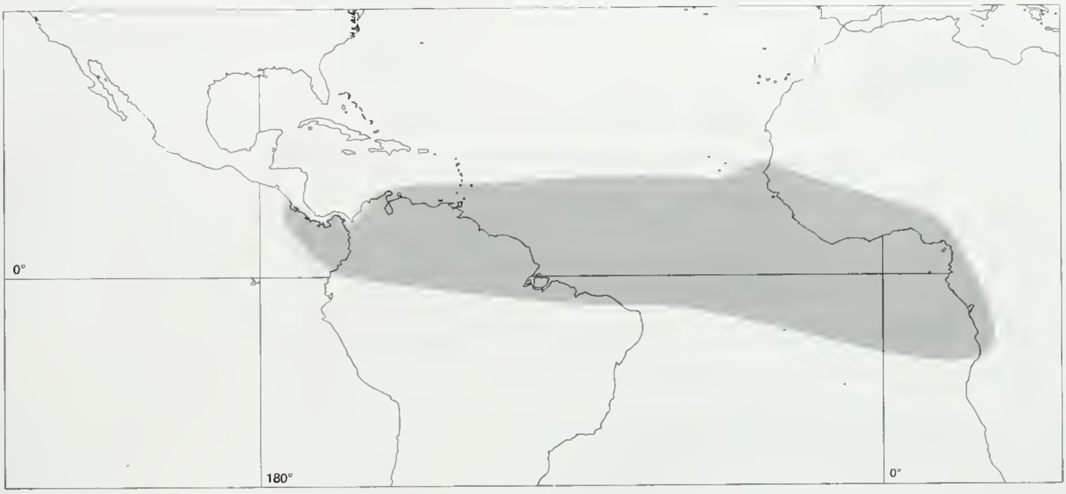


Map 4.27 *Laguncularia racemosa*

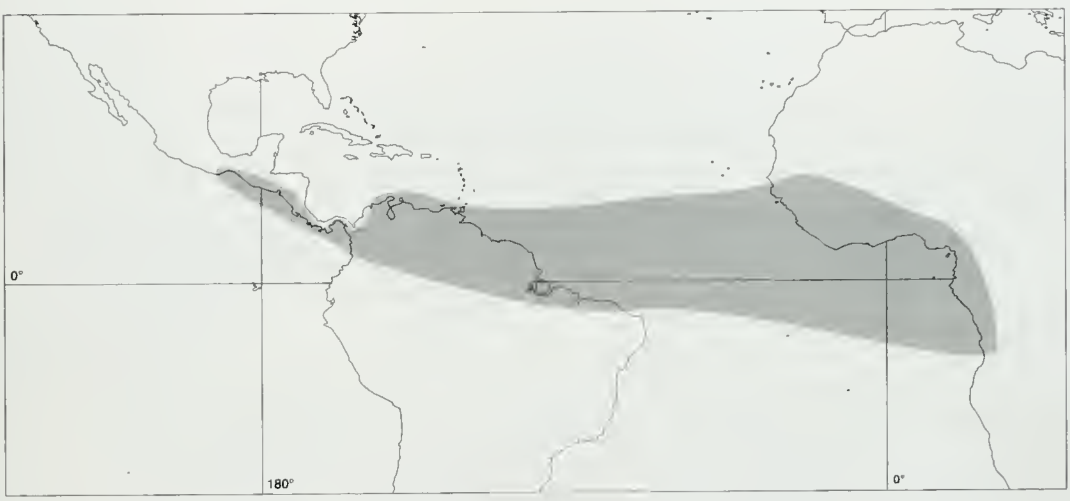
Map 4.28 *Rhizophora mangle*



Map 4.29 *Avicennia germinans*

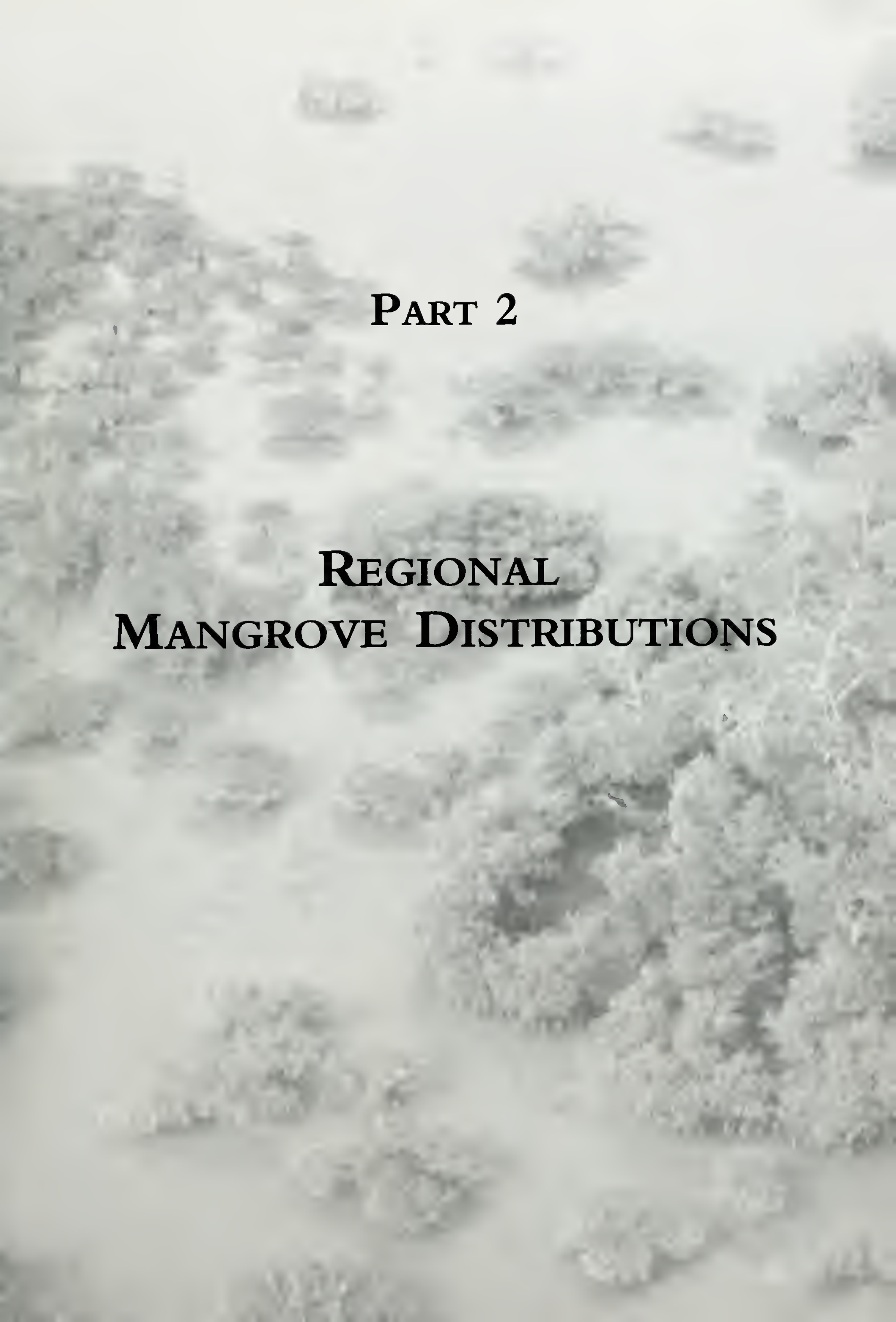


Map 4.30 *Rhizophora racemosa*



Map 4.31 *Rhizophora harrisonii*

Map 4.32 *Conocarpus erectus*



Part 2

Regional Mangrove Distributions

5

South and Southeast Asia

This region stretches from Pakistan in the west to China and Japan in the northeast, and includes insular Southeast Asia to Irian Jaya (Indonesia) in the southeast. The mangroves of South and Southeast Asia have been described in some detail by a number of authors (Clough, 1993; Umali *et al.*, 1986; ISME, 1994; Scott, 1989; and Collins *et al.*, 1991). Table 5.1 gives a list, by country, of the mangrove species found in this region. South and Southeast Asia have some of the largest areas of mangroves in the world. The total area of mangrove in the region is some 75,173 sq km, which represents some 42% of the total area of mangroves in the world.

The total length of coastline in the region is considerable, due to the very large number of islands in Southeast Asia. Over most of the region, coastlines are relatively sheltered and typified by relatively high rainfall with considerable riverine input. Tropical cyclones present a threat to some coastlines and can cause them considerable damage, particularly in the northern and western Bay of Bengal, the Philippines, north Vietnam and China. The role that mangroves can play in mitigating this damage has been recognised in a number of countries.

The region has the highest diversity of mangrove species in the world. Many authors consider the Indo-Malayan region to be the major centre of origin for mangrove taxa, and that dispersal from here to other areas occurred particularly during the Tertiary and Quaternary. A high diversity of associated plant and animal life is also found in the mangrove areas.

Traditional uses of the mangroves can be traced back many centuries and include widespread use for timber, thatching materials, fuelwood, charcoal and fodder. The high diversity of species is paralleled by a wide range of traditional medicinal uses in all countries. In Indonesia and Kerala (southwest India) the development of brackish water ponds for aquaculture can also be traced back for several centuries. This century the utilisation of the mangrove forests has developed in this region more than in any other. Capture fisheries and raft, cage and bottom culture fisheries have developed and, more recently still, pond-based aquaculture systems have increased and intensified. The latter has usually been to the detriment of wide areas of mangrove. Burgeoning populations and considerable economic growth have created conditions for widespread mangrove exploitation and further areas have been lost as a result of timber extraction, conversion to agriculture, reclamation for urban and industrial development, or simple degradation from excessive fuelwood extraction, waste dumping or pollution.

In many countries there is a growing awareness of the importance of mangroves, and since the 1970s National Mangrove Committees have been established within government departments in many countries. Sustainable forestry is being encouraged and appears to be working successfully in a number of sites. Bangladesh and Vietnam have been undertaking large mangrove afforestation and re-afforestation programmes for at least 15 years, with similar, though smaller, operations occurring in other countries.

Table 5.1 Mangrove species list for South and Southeast Asia

	Bangladesh	Brunei Darussalam	Cambodia	China and Taiwan	Hong Kong	India - west	India - east	Indonesia	Japan	Malaysia	Myanmar	Pakistan	Philippines	Singapore*	Sri Lanka	Thailand	Vietnam
Acanthus ebracteatus		•		•			•	•		•			•	•		•	•
Acanthus ilicifolius	•	•		•	•	•	•	•		•			•	•	•	•	•
Acrostichum aureum	•	•		•		•	•	•	•	•	•		•	•	•	•	•
Acrostichum speciosum		•		•				•		•				•		•	
Aegialitis annulata								•									
Aegialitis rotundifolia	•						•				•					•	
Aegiceras corniculatum	•	•		•	•	•	•	•		•	•	•	•	•	•	•	•
Aegiceras floridum								•					•				•
Avicennia alba	•	•				•	•	•		•	•		•	•		•	•
Avicennia marina	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•
Avicennia officinalis	•	•				•	•	•		•	•		•	•	•	•	•
Avicennia rumphiana								•		•			•				
Bruguiera cylindrica		•		•		•	•	•		•	•		•	•	•	•	•
Bruguiera exaristata								•									
Bruguiera gymnorrhiza		•	•	•	•	•	•	•	•	•	•		•	•	•	•	•
Bruguiera hainesii								•		•						•	
Bruguiera parviflora		•				•	•	•		•	•		•	•		•	•
Bruguiera sexangula	•	•		•				•		•	•		•	•	•	•	•
Camptostemon philippinense								•					•				
Camptostemon schultzii								•									
Ceriops decandra	•					•	•	•		•	•		•		•	•	•
Ceriops tagal	•	•		•		•	•	•		•	•	•	•	•	•	•	•
Cynometra iripa																•	
Dolichandrone spathacea		•						•		•			•	•	•	•	•
Excoecaria agallocha	•	•		•	•	•	•	•	•	•	•		•	•	•	•	•
Excoecaria indica	•							•		•	•			•			
Heritiera fomes	•						•				•					•	
Heritiera globosa		•						•									
Heritiera littoralis	Ex	•		•			•	•	•	•			•	•	•	•	•
Kandelia candel	•	•		•	•	•	•	•	•	•	•			•		•	•
Lumnitzera littorea		•		•			•	•		•				•		•	•
Lumnitzera racemosa		•		•		•	•	•	•	•			•	•	•	•	•
Lumnitzera x rosea													•				
Nypa fruticans	•	•	•	•			•	•	•	•	•			•	•	•	•
Osbornia octodonta								•		•			•				
Pemphis acidula								•	•				•	•	•	•	
Rhizophora apiculata	•	•	•			•	•	•		•	•		•	•	•	•	•
Rhizophora mucronata	•	•	•	•		•	•	•		•	•	•	•	•	•	•	•
Rhizophora stylosa				•				•	•				•	•			•
Rhizophora x lamarckii							•	•		•							
Scyphiphora hydrophyllacea		•		•				•		•			•	•	•	•	•
Sonneratia alba		•		•		•	•	•	•	•			•	•	•	•	•
Sonneratia apetala	•					•	•				•				•		
Sonneratia caseolaris	•	•	•	•		•	•	•		•	•		•	•	•	•	•
Sonneratia griffithii							•			•	•					•	
Sonneratia lanceolata								•									
Sonneratia ovata		•		•				•		•				•		•	•
Sonneratia x gulngai		•						•		•							
Sonneratia x urama								•		•							
Xylocarpus granatum	•	•		•		•	•	•		•	•		•	•	•	•	•
Xylocarpus mekongensis	•							•			•			•		•	

Ex Extinct in that country

Bangladesh

Map 5.2

Land area	144,000 sq km
Total forest extent (1990)	7,690 sq km
Population (1995)	128,251,000
GNP (1992)	220 US$ per capita
Mean monthly temperature range (Chittagong)	19-27°C
Mean annual rainfall (Chittagong)	2,831 mm
Spring tidal amplitude	3.4 m
Alternative estimate of mangrove area (Siddiqi, pers. comm., 1995)	6,343 sq km
Area of mangrove on the map	5,767 sq km#
Number of protected areas with mangrove	4

Bangladesh has one of the largest areas of river delta in the world, formed by the Ganges, Brahmaputra and Meghna Rivers. It also has, probably, the largest continuous area of mangroves in the world, the Sundarbans mangrove forest, which extends across the border with India. This is surprising for a country with one of the highest human population densities in the world. In addition to the Sundarbans, a smaller natural area of mangroves, the Chokoria Sundarbans, is located in the east of the country in the delta of the Matamuhuri River. This area covered 750 sq km in 1975, but is now less than 10 sq km. Most of this destruction was due to clearance of mangroves for shrimp farms. There are a few scattered areas of natural mangrove between these two larger areas, while significant additional areas are covered by mangrove plantations. The high degree of riverine sediments, combined with the regular impact of cyclones along the coast, provide a highly dynamic coastline, with the constant appearance of newly accreted land.

Mangroves are an extremely important natural resource to the ten million people living in the coastal zone. Mangrove wood is widely used for timber and fuel; apiculture is an important industry, yielding thousands of tons of honey and wax each year; shrimps, crabs, molluscs and finfish are taken from the surrounding waters. In 1983 some 160,000 people were employed in fishing alone.

Cyclones cause considerable damage in Bangladesh, mostly from storm surges, and 140,000 people were killed in the cyclone of 1991. The role of the mangroves in protecting large parts of the coast has long been recognised, and this has been one of the reasons behind the development of large mangrove afforestation schemes. More than 1,200 sq km of mangroves have been planted, since 1966.

The Sundarbans were declared a Reserved Forest in 1875. They remain heavily utilised, with regular timber harvesting. Parts of the Sundarbans have the designation of Wildlife Sanctuary. They are very important for waterfowl, tigers, deer, monkeys, the Ganges River dolphin, two species of otter, wild cats and the estuarine crocodile.

Map reference

Information for the Sundarbans was derived from World Bank (1981), itself derived from updated and ground-truthed 1977 Landsat satellite imagery. Additional areas are largely plantation forest, taken from a detailed sketch map prepared for this work by N.A. Siddiqi, Bangladesh Forest Research Institute, drawn onto a 1:1,000,000 base map.

World Bank (1981). *Bangladesh-General Vegetation*. Sheet No. G8, 1:500,000. Prepared by the Resource Planning Unit, Agriculture and Rural Development Department, World Bank, Washington.

Country sources for Table 5.1

Bangladesh	Choudhury *et al.*, 1993; Scott 1989	Japan	Baba, 1994
	Seidensticker *et al.*, 1983; Siddiqi, 1986	Malaysia	Chan, 1986
Brunei Darussalam	Zamora, 1987, 1992	Myanmar	Htay, 1994
Cambodia	Sin, 1990	Pakistan	Qureshi and Duke, pers. comm., 1995
China and Taiwan	Davie, 1989	Philippines	Philippine National Mangrove Committee, 1986
Hong Kong	Scott, 1989	Singapore	Corlett, 1986 *
India - west	Untawale, 1986	Sri Lanka	Jayewardene, 1986
India - east	Untawale, 1986	Thailand	Aksornkoae *et al.*, 1993
Indonesia	Soemodihardjo *et al.*, 1993	Vietnam	Hong and San, 1993

* Although a species list is provided for Singapore this is based on relatively old data and it is likely that many of these species have now been lost from this country

Brunei Darussalam

Map 5.7

Land area	5,770 sq km
Population (1995)	288,000
Mean monthly temperature range	27-28°C
Mean annual rainfall	2,800 mm
Spring tidal amplitude	2 m
Alternative estimate of mangrove area (Zamora, 1992)	184 sq km
Area of mangrove on the map	171 sq km#
Number of protected areas with mangrove	1

Due to a lack of human pressure which is probably related to the wealth of the country, the mangroves of Brunei Darussalam are among the best preserved in Southeast Asia. Most are deltaic, estuarine and fringe formations, with the largest concentrations around the Brunei estuary, but they are also found along the Belait and Tutong Rivers. For the most part the forests are very diverse, but some are dominated by single species, notably areas of *Rhizophora apiculata* or *Nypa fruticans*. Uses are relatively limited, but there is some use for poles and pilewood in construction; and there is a small and decreasing use for charcoal production. Crab and shrimp fisheries are also linked to the mangroves. Well over 50% of the total mangrove area is set aside for preservation, conservation and environmental protection, a further 75 sq km have been assigned for timber production, which may be sustainable, while only 2 sq km are being converted to other uses, mostly urban development.

Map references

Data extracted from a 1:25,000 coastal sensitivity map (Fisheries Department/Shell, 1992).

Fisheries Department/Shell (1992). *Coastal Environmental Sensitivity Mapping of Brunei Darussalam.* A joint project of Fisheries Department, Ministry of Industry and Primary Resources and Brunei Shell Petroleum Company Sdn Bhd. Unpublished report, August, 1992. 40 pp + 1:250,000 map.

Cambodia

Map 5.2

Land area	181,040 sq km
Total forest extent (1990)	121,630 sq km
Population (1995)	9,447,000
GNP (1991)	200 US$ per capita
Mean monthly temperature range	26-29°C
Mean annual rainfall	1,875 mm
Alternative estimate of mangrove area (Mekong Secretariat, 1994)	851 sq km#
Area of mangrove on the map	601 sq km
Number of protected areas with mangrove	0

Mangroves are found along the coast in a number of places but are most heavily concentrated in the north around the estuarine and lagoon complex of the Koh Pao and Kep Rivers and in the Koh Kong Bay (160 sq km). They are largely absent from the central part of the coastline where the shore is rocky, but are also found in the south of the country towards Vietnam. Mangroves are used for firewood and charcoal for domestic consumption, which has reduced mangroves in some areas to shrubs of low value. Some areas have been reclaimed for agriculture. Aquaculture remains insignificant, and population pressure in the coastal areas is not high. During the Khmer Rouge regime all conservation and forestry activities ceased, and although conservation has become important since then, there are no proposals for the protection or active management of the mangrove areas. Calculations of the mangrove area based on Landsat imagery (1992/93) show a much larger area than the figure provided by Sin (1990) of 370 sq km. The former suggests that the mangrove area has increased since 1985–87 by nearly 25%. These differences could be an artefact arising from image interpretation.

Map references

Data were digitised from Mekong Secretariat (1991) which is based on 1988/9 Landsat TM images interpreted without ground-truthing. More recent maps (Mekong Secretariat, 1994), showing mangroves (c.1:400,000 to 1:1,000,000) are now available – differences in the mangrove coverage between these two sources are not significant at the scales used for this atlas.

Mekong Secretariat (1991). *Reconnaissance Landuse Map of Cambodia.* 1:500,000. Mekong Secretariat, Bangkok, Thailand.

Mekong Secretariat (1994). *Cambodia Land Cover Atlas 1985/87 - 1992/93 (including national and provincial statistics).* Remote Sensing and Mapping Unit, Mekong Secretariat; United Nations Development Programme; Food and Agriculture Organisation, Cambodia. 124 pp.

Case study

Mangroves of the Ganges and Brahmaputra Deltas

The area around the Ganges and Brahmaputra Deltas includes the largest single area of mangroves of the world, the Sundarbans, with a total extent of dense tidal forest of some 6,050 sq km shared between India (2,000 sq km in West Bengal State) and Bangladesh (4,050 sq km). These mangroves, located at the north of the Bay of Bengal, are directly exposed to tropical cyclones (Figure 5.2). The high winds and tidal surges associated with the cyclonic storms often disturb natural zonation patterns in the mangrove ecosystem, influencing the structure and the morphology of forest stands. Moving south from this area, mangrove ecosystems are usually protected in creeks and bays and are less exposed to cyclonic storms (see The Cauvery Delta (Pichavaram) case study).

A further major natural influence on these ecosystems can be related to plate tectonics. These are responsible for the general tilting of this large delta, which is more than 200 km east to west, causing a slow rising of the western (Indian) part, gradually displacing the main course of the Ganges eastward. The main deltaic region and highest levels of freshwater runoff are now restricted to Bangladesh where the salinity of water and soil is thus lower. The eastward displacement of the Ganges has had a considerable effect on the mangroves of India, increasing salinities in the soils and reducing the input of nutrient-rich alluvium. Relating to this, a gradation can be observed in both the size and physiognomy of the mangroves across this area. In the east, in Bangladesh, trees form a tall dense forest of about 15 m in height where valuable species like *Heritiera fomes* and *Nypa fruticans* are common. In the west, in India, less salt-tolerant taxa (*Heritiera, Nypa*) are rare, while low stands of bushy species such as *Excoecaria agallocha, Aegiceras corniculatum* and *Phoenix paludosa* are common.

Anthropogenic effects on these ecosystems are considerable. Firstly, there is indirect damage caused by the construction of embankments and dams upstream of mangrove areas which is likely to induce ecological and biological modifications. This is probably the cause of the phenomenon of mangrove 'top dying' in Bangladesh. Secondly, there is the huge coastal afforestation programme

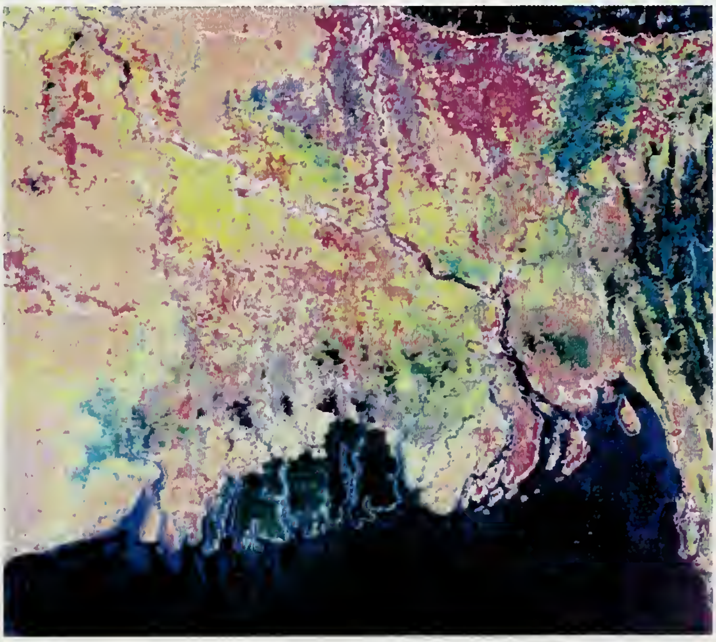


Figure 5.1 False colour composite of NOAA, AVHRR and LAC channels
1 Hatia 2 Ambaria 3 Sella River

in Bangladesh, resulting in the creation of pure stands of *Sonneratia apetala*. More than 150,000 ha having already been planted. Thirdly, the population in this region of Bangladesh and India is one of the most dense in the world with over 1,000 people per sq km. This dense population places considerable pressure on mangrove ecosystems so that, for example, during the first half of the twentieth century about 600 sq km of mangroves forests were disturbed and converted to agriculture, mainly rice fields.

The diagrams and figures presented here show the mangroves of the region and an individual site on Hatia Island. In the former it is quite clear that even a relatively low resolution remote sensing system like NOAA-AVHRR can show large mangrove areas, while SPOT and aerial photography allow considerable refinement. For SPOT, small images and high processing times typically preclude the use of these in the preparation of maps covering very large areas at the current time. Using a time series, even if images were taken with different media, it is possible to observe changes in mangrove area, zonation and areas of erosion and accretion.

Environmental data

• Mean annual rainfall	1,500-2,000 mm/year
• Dry season	4-6 consecutive dry months (November to April)
• Cyclonic storms	High frequency
• Riverine input	From the Ganges and Brahmaputra, with a very large catchment area
• Mean water salinity	25 to 32‰ on the western part; 10 to 20‰ on the east
• Dominant soil types	Loamy-clay (surface)
• pH of the topsoil	7 to 8
• Average tidal amplitude	3-6 m
• Average population density	>500 people per sq km
• Total areal extent	6,050 sq km
• Dominant mangrove types	All types except the *Rhizophora* riverine (Curtis, 1933; Blasco, 1975)
• Main mangrove species	*Heritiera fomes, Sonneratia apetala, Excoecaria agallocha, Avicennia officinalis, Ceriops decandra, Nypa fruticans*

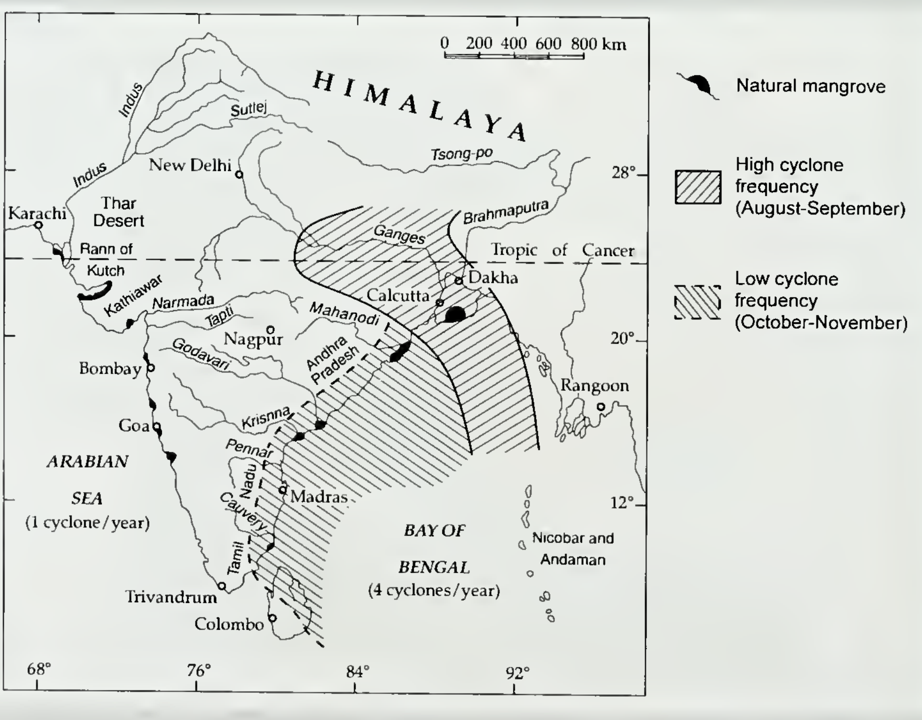


Figure 5.2 Cyclonic tracks in the Bay of Bengal and location of mangroves

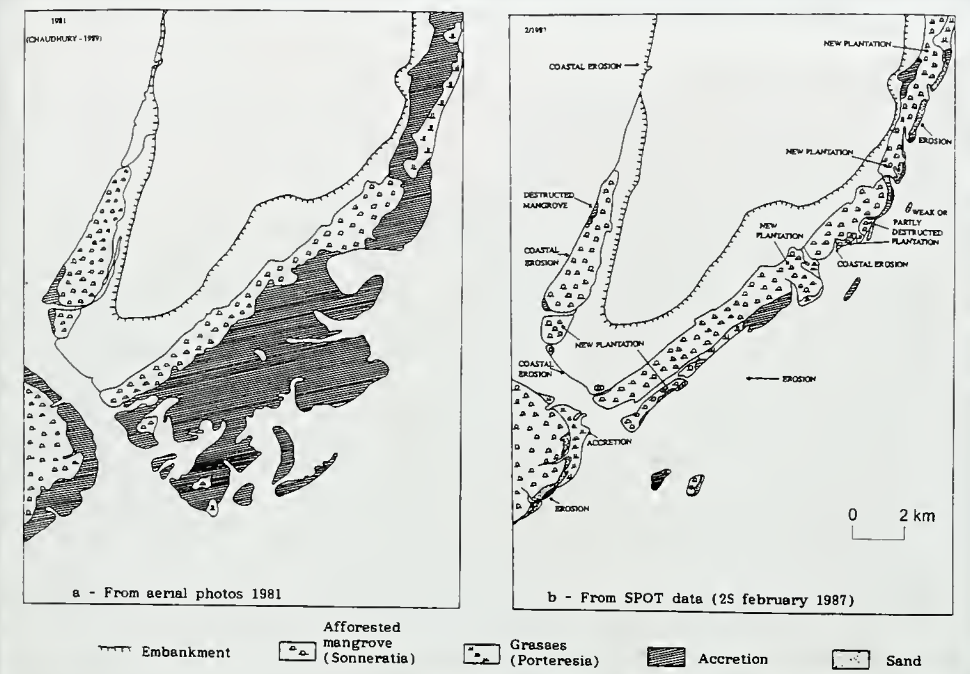


Figure 5.3 Evolution of south Hatia coastal area: interpretation of satellite data

This time-series comparison, undertaken with the superimposition of aerial photographs and satellite data (using Didactim software) clearly shows:

- a conspicuous area of erosion in the southeastern part of Hatia Island
- a conspicuous area of accretion in the western corner of the image
- the notable resistance of newly planted mangrove trees to cyclonic storms and surges

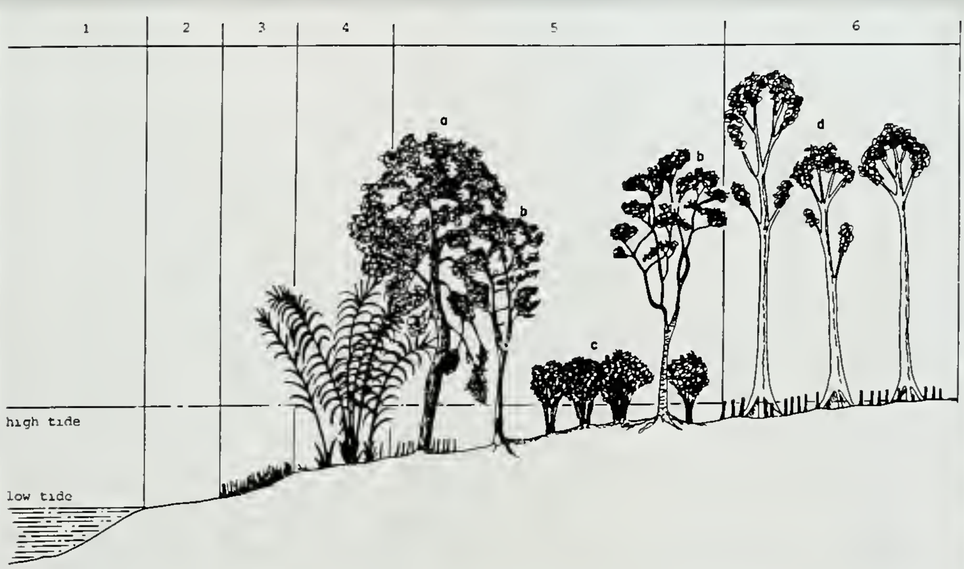


Figure 5.4 Zonation in Sella River near Ambaria Island

1 Water
2 Almost barren mud
3 *Porteresia coarctata*
4 *Nypa fruticans*
5 a) *Sonneratia apetala* b) *Excoecaria agallocha* c) *Ceriops decandra*
6 *Heritiera fomes*

Figure 5.5

SPOT scene KJ 236/306 over the Sundarbans

Figure 5.6

False colour composite of SPOT channels XS3, XS2 and XS1

Plate 5.1 Mangrove zonation in Bengal

Plate 5.2 Human impacts in West Bengal

China and Taiwan

Maps 5.3 and 5.4

Land area	9,596,960 sq km
Population (1995)	1,238,319,000
GNP (1992)	380 US$ per capita
Mean monthly temperature range (Taipei, Taiwan)	15-29°C
Mean annual rainfall	2,500 mm
Area of mangrove on the map	366 sq km#
Number of protected areas with mangrove	22

Mangroves are widespread along the coasts of China and Taiwan, but in almost all cases they are restricted to small stands of relatively stunted and degraded trees. Estimates of mangrove area vary from 200 sq km to 670 sq km. They are most heavily concentrated on the southernmost coasts, in Hainan Island and Taiwan. In Taiwan most remaining mangrove areas are concentrated on the west coast, notably in the Tanshui estuary and further south where a number of sites have some legal protection in the Chan-Yun-Chia reserve. Most of the coast of Hainan was once fringed with mangroves, but these have largely been destroyed. However, a few small areas remain, including ones with well developed mangroves, some of which fall within nature reserves. Mangroves have been used extensively for firewood and charcoal production. This is one of the major reasons why the area of mangroves has decreased and why remaining mangroves are often shrubby. As the mangrove area has decreased, so uses for timber and tannins have declined. Uses in traditional medicine remain important. Since the 1960s large areas have been destroyed as land has been reclaimed for agriculture. This has largely ceased, but areas are still being destroyed for the development of shrimp ponds. By contrast, mangroves, as strip forests, are increasingly being promoted for coastal protection. These strips are typically *Kandelia candel* and they are planted in front of reclaimed land. These have been shown to be very effective in reducing the breaching and erosion of dykes during cyclones.

Map reference

Mangrove coverage gathered from sketch maps drawn onto 1:500,000-1:1,000,000 base maps, prepared for this work by Professor Lin Peng, Xiamen University (mainland China) and Dr Jane Lewis, National Taiwan Ocean University (Taiwan).

Hong Kong

Map 5.3

Land area	1,040 sq km
Population (1995)	5,932,000
GNP (1995)	15,370 US$ per capita
Mean monthly temperature range	16-29°C
Mean annual rainfall	2,214 mm
Spring tidal amplitude	2.8 m
Area of mangrove on the map	2.82 sq km#
Number of protected areas with mangrove	6

Hong Kong, a small dependent territory of the United Kingdom until July 1997, and subsequently a part of China, has a high population density, mostly concentrated around the coasts. Almost all of the coastal areas have been drained and reclaimed for agriculture, fishponds, salt pans and urban development. Tiny areas of mangrove are found in scattered sites around the coast, but the only area of significant size is the Mai Po Marsh, in the northwest, on the shores of Deep Bay. The mangroves in the site are all dwarf. Mai Po is highly managed, most of its area consists of shrimp ponds, or *Gei wais*, and fish ponds. The former often include patches of mangrove, while the latter are devoid of vegetation. The site is managed as a nature reserve, and attracts a large number of visitors, with a visitor centre, boardwalks and about ten full-time staff.

Map references

Coastline and mangrove data from a digital data set provided by WWF HK (1994), prepared at 1:20,000 from 1989 aerial photographs taken at the same scale. Details of the data set are provided in Ashworth *et al.* (1983).

Ashworth, J.M., Corlet, R.T., Dudgeon, D., Melville, D.S. and Tang, W.S.M. (1983). *Hong Kong Flora and Fauna: Computing Conservation: Hong Kong Ecological Database.* World Wide Fund for Nature Hong Kong. 24 pp.

WWF HK (1994). *Hong Kong Vegetation Map.* 1:20,000 GIS on ARC/INFO prepared by World Wide Fund for Nature Hong Kong.

India

Map 5.1

Land area	3,287,590 sq km
Total forest extent (1990)	517,200 sq km
Population (1995)	931,044,000
GNP (1992)	310 US$ per capita
Mean monthly temperature range (Calcutta)	19-29°C
Mean monthly temperature range (Madras)	24-31°C
Mean monthly temperature range (Bombay)	24-27°C
Mean annual rainfall (Calcutta)	1,600 mm
Mean annual rainfall (Madras)	1,270 mm
Mean annual rainfall (Bombay)	1,800 mm
Mean annual rainfall (Andaman-Nicobar Islands)	3,200 mm
Spring tidal amplitude (Calcutta)	5 m
Spring tidal amplitude (Bombay)	3.7 m
Spring tidal amplitude (Andaman-Nicobar Islands)	1.9 m
Alternative estimate of mangrove area (WWF-India, pers. comm.)	6,700 sq km#
Area of mangrove on the map	5,379 sq km
Number of protected areas with mangrove	21

India has a coastline of some 12,700 km, which can be divided into west and east coasts, with patchy mangrove distribution. There are two chains of offshore islands, the Lakshadweep Islands in the west and the Andaman and Nicobar Islands in the east. About 80% of India's mangroves are found in the east where the coastal profile is typically less steeply shelving and rivers and estuaries are better developed. The largest areas are those of the Indian part of the Sundarbans, and the Andaman and Nicobar Islands. The Indian Sundarbans are slightly more saline than the Bangladeshi Sundarbans, with poorer forest development. The Andaman and Nicobar Islands have close affinities to the nearby Southeast Asian mangroves and are the only areas with undisturbed mangrove communities. Elsewhere in India the mangroves have been exploited for thousands of years. Other mangrove areas on the eastern coast are associated with the estuaries of the Mahanadi, Godavari, Krishna, and Cauvery Rivers. On the west coast there are fringing mangroves along the estuaries of the many small rivers, while there are important scrubby communities associated with the arid coast around the Gulf of Kutch. In India, fifty-nine species and associated species of mangrove are listed by Untawale (1986). Some 25 species are found only along the east coast, while eight species are restricted to the west coast. The climate varies around the coastline. In the Andaman and Nicobar Islands and on the southwest coast of Kerala, rainfall of 3,000 mm per year can occur, while the southeast coast of the Gulf of Mannar can receive less than 900 mm per year and the Gulf of Kutch only 400–600 mm per year. In most areas, rainfall shows a distinct seasonal pattern.

Most estuarine mangrove areas have human communities close by, while the Sundarbans mangroves have a resident population of some two million people. Local uses include fuelwood, fisheries, honey production and the use of *Nypa* leaves for roofing materials. Some 10,000 people live by selling mangrove firewood, the only source of firewood in the region in the Gulf of Kutch, and the mangroves are also heavily exploited for grazing by camels and cattle. Salt collection is also an important activity in the supralittoral zone, especially in the Kutch region. Traditional aquaculture has a long history, with pond construction for fish and shrimp cultivation. This has recently been boosted by the development of hatchery technology. In some areas polyculture techniques rotate paddy cultivation with prawn farming. Large areas of land have been reclaimed for agricultural purposes and urban development. This is increasing with population pressure in all areas. For example, Bombay is built on an area that, in 1670, was a group of seven islands surrounded by mangroves. Linked to these issues, pollution from urban and agricultural runoff is an increasing threat. On the east coast, a number of mangrove areas are managed for timber with detailed Forest Working Plans and felling cycles varying from 20 to 100 years. Over-exploitation threatens many areas, including the Gulf of Kutch and the Sundarbans. A National Mangrove Committee was established in 1979, now superseded by a National Committee on Wetlands, Mangroves and Coral Reefs, as an advisory body to the government. This body has identified 15 key mangrove areas, including all of the large sites mentioned above, and has drawn up Management Action Plans for all of them, to be administered by the state governments with financial assistance from the Ministry of Environment and Forests. Small afforestation schemes have been undertaken, notably in the Gulf of Kutch. A number of sites have also been given legal protection, including part of the Gulf of Kutch, the Great Andaman Biosphere Reserve and three sites in the Sundarbans.

Map references

Some data were obtained from FSI (1986). Further information on the mangrove forest of the Sundarbans was taken from Department of Forests (1973). Gaps in these data holdings were filled using Blasco and Bellan (1995), prepared from Landsat MSS, Landsat TM and SPOT data. Further approximate areas were added from edits provided by François Blasco.

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Indonesia

Maps 5.6, 5.7 and 5.8

Land area	1,904,570 sq km
Total forest extent (1990)	1,095,490 sq km
Population (1995)	201,477,000
GNP (1992)	2,080 US$ per capita
Mean annual temperature (Jakarta)	26°C
Mean annual rainfall (Jakarta)	1,775 mm
Spring tidal amplitude (South Sumatra)	3 m
Spring tidal amplitude (Java, north coast)	1 m
Spring tidal amplitude (East Kalimantan)	2 m
Spring tidal amplitude (Irian Jaya, north coast)	2 m
Spring tidal amplitude (Irian Jaya, south coast)	9 m
Alternative estimate of mangrove area (Soemodihardjo *et al.*, 1993)	42,550 sq km#
Area of mangrove on the map	45,421 sq km
Number of protected areas with mangrove	64

Indonesia is a vast archipelago consisting of some 17,000 islands. It has the largest area of mangroves of any country. Over half of these are concentrated in Irian Jaya, which has some of the largest single stands of mangrove in the world. Mangroves are found throughout the country, although they are scarce in west Sumatra. Other very large areas are found along the east coast of Kalimantan and the east coast of Sumatra. The diversity of mangrove species found in Indonesia is very high. Five major mangrove types or 'consociations' are recognised, based on dominant species of *Avicennia*, *Rhizophora*, *Sonneratia*, *Bruguiera* and *Nypa*. The relative occurrence of each of these can be related to ecological factors such as tidal regime, soils and salinity. While more mixed associations also occur in some areas, closer inspection of these often reveals a zonation or succession of some of the consociations already mentioned. Typically mangroves show a high degree of structural development, with trees reaching 50 m in height in many areas such as on the south and east coasts of Sumatra and Kalimantan. It is very difficult to make generalisations about the climate or physical conditions in a country of this size, but most coastal regions have humid tropical or equatorial climates, with high humidity, seasonal wind and precipitation, a high annual rainfall and high temperatures. Where conditions of rainfall or coastal topography are less favourable, mangroves may only form shrubby communities or be virtually absent, such as in the East Nusa Tenggara (Lesser Sunda Islands) and western Sumatra. Tidal fluctuations vary enormously over relatively short distances due, in part, to the complexity of the coastal configuration. The mangroves of the island of Borneo are home to the proboscis monkey *Nasalis larvatus*, which is one of the few large mammals restricted to mangrove environments.

Losses of mangrove areas in Indonesia can mostly be attributed to the development of shrimp ponds and logging activities. Conversion to shrimp ponds is especially prevalent in East Java, Sulawesi and Sumatra. Local use of mangrove products includes timber for construction, considerable usage for fuelwood, the use of *Nypa* for sugar production and *Nypa* leaves for roofing. Commercial uses include charcoal production and large areas of logging concessions. Production of woodchips and pulp is increasing. Chip mills have been built in Sumatra and Kalimantan, while a major mill has been built to process mangroves from a 1,370 sq km lease in Bintuni Bay, Irian Jaya, formerly one of the largest and most pristine mangrove areas in the world. Mangrove associated fisheries are important, including finfish, bivalves and crabs. Brackish water fishponds have been used in Indonesia since the fifteenth century and in the 1970s they began to be used for shrimp farming. Extensive methods are used, relying on natural stocking as well as intensive methods, the fry being obtained from hatcheries, with feeding and predator controls applied. Smaller areas of mangroves have been lost or threatened by conversion to agriculture, salt pans (Java and Sulawesi), oil extraction (East Kalimantan) and pollution. Recognising the importance of mangroves for fisheries, forestry, coastal protection and wildlife, a number of protected areas and mangrove greenbelts have been designated. There are also detailed guidelines for sustainable forestry including recommendations for cutting rotations and leaving uncut strips along the sea front and river channels. There have been small reafforestation schemes in some areas.

Estimates for the total area of mangroves vary considerably. Probably the most widely used is that given by Soemodihardjo *et al.* (1993) of 42,550 sq km, but some estimates are as low as 38,000 or 21,763 sq km.

Case study

The Cauvery Delta (Pichavaram): coastal lagoon mangroves

The coastal lagoon mangroves of the Cauvery Delta (Pichavaram) are a small area of mangroves (about 14 sq km), confined to a lagoon in the north of the Cauvery Delta, about 250 km south of Madras. They are some of the last remnants of the mangrove ecosystems of Tamil Nadu State (India). They provide a very interesting site for the neighbouring Porto Novo Marine Research Station which is involved in research on the relationships between mangrove plants and animals.

The coast in this region is dry, the annual rainfall ranges between 1,200 and 1,500 mm, but nearly 80% of this falls during three months (October to December), and these figures fluctuate considerably from year to year, relating to the location and extent of typhoons. The dry season extends over six to eight months from January to August. The mouth of the Cauvery Delta is crossed by a large sand bar, forming an almost closed lagoon. The chances of strong tides or long lasting inundation of this lagoon are greatest from October to December. Conversely, from February to September, some areas are not flooded at all and it is here that the ecological conditions become extreme (high salt concentrations), resulting in an ecosystem of scattered plant communities, comprising bushes of *Suaeda maritima* and a few other saltmarsh species.

The mangrove area includes a narrow, almost permanently flooded belt of *Rhizophora apiculata* (less than 10 m height) with a few good specimens of *Avicennia officinalis*, but the commonest tree in Pichavaram is *Avicennia marina* which tolerates considerable variations of the water salinity (to over 70‰) as well as a long submergence of its pneumatophores during exceptional floods. Figure 5.8 illustrates the plant zonation in these mangroves.

In this highly populated area, about 500 people per sq km, the mangroves are still an important source of fuelwood, an essential grazing land and a productive fishing ground. Since 1880, they have been declared 'Reserved Forests'. All efforts to protect them and to replant mangrove trees have failed, however, and these systems are threatened by both natural environmental and human influences.

Environmental data

• Mean annual rainfall	1,200 to 1,500 mm/year
• Dry season	6-8 consecutive dry months (January to August)
• Cyclonic storms	Low frequency (<1/year), but risks of long-lasting floods
• Mean water salinity	25 to 33‰
• Dominant soil type	Sandy-clayey
• Average tidal amplitude	0.5 m
• Average population density	>100 people per sq km
• Total areal extent	About 14 sq km
• Dominant mangrove types	Most extensive mangrove type is a back mangrove shrub with *Avicennia*. There are also well defined *Rhizophora* belts

Figure 5.7 Mangroves of Pichavaram

Plate 5.3 The mangroves of Pichavaram. One of the last remnants of the mangroves of Tamil Nadu State (India). Commonest trees are scattered *Avicennia marina*

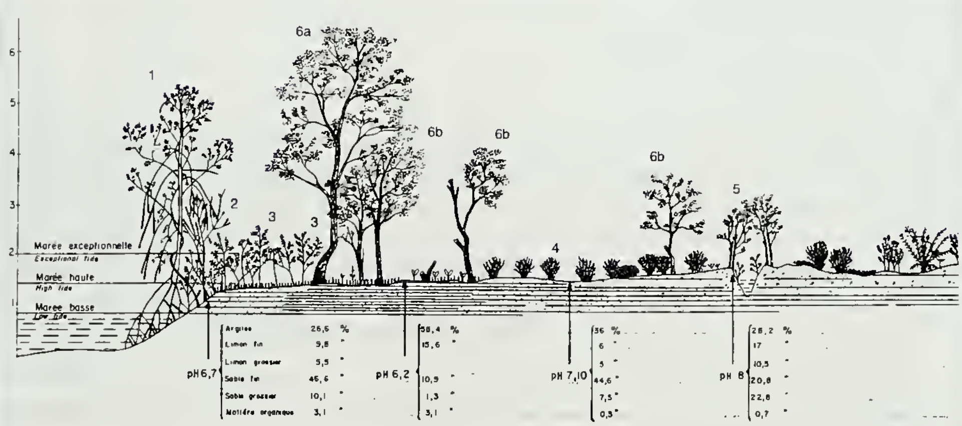

Figure 5.8 Zonation in Pichavaram estuary

1 *Rhizophora apiculata* BL.
2 *Dalbergia spinosa* Roxb.
3 *Ceriops decandra* (Griff.) Ding Hou
4 *Sueda maritima* (L.) Dum.
5 *Excoecaria agallocha* L.
6a *Avicennia officinalis* L.
6b *Avicennia marina* Vierh.

Map references (Indonesia)

Data are based on the Regional Physical Planning Programme for Transmigration (RePPProT) work begun in 1984 in association with the National Centre for Coordination of Surveys and Mapping (BAKOSURTANAL). Surveys were based on existing reports, air photographs and satellite or radar imagery with selective field checking. Data were generously provided to WCMC by the RePPProT team in the form of hand-coloured draft maps at 1:2.5 million scale: Sumatra (1988), Java and Lesser Sundas (1989), Lesser Sundas (1989), Kalimantan (Central, 1985; South, West and East, 1987), Sulawesi (1988), Moluccas (1989), Irian Jaya (1986). These maps have been further updated from a series of maps provided by Wim Giesen of the Asian Wetlands Bureau showing key mangrove areas, notably on Sumatra and Irian Jaya. Most maps are from unpublished reports (see list below). The information was transferred to eight A2 maps before digitising. Where these data differed from the data described above they were assumed to be more accurate and the latter were removed from the present coverage. Areas marked as 'disappeared or very disturbed' were not included. A small number of additional edits were provided by Dr Jim Davie, University of Queensland, Australia, and by François Blasco.

AWB (1992). *Proposal: Buffer Zones Development of the Berbak National Park.* Final Draft. Asian Wetland Bureau, October, 1992.

Erftemeijer, P., Allen, G.R. and Zuwendra (1989). *Preliminary resource inventory of Bintuni Bay, Irian Jaya, and recommendations for conservation and management.* AWB-PHPA, Bogor, November 1989.

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Giesen, W. (1991). *Bakung Island, Riau (Pulau Bakung, Pulau Basu) Survey Report.* PHPA/AWB Sumatra Wetland Project Report No. 11. December 1991.

Giesen, W., Baltzer, M. and Baruadi, R. (1991). *Integrating Conservation with Land-use Development in Wetlands of South Sulawesi.* PHPA/AWB, Bogor, October 1991.

PETA (1992). *Profil Lingkungan Hidup Daerah Lahan Basah Propinsi Jambi Sumatera, Indonesia.* PHPA/AWB Proyek Lahan Basah Sumatera, Laporan No. 20b. February 1992.

Silvius, M.J. and Taufik, A.T. (1990). Conservation and land use of Pulau Kimaam, Irian Jaya. PHPA - AWB/INTERWADER, January 1990. Unpublished Report.

Zieren, M., Yus Rusila Noor, Baltzer, M. and Najamuddin Saleh (1990). *Wetlands of Sumba, East Nusa Tengarra: an assessment of the importance to man, wildlife and conservation.* PHPA/AWB-Indonesia, Bogor, August 1990.

Japan

Map 5.4

Land area	377,800 sq km
Total forest extent (1990)	241,580 sq km
Population (1995)	125,879,000
GNP (1992)	28,220 US$ per capita
Mean annual temperature (Naha, Okinawa)	22°C
Mean annual rainfall (Naha, Okinawa)	2,037 mm
Spring tidal amplitude (Naha, Okinawa)	2 m
Alternative estimate of mangrove area (Baba, pers. comm.)	4 to 5 sq km#
Area of mangrove on the map	75 sq km
Number of protected areas with mangrove	6

Mangroves are found in the southern part of Japan, scattered throughout the Ryukyu Archipelago and reaching as far north as Kiire on southern Kyushu. These are the northernmost mangroves in Asia, at latitude 31°22'N, and consist of small stands of *Kandelia candel.* The total area is small and is largely concentrated on the islands of Ishigaki and Iriomote in the Okinawa prefecture. Iriomote has the largest and most diverse communities and eleven species of mangrove have been recorded. A few strong typhoons pass over the Ryukyu Islands every year and these can damage the trees, typically restricting canopy height to 10-15 m. In some areas they are shrubby, but the canopy can be very dense. Some traditional use of mangroves for tannins was recorded from Iriomote until just after 1945. More recently many areas have been destroyed for urban development and road construction, although Okinawa prefectural and local governments, together with non-governmental organisations have started activities to conserve and restore mangrove ecosystems. A traditional proverb is often cited: "no forest on the land, no fish in the sea".

Map references

Mangroves of Iriomote Island digitised from 1:50,000 map appended to Aramoto (1986) (map title: Map of Land Utilisation of Iriomote Island). Mangroves for the remainder of the islands around Okinawa were digitised from Environment Agency (1981-1987), while locations of mangrove areas not covered on these maps were gathered from approximate distribution maps provided by Dr Shigeyuki Baba (June 1995).

Aramoto, M. (1986). *Iriomote-jima wo chusin to shita shigen shokubutsu huzon genkyo (Bio-resources distribution in Iriomote Island, Okinawa).* Published by Chiiki-sanjyo-gijutsu-shinko-kai, Okinawa Japan. 97 pp.

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Malaysia

Maps 5.6 and 5.7

Land area	329,750 sq km
Total forest extent (1990)	175,830 sq km
Population (1995)	20,125,000
GNP (1992)	2,800 US$ per capita
Mean annual temperature (Penang)	28°C
Mean annual temperature (Sabah)	27°C
Mean annual rainfall (Penang)	2,736 mm
Mean annual rainfall (Sabah)	3,700 mm
Alternative estimate of mangrove area (Chan *et al.*, 1993)	6,412 sq km
Area of mangrove on the map	6,424 sq km#
Number of protected areas with mangrove	12

Mangroves are found on all coasts, with the largest area (57%) on the coast of Sabah, concentrated particularly in the northeast. Sarawak also has considerable areas (26%), mostly concentrated in the deltas of the Sarawak, Rajang and Trusan-Lawas rivers. Despite having the longest coastline, Peninsular Malaysia has only 17% of the country's mangroves, most of which are concentrated on the more sheltered west coast. In all areas the climate is hot and humid with high rainfall. There is a very high diversity of species, which in some areas show a relatively clear zonation pattern. Typically, there is an *Avicennia-Sonneratia* community on the seaward sediments, where there is soft, deep mud, though *Rhizophora-Bruguiera* forest is often the most dominant. More inland, where the soils are firmer, a much wider array of species are typically found. In some areas, *Nypa* palms form the dominant species, particularly where there is a greater freshwater influence. Rates of accretion can be very high, with some areas in southern Peninsular Malaysia gaining 40 m per year. Coastal erosion rates can also be high, however, and it has been suggested that these have been exacerbated by the removal of mangroves from many areas.

Mangrove losses have been considerable in many parts of Malaysia: the area of forest reserves decreased by 12% between 1980 and 1990, mostly through loss of forest area to agriculture, urban development, shrimp ponds and deforestation. The use of mangrove areas in Malaysia has a long history. Traditionally, they have been harvested for fuelwood, charcoal, timber and poles. The Matang forest on the west coast of Peninsular Malaysia has been sustainably managed since the start of this century and is one of the very few examples of successful sustained management of a tropical forest ecosystem in the world. In addition to a timber industry employing some 2,400 people, with a revenue of US$ 6 million per year, there is an associated fishing industry in the area which employs about 10,000 people with an annual revenue of US$ 12-30 million. This contrasts strongly with the former Japanese woodchip industries established on Sabah and Sarawak, now closed, which caused long-term degradation of wide areas. These had an estimated yield of only 2.5% of the Matang yield per hectare, based on economic considerations and provision of employment. As in other countries, offshore fisheries are very important and have been closely linked to the mangroves for a number of fish and prawn species. Aquacultural practices include cockle culture, the widespread use of floating cages for fish, and the destructive development of ponds, mostly for prawn culture. Although recent, this latter activity has spread very quickly, particularly in Peninsular Malaysia, leading to the clearance of large areas. The National Mangrove Committee of Malaysia has strongly suggested that strict guidelines should be established for the development of this industry in the future. Clearance for agriculture has occurred, but in some cases has been very unsuccessful due to the acidification of the soils. Considerable areas are now being reclaimed, again particularly in Peninsular Malaysia, for urban development and the development of tourist resorts. In some areas the replanting of mangroves is taking place and this is a routine activity in the Matang mangrove forest. All mangroves come under the jurisdiction of the respective State Forest Departments. Only a very small percentage of Malaysian mangroves fall within legally gazetted protected areas: 0.3% in Peninsular Malaysia; 0.2% in Sarawak; and 1.3% in Sabah.

Map references

Data for Sabah are taken from Sabah Forestry Department (1989). This provides a useful representation of forests within the protected and gazetted forests in the Permanent Forest Estate, but gives no indication of the extent (if any) of additional natural stateland forests. For Sarawak the key source was Lands and Surveys (1979). The data for Peninsular Malaysia are taken from Forest Department (n.d.). Although undated, this unpublished map is an updated version of a map published in 1986.

Sabah Forestry Department (1989). *Sabah Malaysia, Natural and Plantation Forests.* 1:1,270,000. Sabah Forestry Department, Malaysia.

Lands and Surveys (1979). *Sarawak: Forest Distribution and Land Use Map.* 1:1,000,000. Director of Lands and Surveys, Sarawak, Malaysia.

Forest Department (n.d.). *Peninsular Malaysia: The Forest Area.* 1:1,000,000. Hand-coloured map obtained from the Forest Department, Kuala Lumpur in May 1989.

Myanmar

Map 5.2

Land area	676,550 sq km
Total forest extent (1990)	288,560 sq km
Population (1995)	46,548,000
Mean annual temperature	27°C
Mean annual rainfall	2,616 mm
Alternative estimate of mangrove area (Htay, 1994)	3,786 sq km#
Area of mangrove on the map	3,444 sq km
Number of protected areas with mangrove	0

There is little published information on the mangroves in Myanmar. The largest areas are in the Irrawaddy Delta, but these are reported as being heavily degraded and in 1983 it was reported that there were only 235 sq km of undisturbed mangrove in the country. These pristine areas are mostly concentrated away from the Irrawaddy in the two other major areas of mangrove in the country: the northern state of Arakan, and in the south near the border with Thailand in Tenasserim. Mangroves are also found on the offshore islands. In the Irrawaddy Delta, mangroves have largely gone from the eastern areas. There are several forest reserves in the western areas, and scrubby mangrove forest remains in these, although it is heavily utilised as a source of fuelwood and charcoal for Rangoon. Mangrove plantations have been established in Taikkyi near Rangoon.

Map references

Data for the Irrawaddy Delta were obtained from Blasco and Bellan (1995), prepared from Landsat MSS, Landsat TM and SPOT data. Further data were added based on the mangrove arcs shown on Petroconsultants SA (1990).

Blasco, F and Bellan, M.F. (1995). *A Vegetation Map of Tropical Continental Asia*. 1:5,000,000. Institut de la Carte Internationale de la Végétation, Toulouse, France.

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Pakistan

Map 5.1

Land area	796,100 sq km
Total forest extent (1990)	18,550 sq km
Population (1995)	134,974,000
GNP (1992)	410 US$ per capita
Mean monthly temperature range	18-31°C
Mean annual rainfall	220 mm
Alternative estimate of mangrove area (Qureshi, pers comm.)	1,600 sq km
Area of mangrove on the map	1,683 sq km#
Number of protected areas with mangrove	2

The coastline of Pakistan is essentially arid, with low rainfall, mostly falling during the monsoon period (April to September). This has an important effect on the distribution and development of mangroves, with the largest area being found in the Indus Delta, and the remainder being mostly restricted to small patches in bays and river mouths. The mangroves of the Indus Delta are almost completely monospecific *Avicennia marina*, which is highly resistant to the relatively extreme conditions of temperature and salinity.

Mangroves in the Indus Delta have been heavily used by man for fuelwood, fodder and grazing, particularly camels. There is some collection of timber for supply to markets in Karachi. Artisans and commercial fisherfolk use the mangrove areas for prawn and fish capture and, during the fishing season (October to May), move into the mangroves and establish temporary villages in some of the creeks. Fisherfolk also use the mangroves for poles and fuelwood. Such activities are a threat to mangroves, only if there is overuse - this has occurred in a number of areas, leading to extensive loss and degradation. Considerable threats also arise from pollution and increasing salinities, the former particularly from industrial effluents from Karachi, and the latter from interruptions to the flow of the Indus with the construction of barrages and diversion of water for irrigation. Increasing salinities are likely to further stunt tree growth, and may be the cause of reduced seedling recruitment observed in some areas. The reduced flow of the Indus is also reducing the input of silt into the system, which could have further long-term effects. Oil pollution discharged from the many ships visiting Karachi is a large and increasing threat. A number of mangrove species have been disproportionately affected by anthropogenic impacts, even to the point of probable extermination. This may be attributable to increasing salinities in the Delta, over-exploitation, or both. Two large areas within the Indus Delta were declared as protected forest in 1957 and are managed by the Forest Department, while there are increasing efforts to establish mangrove plantations. Some 50 sq km have now been planted in the Indus Delta.

Map reference

Mangroves for the Indus Delta were extracted from 1:1,000,000 map in Meynell and Qureshi (1993). Remaining areas were added to a 1:1,000,000 base map by S.M. Saifullah, Karachi University.

Meynell, P.J. and Qureshi, M.T. (1993). Sustainable management of the mangrove ecosystem in the Indus Delta. In: *Wetlands and Waterfowl Conservation in South and West Asia*. Moser, M. and van Wessen, J. (Eds). IRWB Publications, No. 25, Gloucester, UK.

The Philippines — Map 5.5

Land area	300,000 sq km
Total forest extent (1990)	78,310 sq km
Population (1995)	69,257,000
GNP (1992)	770 US$ per capita
Mean monthly temperature range (Manila)	25-28°C
Mean annual rainfall (Manila)	2,083 mm
Spring tidal amplitude (Luzon)	1.68 m
Spring tidal amplitude (Panay)	2.16 m
Alternative estimate of mangrove area (Ajiki, 1994)	1,325 sq km
Area of mangrove on the map	1,607 sq km#
Number of protected areas with mangrove	7

The Philippines is a large archipelago of approximately 7,000 islands. Mangroves in the Philippines were once estimated to cover 4,000 sq km, but have decreased to one third or one quarter of their original extent. The largest remaining areas are located to the south of the archipelago, on Mindanao and Samar, and also on Palawan in the west. The diversity of mangrove species is high, and quite clear, though complex zonation patterns have been described for undisturbed communities. The country has a tropical monsoon climate, with high humidity and rainfall. It is also strongly affected by tropical cyclones which can have a devastating effect on human populations on the coast.

Offshore fisheries are of considerable importance in the Philippines. There have been few studies to look at the effect of mangrove loss on these, although anecdotal evidence suggests there have been reduced yields. There is little or no commercial extraction of timber, but mangrove wood is widely used locally for fuel, charcoal and for the manufacture of poles and piles. There has been some mangrove afforestation, notably in the Sulu Archipelago and the central Visayas, including Negros, Bohol and Cebu, much of this carried out at the local and community level. Research into afforestation methods is also underway. Traditional or non-destructive fishing within mangrove areas is still important, notably in Bohol, Sulu and Cebu. Target species include shellfish and crabs as well as fish caught by net or line. The greatest loss of mangrove areas has been caused by the development of large areas of brackish fishponds, increased from 900 sq km in 1952 to over 2,100 sq km today. This conversion has been strongly encouraged by the government policy of leasing out mangrove areas to increase fish production. Mangrove reclamation for agricultural or urban development is significant in some areas.

Although some legislation exists for the protection of mangroves, for example all of the mangroves of Palawan and other sites have been declared a mangrove forest reserve, there is little evidence that such protection is effective on the ground.

Map reference

Processed satellite imagery has been kindly provided by NAMRIA (1988), prepared from SPOT images taken in 1987, at a scale of 1:250,000. Some of the smallest islands in the southwest, central and northern parts of the country are not included in the coverage, but are not likely to make a significant difference to the total area.

NAMRIA (1988). *Land Cover Maps.* 1:250,000. National Mapping and Resources Information Authority, Manila, Republic of the Philippines.

Singapore

Map 5.6

Land area	620 sq km
Total forest extent (1990)	40 sq km
Population (1995)	2,853,000
GNP (1992)	15,790 US$ per capita
Mean monthly temperature range	26-27°C
Mean annual rainfall	2,358 mm
Spring tidal amplitude	3.5 m
Alternative estimate of mangrove area (Chou, 1990)	6 sq km#
Area of mangrove on the map	No data
Number of protected areas with mangrove	2

Singapore is a small, densely populated island at the southern tip of the Malaysian peninsula. Originally mangroves covered 13% of the island, or some 75 sq km, but they have now been almost totally destroyed. Original uses included fuelwood and charcoal and over-exploitation led to wide-scale degradation by the mid-nineteenth century. The first land reclamation activities were begun on the Singapore River in 1822. By the middle of this century large areas had been reclaimed and this continues today. Shrimp farming was introduced in the 1900s and led to the loss of wide areas of mangroves as brackish water ponds were developed. Today, the total area occupied by shrimp farming is decreasing as the ponds themselves are reclaimed for urban expansion. The most recent, and now widespread, threat is the barraging of all the major non-urban estuaries as freshwater reservoirs. These estuaries were the last areas where mangroves were found to any extent. All that now remains are a few scattered patches of degraded mangrove along the north shore and some of the offshore islands. Although a species list is given it is likely that some of the species listed may now be extinct in Singapore.

Map reference

No data

Sri Lanka

Map 5.1

Land area	65,610 sq km
Total forest extent (1990)	17,460 sq km
Population (1995)	18,346,000
GNP (1992)	540 US$ per capita
Mean monthly temperature range (Colombo)	27-28°C
Mean monthly temperature range (Trincomalee)	26-30°C
Mean annual rainfall (Colombo)	2,424 mm
Mean annual rainfall (Trincomalee)	1,580 mm
Spring tidal amplitude	<1 m
Alternative estimate of mangrove area (Jayewardene, 1986)	(63 sq km)*
Area of mangrove on the map	89 sq km#
Number of protected areas with mangrove	8

* does not include entire country

Although mangroves are found on all coasts they are restricted in some areas by high exposure. The greatest concentrations are along the east and west coasts and around the Jaffna Peninsula in the north, with the largest single area probably being that around the Puttalam Lagoon on the west coast. Low tidal ranges throughout the country typically preclude the development of wide areas of mangrove although tidal zonation patterns have been observed. Five kinds of mangrove system have been described: riverine, fringing, basin, scrub and overwash. Each system has a characteristic flora. The best developed system is riverine. Traditionally, mangroves have been used for firewood, tannins and poles for construction. Mangrove poles and posts are also used in the construction of large fish traps. Large-scale commercial exploitation does not take place although there are some mangrove plantations, notably in the Negombo Lagoon, which are managed largely for firewood and poles for local markets. Aquaculture is not widespread, but is found in a few ponds around Negombo Lagoon. Conversion of land for agriculture has been one of the major causes of mangrove loss, notably for coconut plantations, while, more recently, the conversion of mangrove areas for tourist resort development is increasing.

Map reference

Data were kindly provided by the ODA Forest Mapping and Planting Project of the Forest Department in Sri Lanka, prepared from Landsat TM imagery, incorporated onto a 1:50,000 base map. Most source images were from 1992, with analysis and ground-truthing completed by 1994. Details of the dataset provided in Legg and Jewell (n.d.).

Legg and Jewell (n.d.). A 1:50,000 scale forest map of Sri Lanka: the basis for a national forest GIS. Unpublished report of the ODA Forest Mapping and Planting Project, Forest Department, Colombo, Sri Lanka.

Case study

The mangroves of Balochistan, Pakistan

(Text and data for this section were kindly supplied by Dr M. Tahir Qureshi, IUCN, Karachi, Pakistan)

The mangroves in the east of Balochistan are very limited in extent, covering a total area of under 80 sq km. Figures giving the mangrove coverage in the area are provided in Table 5.2. These have been derived from satellite imagery by the Space and Upper Atmosphere Research Commission (SUPARCO). There is considerable variation in the density of these mangrove stands and much of the mangrove area in Kalmot Hor and Gawater Bay is predominantly sparse growth with only a few dense stands.

Out of the eight species recorded from Pakistan, only three are found along the Balochistan coast: *Avicennia marina*, *Rhizophora mucronata*, and *Ceriops tagal*. At present, *A. marina* is the dominant species growing in the mangrove forests of Sonmiani. Stands of *R. mucronata* occur at the front of some creeks and *Ceriops tagal* is found occasionally in localised patches. The total cover of these latter two species is small compared with that of *A. marina*.

The mangroves in this area are stressed by the naturally harsh conditions of high salinity and aridity. Most of the *Avicennia* and *Rhizophora* stands are stunted and the rate of soil erosion is severe in such areas. There is also pressure from the coastal population on the mangrove ecosystems. The local fishermen intensively collect fuelwood and fodder from the forest and this has led to the development of large salt pans in various places.

Figure 5.9 shows the distribution of mangroves in the Indus Delta, where most of Pakistan's mangroves are located. Figure 5.10 is a SPOT image showing the mangroves of Sonmiani in more detail.

Environmental data - Sonmiani Bay

• Mean annual rainfall	180 mm
• Dry season	8 consecutive dry months (September to April)
• Riverine input	From the Piroli River, which is seasonal, flooding the mangrove area during the rainy season
• Mean water salinity	30 to 50‰
• Dominant soil types	Clayey-loamy, sandy-loamy
• pH of the topsoil	7 to 8
• Average tidal amplitude	2-3 m
• Local population	Dam village has a population of 12-15,000 - these are predominantly fisherfolk, with a few graziers
• Total areal extent	31 sq km (Sonmiani); 73 sq km (Balochistan coast)
• Main mangrove species	*Avicennia marina*, *Rhizophora mucronata* and *Ceriops tagal*

Table 5.2 The distribution of mangrove vegetation along the east coast of Balochistan, Pakistan

Site	Area (sq km)	Percentage of total
Miani Hor/Sonmiani	31.0	42
Dense mangrove	16.6	
Normal mangrove	10.9	
Sparse mangrove	3.5	
Kalmot Hor	21.6	30
Normal mangrove	2.6	
Sparse mangrove	19.0	
Gawater Bay	20.8	28
Normal mangrove	0.6	
Sparse mangrove	20.2	
Total	73.4	100

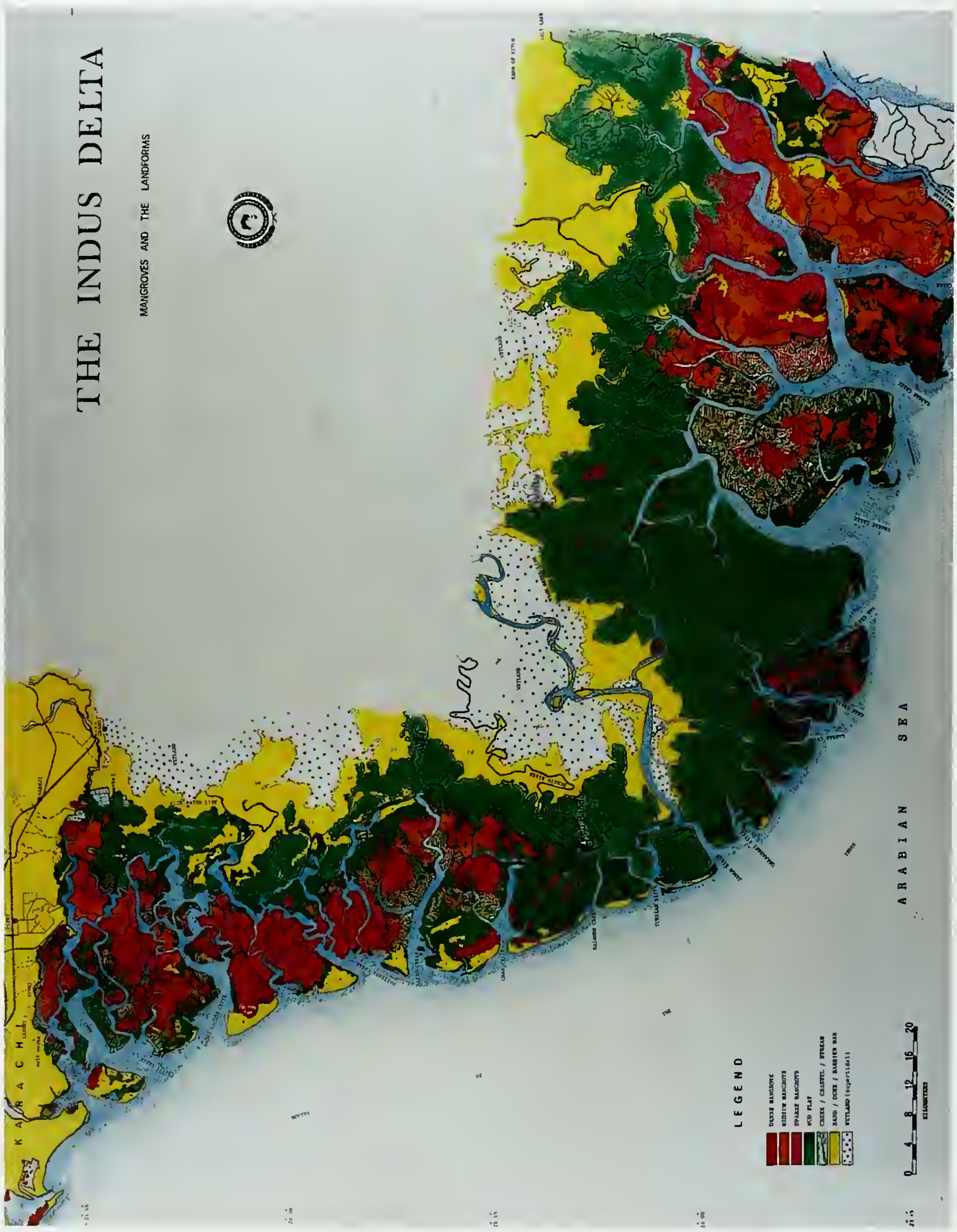

Figure 5.9 Mangroves of the Indus Delta

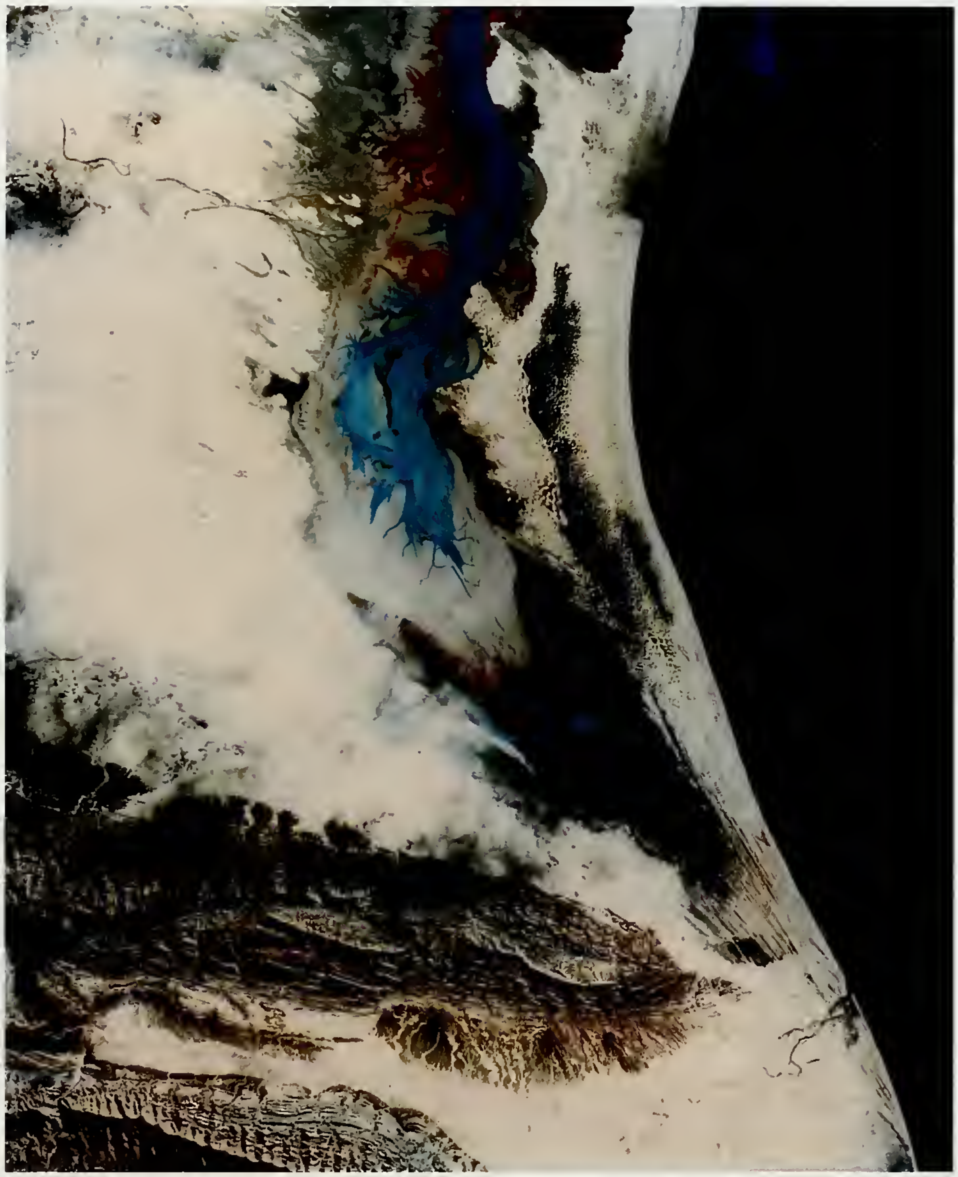

Figure 5.10 Mangroves of Sonmiani Bay

Thailand

Maps 5.2 and 5.6

Land area	513,120 sq km
Total forest extent (1990)	127,350 sq km
Population (1995)	58,265,000
GNP (1992)	1,750 US$ per capita
Mean monthly temperature range (upper Gulf of Thailand)	28-30°C
Mean monthly temperature range (Andaman Sea)	26-29°C
Mean annual rainfall (upper Gulf of Thailand)	1,556 mm
Mean annual rainfall (Andaman Sea)	4,015 mm
Spring tidal amplitude (Gulf of Thailand)	1-2 m
Spring tidal amplitude (Andaman Sea)	3-6 m
Alternative estimate of mangrove area (IDRC/NRCT/RFD, 1991)	1,964 sq km
Area of mangrove on the map	2,641 sq km#
Number of protected areas with mangrove	13

Thailand has an extensive coast along the Gulf of Thailand and a shorter coast on the Andaman Sea. It is on the latter coast that mangroves are most heavily concentrated with 75-80% of the country's mangroves, and it is also here that most of the remaining old growth forest is to be found.

Wide areas of Thailand's mangroves have been selectively cut. About 90% of the wood harvest is for charcoal manufacture and about 40% of this is exported to Malaysia, Singapore and Hong Kong. Offshore capture fisheries, fish and shrimps, are important and partly dependent on the mangrove environment. Mollusc culture on the mudflats and channels has been practised for many years in some areas. Shrimp farming has boomed since the 1970s, particularly on the Gulf coast and has led to the clearance of large areas. Poor practices have led to a limited lifespan of 3-4 years on some farms which have then been abandoned, creating large areas of degraded land. The other major cause of mangrove clearance has been coastal development, mostly urban and industrial, but also for agriculture. Salt ponds and tin mining have also led to the loss of some areas. Rates of loss can be very high indeed and were reported at 130 sq km per year for the period 1979-1986, with a 50% loss of the entire mangrove area between 1975 and 1991. Active erosion processes along the northern Gulf of Thailand may have been exacerbated by the mangrove clearance that has taken place in this region. Concern about the loss of mangroves has led to a number of legal and policy measures for their protection and sustainable use: strict rules are applicable on mangrove concessions to maintain sustainability; there are also three state owned seedling production centres. State owned forest plantations cover some 295 sq km, with private plantations on a further 28 sq km. Some of the mangroves fall within national parks and other protected areas, notably those on the Andaman Sea.

The considerable discrepancy between the map figure and the quoted alternative estimate of mangrove area is of some concern as both figures purport to be derived from the same source.

Map reference

Mangrove polygons were prepared from the four-map series (IDRC/NRCT/RFD, 1991) produced as a part of the Remote Sensing and Mangroves Project (Thailand) at a scale of 1:500,000. Sources for these maps were Landsat MSS data recorded in 1986-1987.

IDRC/NRCT/RFD (1991). *Remote Sensing and Mangroves Project (Thailand).* Series of four maps prepared at 1:500,000 by the Remote Sensing Division of the National Research Council. International Development Research Centre, National Research Council of Thailand and the Royal Forestry Department.

Case study

Estuarine mangroves in Thailand: Ranong

In recent years the total area of the mangroves in Thailand has declined considerably, being reduced from over 4,744 sq km in 1961 to 2,451 sq km in 1986. In the seven years from 1979 to 1986, over 1,500 sq km of mangrove disappeared in Thailand (see Table 5.3).

Much of the loss of mangroves in Thailand has occurred because the mangrove areas have been converted to aquaculture ponds. Several techniques are currently used by aquaculture operators (Plate 5.4), but all result in the construction of dykes with sluice gates leading to major changes in the drainage conditions and hydrological regime. Many mangrove species (flora as well as fauna in the impounded areas are destroyed. Table 5.4 shows the evolution of shrimp aquaculture in Thailand.

The mangroves of Ranong

The mangrove communities of the Klong Ngao and Kra Buri estuaries, near Ranong (Figure 5.12 are located some 600 km southwest of Bangkok, in the Andaman Sea. Their relative isolation partly explains why they are less disturbed than most Thai mangroves. They have been studied for many years thanks to the facilities provided by the Mangrove Forest Research Centre. The current account and images provide an overview of the key features of these mangroves as they can be observed either from space, from aerial photographs, from the field or from the laboratory.

Environmental data

• Mean annual rainfall	>4,000 mm/year
• Dry season	4 consecutive dry months
• Riverine input	On the estuaries of the Kra Buri and Klong Ngao Rivers; good freshwater supply
• Water salinity	15 to 30‰
• pH of the topsoil	7 to 8
• Dominant soil type	Clayey or loamy clayey
• Average tidal amplitude	2.5 m
• Maximum spring tide	4 m
• Average population density	Unknown. Probably lower than 10 people/sq km. Few villages of mangrove dwellers with little human pressure on the ecosystem
• Total areal extent	1,964 sq km
• Dominant mangrove type	Estuarine with a complex mangrove species distribution. Very unclear zonation
• Main mangrove species	*Avicennia alba, Bruguiera cylindrica, B. parviflora, Ceriops tagal, Rhizophora apiculata, R. mucronata*

The Ranong mangroves cover 11.5 sq km, on the Andaman coastline, at about 9°50' North on the estuary of the Kra Buri River which forms the border between Thailand and Myanmar. Due to the very moist climatic conditions (4,000-5,000 mm of rainfall, 180-200 rainy days per year), it is quite difficult to obtain good quality satellite data in the visible and infrared wavelengths. In spite of the high frequency of a dense cloudy coverage a reasonably good Landsat TM scene was recorded on the 19th of January 1989 (Figure 5.11). The corresponding map is the result of the analysis of this image.

Patterns of zonation are usually indistinct. From one site to another, species distribution varies considerably, without any clear natural explanation. This is probably the result of ancient human interference, including wood extraction and mining. Other factors, including erosion, accretion,

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tectonic activity and sea level fluctuations, have probably affected the complex mangrove species distribution patterns observed.

The largest trees (*Rhizophora apiculata*) reach 30 m in height. Although the exact response of trees to the various seasonal parameters is not known, the mangroves of Ranong are primarily evergreen with some deciduous species, such as *Excoecaria agallocha*, although this is not common at Klong Ngao. The fraction of primary production (leaf litter) exported during every tidal cycle to adjacent coastal waters is probably in the order of 10 to 15%.

These mangroves have been the subject of a considerable amount of integrated studies (plants, animals, soils, waters, etc.): a summary of some of the results of this work is published in UNDP-UNESCO (1991).

Plate 5.4 Most of the mangroves of Thailand are threatened by the development of shrimp-pond aquaculture. Along the eastern coast (Gulf of Thailand) only remnants of the original ecosystems remain, as seen here in Khlung

Table 5.3 Changes in the distribution of mangroves in Thailand (from Silapathong, 1992)

Region	**Area (sq km)**				**Rainfall**	
	1961	1975	1979	1986	mean (mm/yr)	rainy days
Gulf of Thailand eastern coast		490	441	280	1,311–4,761	109-192
Gulf of Thailand northern coast		273	231	3	–	–
Gulf of Thailand western coast	1,065	447	419	204	1,119–2,382	128–172
Eastern coast of Andaman Sea	3,679	3,127	2,873	1,964	2,232–4,198	170–199

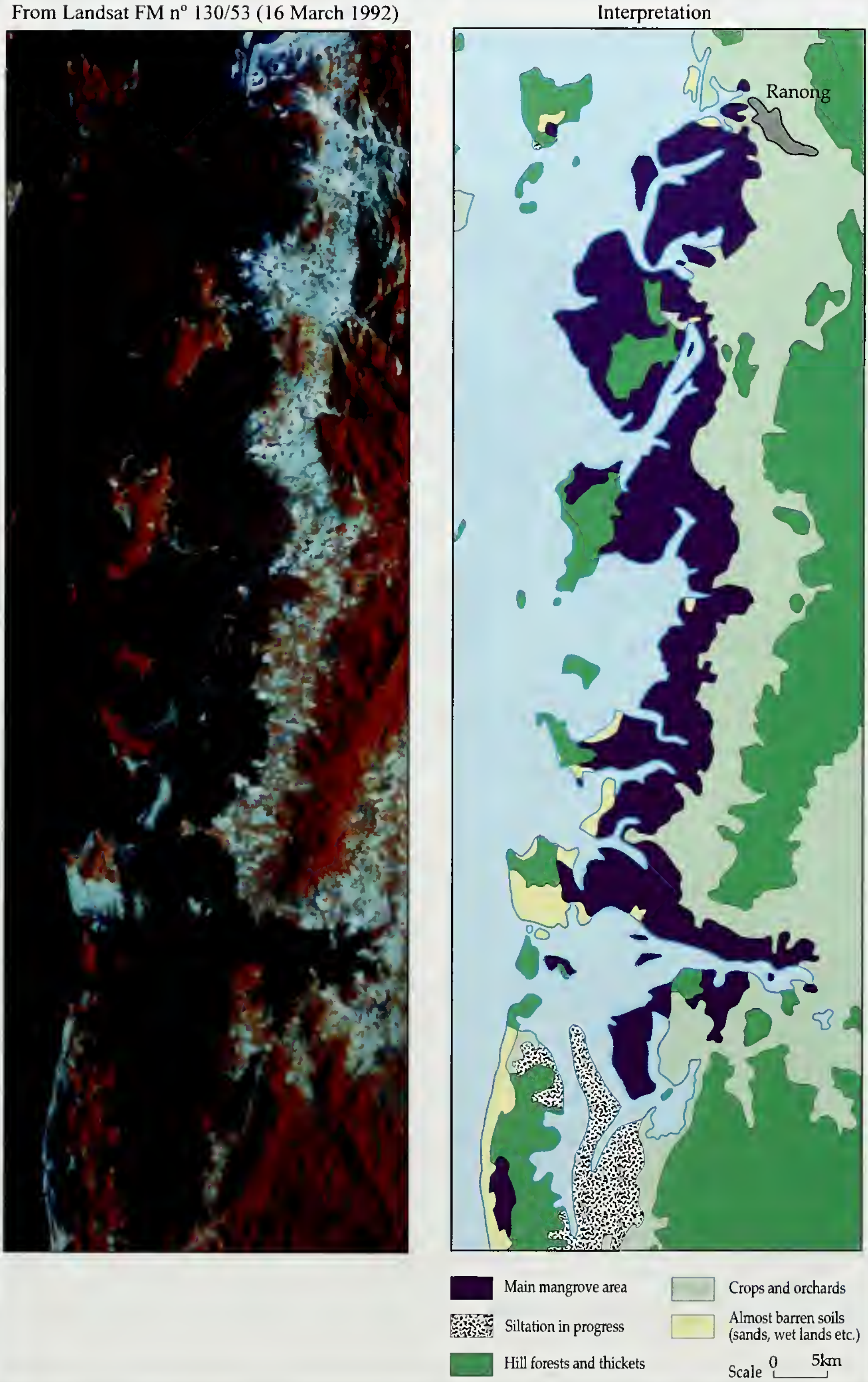

Figure 5.11 A satellite view of the distribution of the mangroves of the Ranong area

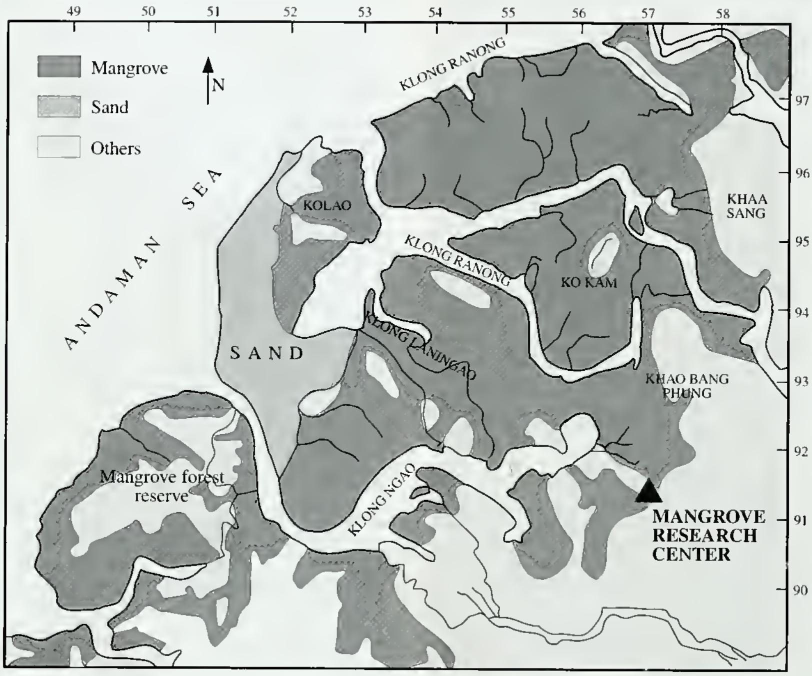

Figure 5.12 A detailed map of the Ranong mangrove ecosystem. The mangrove research centre is located upstream on the Klong Ngao River (from UNDP-UNESCO, 1991)

Table 5.4 Changes in marine shrimp aquaculture in Thailand (1972-1988) (Chomdecha and Phoochareon, 1979)

Year	Area (sq km)	Number of owners	Production (tonnes/year)				
			Penaeus monodon	*Penaeus merguiensis*	*Metapenaeus monoceros*	Others	Total
1972	91	1,154	-	-	-	1,450	1,450
1977	124	1,437	20	721	599	250	1,590
1982	308	3,943	96	6,346	2,454	1,195	10,091
1988	667	11,838	40,774	9,226	3,560	2,037	55,597

Vietnam

Map 5.3

Land area	331,690 sq km
Total forest extent (1990)	83,120 sq km
Population (1995)	73,811,000
Mean monthly temperature range (Hanoi)	17-29°C
Average temperature (south Vietnam)	27°C
Mean annual rainfall (Hanoi)	1,830 mm
Mean annual rainfall (Ca Mau peninsula)	2,550 mm
Spring tidal amplitude (Ca Mau peninsula)	3 m
Alternative estimate of mangrove area (Hong and San, 1993)	2,525 sq km#
Area of mangrove on the map	(2,723 sq km)
Number of protected areas with mangrove	2

Vietnam has a long coastline facing the South China Sea. It has been estimated that mangroves in this country once covered an area of some 4,000 sq km. This area has now been reduced considerably, one of the major causes being the widespread use of herbicides and napalm during the Vietnam war (1962-1972). About 1,050 sq km (36%) of the total mangrove area in the south was destroyed during the Vietnam war. Remaining forests consist mainly of secondary growth, much of it scrubby, and plantations. The largest areas of mangrove are in the Mekong Delta and further south on the Ca Mau peninsula. These were also the areas most heavily degraded during the Vietnam war and primary forest is not widespread. There are very few mangroves along the central parts of the country where the coastline is quite exposed and tidal fluctuations are low. In the north, mangroves have developed in river deltas and estuaries and on wide tidal flats. There are fewer species here than in the south of the country, possibly due to the lower temperatures, but there are some primary forests with mixed stands of trees reaching 8 m in height.

The forests have a wide range of traditional uses: charcoal, fuelwood, honey production, timber and thatching materials. In the south many villages consist of houses built on stilts on the river banks and people make a good part of their living from fish, shrimp and crab fisheries. Severe erosion has occurred in some areas as a direct result of this and vast areas have degraded soils where mangroves have not regenerated, or have formed scrubby and commercially worthless formations. Since the 1980s there have been further considerable losses, particularly in the southwest, with the development of shrimp ponds. Conversion of land to salt ponds and to agriculture has also been widespread, although the latter, typically, only lasts a few years before the soils become degraded. Vietnam has made considerable efforts to restore mangrove areas and there are estimated to be some 466 sq km of mangrove plantations in the country.

Map reference

Data showing mangrove in the Mekong Delta only are taken from Anon. (1987), believed to be the result of a forest inventory in 1987. Further approximate areas were added from edits provided by François Blasco.

Anon. (1987). *Cac Loai Thuc Vât bi de Doa Dien Hinh va Môt Vung Tâp Trung.* 1:4,000,000. Publisher unknown.

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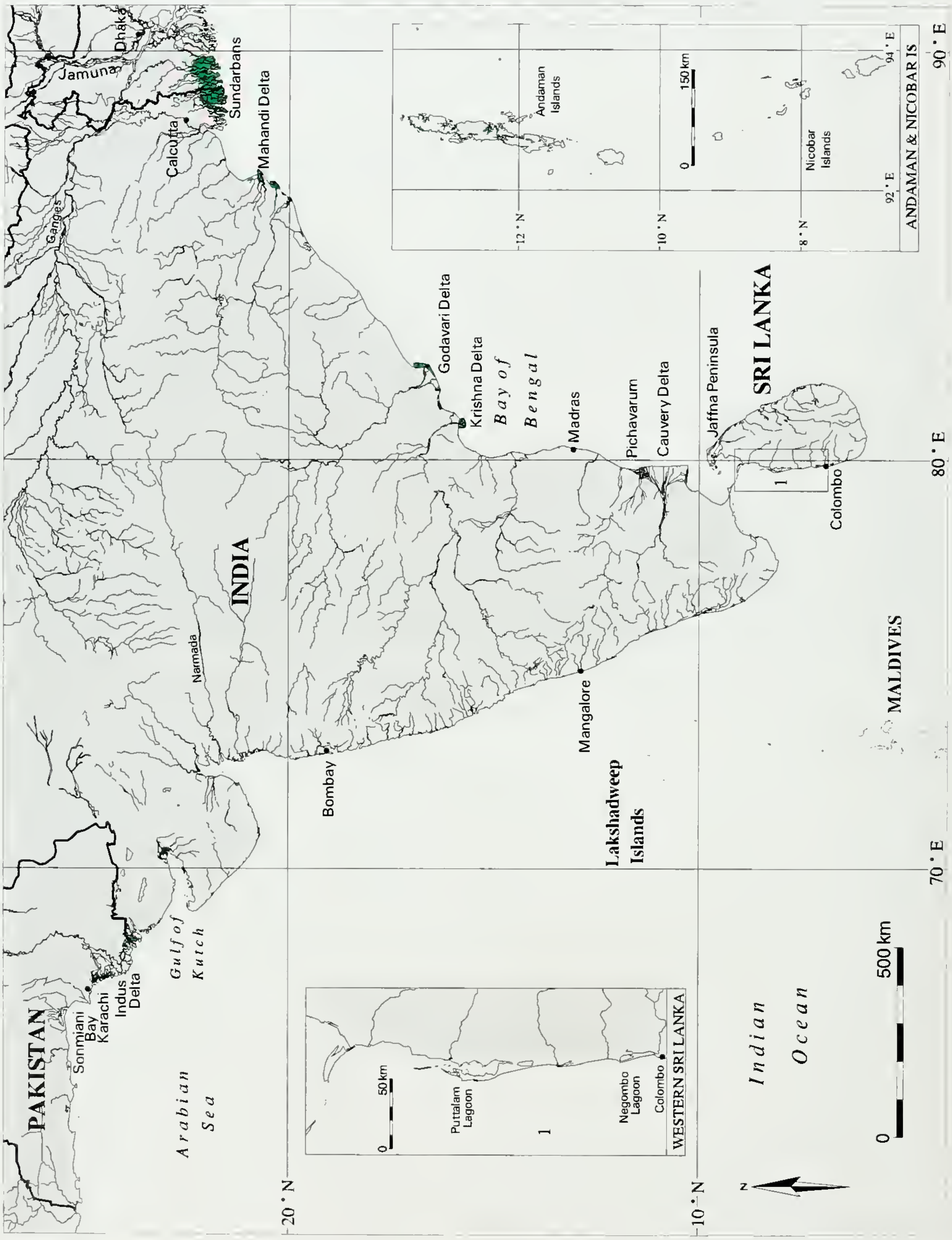
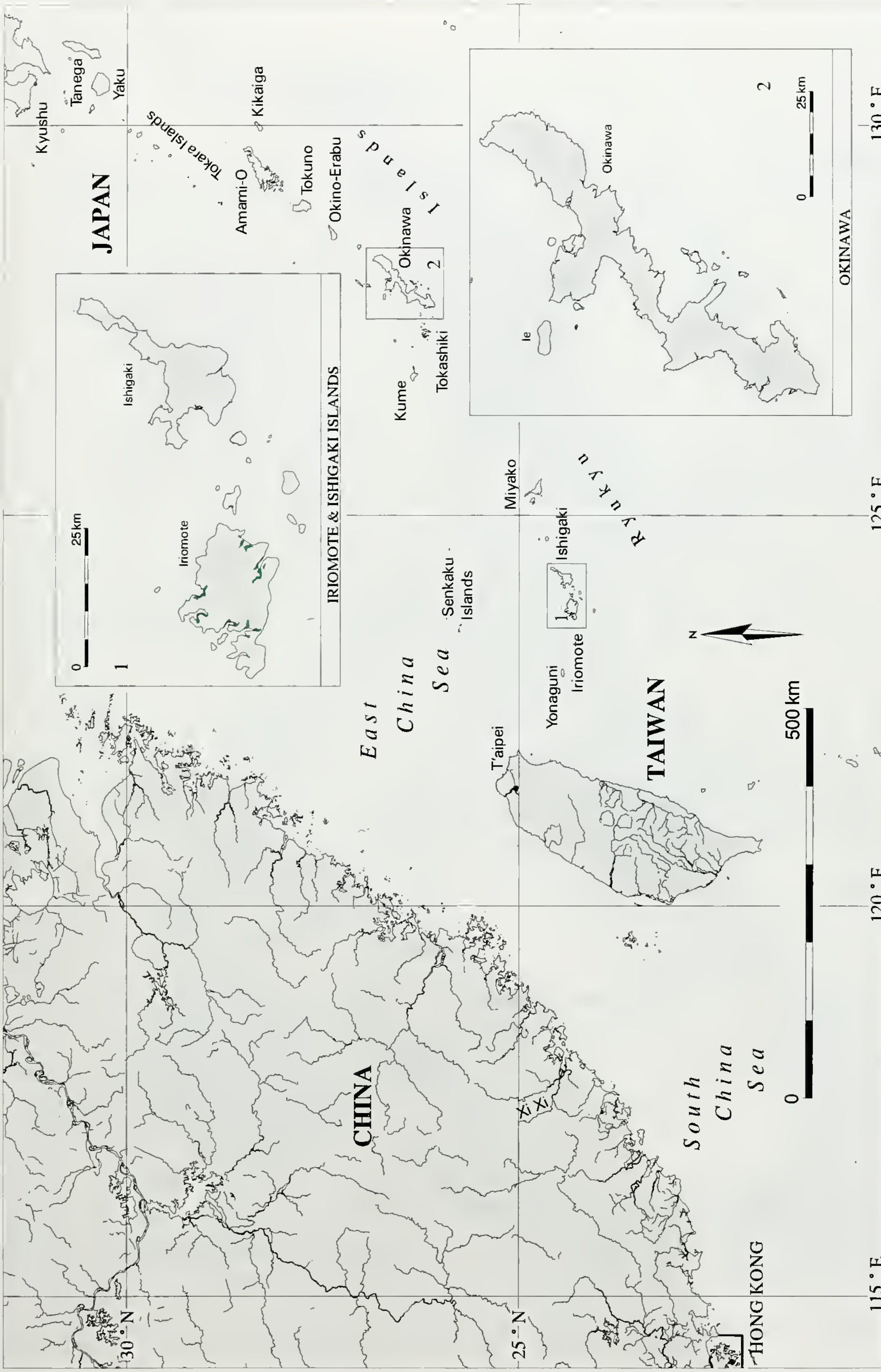


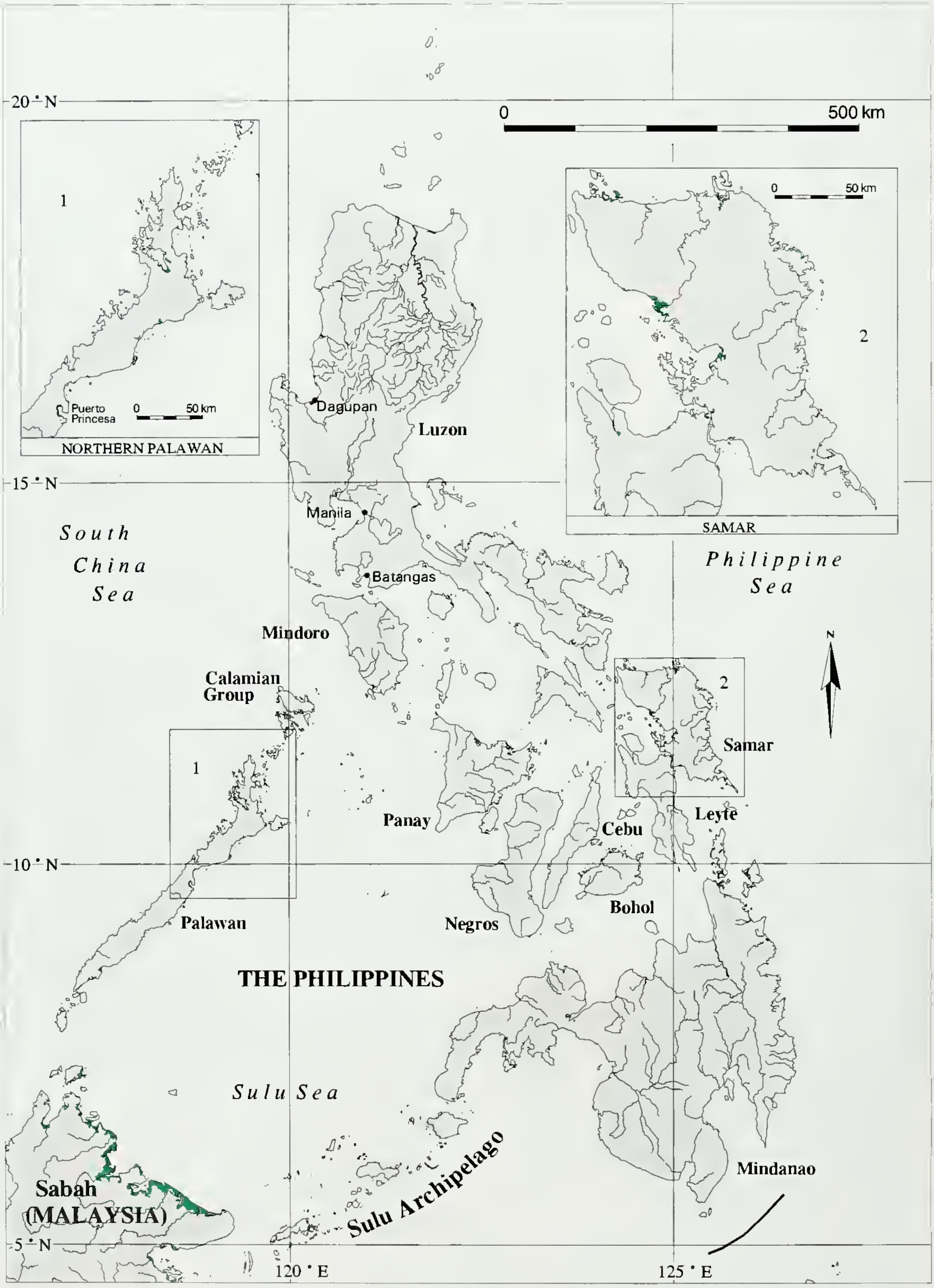
Map 5.1 Pakistan, India and Sri Lanka

Map 5.2 Continental Southeast Asia

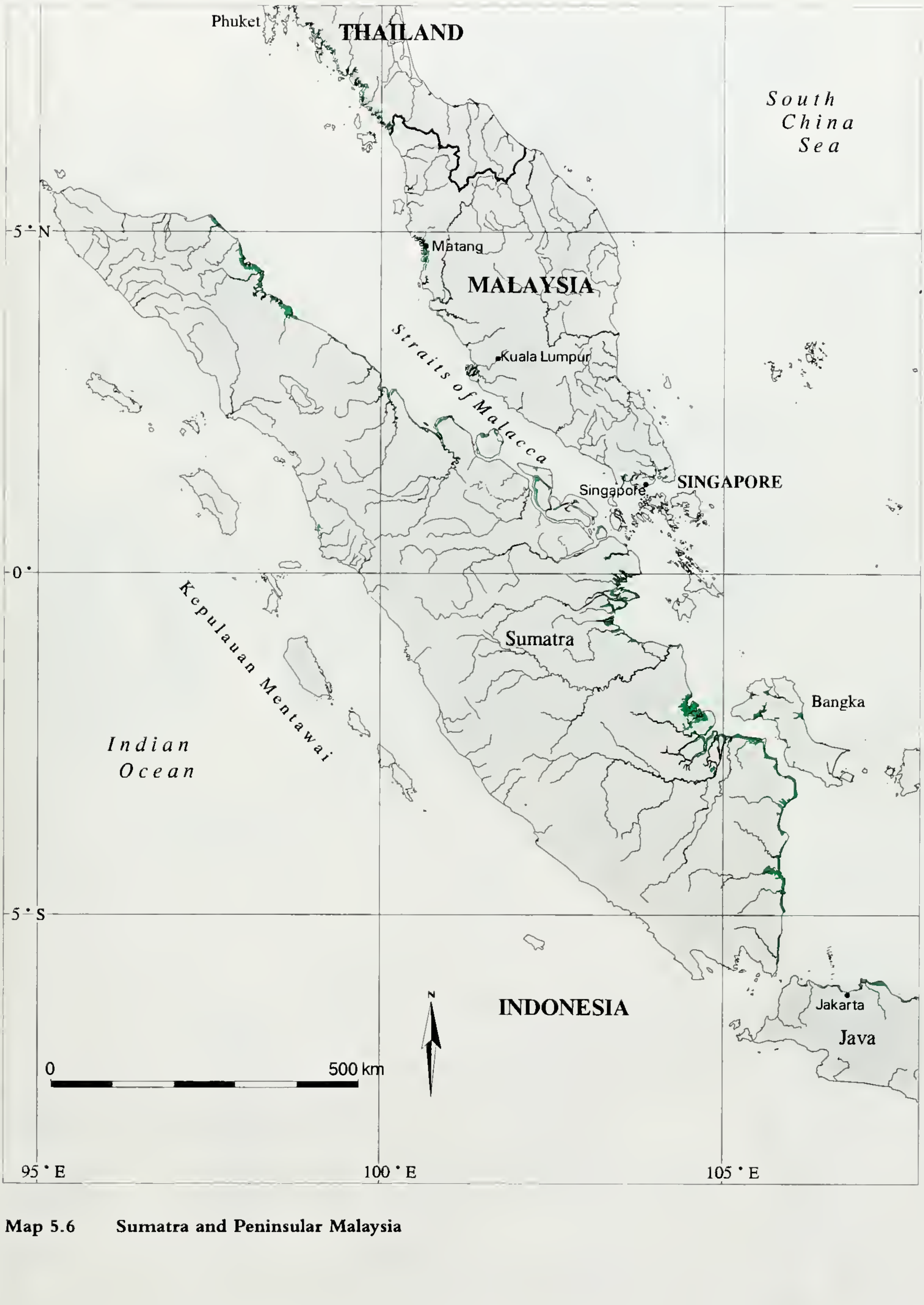
Map 5.3 Vietnam, Southern China and Hong Kong



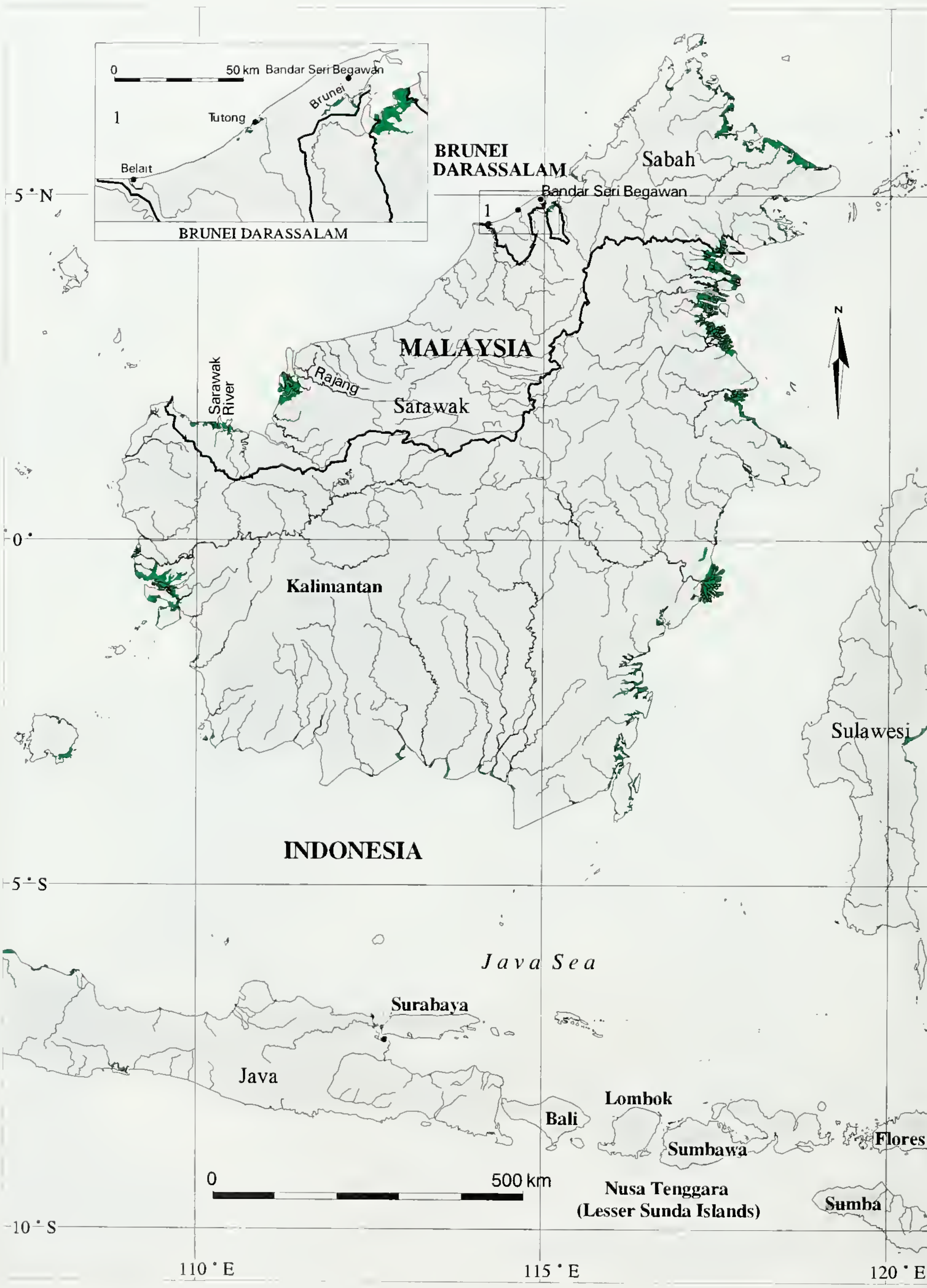
Map 5.4 East China, Taiwan and Japan



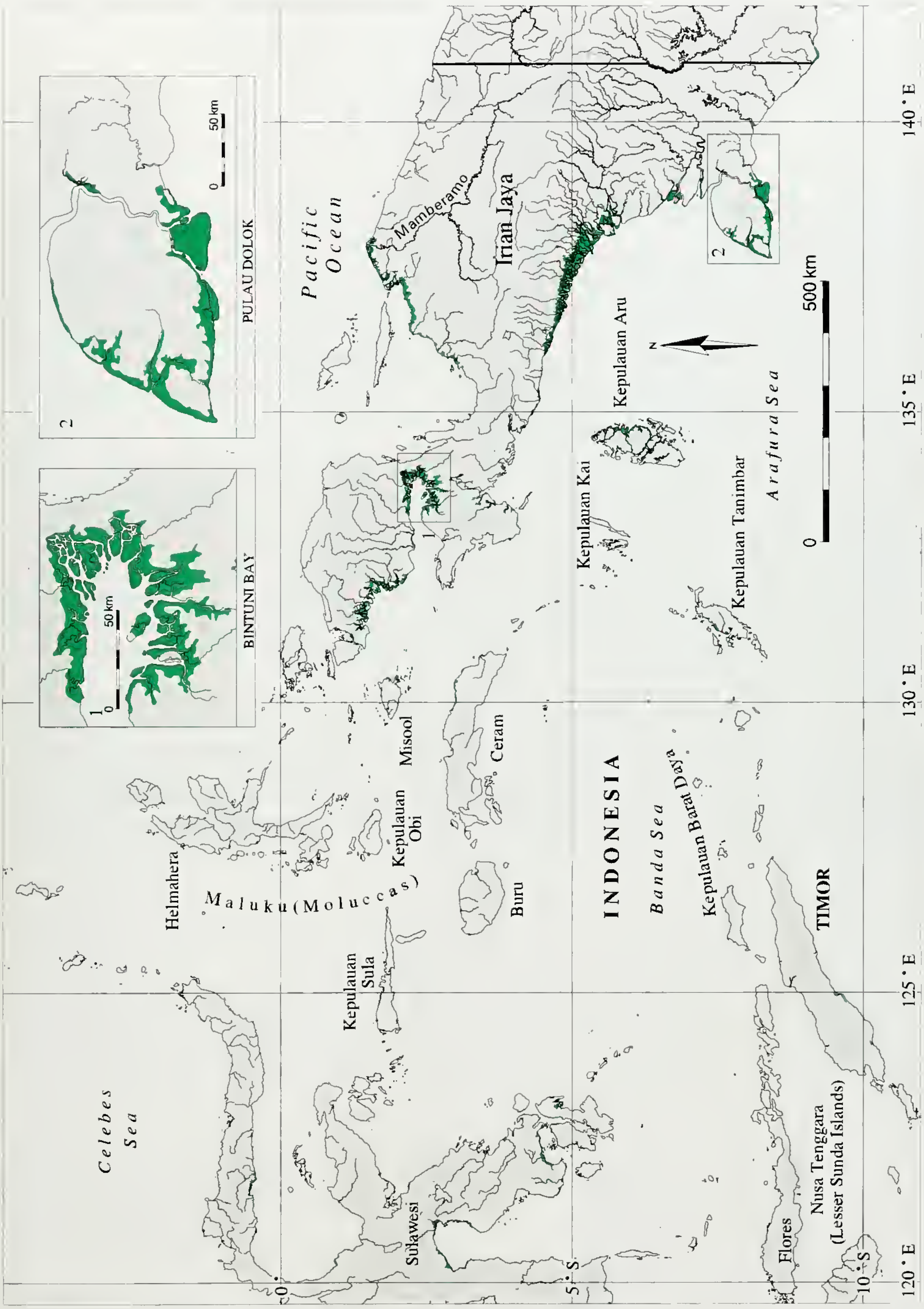
Map 5.5 **The Philippines**



Map 5.6 **Sumatra and Peninsular Malaysia**



Map 5.7 Borneo and Java



Map 5.8 Eastern Indonesia

6

Australasia

The Australasian region includes Australia, Papua New Guinea, New Zealand, and the islands of the South Pacific. Australia, southern Papua New Guinea, New Caledonia and New Zealand can be considered as part of the Australian Continental Plate; while northern Papua New Guinea, and the western and central Pacific Islands represent the western Pacific Plate (Duke, 1992). This region is home to a great diversity of mangrove species, including some endemic species (Table 6.1). The greatest concentration is found in northern Australia and southern Papua New Guinea, which together share 45 species, in Western Samoa the number of species drops to three and in New Zealand there is only one species, *Avicennia marina*. Duke (1992) suggests that there are no obvious barriers to the dispersal of propagules within this region, although others would argue that the distances between islands present large, and in some cases, insurmountable barriers. Whichever view is correct, there are some remarkable discontinuities of species.

One interesting issue is the presence of *Rhizophora samoensis* in the southwestern Pacific and its apparent western migration across the southern Pacific. This species has been recorded in New Caledonia, Fiji, Tonga and Samoa (Tomlinson 1986). Tomlinson also states that *Rhizophora samoensis* is scarcely distinguishable in its morphology from *Rhizophora mangle*. It is usual to maintain that *R. samoensis* and *R. mangle* are different species and Tomlinson maintains that it is more than useful to retain the separate names. He does, however, speculate that the presence of *R. samoensis* in the southern Pacific may represent the spread of *R. mangle* westwards. Ellison (1995a) takes a more radical approach and states.that *R. samoensis* is merely a synonym for *R. mangle*. It is generally agreed that *R. mangle* occurs on Oahu, Hawaii, but it, and several other mangrove species are considered to have been introduced by early travellers. There are several other examples in the Pacific of mangrove species being introduced beyond their natural limit.

The total area of mangroves in this region is some 18,789 sq km. This represents some 10% of the global total area. The great majority, some 90%, of the region's mangroves are restricted to Australia and Papua New Guinea.

Duke (1992) indicates that Papua New Guinea has fourteen fewer species of mangrove in the north than in the south and he expresses the opinion that, in the light of current evidence, Papua New Guinea marks a fusion boundary between two previously isolated and different mangrove floras. The biogeography of this region and the reasons for the floral discontinuities of mangrove species are still a matter of debate (Duke, 1992; Ellison, 1995a; Stoddart, 1992).

Table 6.1 Mangrove species list for Australasia

	American Samoa	Australia, southwest	Australia, northwest	Australia, northeast	Australia, southeast	Federated States of Micronesia	Fiji	Guam	New Caledonia	New Zealand	Palau	Papua New Guinea	Solomon Islands	Tonga	Tuvalu	Vanuatu	Western Samoa
Acanthus ebracteatus				•								•					
Acanthus ilicifolius			•	•								•					
Acrostichum aureum												•					
Acrostichum speciosum			•	•	•							•					
Aegialitis annulata		•	•	•	•							•					
Aegiceras corniculatum		•	•	•	•							•	•				
Avicennia alba						•		•			•	•	•				
Avicennia integra			•														
Avicennia marina		•	•	•	•				•	•		•	•			•	
Avicennia officinalis												•					
Avicennia rumphiana												•					
Bruguiera cylindrica				•								•					
Bruguiera exaristata		•	•	•								•					
Bruguiera gymnorrhiza	•		•	•	•	•	•	•	•		•	•	•	•		•	•
Bruguiera hainesii												•					
Bruguiera parviflora			•	•								•	•			•	
Bruguiera sexangula			•	•					•			•	•				
Camptostemon schultzii			•	•								•					
Ceriops australis			•	•								•					
Ceriops decandra			•	•								•					
Ceriops tagal		•	•	•		•			•		•	•	•			•	
Cynometra iripa				•								•					
Diospyros ferrea				•								•					
Dolichandrone spathacea				•								•					
Excoecaria agallocha			•	•	•	•	•	•	•		•	•	•	•		•	
Heritiera littoralis				•		•	•	•	•		•	•	•	•		•	
Lumnitzera littorea			•	•		•	•	•	•		•	•	•	•	•	•	
Lumnitzera racemosa			•	•	•							•					
Lumnitzera x rosea				•								•					
Nypa fruticans			•	•		•		•			•	•	•				
Osbornia octodonta		•	•	•								•	•				
Pemphis acidula			•	•								•					
Rhizophora apiculata			•	•		•		•	•		•	•	•			•	
Rhizophora mucronata				•		•		•			•	•	•			•	
Rhizophora samoensis	•						•		•					•			•
Rhizophora stylosa		•	•	•	•	•	•	•	•			•	•	•	•	•	
Rhizophora x lamarckii			•	•					•			•	•				
Rhizophora x selala							•		•								
Scyphiphora hydrophyllacea			•	•		•			•		•	•	•				
Sonneratia alba			•	•		•			•		•	•	•			•	
Sonneratia caseolaris				•								•	•			•	
Sonneratia lanceolata			•	•								•					
Sonneratia ovata												•					
Sonneratia x gulngai				•								•	•			•	
Sonneratia x urama			•									•					
Xylocarpus granatum			•	•		•	•		•		•	•	•	•		•	
Xylocarpus mekongensis	•		•	•		•	•	•	•		•	•	•	•		•	•

Country sources

American Samoa	Ellison, 1995a
Australia, southwest (Eucla to Broome, Western Australia)	Duke, 1992*
Australia, northwest (Broome to Archer Basin, Queensland)	Duke, 1992*
Australia, northeast (Archer Basin to Curtis Island, Queensland)	Duke, 1992*
Australia, southeast (Curtis Island to Eucla)	Duke, 1992*
Federated States of Micronesia	Ellison, 1995a
Fiji	Ellison, 1995a
Guam	Ellison, 1995a
New Caledonia	Ellison, 1995a
New Zealand	Ellison, 1995a
Palau	Ellison, 1995a
Papua New Guinea	Duke, 1992
Solomon Islands	Ellison, 1995a
Tonga	Ellison, 1995a
Tuvalu	Ellison, 1995a
Vanuatu	Ellison, 1995a
Western Samoa	Ellison, 1995a

* Australia has been subdivided into four regions. The number of mangrove species in each region is closely correlated with latitude and rainfall (Duke, 1992). See the relevant regional maps for the location of the limits to these regions

Australia

Maps 6.1 and 6.2

Land area	7,713,360 sq km
Total forest extent (1990)	398,370 sq km
Population (1995)	18,338,000
GNP (1992)	17,070 US$ per capita
Mean monthly temperature ranges:	
Darwin (sea temperature range)	25-28°C
Dampier (sea temperature range)	18-32°C
Townsville (sea temperature range)	23-32°C
Melbourne (sea temperature range)	14-17°C
Mean annual rainfall (Darwin)	1,536 mm
Mean annual rainfall (Dampier)	311 mm
Mean annual rainfall (Townsville)	1,161 mm
Mean annual rainfall (Melbourne)	659 mm
Spring tidal amplitude (Darwin)	1.2-6.8 m
Spring tidal amplitude (Dampier)	0.9-4.5 m
Spring tidal amplitude (Townsville)	0.5-2.8 m
Spring tidal amplitude (Melbourne)	0.1-0.9 m
Alternative estimate of mangrove area (Galloway, 1982)	11,500 sq km#
Area of mangrove on the map	9,695 sq km
Number of protected areas with mangrove	180

The mangrove flora of Australia is one of the richest in the world: some thirty-nine species have been recorded. The mangrove floristics and biogeography have been described by Hutchings and Saenger (1987), Galloway (1982) and, most recently, Duke (1992). Hutchings and Saenger (1987) divided the country into twelve regions and later modified it to thirteen while Galloway (1982) described the mangrove distribution by State. Duke (1992) divided Australia into four main regions: northwest, southwest, northeast and southeast. As far as mangrove distribution is concerned, some of these regions merge into other nearby countries, such as New Caledonia, but these are described in separate accounts. For purposes of simplicity the approach used by Duke (1992) will be described.

The mangroves of Australia are distributed around most of the mainland coast, except for a region in southwestern Australia, the Great Australian Bight. They do not occur in Tasmania. The largest number of species occurs in the northern and northeastern coastlines. The concentration of species and the large area of mangroves in this region can be attributed to the tropical climate of high temperatures and good rainfall in northern Australia. As one moves south on both the east and west coasts there is a progressive decline in the number of species of mangrove. *Avicennia marina* is the sole species present in the state of Victoria. This probably reflects changes in average temperature of both air and water. However, the greater southward extent of mangroves on the east coast is most likely due to the east coast being appreciably wetter than the west coast. These east coast mangroves are actually at the highest latitude of any mangrove communities in the world (38°45'S) and are significantly further south than the mangroves of New Zealand (38°03'S). It has been suggested that the concentration of species in the northern part of Australia may be because the region was the centre of origin of mangroves and that the coastline configuration, with numerous estuaries and regions sheltered by the presence of the Great Barrier Reef, provide an ideal setting for mangroves.

The estuaries of northern Australia have been extensively surveyed, and Duke (1992) suggests that there is a significant influence of freshwater runoff and estuary size on the composition of mangrove floras in this region. It is generally considered that large estuaries have more species because they offer larger amounts of habitat, but the influence of the salinity of the water is also an important factor.

Direct use of mangroves in Australia is not large and vast areas of mangrove remain in a pristine state. The Aboriginal inhabitants of Australia had, and in some places still have, many uses for the products that can be derived from mangroves. However, the sustainable use of mangroves has been on a small scale because the Aboriginals were essentially a non-agricultural nomadic community. Exploitation of the mangroves with less regard for preservation came with the European colonists. They cleared areas of mangroves for community development but the use of mangroves for timber never developed because there was a plentiful supply of timber from terrestrial forests. Today, mangroves are still being cleared for urban development, ports, airports and tourist resorts, but as the population density in the northern part of Australia is very low, the impact on the overall area of mangroves in Australia remains small.

Map reference

 These data are derived from the 1:250,000 National Topographic Map Series and are thus from various sources and ages.

AUSLIG (1995). 1:250,000 digital coverage of mangroves from: *TOPO250K GEODATA*. The Australian Geographic Database Program: GEODATA. Australian Surveying and Land Information Group, ACT Australia.

The South Pacific

Maps 6.3 and 6.4

This area is composed of the countries and territories of the South Pacific Commission and the South Pacific Regional Environment Programme with the addition of New Zealand. A review of the taxonomy, distribution and conservation of mangroves in this region has recently been undertaken by Ellison (1995a, 1995b). In the area of the present map there are 21 species of mangrove and three hybrids.

The scientific information about mangroves in the Pacific islands tends to be generally poor and not well documented, though the local knowledge of mangroves in some countries is very detailed. To the east of Samoa there are no naturally occurring mangroves, though they have been introduced in Hawaii and Tahiti. The greatest species diversity and area of mangroves is in the Solomon Islands. The next largest areas of mangroves are in Fiji, where 90% of the mangroves occur on Viti Levu and Vanua Levu, and New Caledonia, though the number of species is much reduced. Four species do not extend eastward beyond the Solomon Islands to the rest of the Pacific Islands: *Aegiceras corniculatum*, *Avicennia alba*, *Osbornia octodonta* and *Sonneratia* x *gulngai*. In New Caledonia, Fiji, Tonga and Samoa, *Rhizophora samoensis* occurs and this may represent the westward spread of *R. mangle* from the Americas. The southern limit of mangroves is New Zealand, where the sole species is *Avicennia marina*. It occurs in the harbours and estuaries of the northern third of the North Island.

Mangrove areas in the Pacific have been used traditionally for fishing and collecting crabs. Mangrove timber is extensively used for firewood and construction of houses and boats. As in other parts of the world, mangroves are being removed for coastal development. In the Solomon Islands, Western Samoa, American Samoa and Tonga, legislation exists to control the use of mangroves but is not always exercised. In Vanuatu there is no legislation specifically relating to the protection of mangroves. Fiji has had a long history of mangroves being considered as part of the national forest reserve but in 1975 mangroves were placed under the jurisdiction of the Department of Lands and Survey and usage was not regulated in a systematic fashion. Today, mangroves have little legal protection in Fiji and significant areas have been degraded.

In New Zealand the monospecific mangrove ecosystem is of particular interest because it is very close to the southern limits of world mangrove distribution and has a relatively simple structure. Mangrove productivity in New Zealand is considered to be as great as the more complex mangrove ecosystems of the tropics. Infilling for agriculture and commercial land development has led to significant loss of mangrove areas. Recent legislation in New Zealand has greatly enhanced the management of mangrove areas.

Federated States of Micronesia

Land area	701 sq km
Population (1995)	107,900
GNP (1992)	1,500 US$ per capita
Mean monthly temperature range (Pohnpei)	26-27°C
Mean annual rainfall	4,859 mm
Spring tidal amplitude (Palau)	0.3-1.8 m
Spring tidal amplitude (Truk)	0.3-0.7 m
Spring tidal amplitude (Yap Islands)	0.0-1.5 m
Alternative estimate of mangrove area (Ellison, 1995b)	86 sq km#
Area of mangrove on the map (Yap only)	10 sq km
Number of protected areas with mangrove	0

Map reference

Data were available for Yap only, taken from USDI (1983) based on aerial photographs of 1969 with field checking in 1980.

USDI (1983). *Topographic map of the Yap Islands (Waqab), Federated States of Micronesia*. 1:25,000. United States Department of the Interior, Geological Survey.

Fiji

Land area	18,270 sq km
Total forest extent (1990)	9,350 km
Population (1995)	762,000
GNP (1992)	2,070 US$ per capita
Mean monthly temperature range	20-30°C
Mean annual rainfall	2,974 mm
Spring tidal amplitude (Wairiki creek)	1.3 m
Alternative estimate of mangrove area (Anon. 1993)	385 sq km#
Area of mangrove on the map	517 sq km
Number of protected areas with mangrove	1

Map reference

The remaining indigenous forest in Fiji was digitised from a 1:500,000 scale forest cover map, prepared by the Ministry of Forests, Fiji, from a 1985 survey. Forest types were added with the help of the Maruia Society, Auckland, New Zealand, whose staff generously prepared a summary forest map based on the Fiji Forest Inventory carried out in 1966-9 and published in 1972, in 29 map sheets at 1:50,000 by the Directorate of Overseas Surveys, London.

Guam

Land area	1,478 sq km
Population (1995)	183,152
Mean monthly temperature range	25-31°C
Mean annual rainfall	2,362 mm
Spring tidal amplitude	0.0-0.5 m
Alternative estimate of mangrove area (Ellison, 1995b)	0.7 sq km
Area of mangrove on the map	0.94 sq km#
Number of protected areas with mangrove	0

Map references

Mangroves copied from Randall and Eldredge (1976) onto a 1:100,000 base map (USDA, 1983). Original source: 1:4,800 aerial photos. Information kindly supplied by Dr Charles Birkeland, University of Guam. Coastline and rivers digitised from USDA (1983).

Randall, R.H. and Eldredge, L.G. (1976). *Atlas of the Reefs and Beaches of Guam*, with Appendix: Estuarine and mangrove shorelines (by M.J. Wilder). Coastal Zone Management Section, Bureau of Planning, Government of Guam, Agana, Guam. 191 pp.

USDA (1983). *Island of Guam*. Approximately 1:100,000 scale. Soil Conservation Service, US Department of Agriculture.

New Caledonia

Land area	18,576 sq km
Total forest extent (1990)	9,800 sq km
Population (1995)	164,173
Mean monthly temperature range (Noumea)	19-26°C
Mean annual rainfall (Noumea)	1,020 mm
Mean annual rainfall (Poindimie, east coast)	2,687 mm
Spring tidal amplitude	0.4-1.5 m
Alternative estimate of mangrove area (Ellison, 1995b)	203 sq km
Area of mangrove on the map	456 sq km#
Number of protected areas with mangrove	0

Map reference

ORSTOM (1981). *Atlas de la Nouvelle Calédonie et Dépendances*. 1:1,000,000. Office de la Recherche Scientifique et Technique Outre-Mer, Paris, France.

New Zealand

Land area	270,990 sq km
Total forest extent (1990)	75,000 sq km
Population (1995)	3,552,000
GNP (1992)	12,000 US$ per capita
Mean monthly temperature range (sea)	15-20°C
Mean annual rainfall (Auckland)	775 mm
Spring tidal amplitude (Auckland)	0.3-3.2 m
Alternative estimate of mangrove area (Hackwell, 1989)	194 sq km
Area of mangrove on the map	287 sq km#
Number of protected areas with mangrove	1

Map references

Mangroves were copied from NZ topographic map series (Department of Lands and Survey) (various) onto a 1:700,000 base map before digitising. Source data from these maps was aerial photography undertaken between 1960 and 1982.

Department of Lands and Survey (1979-85) 1:50,000 NZMS 260. Department of Lands and Survey, New Zealand.

Department of Lands and Survey (1968-85) 1:63,360 NZMS 1. Department of Lands and Survey, New Zealand.

Solomon Islands

Land area	28,900 sq km
Total forest extent (1990)	24,000 sq km
Population (1995)	378,000
GNP (1992)	710 US$ per capita
Mean monthly temperature range	27-31°C
Mean annual rainfall	3,048 mm
Spring tidal amplitude	0.4-0.9 m
Alternative estimate of mangrove area (Ellison, 1995b)	642 sq km#
Area of mangrove on the map	No data
Number of protected areas with mangrove	0

Map reference

No data

Tonga

Land area	750 sq km
Population (1995)	99,000
GNP (1992)	1,350 US$ per capita
Mean monthly temperature range (Vava'u)	24-27°C
Mean annual rainfall	875 mm
Spring tidal amplitude	0.3-1.4 m
Alternative estimate of mangrove area (Ellison, 1995b)	10 sq km#
Area of mangrove on the map (Tongatapu only)	3.3 sq km
Number of protected areas with mangrove	1

Map reference

Data for Tonga taken from D.O.S. (1971), based on aerial photographs taken in 1968 and field checked in 1972.

D.O.S. (1971). *Tongatapu Island, Kingdom of Tonga.* 1:50,000. Series X773 (D.O.S. 6005) Sheet TONGATAPU, Edition 1-D.O.S. 1971 (reprinted 1976). Directorate of Overseas Surveys, UK and Ministry of Lands and Survey, Tonga.

Vanuatu

Land area	12,190 sq km
Total forest extent (1990)	9,140 sq km
Population (1995)	169,000
GNP (1992)	2,900 US$ per capita
Mean monthly temperature range (Vila)	22-27°C
Mean annual rainfall	2,103 m
Spring tidal amplitude	0.3-1.6 m
Alternative estimate of mangrove area (Ellison, 1995b)	28 sq km
Area of mangrove on the map	16 sq km#
Number of protected areas with mangrove	0

Map reference

Data extracted from relevant vegetation maps in Quantin (1972). (Mangroves are only shown for Vaté (1:250,000), Ile Emaé (1:100,000), Malikolo (1:200,000), Épi (1:200,000), Iles Torrès (1:100,000), Iles Banks (1:100,000), Ile Aniwa (1:100,000).)

Quantin, P. (1972). *Archipel des Nouvelles-Hébrides. Atlas des Sols et de Quelques données du Milieu Naturel.* 1:100,000-1:200,000. Office de la Recherche Scientifique et Technique Outre-Mer, Paris, France.

Western Samoa

Land area	2,840 sq km
Population (1995)	159,000
GNP (1992)	940 US$ per capita
Mean monthly temperature range (Apia)	25-27°C
Mean annual rainfall	2,800 mm
Spring tidal amplitude	<0.5 m
Alternative estimate of mangrove area (Ellison, 1995b)	7 sq km#
Area of mangrove on the map	No data
Number of protected areas with mangrove	0

Map reference

No data

Papua New Guinea

Map 6.4

Land area	462,840 sq km
Total forest extent (1990)	360,000 sq km
Population (1995)	4,344,000
GNP (1992)	950 US$ per capita
Mean monthly temperature range (Port Moresby)	27-28°C
Mean monthly temperature range (Madang)	26-30°C
Mean annual rainfall (Port Moresby)	1,011 mm
Mean annual rainfall (Madang)	3,485 mm
Spring tidal amplitude (Port Moresby)	0.6-2.3 m
Alternative estimate of mangrove area (IUCN, 1983)	4,116 sq km
Area of mangrove on the map	5,399 sq km#
Number of protected areas with mangrove	3

Papua New Guinea has large tracts of intact mangrove forest with a high species diversity extending over many thousands of shore kilometres and, in many regions, penetrating quite deeply inland. In general, mangrove development, especially of large stands, is better on the mainland along the southern coast than along the northern coast. The northern coast also has fewer species. In the islands, significant stands of mangroves are to be found, but they are patchy. Fringing mangroves are widespread where conditions are not too sandy, rocky or exposed; most river mouths have concentrations of mangroves. There are large concentrations of mangroves in the Gulf of Papua and along the coast of the Central Province. There are also significant stands of mangroves in the deltas of the Fly, Ramu and Sepik Rivers.

Mangroves in Papua New Guinea often consist of narrowly crowned trees, 20-30 metres in height, sometimes with extensive above-ground root systems without extensive undergrowth. A structure similar to this is found throughout the Indo-Malesian region. However, one distinctive feature of mangroves in Papua New Guinea is their development in seasonally dry zones, such as around Port Moresby. In these regions the height of the trees is reduced, and there is a lower species diversity.

Most mangrove forests in Papua New Guinea occur in sparsely populated regions where they remain largely pristine. Mangroves have been used for building materials, firewood, medicinal purposes and the production of tannins. *Nypa fruticans* remains one of the most useful of the mangroves, and is used for thatching, weaving and the production of sugar and ethanol. There has been little commercial exploitation of mangroves for timber, but consideration is being given to the establishment of large-scale wood-chipping operations.

Map references

Digital mapped data have kindly been provided by the Research School of Pacific and Asian Studies, Australian National University, with generous permission from the Department of Agriculture and Livestock, Papua New Guinea. These data are taken from the Papua New Guinea Resource Information System, developed by the Australian Commonwealth Scientific and Industrial Research Organisation. The source data have been generated from extensive field studies, extrapolated over the whole country by air photo interpretation of 1:50,000 and 1:80,000 images taken in the 1960s and 1970s, and mapped at a scale of 1:500,000. Although data are old it is thought that rates of change may not be large in this country, while these data are the most accurate available for this country.

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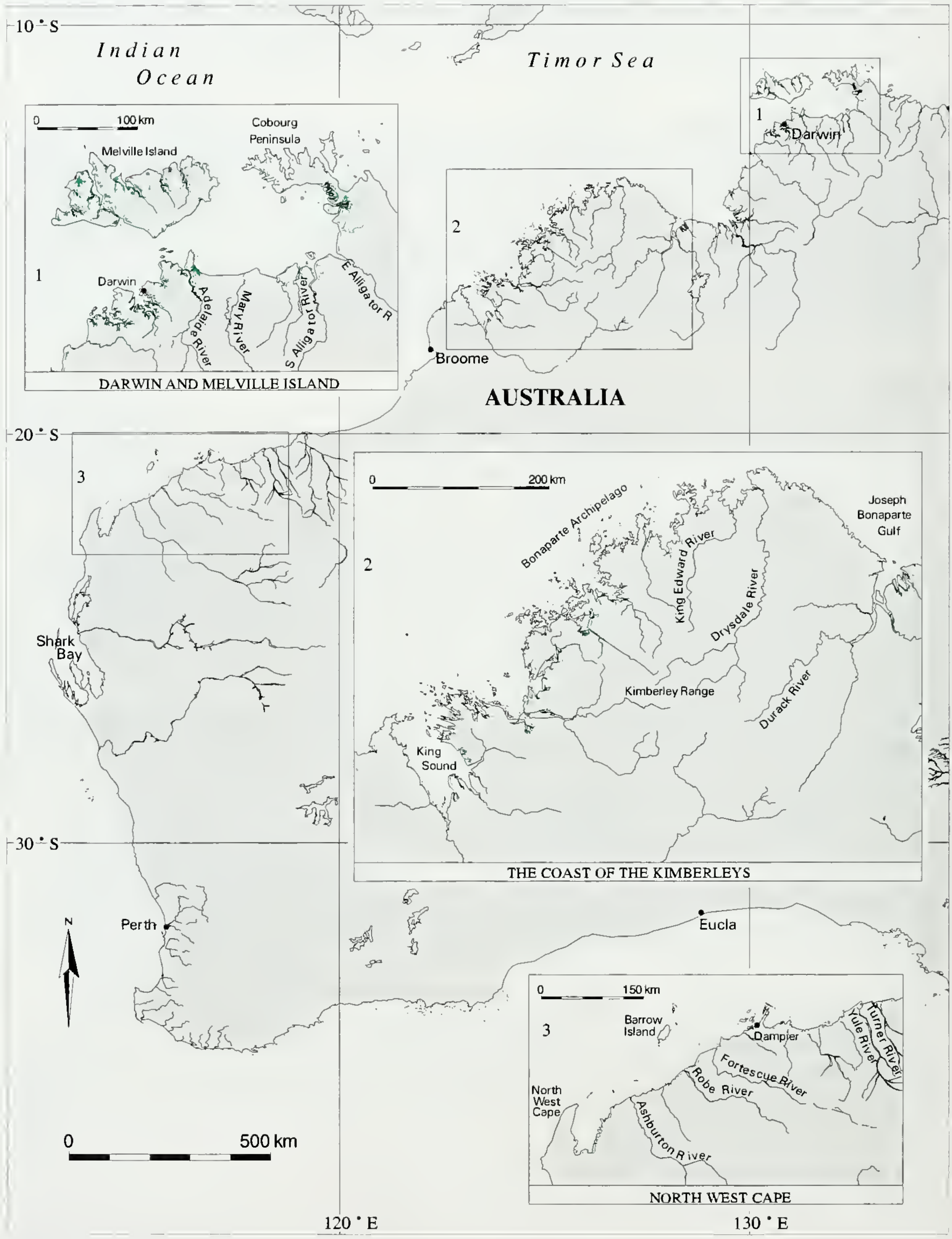
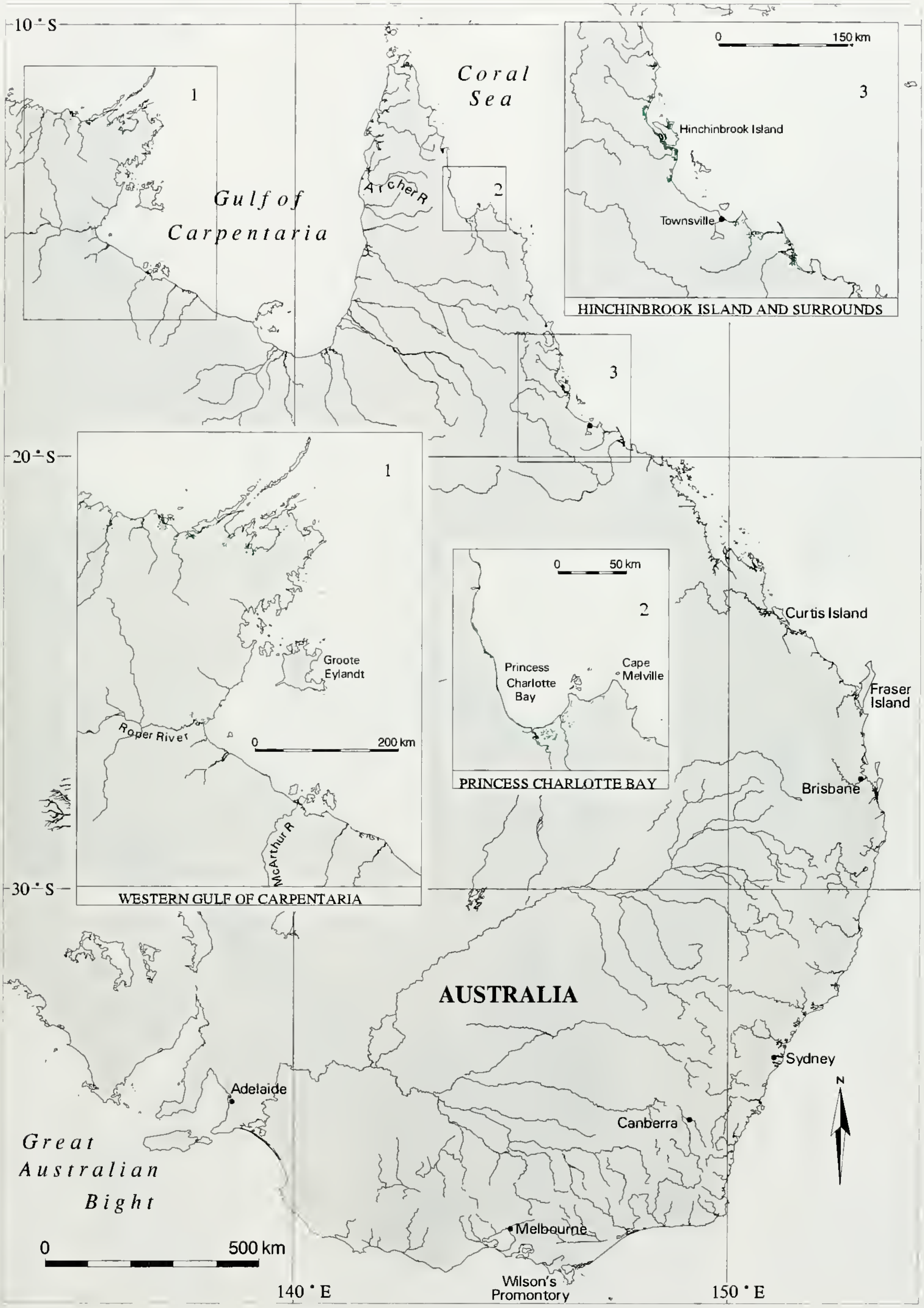
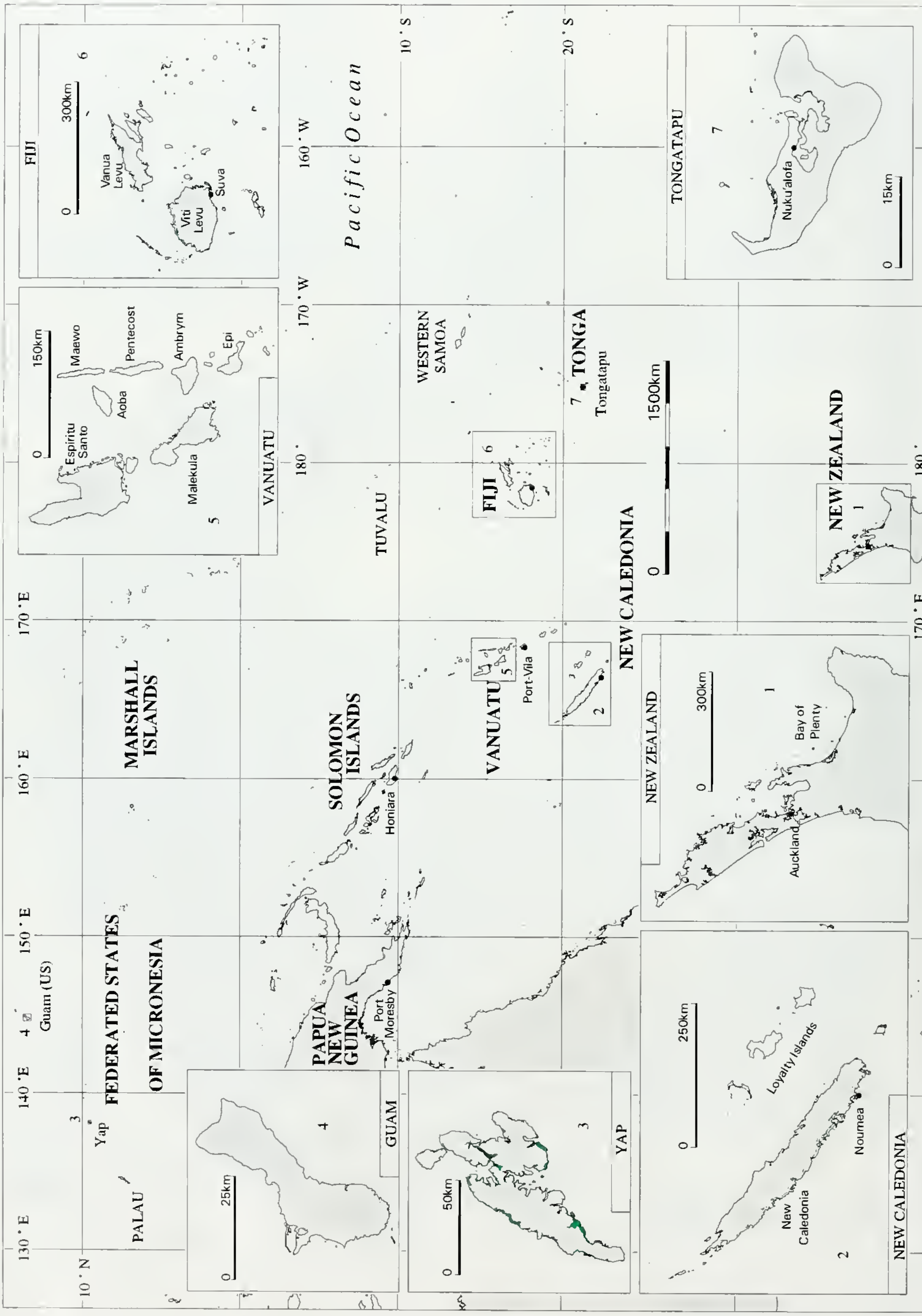


Map 6.1 Western Australia



Map 6.2 **Eastern Australia**



Map 6.3 South Pacific Islands

Map 6.4 Papua New Guinea and the Solomon Islands

7

The Americas

Mangroves in the Americas stretch from Mexico, the USA and Bermuda in the north to Peru and Brazil in the south. The mangroves of the region have been described in some detail by a number of authors (Suman, 1994; Lacerda and Field, 1993; Lacerda 1993; Scott and Carbonell, 1986; Harcourt and Sayer, 1996; Olsen *et al.*, 1996). Table 7.1 gives the mangrove species found in the Americas, by country. Mangroves are a widespread and important resource in most countries of the Americas. On the Atlantic coast, they extend from the United States of America to Brazil and on the Pacific coast from Mexico to Peru, including all of Central America and the Caribbean. The figures from this atlas suggest that mangroves cover some 49,096 sq km in the Americas, which represents some 27% of the total area of mangroves in the world. This figure comes close to the estimate of 28.6% by Lacerda (1993).

One of the most notable features of the American mangroves is their low diversity when compared to those of the Indo-Pacific region. They bear a close affinity to the mangroves of West Africa. In all, there are only thirteen native species of mangrove found in the Americas.

Six functional types of mangrove forest have been described in the New World: fringe, riverine, basin overwash, scrub and hammock (Lugo and Snedaker, 1974). Although patterns of zonation and succession have been described for many areas these often appear to be highly site specific. Hurricanes are a major natural phenomenon affecting mangrove areas, particularly in the Caribbean, and have been observed to cause total loss of mangroves from some areas. Recovery of the mangrove forests can take years or decades.

Mangroves have been used by man in the region from pre-historic times. There is evidence of human use of these areas dating back five to six thousand years. Early uses may have included timber harvesting and fishing in surrounding waters. Over time other uses developed, including collecting oysters and the use of mangroves for resins, fibres, dyes and medicine. The first detailed description of mangroves in the Americas, dating from the early sixteenth century, was by Gonzalo Fernández Oviedo y Valdés in his *Historia General de las Indias, Islas y Tierra-firme del Mar Oceano*, which includes an entire chapter on mangroves. With the European conquest of the Americas came the increased use of mangroves for timber and tannins.

More recently, important offshore fisheries that include a number of fish species that are dependent on mangroves for at least part of their life history, have been developed by a number of countries. However, large areas of mangroves are now being cleared for the development of land for agriculture, grazing, urban development and the booming tourist industry, as well as for timber and fuel. The preparation of ponds for shrimp farming is another major activity causing loss of mangroves. This activity is not so widespread as it is in southeast Asia. Other forms of damage and loss arise from the use of areas of mangroves for solid waste disposal, landfill and pollution from agricultural runoff and the oil industry. Unlike southeast Asia, few areas have been replanted with mangroves and there has been little silvicultural effort. There is now a wide range of legislation in place throughout the region to conserve mangroves including protection of mangrove areas, coastal zone management planning and restriction of land clearance, waste disposal and timber cutting.

Table 7.1 Mangrove species list for the Americas

	Aruba	Bahamas	Belize	Bermuda	Brazil	Cayman Islands	Colombia	Costa Rica	Cuba	Ecuador	El Salvador	French Guiana	Guatemala	Guyana	Hispaniola	Honduras	Jamaica	Lesser Antilles	Mexico	Netherlands Antilles	Nicaragua	Panama	Peru	Puerto Rico	Surinam	Trinidad and Tobago	Turks and Caicos	United States of America	Venezuela
Acrostichum aureum†			•				•	•	•	•					•		•	•			•	•			•			•	
Avicennia bicolor							•	•			•					•					•	•							
Avicennia germinans	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Avicennia schaueriana					•							•		•				•								•	•		•
Conocarpus erectus	•	•	•	•	•	•	•		•	•	•		•	•	•	•	•	•	•		•	•	•	•		•	•	•	•
Laguncularia racemosa		•	•		•		•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•
Mora oleifera							•															•							
Nypa fruticans																						I*							
Pelliciera rhizophorae							•	•		•											•	•							
Rhizophora harrisonii					•		•	•		•			•						•		•	•	•			•			•
Rhizophora mangle		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Rhizophora racemosa					•		•	•			•	•									•	•				•			•
Tabebuia palustria							•	•							•							•						•	

† *Acrostichum danaeifolium* exists in most places that *Acrostichum aureum* occurs but it is rarely distinguished

I* Introduced

Country sources

Aruba	Scott and Carbonell, 1986
Bahamas	Scott and Carbonell, 1986
Belize	Zisman, 1990
Bermuda	Scott and Carbonell, 1986
Brazil	Kjerfve and Lacerda, 1993
Cayman Islands	Scott and Carbonell, 1986
Colombia	Alvarez-León, 1993b
Costa Rica	Polanía, 1993
Cuba	Padrón *et al.*, 1993
Ecuador	Bodero, 1993
El Salvador	Funes, 1994
French Guiana	Blasco, this document
Guatemala	Aragón de Rendón *et al.*, 1994
Guyana	Harcourt and Sayer, 1996
Hispaniola	Harcourt and Sayer, 1996 - data for Dominican Republic
Honduras	Scott and Carbonell, 1986
Jamaica	Bacon, 1993b; Scott and Carbonell, 1986
Lesser Antilles	Bacon, 1993b; Scott and Carbonell, 1986
Mexico	Lot and Novelo, 1990
Netherlands Antilles	Scott and Carbonell, 1986
Nicaragua	Polanía and Mainardi, 1993
Panama	D'Croz, 1993b
Peru	Echevarría and Sarabia, 1993
Puerto Rico	Scott and Carbonell, 1986
Surinam	Scott and Carbonell, 1986, various WCMC files
Trinidad and Tobago	Bacon, 1993b
Turks and Caicos	Bacon, 1993b
United States of America	Snedaker, pers. comm., 1995
Venezuela	Conde and Alarcón, 1993b

Aruba and the Netherlands Antilles (leeward group) Map 7.6

Aruba and the leeward Netherlands Antilles are a group of three islands close to the Venezuelan coast. All are semi-arid, with sparse mangrove development. On Aruba, fringe communities are found along the shore of Spaans Lagoon and on some of the barrier islands which lie in a chain along the southwest coast. An important mangrove community has also developed in the brackish lake of Bubali Pond, a former saline lagoon now fed by fresh water from treated sewage discharges. Curaçao only has a few small fringe mangrove communities, while Bonaire has important fringing mangroves in the more sheltered bays. (See Lesser Antilles section for information on the windward group of the Netherlands Antilles.)

Aruba

Land area	193 sq km
Population (1991)	68,900
Average monthly temperature range	26-29°C
Mean annual rainfall	432 mm
Area of mangrove on the map	4.2 sq km#
Number of protected areas with mangrove	0

Map reference

ECNAMP - See notes under Lesser Antilles.

Netherlands Antilles (leeward)

Land area	732 sq km
Population (1991)	154,955
Average monthly temperature range	26-28°C
Average rainfall range	582 mm
Area of mangrove on the map	10.51 sq km
Number of protected areas with mangrove	0

Map reference

ECNAMP - See notes under Lesser Antilles.

Bahamas Map 7.3

Land area	13,880 sq km
Population (1995)	277,000
GNP (1992)	11,990 US$ per capita
Mean monthly temperature range	22-27°C
Average rainfall range	750-1,500 mm
Alternative estimate of mangrove area (Snedaker, pers. comm.)	2,332 sq km*
Area of mangrove on the map	2,114 sq km
Number of protected areas with mangrove	10

* considered to be an underestimate

The Bahamas constitute an archipelago of some 2,750 islands, cays and rocks spread over some 260,000 sq km of ocean. Together with the Turks and Caicos, they stand a little separate from the true Caribbean islands to the south. Mangroves form a major vegetation type on a number of the islands, with particular concentrations on Great Inagua, the Bight of Aklins (between Crooked Island and Aklins Island), the western shores of Andros and Great Abaco and the north shore of Grand Bahama. There are no major rivers and most of the mangroves are coastal or lagoon formations. The islands themselves are relatively dry, and inland the vegetation is typically low thorn-scrub with some areas of pine forest. Mud flats or 'swashes', with little or no permanent vegetation, are another important feature in the intertidal zone. Four mangrove species are found throughout the islands. Despite their extensive area, there seems to be little published material describing the mangroves of the islands. A number of mangrove sites fall within protected areas and there do not appear to be any major threats.

Map references

Maps have been copied onto a 1:1,000,000 base map from three sources: B&B (n.d.) and Sealey and Burrows (1992). None of these sources should be considered highly accurate, but better data were unavailable.

B&B (n.d.). *Bahamas North 1:500,000 Road Map.* Berndtson and Berndtson Publications, Fürstenfeldbruck, Germany. (Used for: Bimini Island - 1:100,000.)

B&B (n.d.). *Bahamas South 1:500,000 Road Map*. Berndtson and Berndtson Publications, Fürstenfeldbruck, Germany. (Used for Aklins Island - 1:500,000; Mayaguana - 1:500,000; Great Inagua - 1:500,000; Exuma Cays - 1:500,000; Cat Island - 1:500,000; San Salvador - 1:250,000; Long Island - 1:500,000.)

Sealey, N. and Burrows, E.J. (Eds) (1992). *School Atlas for the Commonwealth of the Bahamas*. Longman Group UK Ltd, Harlow, UK. 49 pp. (Used for Grand Bahama - 1:600,000; Abaco - 1:650,000; New Providence - 1:110,000; Andros - 1:730,000.)

Belize **Map 7.2**

Land area	22,960 sq km
Total forest extent (1990)	19,960 sq km
Population (1995)	209,000
GNP (1992)	2,220 US$ per capita
Average monthly temperature range	16-33°C
Mean annual rainfall range (north)	1,400-1,500 mm
Mean annual rainfall (south)	>4,000 mm
Spring tidal amplitude	0.21-0.3 m
Alternative estimate of mangrove area (ODA, 1989)	748 sq km
Area of mangrove on the map	719 sq km#
Number of protected areas with mangrove	11

Belize has a relatively extensive and varied coastline, with numerous islands and cays associated with its barrier reef and three large coral atolls. Mangroves are widespread on the coast, islands and cays. Mangrove communities include fringe mangrove forest, which on some cays extends to cover entire islands as overwash formations; sparse mangrove communities adjacent to saltmarsh; basin mangrove communities forming in depressions behind river levées and beach ridges; and riverine mangrove forests. There are some small freshwater mangrove communities, some distance inland, surrounded by non-mangrove vegetation, which appear to be relict formations. The mapping of mangroves and other habitats in Belize is well documented. The low population density in Belize means that there is relatively little pressure on the mangrove forests. Conservation efforts are being made in Belize to protect the coastal zone and this should lead to increased protection for some mangrove areas. The energy absorbing capacity of mangroves is important during tropical storms as this helps to reduce erosion on the low islands and the mainland coast, although mangroves are susceptible to considerable damage from the largest hurricanes.

Map reference

Maps were provided in digital form - this data set is described in Zisman (1992).

Zisman, S. (1992). Mangroves in Belize: their characteristics, use and conservation. Consultancy Report No 3. Forest Planning and Management Project. ODA/Ministry of Natural Resources, Belmopan, Belize. 152 pp.

Bermuda **Map 7.3**

Land area	53 sq km
Population (1990)	71,950
GNP (1991)	24,000 US$ per capita
Average monthly temperature range	17-26°C
Mean annual rainfall	1,500 mm
Alternative estimate of mangrove area (Scott and Carbonell, 1986)	0.17 sq km
Area of mangrove on the map	0.10 sq km#
Number of protected areas with mangrove	5

Bermuda has only three species of mangroves which occupy only a small area. They are of particular interest, however, because they represent the most northerly mangroves in the world (32°20'N). These mangroves are of the low island type, with salinity regimes controlled by ground water outflow. There has been some decrease in mangrove area this century due to land reclamation, anchorage and harbour development and waste disposal but it is doubtful whether the total area of mangroves has ever exceeded 0.25 sq km.

Map reference

Mangrove polygons were copied from the 1:10,560 six-map series (D.O.S., 1975) onto a c.1:100,000 base map and digitised.

D.O.S. (1975). *Bermuda*. 1:10,560 - six sheets. Series: E8110 (Bda 311) Edition: 2-Bda 1975. Directorate of Overseas Surveys, London, UK.

Brazil

Map 7.5 and 7.7

Land area	8,511,970 sq km
Total forest extent (1990)	5,611,070 sq km
Population (1995)	161,382,000
GNP (1992)	2,770 US$ per capita
Mean monthly temperature range (Maranhão)	25-27°C
Mean monthly temperature (Santa Catarina)	20°C
Mean annual rainfall (Maranhão)	2,500 mm
Mean annual rainfall (northeast)	1,500 mm
Spring tidal amplitude (Maranhão)	4-8 m
Spring tidal amplitude (Santa Catarina)	0.2-2 m
Alternative estimate of mangrove area (Kjerfve and Lacerda, 1993)	13,800 sq km
Area of mangrove on the map	13,400 sq km#
Number of protected areas with mangrove	63

Mangroves cover very large areas in Brazil with a patchy distribution along the 6,800 km of coast. The most extensive mangrove areas are in the north, in the states of Amapá, Pará, and Maranhão, where very wide tidal ranges, combined with high rainfall, encourage their development. Mangroves can extend up to 40 km inland, along estuaries. In these areas, the trees can reach a considerable height and girth, with *Avicennia* reaching more than 1 m in diameter and *Rhizophora harrisonii* being 40 to 45 m tall. The very large amount of fresh water in the Amazon estuarine area tends to restrict the distribution of mangroves, although there are many fresh water hardwoods found in this region. Around the northeastern coast the rainfall decreases, as does the tidal range. Mangroves are still widespread along the inside of bays, and along estuaries, where they are dominated by *Rhizophora mangle* which can reach 10 to 20 m in height. Mangroves are more sparsely distributed along the southeastern coast from Rio de Janeiro to Santa Catarina, where they are restricted to river deltas, coastal lagoons and the inner parts of bays. There are fewer species in these areas, which are dominated by *R. mangle*. The trees rarely exceed 10 m in height. The southernmost mangroves are found at 28°56'S.

Mangroves have a wide range of different commercial uses, some of which are very important, notably the crab, timber and tannin industries. Mangroves have been destroyed in some areas, notably for timber and for urban development in the southeast, but large areas remain relatively unthreatened, particularly in the north. Salt extraction and mariculture are practised on a very small scale, but are not expanding significantly, while reclamation for agricultural development is unlikely while there are still extensive areas of forest inland, on better soils. The earliest record of legal protection of mangroves in the region dates from 1760, when the King of Portugal, concerned about the loss of potential sources of tannin, issued an edict to restrict the cutting of mangroves for firewood unless their bark was also utilised. Some recent laws also provide for the protection of mangroves in certain areas, although enforcement is far from complete.

A highly detailed atlas of mangroves for Brazil has been prepared which maps the mangroves of the entire coast at 1:250,000, with higher resolution maps for wide areas. These maps have been prepared from aerial photography and satellite imagery (Herz, 1991).

Map reference

Data are taken from Herz (1991). The 1:250,000 maps were photo-reduced prior to digitising and hence the map prepared for this atlas does not contain the full detail portrayed in the source.

Herz, R. (1991). *Manguezais do Brasil.* Instituto Oceanográfico da Universidade de São Paulo, São Paulo, Brazil.

Cayman Islands

Map 7.3

Land area	259 sq km
Population (1990)	29,700
GNP (1992)	25,300 US$ per capita
Mean annual rainfall (Grand Cayman)	1,400 mm
Spring tidal amplitude	0.12-0.5 m
Alternative estimate of mangrove area (Bacon, 1993b)	75 sq km
Area of mangrove on the map	71 sq km#
Number of protected areas with mangrove	11

The Cayman Islands consist of three low-lying limestone islands which, although small in total area, have a relatively large area of mangroves. Mangrove lands make up some 36% of Grand Cayman, 40% of Little Cayman and 1% of Cayman Brac. Mangroves are fringe communities around the coast, lagoons and saline to brackish ponds found on the islands. The largest single community is that of the central mangrove swamp on Grand

Cayman which covers nearly 50 sq km. Extensive loss of the mangroves has occurred as a result of the 1977 Development Plan for Grand Cayman and many areas have been reclaimed for tourist development, mostly for road construction, golf courses, marinas and housing.

Map reference

D.O.S. (1978). *Cayman Islands.* 1:25,000 - four sheets. Series: E821 (D.O.S. 328) Edition: 2-D.O.S. 1978. Directorate of Overseas Surveys, UK and Survey Department, Cayman Islands.

Colombia

Map 7.6

Land area	1,138,910 sq km
Total forest extent (1990)	540,640 sq km
Population (1995)	35,101,000
GNP (1992)	1,290 US$ per capita
Mean monthly temperature range (Baranquilla)	27-28°C
Mean annual rainfall (Baranquilla)	799 mm
Spring tidal amplitude (Pacific)	>4 m
Spring tidal amplitude (Caribbean)	0.3-0.6 m
Alternative estimate of mangrove area (Alvarez-León, 1993b)	3,659 sq km#
Area of mangrove on the map	4,975 sq km
Number of protected areas with mangrove	8

Colombia has extensive coastlines along the Pacific Ocean and the Caribbean Sea. These two areas are very distinctive, with the majority of mangroves occurring in the former (70–80% of total). The Pacific coast harbours some ten species of mangroves which form dense high forests, comparable to many of those found in southeast Asia. Trees can reach a height of 40 to 50 m and form an almost continuous fringe, sometimes 20 km deep, from Cabo Corrientes to the border with Ecuador. By contrast, the much smaller Caribbean mangroves are limited in their development by drier conditions and low tidal fluctuations. On the Caribbean coast only five species of mangrove are reported.

Mangrove exploitation for timber by the Spanish began as early as the 16th century. Mangroves have been also used for tannin production, but today they are used mainly for firewood, charcoal and construction timber. Some mangrove areas have been cleared for aquacultural purposes, notably shrimp farming. In other areas, mangroves have been cleared for urban development, or degraded by agricultural contamination. Some parts of the Caribbean coast may also be suffering from reduced fresh water inputs arising from inland diversion and utilisation of water. Natural processes of erosion, accretion and siltation along central areas of the Caribbean coast have led to rapidly changing mangrove areas in this region. Accretion is also an important process on the Pacific coast south of Buenaventura.

Map reference

Basic data were derived from Ministerio de Hacienda (1985), with further edits estimated from two basic (1:5,000,000) maps provided by Sánchez, Ministerio del Medio Ambiente (1995) and minor corrections provided by François Blasco.

Ministerio de Hacienda (1985). *República de Colombia: Mapa de Bosques.* 1:1,500,000. Produced by the Ministerio de Hacienda and Instituto Geográfico 'Agustin Codazzi'.

Costa Rica

Map 7.2

Land area	51,100 sq km
Total forest extent (1990)	14,280 sq km
Population (1995)	3,424,000
GNP (1992)	2,010 US$ per capita
Average temperature	26°C
Mean annual rainfall (Lepanto - Golfo de Nicoya)	1,654 mm
Mean annual rainfall (Palmar Sur)	3,676 mm
Mean tidal range	3.6 m
Alternative estimate of mangrove area (Polanía, 1993)	412 sq km
Area of mangrove on the map	370 sq km#
Number of protected areas with mangrove	9

The Pacific coast of Costa Rica is about five times as long as the Caribbean coast due to a complex structure of many embayments, estuaries and gulfs. Mangrove forests occupy about 35% of this coast and make up 99% of all of Costa Rica's mangrove area. In the north, mangroves are not highly developed structurally as they have a canopy height of only about 20 m due to the low rainfall and a long dry season (December to April). South of the Golfo de Nicoya, there is a transition zone where the forests are more diverse and better developed, with trees reaching a height of 45 m as a result of higher rainfall and a shorter dry season (less than three months). The Golfo de Nicoya has an important fin fishery associated with the mangroves, while cockles (*Anadara tuberculosa* and *A. similis*) are widely exploited commercially. Mangroves have been used for timber, charcoal and tannin production, but not extensively. Forest clearance for aquaculture, salt production and fuelwood for salt crystallisation has led to loss of mangrove areas in the north. To the south, the mangroves of Térraba-Sierpe are of considerable interest and have been declared a Mangrove Forest Reserve, with a series of management and conservation activities, including sustainable development of charcoal production.

Map reference

Instituto Geográfico Nacional (various dates). *Costa Rica.* 1:200,000. Instituto Geográfico Nacional, San José, Costa Rica. Individual maps titled as follows: *CR2CM-1 Liberia.* Edición 1-IGNCR. Prepared: 1970; *CR2CM-2 San Carlos.* Edición 1-IGNCR. Prepared: 1970, revised: 1988; *CR2CM-3 Barra del Colorado.* Edición 1-IGNCR. Prepared: 1970, revised: 1988; *CR2CM-4 Nicoya.* Edición 2-IGNCR. Prepared: 1968, revised: 1988; *CR2CM-5 San José.* Prepared: 1968, revised: 1988; *CR2CM-6 Limon.* Edición 1-IGNCR. Prepared: 1969; *CR2CM-7 Quepos.* Prepared: 1969, revised: 1988; *CR2CM-8 Talamanca.* Prepared: 1970, revised: 1988; *CR2CM-9 Golfito.* Prepared: 1970, revised: 1988.

Cuba **Map 7.3**

Land area	110,860 sq km
Total forest extent (1990)	17,150 sq km
Population (1995)	11,091,000
Mean annual temperature and range	26°C (10-36°C)
Mean annual rainfall	1,200 mm
Spring tidal amplitude	0.9 m
Alternative estimate of mangrove area (Padrón *et al.*, 1993)	5,569 sq km
Area of mangrove on the map	7,848 sq km#
Number of protected areas with mangrove	8

Cuba is the largest of the Caribbean islands. It has a long coastline with numerous bays, lagoons and barrier islands. Mangroves cover nearly 5% of the total area of Cuba, making up one quarter of the total forest area. They play an important role protecting large parts of the coast from erosion, particularly during tropical storms, although coastal erosion processes themselves are responsible for mangrove loss in some areas. Mangroves are not heavily used for timber production, but are increasingly used for fuelwood, notably by the sugar industry. During the flowering of the mangroves, particularly *Avicennia*, over 40,000 bee hives are transported to the mangrove areas, particularly on the south coast. Fin and shell fisheries are also important. Human impacts have caused industrial and agricultural contamination and some deforestation. The largest single area of mangroves occurs on the Zapata peninsula on the south coast which contains very important waterfowl and other wildlife, including the endemic Cuban crocodile, *Crocodylus rhombifer*. This site is partially protected by legislation. Since 1980, there has been a mangrove replanting scheme which has planted mangroves over some 257 square kilometres. Under the National Forestry Policy replanting will continue, while other management plans are developed for protection and utilisation of mangrove resources.

Map reference

Academia de Ciencias de Cuba (1989). *Nuevo Atlas Nacional de Cuba: X Flora y Vegetación: 1 Vegetación Actual.* 1:1,000,000 Academia de Ciencias de Cuba. The vegetation map was prepared by Capote López, R.P., Ricardo Nápoles, N.E., González Areu, A.V., Garcia Rivera, E.E., Vilamajo Alberdi, D. and Urbino Rodríguez, J.

Dominican Republic and Haiti **Map 7.3**

The island of Hispaniola comprises the countries of the Dominican Republic and Haiti. It is second only to Cuba in size in the Caribbean. Mangroves are found in both countries, with the largest single areas being along the north coast of the Dominican Republic, in the bay areas at Monte Cristi and at Bahia de Samaná. In Haiti, the main areas for mangroves are along the north coast, east from Cap Haitien and on the west coast, south of Gonaives. Widespread destruction of mangrove areas is expected in the Dominican Republic arising from extensive development for the tourism industry. By contrast, in Haiti, mangroves are one of the least threatened ecosystems; they are used for charcoal and polewood, but this is not thought to have a significant impact.

Dominican Republic

Land area	48,730 sq km
Total forest extent (1990)	10,770 sq km
Population (1995)	7,915,000
GNP (1992)	1,040 US$ per capita
Mean monthly temperature range	24-27°C
Mean annual rainfall	1,400 mm
Alternative estimate of mangrove area (Alvarez, 1994)	325 sq km#
Area of mangrove on the map	(696 sq km)
Number of protected areas with mangrove	6

Map reference

Data taken from map in Schubert (1993) which is approximately 1:2,000,000, based on 1984 aerial photographs.

Schubert, A. (1993). Conservation of biological diversity in the Dominican Republic. *Oryx* 27: 115-121.

Haiti

Land area	27,750 sq km
Total forest extent (1990)	230 sq km
Population (1995)	5,968,000
GNP (1991)	380 US$ per capita
Mean monthly temperature range	25-29°C
Mean annual rainfall	1,321 mm
Area of mangrove on the map	134 sq km#
Number of protected areas with mangrove	0

Map reference

The full reference for the source map is unavailable, but its source data include aerial photographs from 1978 taken at 1:40,000 and 1982 agriculture maps.

Unknown (n.d.). *Atlas d'Haiti*. Planche 8 Ecologie, by Roca, P.-J. 1:1,000,000. Full reference unavailable.

Ecuador

Map 7.6

Land area	283,560 sq km
Total forest extent (1990)	119,620 sq km
Population (1995)	11,822,000
GNP (1992)	1,070 US$ per capita
Mean annual temperature (Motaje-Santiago-Cayapas)	23°C
Mean annual temperature (Guayas Basin)	25°C
Average rainfall range (Motaje-Santiago-Cayapas)	3,000-4,000 mm
Average rainfall range (Guayas Basin)	300-400 mm
Spring tidal amplitude	2.5-3 m
Spring tidal amplitude (Gulf of Guayaquil)	5.29 m
Alternative estimate of mangrove area (Bodero, 1993)	1,621 sq km
Area of mangrove on the map	2,469 sq km#
Number of protected areas with mangrove	4

In Ecuador, mangroves are concentrated around river estuaries, with the largest single area being around the Guayas River estuary and Guayaquil Gulf (1,099 sq km). The other major area lies close to the Colombian border in the north, the Santiago-Cayapas-Mataje estuarine zone, where very high rainfall provides for some of the best developed mangroves in the Pacific, with trees reaching over 50 m in height. Away from the estuaries, substantial areas of the coast are steeply shelving and provide little opportunity for mangrove development. Riverine mangroves are the most structurally developed, due to the high levels of freshwater input. Two other structural forest types occur: basin forests, flooded by the highest tides and characterised by high salinity, and fringe mangroves which include the bulk of mangroves in the country. As in other countries in the region, mangroves have been used for timber, charcoal and tannins, but in Ecuador, the most important uses have been the conversion of mangrove land for aquaculture, salt production and agriculture. The creation of shrimp farms has led to the conversion of some 400 sq km of mangrove. A further 400 sq km has been converted for cattle grazing. The shrimp industry has been extremely profitable to Ecuador, but a large number of ponds are now unproductive due to salinisation and acidification. The creation of new ponds is now largely restricted to tidal flats. Scallops and crabs provide important shellfish products from the mangroves, with the river estuaries in the north producing 2 to 2.5 million scallops per month. Estimates as to the total area of mangrove in Ecuador vary considerably; two extremes are given in the table, but other estimates include 2,377 sq km (in 1987) and

1,776 sq km (in 1991) (Harcourt and Sayer, 1996). In the absence of further details as to how these areas were calculated, it is difficult to assess which is the most accurate.

Map reference

CLIRSEN/DINAF (1991). *Republica del Ecuador - Mapa Forestal.* 1:1,000,000. Centro de Levantamientos Integrados de Recursos Naturales por Sensores Remotos (CLIRSEN) and Dirección Nacional Forestal (DINAF).

El Salvador

Map 7.2

Land area	21,040 sq km
Total forest extent (1990)	1,230 sq km
Population (1995)	5,768,000
GNP (1992)	1,170 US$ per capita
Mean monthly temperature range (San Miguel)	25-28°C
Mean annual rainfall (San Miguel)	1,700 mm
Alternative estimate of mangrove area (Funes, 1994)	268 sq km#
Area of mangrove on the map	446 sq km
Number of protected areas with mangrove	2

El Salvador is the smallest of the Central American countries and the only one without a Caribbean coastline. High population densities have led to massive deforestation inland and mangroves now represent one of the major forest types in the country. Mangroves are found all along the coast but are concentrated in the coastal lagoons and estuaries. The most notable areas are the Punta San Juan and the Rio Lempa estuaries in the centre and east of the country, and Golfo de Fonesca on the Nicaraguan border. In the west, mangrove communities are found behind the Barra de Santiago Lagoon. Mangroves have been exploited for tannins, charcoal and timber and may be threatened by agricultural encroachment and the development of salt pans and shrimp ponds, although by law they belong to the government. The area of mangrove presented on the map is likely to be a considerable over-estimate and includes related habitats. A government estimate based on a forest inventory between 1973 and 1975 put the total area of mangroves at 344 sq km, while a more recent study, based on aerial photographs, showed a 22% decrease. The latter study showed a total mangrove area of 268 sq km, but pointed to the original area of 459 sq km of which some 60% was actual mangrove habitat, with much of the remainder being made up of agricultural land on former mangrove areas, salt flats and open water. It is likely that the rate of mangrove loss is accelerating.

Map reference

Ministerio de Agricultura y Ganadería (1981). *Mapa de Vegetación Arbórea de El Salvador.* 1:200,000. Ministerio de Agricultura y Ganadería, Direccion General de Recursos Naturales Renovables, Programa Determinacion del Uso Potential del Suelo.

French Guiana

Map 7.5

Land area	90,000 sq km
Population (1995)	114,000
Mean annual rainfall	2,000 mm
Average tidal range	2 m
Alternative estimate of mangrove area (Saenger *et al.*, 1983)	(55 sq km)#
Area of mangrove on the map	(951 sq km)
Number of protected areas with mangrove	0

The coastline of French Guiana is highly dynamic, with rapid accretion and erosion processes occurring. Mangroves are largely fringe communities occupying a thin band along most of the coastline, broken by a few sandy beaches and rocky headlands. In many areas there appears to be a clear coastal zonation, with *Laguncularia racemosa* on the seaward edge, backed by well-developed stands of *Avicennia germinans*, typically reaching 5-8 m in height. *Rhizophora* is more closely associated with riverine mangrove communities. Behind the mangrove communities there are typically swamp forests or herbaceous swamps. There is very little threat to the mangroves for timber or fuel as the rest of the country is heavily forested. Mangroves are important for the shrimp industry and as a nursery for penaeid shrimp larvae. The shrimp industry provides the country's main export and is a major source of employment. Estimates of mangrove area vary considerably, which may in part be a function of the highly dynamic nature of these communities.

Map reference

ORSTOM (1979). *Végétation - La Guyane: Planche 12.* Atlas des Départements d'Outre-Mer, Centre d'Etudes de Géographie Tropicale - Office de la Recherche Scientifique et Technique Outre-Mer, Paris, France.

Case study

The mangroves of French Guiana: a dynamic coastal system

The three countries commonly known as the Guianas stretch along the South American coast from Brazil to Venezuela, between the mouth of the Amazon and the delta of the Orinoco. They harbour a set of highly dynamic coastal mangroves. The great instability of the mangroves is almost certainly related to the strong coastal currents in this region, which carry heavy sediment loads from the Amazon. Sudden and aperiodic mass mortality of the mangroves has been observed in the region (Plate 7.1), immediately followed by spectacular coastal erosion, but the exact biophysical mechanisms causing this are unknown. The case study presented here relates to the mangroves of French Guiana near the launching site of Earth Observation Satellites, at Kourou.

The coastal vegetation of French Guiana is shown in Figure 7.1. The mangroves are not very extensive (55 sq km), when compared to those of neighbouring countries such as Surinam (1,150 sq km) and Guyana (800 sq km). However, their evolutionary trends, community dynamics, dominant species (*Avicennia germinans*), as well as their characterisation from space, may be considered typical for this part of the world.

The general formation of these mangroves (see Figure 7.2) is coastal, a few metres to a few kilometres in width. This fringe includes only two species of trees, the commonest being *Avicennia germinans*, a fast growing tree (about 1 m per year) usually creating monospecific stands of about 5 m to 8 m in height, together with *Laguncularia racemosa*, a pioneering bushy species often found on the seaward edge of the mangrove, mixed with *Spartina brasiliensis*, an American saltmarsh species (Graminae) which can be considered as ecologically equivalent to *Porteresia coarctata* in Asia (Bay of Bengal). Competition between *Laguncularia* and *Avicennia* is a common feature. The latter usually eliminates the former in older mangrove stands.

This zonation pattern can easily be detected from satellite images. Upstream, along the river banks, a further narrow mangrove type can be discriminated with aerial photography. This is a common riverine vegetation type with *Rhizophora mangle*. The appearance of *Pterocarpus officinalis*, a tree with conspicuous buttresses, in the environment is indicative of a classic freshwater swamp forest.

In this densely wooded country the mangroves are not widely utilised. The irregular and unexplained cycle of spectacular erosion and accretion does not appear to affect the total areal extent of mangroves, which remains almost constant.

The image presented in Figure 7.3 has been prepared from the combination of SPOT imagery with radar satellite imagery (ERS-1). Using these techniques it is possible to distinguish quite fine variation in land cover and basic zonation patterns.

Environmental data

• Mean annual rainfall	≥2,000 mm/year
• Dry season	2 to 4 dry months
• Mean water salinity	10 to 25‰
• pH of the topsoil	7
• Dominant soil type	Grey, blueish clay
• Average tidal amplitude	2 m
• Average population density	About 0.7 people per sq km for the total territory (90,000 sq km)
• Total areal extent	55 sq km
• Dominant mangrove type	Almost monospecific coastal stands of *Avicennia germinans*, with some *Laguncularia racemosa*

Plate 7.1 An illustration of the natural changes in *Avicennia* mangrove stands. Mass mortality in some areas is compensated by the colonisation of areas of new accretion

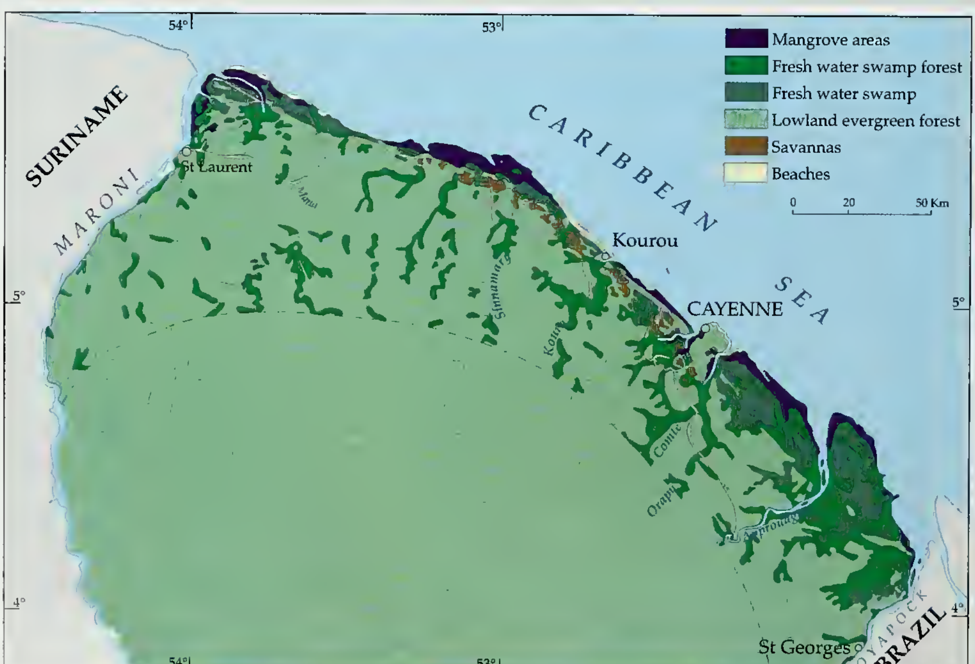


Figure 7.1 Coastal vegetation of French Guiana

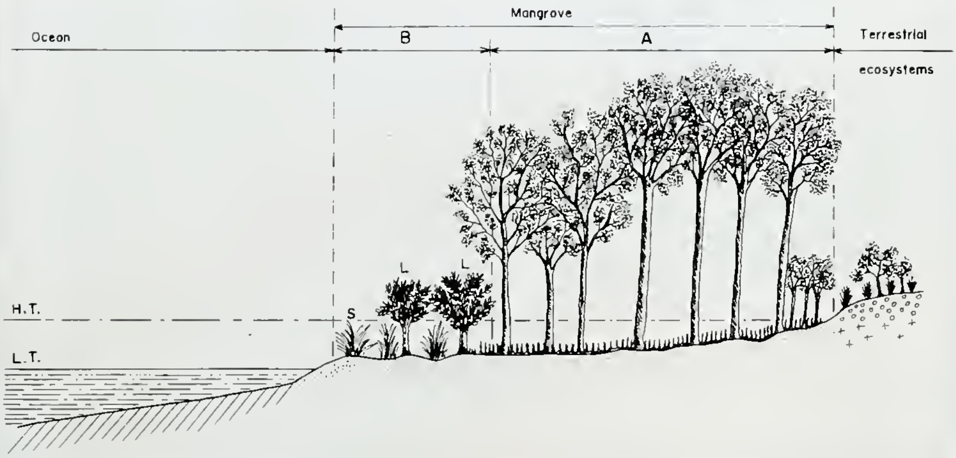


Figure 7.2 Zonation in the mangroves of French Guiana

A *Avicennia germinans* belt. Almost monospecific stands. The individual stands have practically the same size and the same age

B *Laguncularia* (= L) belt in which a grass (S = *Spartina brasiliensis*) is often found, especially on recently accreted mud

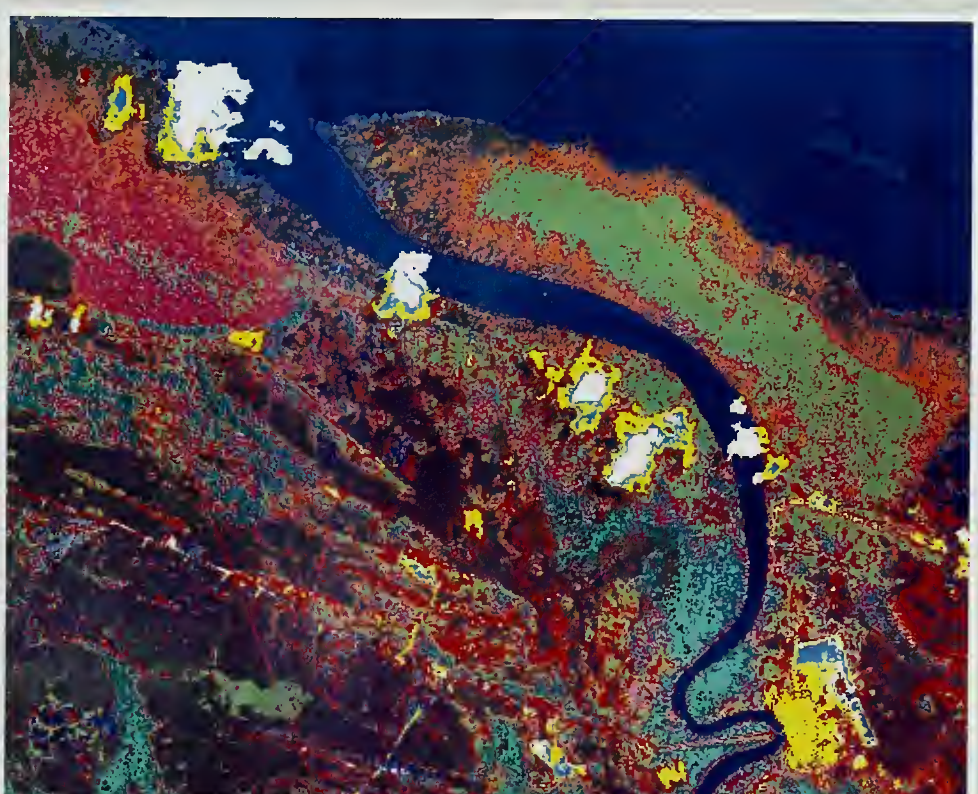


Figure 7.3 A satellite view of the mangroves of Sinnamary estuary in French Guiana. A colour classification resulting from a combination of SPOT and ERS-1

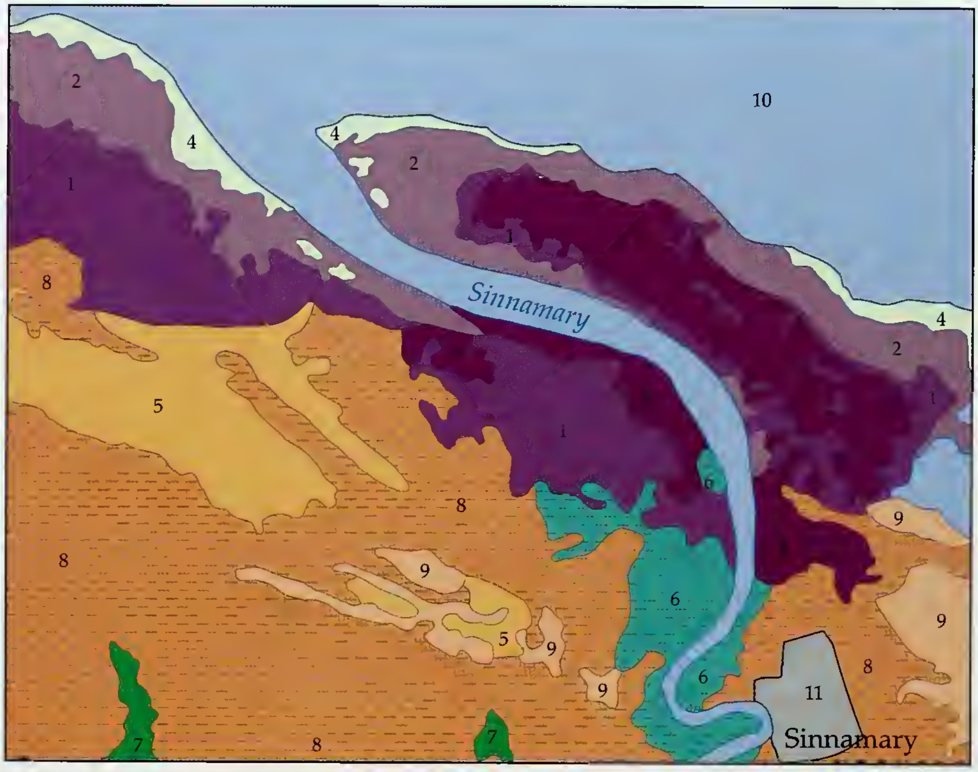


Figure 7.4 A rough interpretation of Figure 7.3 after field trip investigations

Coastal zone

1. Dense, mature mangrove stands (*Avicennia germinans*)
2. Dying mangroves
3. Mixed types (mangroves with *Rhizophora* and freshwater swamp forests)
4. Naturally destroyed mangove

Mainland

5. Thickets and forests on sandy soils
6. Freshwater swamp forest
7. Dense evergreen forest
8. Permanently flooded grassland
9. Periodically flooded grassland
10. Water
11. Town

Guatemala

Map 7.2

Land area	108,890 sq km
Total forest extent (1990)	42,250 sq km
Population (1995)	10,621,000
GNP (1992)	980 US$ per capita
Average tidal range (Caribbean)	0.9 m
Spring tidal amplitude (Pacific)	2 m
Area of mangrove on the map	161 sq km#
Alternative estimate of mangrove area (Aragón de Rendón *et al.*, 1994)	160 sq km
Number of protected areas with mangrove	3

In Guatemala, the mangroves are concentrated in lagoons along the Pacific coast. The largest single area is around the lagoons, estuaries and deltas in the west near the Mexican border and the Rio Ococito. Towards the east, significant mangrove areas are found in the Rio Acome estuary, the Monterrico Lagoons and the Rio Paz estuary. There are only a few small areas on the Caribbean coast (total 6 sq km) along the Bahia de Amatique and the delta of the Rio Chocon. In all areas mangroves are exploited for charcoal, firewood and timber. Shrimp farming, shrimp fishing and salt extraction are important. and also represent a threat to many areas. Significant areas are also being cleared for agriculture and urban development. There has been a considerable loss of mangroves in Guatemala. The total area of mangroves in 1965 was estimated at 234 sq km, and was reduced to 165 sq km by 1974 and 139 sq km by 1984. These estimates were based on aerial photographs. A subsequent figure, calculated from 1988 satellite imagery, of 160 sq km, was published in the 1989 Forestry Action Plan.

Map reference

Data for the source map originate from a 1992 1:250,000 map, *Mapa Preliminar de la Cubierta Forestal de Guatemala.*

Anon. (n.d.). *Cubierta Forestal de la República de Guatemala - Plan de Acción Forestal de Guatemala.* 1:500,000.

Guyana

Map 7.5

Land area	214,970 sq km
Total forest extent (1990)	184,160 sq km
Population (1995)	834,000
GNP (1992)	330 US$ per capita
Mean monthly temperature range	26-27°C
Average rainfall range	2,280 mm
Alternative estimate of mangrove area (GFC/CID, 1989)	800 sq km#
Area of mangrove on the map	(717 sq km)
Number of protected areas with mangrove	0

Mangroves are the only trees in this densely forested country which have been significantly depleted by man. They originally covered a large proportion of the country's coastal zone, but have been heavily reclaimed for agriculture and cut for fuelwood, charcoal and timber. Major remaining mangrove stands exist between the Pomeroon and Waini Rivers to the west, where there are few people. *Avicennia germinans* tends to dominate on the exposed coastal mudflats, where it can grow to 20 to 25 m in height. *Rhizophora mangle* occurs in more sheltered areas. Honey production is important in some areas using the flowers of *A. germinans*, while the bark of *R. mangle* is still used for tannin production. There have been some proposals for the protection of mangroves and for afforestation projects as a means of shoreline protection, but there has been little action to date.

Map reference

Map data were supplied in digital format from the World Wildlife Fund (USA). These data are of unknown origin, but have been published in Olson *et al.* (1996).

Olson, D. M., Dinerstein, E., Cintrón, G. and Iolster, P. (1996). A conservation assessment of mangrove ecosystems of Latin America and the Caribbean. Report from WWF's Conservation Assessment of Mangrove Ecosystems of Latin America and the Caribbean Workshop, December 2-4, 1995, Washington D.C., USA.

Honduras

Map 7.2

Land area	112,090 sq km
Total forest extent (1990)	46,050 sq km
Population (1995)	5,968,000
GNP (1992)	550 US$ per capita
Alternative estimate of mangrove area (Oyuela, 1994)	1,458 sq km#
Area of mangrove on the map	(2,316 sq km)
Number of protected areas with mangrove	12

In Honduras, substantial areas of mangrove are found on both the Caribbean and Pacific coasts. The Pacific coastline is small and lies entirely within the Golfo de Fonesca which is largely fringed by mangrove communities. The Caribbean coastline has wide areas of mangroves associated with lagoons, estuaries and deltas. The largest areas are in the west of the country, around the numerous lagoons in that area, notably Laguna de Caratasca. Clearance of mangroves for shrimp farms has been extensive and rapid in recent years, but it is probable that mangroves play an important role in the local and commercial estuarine fishing industry. Estimates of mangrove area in Honduras vary considerably from 460 sq km to 1,450 sq km (see Harcourt and Sayer, 1996). It is likely that the mangrove area taken from the map of 2,310 sq km is a considerable over-estimate, errors having arisen during the harmonisation of the data from the source map with a different coastline.

Map reference

COHDEFOR (n.d.). Mapa de Recursos Costeros. 1:1,000,000. Unpublished map. COHDEFOR.

Jamaica

Map 7.3

Land area	10,990 sq km
Total forest extent (1990)	2,390 sq km
Population (1995)	2,547,000
GNP (1992)	1,340 US$ per capita
Mean monthly temperature range (Kingston)	24-27°C
Average rainfall range (Kingston)	800 mm
Alternative estimate of mangrove area (Bacon, 1993)	106 sq km#
Area of mangrove on the map	(19 sq km)
Number of protected areas with mangrove	1

Mangroves are found around the entire coast of Jamaica, but the largest concentrations are on the south coast, associated with a variety of bays, lagoons and inlets. By contrast, the best structural development occurs on the north coast with tree densities of forty or more per hectare and with a mean height of 16 m (Florida Lands, Falmouth). The south coast is much drier and trees rarely exceed 6 m in height. The largest single areas are lagoon fringe communities, but a wide range of other community types are found, including basin, estuarine and even small overwash communities on offshore cays. Traditional uses include charcoal production, fishing and oyster collecting. Substantial areas have been cleared for urban development and the backs of other areas reclaimed for agriculture. About 30% of the original mangrove area is thought to have been lost, and damage is continuing with uncontrolled artisan activities, urban sprawl and the dumping of waste. Map 7.3 shows only 19 sq km of mangrove. This figure was derived from recent satellite imagery and a large underestimate may have arisen from the patchy nature of the mangroves coupled with their scrub-like physiognomy in many areas. Both these factors might preclude appearance on satellite images. Interestingly, a similar area was estimated in another report which differentiated 'mangrove forest' (22 sq km) from areas described as 'mangrove scrub' (see Harcourt and Sayer, 1996).

Map reference

Digital data of Jamaica's vegetation were kindly made available by Doug Muchoney and Susan Iremonger of TNC, who, together with Robb Wright and in collaboration with the Conservation Data Centre - Jamaica, have compiled vegetation cover information for the whole of the country. A written report titled *Jamaican Vegetation Types: a New Classification and Map* (in press), outlines detailed findings of their data collection and research and presents a description of the new classification.

Lesser Antilles **Map 7.4**

The islands of the Lesser Antilles comprise Anguilla, Antigua and Barbuda, Barbados, British Virgin Islands, Dominica, Grenada, Guadeloupe, Martinique, Montserrat, Netherlands Antilles, St Kitts and Nevis, St Lucia, St Martin and Barthélemy, St Vincent and the Grenadines, and the US Virgin Islands.

These islands make up the eastern edge of the Caribbean Sea, stretching from the Virgin Islands in the north to Grenada in the south. They include a wide range of high and low islands, some large and heavily forested, others dry and barren. The most widespread mangrove communities are small fringing communities associated with bays, lagoons and ponds, while the largest communities occur in river mouths. Use of mangroves is highly varied between islands, as might be expected, not only from the differences in area and condition of mangroves, but also from the differences in economic status and culture. In some islands, mangroves are widely used for timber and fisheries. In many of the islands there is a threat to the mangroves from the rapidly expanding tourist industry. The following brief notes are provided on an island by island basis.

Anguilla is a low-lying island with only a very small area of mangrove.

Antigua and Barbuda have many mangrove areas on both islands with the largest being the 2.25 sq km Hansons Bay (Antigua) swamp, with some trees reaching over 10 m, and the 3.52 sq km forest in Codrington Lagoon (Barbuda). Elsewhere, mangrove areas are mostly fringe and basin communities with scrubby trees.

Barbados has only one significant mangrove area, at Graeme Hall (0.07 sq km). This is largely surrounded by urban development.

British Virgin Islands have mangroves scattered throughout the islands, mostly as scrubby fringe communities with the largest single area being some 3.4 sq km on the eastern end of Anegada. Mangroves have been declared a "critical natural resource" by the government and some areas are protected under conservation and planning legislation.

Dominica has very restricted mangrove development, probably due to the steeply shelving coast.

Grenada and the Grenadines have a number of small, mostly shrubby mangrove communities, but at the largest site on Grenada, Levera Pond (0.33 sq km), trees have a mean height of 15 m.

Guadeloupe has extensive mangroves (61 sq km) in the Grand Cul de Sac Marin and the narrow channel between Grand-Terre and Basse-Terre. These partly fall within protected areas. Smaller mangrove communities are found in the various bays and estuaries of both islands.

Martinique has a large area of mangrove swamps along the Baie de Fort-de-France. Smaller mangrove areas occur in the sheltered bays along the south and east coasts of the island.

Montserrat has poorly developed mangroves due to the steeply shelving shores. Fox's Bay (0.02 sq km) is the only significant site and is a bird sanctuary.

Netherlands Antilles (windward group) have fringe mangroves in parts of the Simpson Bay Lagoon on St Martin, although most have been destroyed by extensive tourism developments. Mangroves are not found on Saba or St Eustatius. (See Aruba for leeward group.)

St Kitts and Nevis have a few small mangrove sites, as basin communities on St Kitts and estuarine communities on Nevis. The largest site is Greatheeds (0.22 sq km), on St Kitts. It is largely scrubby but has five mangrove species. Some sites are protected.

St Lucia has a number of well-developed mangrove areas, notably estuarine and basin formations. These are not threatened although there is some charcoal production. Stands of *Rhizophora mangle* have a mean height of 23 m at Esperance Harbour. In recognition of their importance for fisheries, most of the larger sites have been protected as Marine Reserves.

St Martin and St Barthélemy are administered with Guadeloupe. St Martin shares the Grand Etang de Simpsonbaai (Simpson Bay Lagoon) with the Dutch half of the island. Mangroves are found in a number of small lagoons to the north and east. The eastern part of St Barthélemy has well-developed fringing and lagoon mangrove areas.

St Vincent and the Grenadines have scattered mangrove communities throughout the islands, mostly small and scrubby. In a number of areas they are threatened by solid waste disposal and land reclamation.

US Virgin Islands have mangrove sites scattered throughout the islands, with the largest sites being found on St Croix. These are mostly associated with saline ponds and lagoons. Some sites are threatened by urban development, dumping and landfill. The Virgin Islands National Park on St John includes some mangrove areas.

Anguilla

Land area	155 sq km
Population (1992)	8,960
Alternative estimate of mangrove area (Bacon, 1993b)	0.9 sq km
Area of mangrove on the map	5.17 sq km#
Number of protected areas with mangrove	0

Map reference

ECNAMP *

Antigua and Barbuda

Land area	440 sq km
Population (1995)	68,000
Alternative estimate of mangrove area (Bacon, 1993b)	(49 sq km)†
Area of mangrove on the map	13.16 sq km#
Number of protected areas with mangrove	0

† Figure includes salt ponds

Map reference

CCA (1991). *Antigua and Barbuda: Country Environmental Profile.* Caribbean Conservation Association, St Michael, Barbados. 212 pp.

Barbados

Land area	430 sq km
Population (1995)	261,000
GNP (1992)	6,530 US$ per capita
Alternative estimate of mangrove area (Bacon, 1993b)	0.07 sq km#
Area of mangrove on the map	0.30 sq km
Number of protected areas with mangrove	1

Map reference

ECNAMP *

British Virgin Islands

Land area	130 sq km
Population (1991)	16,749
GNP (1989)	10,000 US$ per capita
Area of mangrove on the map	4.35 sq km#
Number of protected areas with mangrove	1

Map reference

ECNAMP *

Dominica

Land area	750 sq km
Population (1995)	71,000
GNP (1992)	1,040 US$ per capita
Area of mangrove on the map	1.56 sq km#
Number of protected areas with mangrove	7

Map reference

ECNAMP *

Grenada

Land area	340 sq km
Population (1995)	92,000
GNP (1992)	2,310 US$ per capita
Mean annual temperature	24°C
Mean annual rainfall (coastal areas)	1,500 mm
Alternative estimate of mangrove area (Bacon, 1993b)	2.35 sq km#
Area of mangrove on the map	5.36 sq km
Number of protected areas with mangrove	0

Map reference

ECNAMP *

Guadeloupe (including St Martin and St Barthélemy)

Land area	1,705 sq km
Population (1990)	378,178
Average monthly temperature range	23-27°C
Mean annual rainfall	1,814 mm
Area of mangrove on the map	39.83 sq km#
Number of protected areas with mangrove	1

Map reference

St Martin and Barthélemy data taken from ECNAMP *, Guadeloupe from CNRS (1980).

CNRS (1980). *La Guadeloupe, Végétation.* Planche 9, Atlas des Départements d'Outre-Mer. 1:150,000. Centre d'Études de Géographie Tropicale, C.N.R.S. 33405 Talence, France.

Martinique

Land area	1,079 sq km
Population (1990)	359,572
Area of mangrove on the map	15.87 sq km#
Number of protected areas with mangrove	3

Map reference

IGN (n.d.). *Martinique.* Carte 511, 1:100,000. Institut Géographique National, Paris, France.

Montserrat

Land area	106 sq km
Population (1985)	11,852
GNP (1985)	3,127 US$ per capita
Average monthly temperature range	24-27°C
Mean annual rainfall	1,628 mm
Alternative estimate of mangrove area (Bacon, 1993b)	0.02 sq km#
Area of mangrove on the map	0.31 sq km
Number of protected areas with mangrove	1

Map reference

ECNAMP *

Netherlands Antilles (windward group)

Land area	68 sq km
Population (1991)	36,356
Area of mangrove on the map	0.87 sq km
Number of protected areas with mangrove	0

Map reference

ECNAMP *

St Kitts and Nevis

Land area	360 sq km
Population (1995)	41,000
GNP (1992)	4,670 US$ per capita
Alternative estimate of mangrove area (Bacon, 1993b)	0.71 sq km#
Area of mangrove on the map	0.43 sq km
Number of protected areas with mangrove	0

Map reference

ECNAMP *

St Lucia

Land area	610 sq km
Population (1995)	142,000
GNP (1992)	2,910 US$ per capita
Alternative estimate of mangrove area (Bacon, 1993b)	1.54 sq km
Area of mangrove on the map	1.25 sq km#
Number of protected areas with mangrove	12

Map reference

OAS (1984). *Saint Lucia - Land Use and Vegetation*, 1:50,000. Prepared by the Department of Regional Development, of the Organisation of American States, with the collaboration of the Ministry of Agriculture, Lands, Fisheries, Co-operatives and Labour, of the Government of Saint Lucia.

St Vincent and the Grenadines

Land area	390 sq km
Population (1995)	112,000
GNP (1992)	1,990 US$ per capita
Alternative estimate of mangrove area (Bacon, 1993b)	0.45 sq km#
Area of mangrove on the map	1.54 sq km
Number of protected areas with mangrove	2

Map reference

ECNAMP *

US Virgin Islands

Land area	353 sq km
Population (1995)	101,809
GNP (1990)	8,717 US$ per capita
Alternative estimate of mangrove area (Bacon, 1993b)	9.78 sq km#
Area of mangrove on the map	1.06 sq km
Number of protected areas with mangrove	1

Map reference

Berndtson and Berndtson (n.d.). *Virgin Islands: US and British*. 1:80,000. Berndtson and Berndtson Publications, Fürstenfeldbruck, Germany.

* **ECNAMP** - Data for a number of the smaller Caribbean islands have been prepared from a series of *Preliminary Data Atlases* published in 1980 by the Eastern Caribbean Natural Area Management Program, a co-operative effort of the Caribbean Conservation Association and the School of Natural Resources, University of Michigan. Data for these atlases have been drawn from a wide range of sources, in most cases the scale of the maps is between 1:50,000 and 1:300,000.

Mexico

Map 7.1

Land area	1,958,200 sq km
Total forest extent (1990)	485,860 sq km
Population (1995)	93,670,000
GNP (1992)	3,470 US$ per capita
Mean monthly temperature range (Mazatlan, Pacific coast)	19-28°C
Mean monthly temperature range (Mérida, Yucatan)	22-28°C
Mean annual rainfall (Mazatlan)	828 mm
Mean annual rainfall (Mérida)	957 mm
Alternative estimate of mangrove area (SARH, 1992)	5,315 sq km#
Area of mangrove on the map	9,328 sq km
Number of protected areas with mangrove	12

Mangroves are being lost very rapidly in Mexico. Estimated cover in the 1970s was 15,000 sq km and it may now be as low as 5,000 sq km, mainly as a result of clearance for agriculture, mariculture and urban development. Mangroves are also being increasingly used for firewood in coastal areas. The largest and best developed mangrove areas are associated with lagoons in the south and east of the country. These include the Asta and Pom Lagoons in Campeche, along the northern coast of the Yucatán Peninsula; and the delta of the Usumascinta River and the Laguna de Términos in the southern Gulf of Mexico. On the Pacific coast, there are mangrove communities in the lagoons along the coast to the border with Guatemala. There are also important mangrove areas much further north, associated with the Agua Brava and Teacapán Lagoons. In the humid areas of the southeast, tree height reaches 30 m and mangrove communities may extend inland for several kilometres. With increasing latitude, ecosystem complexity decreases and dwarf or shrubby communities are widespread. The mangrove coverage on the map is from a recent but relatively low resolution source which could account for the difference in area between the map and the alternative reference.

Map reference

Digital mangrove data were kindly provided by Conservation International and are part of the map coverage for CI/NAWCC/USFWS/SEDESOL (1992).

CI/NAWCC/USFWS/SEDESOL (1992). *Humedales de Mexico*. 1:3,800,000. Conservation International, North American Wetlands Conservation Council, US Fish and Wildlife Service and SEDESOL (Secretaria de Desarrollo Social).

Nicaragua

Map 7.2

Land area	130,000 sq km
Total forest extent (1990)	60,130 sq km
Population (1995)	4,433,000
GNP (1992)	410 US$ per capita
Mean annual temperature (Pacific)	27°C
Average annual rainfall range (Pacific)	1,500-1,700 mm
Spring tidal amplitude (Pacific)	3.3 m
Alternative estimate of mangrove area (Polanía and Mainardi, 1993)	1,550 sq km
Area of mangrove on the map	1,718 sq km#
Number of protected areas with mangrove	3

The mangroves of Nicaragua are found along some 30% of the coast, and are approximately equally distributed between the Pacific and Caribbean coasts. They are best developed at the northern end of the Pacific coast, particularly on the Golfo de Fonesca (Estero Real), bordering El Salvador and Honduras. They are distributed right along the Caribbean coast and are associated with deltas and lagoons. These communities tend to be less degraded than those on the Pacific coast. There is widespread use of mangroves for fuelwood, which is a major energy source for many people, including a large proportion of the populations of some coastal towns and cities. It has been calculated that legal extraction of fuelwood is 9,000 m^3 per year, with between 4,000 and 7,000 m^3 per year for timber posts and a further 5,000 m^3 per year for other timber uses. Extraction without a permit is likely to be considerably greater. Mangrove bark is important for tannin production, while the extraction of crabs, shrimps and molluscs is also economically important. Shrimp farming and the conversion of mangrove areas to other uses is not yet a major problem. Legislation to restrict the cutting of mangroves for timber is in place, although difficult to enforce. Projects are underway with international agencies to develop plans for the integrated management and sustainable use of the mangrove resources, particularly along the Pacific coast.

Map reference

Mangroves prepared from INRNA (1991), which plots all mangroves on the Pacific coast as *'Bosque claro sempervirente de manglares y tierras pantanosas de manglares sin vegetación arborescente'*, effectively degraded mangrove.

INRNA (1991). *Estado Actual de la Vegetación Forestal de Nicaragua.* 1:1,000,000. Instituto Nicaraguense de Recursos Naturales y del Ambiente, Dirección de Administración de Bosques Nacionales.

Panama

Map 7.6

Land area	77,080 sq km
Total forest extent (1990)	31,170 sq km
Population (1995)	2,659,000
GNP (1992)	2,440 US$ per capita
Mean monthly temperature range	26-27°C
Average rainfall range	1,000-7,000 mm
Spring tidal amplitude (Pacific)	6 m
Spring tidal amplitude (Caribbean)	0.5 m
Alternative estimate of mangrove area (see map reference)	1,708 sq km
Area of mangrove on the map	1,814 sq km#
Number of protected areas with mangrove	5

In Panama, mangroves are found along both coasts, but are most heavily developed on the Pacific coast, particularly the Gulfs of San Miguel and Chiriqui, both of which have nearly 500 sq km of mangroves. These forests are structurally well developed with stands of *Rhizophora* reaching 30-40 m in height and making up the dominant species over wide areas, with other species making more mixed communities along the salinity gradients in rivers and estuaries. The total coverage for the Caribbean coast is 60 sq km, most of which is concentrated in the Bocas del Toro region near the Costa Rican border. The Caribbean mangroves are generally not well developed, with trees less than 5 m in height. Rainfall is highly varied across the country, reaching 6,000 mm per annum in the Bocas del Toro mangrove areas, but more typically 2,000 to 4,000 mm per annum in most coastal areas. Mangrove areas are used for the gathering of penaeid shrimp seed to supply numerous small shrimp farms along the Pacific coast. They are also of considerable importance in the life cycles of most shrimp and a number of finfish species that are important in commercial catch fisheries. On land, mangroves are exploited for timber, fuelwood and charcoal and there is a small tannin extracting industry. These uses are not causing widespread loss of mangrove areas. Some areas have been converted for agriculture, cattle grazing and urban development with these losses being most significant along the Gulf of Chiriqui. An oil spill severely affected mangroves along some 27 km of coast in 1986 and oil is considered a major potential threat to other areas, based on the large quantity transported (70 million tons) through the Panama Canal each year. There has been little or no legislation or management policy developed for the protection and development of mangrove resources. Although the available maps and area calculations are recent and accurate there is some confusion over the definition of mangrove that was used. In a recent study Duke *et al.* (1993) have found these estimates to underestimate considerably the total area of mangroves and it has been suggested (Duke, pers. comm., 1995) that the maps may have only considered *Rhizophora* distribution.

Map reference

Instituto Geográfico Nacional 'Tommy Guardia' (1988). *Republica de Panama - Inventario de Manglares.* 1: 250,000. Five sheets. Instituto Geográfico Nacional 'Tommy Guardia', Panama.

Peru

Map 7.6

Land area	1,285,220 sq km
Total forest extent (1990)	679,060 sq km
Population (1995)	23,854,000
GNP (1992)	950 US$ per capita
Mean monthly temperature range	18-30°C
Average rainfall range	100-300 mm
Spring tidal amplitude	4 m
Alternative estimate of mangrove area (Echevarría and Sarabia, 1993)	48 sq km
Area of mangrove on the map	51 sq km#
Number of protected areas with mangrove	1

In Peru, mangroves are found in two distinct areas: a large area extending from the Ecuadorian border to the Rio Tumbes, and a much smaller area on the Piura River (approximately 3 sq km). The latter site is the southernmost site for mangroves on the Pacific and is restricted to one species, *Avicennia germinans*. The climate is semi-arid, but is highly variable from one year to another, and greatly affected by El Niño events which result in the displacement of the intertropical convergence zone and greatly increased rainfall, which can be 10 to 60 times higher than average in some years. Salinity levels are quite variable, but can be high (33 ‰) during the summer period of January to March. The coastline at Tumbes is highly dynamic and is affected by patterns of tidal flow, coastal currents and the sediment load carried by the river. This can lead to varying processes of accretion or deposition in different years. Traditionally, mangroves have been used for fuelwood, charcoal, timber and poles. Recently, shrimp mariculture has expanded, causing reduction in the total area of mangrove by some 12.5 sq km between 1982 and 1992, though there had been a considerable area removed before this time. Shrimp farming now occupies 70 sq km, of which 27 sq km are no longer working. Large numbers of people work on these farms catching shrimp larvae to export to Ecuador. This industry has led to the considerable expansion of the city of Tumbes, which has doubled in size since 1961. A threat to the mangroves and, indeed, to the human population in the area is likely to arise from a dam and irrigation scheme in the watershed of the Puyango-Tumbes Rivers. Mercury pollution from gold mining upstream, together with locally based urban and industrial pollution, may also affect the mangroves. There has been some natural regeneration of mangroves in a few areas, and in 1980 the Santuario Nacional los Manglares de Tumbes, covering some 29.72 sq km, was declared. A detailed GIS has been prepared of the mangroves in this area (see map references).

Map references

Unpublished maps (ONERN/ODC/FPCN, 1992) were kindly provided by Jorge Echevarria, Universidad Nacional de Tumbes. These cover the largest area of mangroves in Peru. Sources for these data come from 1:25,000 'carta fotogramétrica' and HRV SPOT imagery from 30 March 1991. A second, smaller, area on the Piura River (estimated at 300 ha, J Echevarria, pers. comm., 1995) has been added from a sketch map taken from Peña and Vásquez (1985).

ONERN/ODC/FPCN (1992). *Mapa de cobertura y uso de la tierra (Año 1992).* Oficina Nacional de Evaluación de Recursos Naturales (ONERN), Oficina de Coordinación del Progama de Desarollo Forestal Peru-Canada (ODC) and Fundación Peruana para la Conservación de la Naturaleza (FPCN).

Peña, G.M. and Vásquez, P. (1985). Un Relicto de Manglar en San Pedro (Piura). *Boletín de Lima* 42: 1-7.

Puerto Rico — Map 7.4

Land area	8,900 sq km
Population (1995)	3,691,000
GNP (1992)	6,580 US$ per capita
Mean monthly temperature range	26-28°C
Average rainfall range	1,000-5,000 mm
Alternative estimate of mangrove area (Martinez *et al.*, 1979)	<60 sq km
Area of mangrove on the map	92 sq km#
Number of protected areas with mangrove	9

In Puerto Rico, mangroves are distributed on all coasts. The south coast, which is slightly drier, has mostly fringe and overwash communities with some scrubby basin communities, while the north coast has some riverine and basin communities. The largest single area is on the northeast coast around Torrecilla, which is a complex of estuarine and lagoon communities. By the late 1970s over 75% of Puerto Rico's mangroves had been destroyed. There was legal encouragement for this action as a means of reducing the numbers of malarial mosquitoes. Wide areas have been drained or filled and used for agriculture or urban development, while the major estuary of San Juan and large parts of the Jobos Bay have been developed as harbour facilities. Human activity continues to threaten mangroves both directly through cutting or reclamation and through pollution, despite the recognised importance of mangroves in commercial fisheries. Part of the Jobos Bay was declared a national estuarine research reserve in 1987. In the 1980s the total area of mangroves increased considerably, the changes being the result of increased legal protection, the reversion of agricultural land to its original state, and the colonisation of new areas.

Map reference

Mangrove areas were copied onto a 1:500,000 base map from a series of eight maps contained in UNDC (1978). Subsequent to this work a more recent sketch map (Martínez, 1994) was made available. The mangrove distribution on this map is similar to that already prepared, but was used to add a coverage for Isla de Vieques.

UNDC (1978). *Puerto Rico Coastal Management Program and Final Environmental Impact Statement.* Office of Coastal Zone Management, National Oceanic and Atmospheric Administration, US Department of Commerce.

Surinam

Map 7.5

Land area	163,270 sq km
Total forest extent (1990)	147,680 sq km
Population (1995)	463,000
GNP (1992)	3,690 US$ per capita
Average temperature	27°C
Mean annual rainfall	2,200 mm
Alternative estimate of mangrove area (SPS, 1988)	1,150 sq km#
Area of mangrove on the map	1,097 sq km
Number of protected areas with mangrove	4

The coast of Surinam, like that of Guyana and French Guiana, is low-lying and geologically very young. It receives riverine deposits from the Amazon in the east, the Orinoco in the west and the numerous rivers in between. Fringe mangroves are found along most of the coast, typically fronted by wide mudflats. Estuarine mangroves are also well developed. Inland from the fringe mangroves there are, typically, swamp or lagoon systems varying from fresh to hypersaline, with both swamp forest and grasslands. Large parts of these systems dry out during the long dry season from September to November. The beaches are extremely important for nesting sea turtles, and the wider coastal ecosystems for enormous numbers of seabirds. It is the most important wintering area for north American and arctic shorebirds within South America. Surinam has a very low population density. The majority of people live in the coastal zone, but as most of these are living in the capital, Paramaribo, there is relatively little human pressure on most of the mangrove areas. Small areas of mangroves have been cleared for rice cultivation, and there is some contamination by pesticides. Some mangrove areas are protected, including the 120 sq km Coppename Monding and the 360 sq km Wia-wia nature reserve. The 683 sq km Bigi Pan area is a multiple-use management area. Further areas have also been proposed for protection.

Map reference

The source map is largely based on 1978 data.

SPS (1988). *Suriname Plantatlas.* Stichting Planbureau Suriname. Department of Regional Development, O.A.S., Washington DC, USA.

Trinidad and Tobago

Map 7.5

Land area	5,130 sq km
Total forest extent (1990)	1,550 sq km
Population (1995)	1,305,000
GNP (1992)	3,950 US$ per capita
Average temperature	26°C
Mean annual rainfall	1,556 mm
Alternative estimate of mangrove area (Bacon, 1993b)	>70 sq km#
Area of mangrove on the map	54 sq km
Number of protected areas with mangrove	4

Trinidad and Tobago have mangroves on all shores. They are best developed in estuaries on Trinidad, with the most important single area being the 37 sq km Caroni Swamp on the west coast. Lagoon and coastal fringe mangrove communities are also found, although estuarine swamps are the best developed, with trees reaching 23 m high. In most areas, the landward side of mangrove areas is backed by agriculture, although the Nariva Swamp mangroves form part of a much larger wetland system. Conversion to cultivation has led to the loss of wide areas of mangrove. Current uses of mangroves include a small amount of timber and charcoal extraction and direct-catch fisheries products including crabs, oysters and shrimps. Offshore fisheries close to mangrove areas are also important. The Caroni swamp, which is a tourist attraction, is home to the national bird, the scarlet ibis *Eudocimus ruber*. Although the site is protected, it suffers from industrial and agricultural pollution.

Map reference

Data are for Trinidad only, no data were found for Tobago.

Institutional Consultants (International) Ltd. (1980). *Inventory of the Indigenous Forest of Trinidad - Forest Resource Inventory and Management Section.* 1:150,000. Prepared for the Government by Institutional Consultants (International) Ltd. in co-operation with the Forestry Division Ministry of Agriculture, Lands and Fisheries and the Canadian International Development Agency (CIDA).

Turks and Caicos **Map 7.3**

Land area	430 sq km
Population (1990)	11,696
Average monthly temperature range	24-28°C
Mean annual rainfall	725 mm
Alternative estimate of mangrove area (Bacon, 1993b)	236 sq km
Area of mangrove on the map	111 sq km#
Number of protected areas with mangrove	3

The Turks and Caicos are a small group of low-lying islands which form the southernmost part of the Bahamas group. They are separated into the Turks Islands, lying on a small marine bank, and the Caicos Islands lying on the very large, shallow Caicos Bank. The latter islands have a very large area of mangrove, particularly concentrated in the southern portions of North, Middle and East Caicos Islands. For the most part mangroves are relatively scrubby or dwarf, with the tallest stands on Parrot Cay reaching 10 m in height. Mangrove communities are predominantly fringe, basin, lagoon and/or linked to salinas. The scrubby nature of the mangroves can be linked to the high salinities, which has been measured as 38‰ in the sea and up to 84‰ in the salinas. Mangroves have historically been used for poles, charcoal and salt manufacture. These activities have decreased and mangroves are recolonising many salinas. Other mangrove areas are being cleared for resort and urban development, but most areas are not threatened. A large proportion of the mangroves on North, Middle and East Caicos Islands have been protected as wetlands of international significance.

Map reference

D.O.S. (1984). *Turks and Caicos Islands*. 1:200,000. Series: D.O.S. 609 Ed.2. Directorate of Overseas Surveys, UK.

United States of America **Maps 7.1 and 7.3**

Land area	9,372,610 sq km
Land area (Florida)	139,697 sq km
Total forest extent (1990)	2,095,730 sq km
Population (1995)	263,138,000
Population (Florida) (1993)	13,642,540
GNP (1992)	23,150 US$ per capita
Mean monthly temperature range (Miami)	19-28°C
Mean annual rainfall (Miami)	1,516 mm
Spring tidal amplitude	1 m
Alternative estimate of mangrove area	No information
Area of mangrove on the map (Florida only)	1,990 sq km#
Number of protected areas with mangrove	48

In the United States of America, mangroves are largely concentrated in the southern parts of Florida and form a major vegetation type in the southern three counties of that state. They show their greatest structural development in the southwest region where there are wide areas of low-lying sediments and there is considerable freshwater input from the Florida Everglades, delivering nutrients and moderating coastal salinity regimes. Although mangroves occur further north, their distribution is restricted by cold winter temperatures. There are isolated occurrences of *Avicennia germinans* in Texas, and at several locations marginal to the Mississippi deltaic plain in Louisiana, including the Chandeleur Islands (30°02'N). Hurricanes are a major climatic feature in southern Florida and these can have devastating effects on mangrove communities. The most recent event was in 1992 and there is an average return time of 20 years, which means that hurricanes can limit the development of mangroves in most areas. Human induced stresses have been considerable in southern Florida, including drainage for agriculture, reclamation for urban development and alterations to the salinity regime, most notably caused by the development of a railway along the Florida Keys (now dismantled). Estimated losses range from 44% in Tampa Bay to 82% in Biscayne Bay, south of Miami, and these losses were reported to have resulted in a 20% decline in commercial fisheries. Research connecting mangroves to fisheries yields, combined with a growing environmental movement, led to a great reduction in rates of mangrove loss in the 1970s and 1980s. Strict laws were enacted for the protection of mangroves. Where destruction is permitted there are now typically complex mitigation procedures, including, in a number of cases, funding for major restoration or rehabilitation projects in other areas. Large areas of mangrove fall within the complex of protected areas which make up much of the land and sea area of southern Florida, notably the Florida Everglades National Park.

Map reference

Data were generously provided by the Florida Marine Research Institute in digital format (FMRI, 1995). These are based on data gathered in the National Wetlands Inventory and are based on aerial photographs taken between 1984 and 1986 which were transferred and rectified to the US Geological Survey 1:24,000 quads.

FMRI (1995). *South Florida (Sanibel Island to Biscayne Bay).* 1:40,000. Digital dataset compiled by the Florida Marine Research Institute from various sources.

Venezuela

Maps 7.5 and 7.6

Land area	912,050 sq km
Total forest extent (1990)	456,900 sq km
Population (1995)	21,483,000
GNP (1992)	940 US$ per capita
Mean monthly temperature range (Orinoco)	25-27°C
Mean monthly temperature range (Cocinetas Lagoon)	27-31°C
Average monthly rainfall range (Orinoco)	99-330 mm
Average monthly rainfall range (Cocinetas Lagoon)	85-277 mm
Alternative estimate of mangrove area (Conde and Alarcón, 1993a)	2,500 sq km#
Area of mangrove on the map	(6,302 sq km)
Number of protected areas with mangrove	10

Mangroves have a long history of use by man in Venezuela: archaeological sites within mangrove areas date back as far as 5,000 to 6,000 years. In recent years the mangroves have been extensively studied in many areas. The largest areas of mangroves are those associated with the Orinoco Delta, the San Juan River and the Gulf of Paria, in the far east of the country. The total area of mangrove in this region occupies over 1,300 sq km. These mangroves are well developed with trees reaching from 25 m to 40 m. To the west of these areas, most of the coast is arid or semi-arid and mangroves are less well developed, with trees rarely reaching heights of 20 m. Other key areas to the west include Tacarigua Lagoon, Morrocoy Bay and a number of sites in the Maracaibo system in the far west. The latter area has three distinct bodies of water: the marine Gulf of Venezuela, the estuarine waters of the Maracaibo Strait and the limnetic waters of the Lago de Maracaibo, the latter with typical salinities in the range of 6 to 10‰. Distinct mangrove systems are associated with each of these. Both artisanal and commercial fisheries are important, with commercial fisheries being particularly so in Maracaibo, off Tacarigua Lagoon, and in the Orinoco Delta. Threats to mangroves include indiscriminate use for timber and fuelwood, oil pollution, urban and tourism development and reclamation for agriculture. Expansion of salt pans and shrimp farms could represent a threat in the future. Actual quantification of mangrove losses is not possible, but concern to reduce these losses is increasing and a number of sites, totalling over 500 sq km, now fall within legally protected areas, while mangroves generally are also protected, and authorisation must be obtained for their utilisation.

Major discrepancies exist between estimates of mangrove area in Venezuela. A number of authors have given figures close to 6,500 sq km, but it has been suggested that this is a gross over-estimate based on the misinterpretation of remote images, as the widespread tree *Symphonia globulifera* has similar spectral and structural characteristics to those of mangroves. It is not known whether there exist any maps which show this corrected distribution, if indeed it is correct.

Map references

Data were obtained from Huber and Alarcón (1988), which, although published in 1988, reflects the status of the vegetation cover in Venezuela for approximately 1982. Further reference was made to MARNR (1989) to improve this coverage.

Huber, O. and Alarcón, C. (1988). *Mapa de Vegetación de Venezuela.* 1:2,000,000. Ministerio del Ambiente y los Recursos Naturales Renovables and The Nature Conservancy.

MARNR (1989). *Manglares de Venezuela. Distribución Geográfica de los Manglares en Venezuela.* Cuadernos, Lagoven, Caracas.

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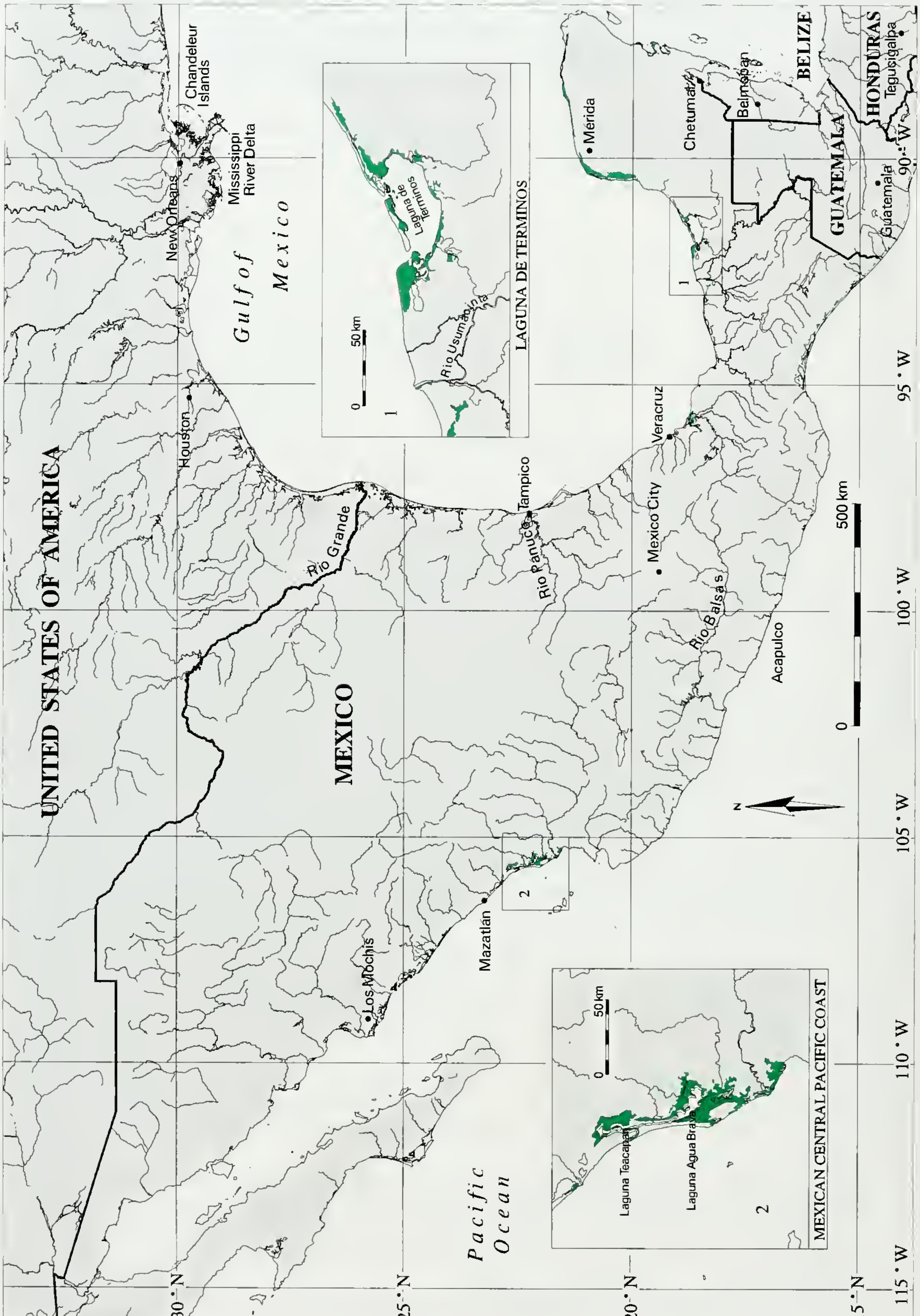
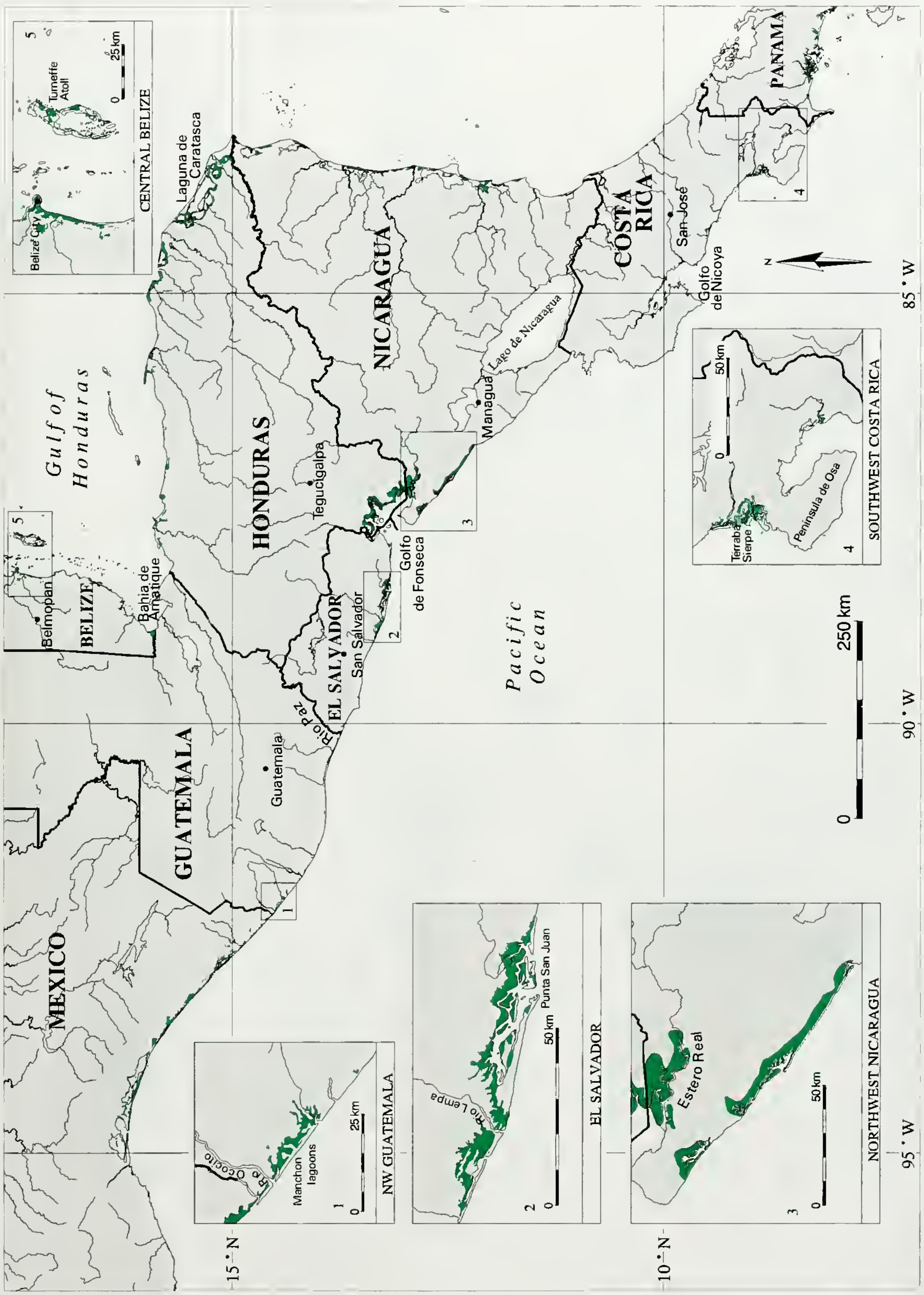
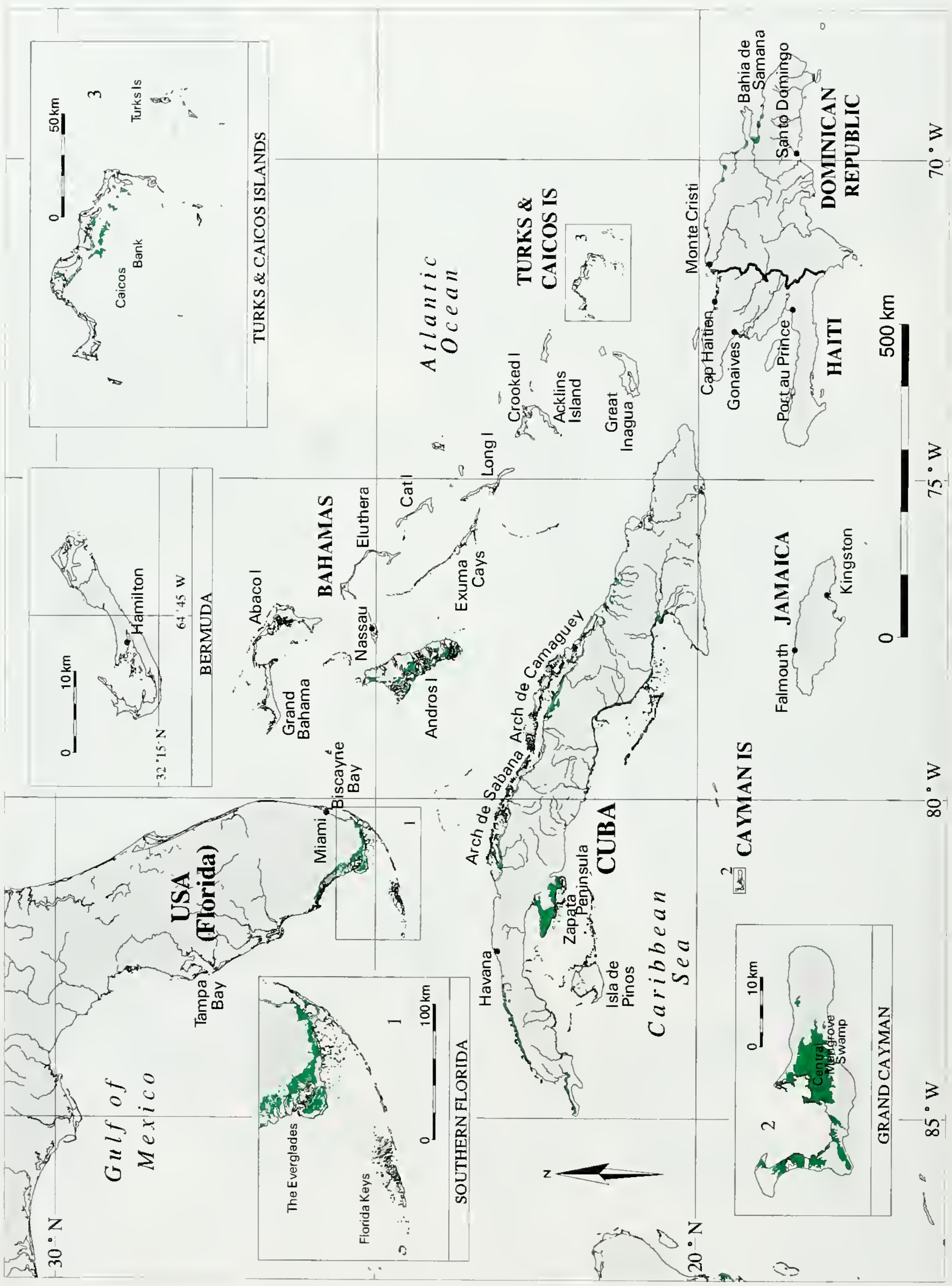


Map 7.1 **Mexico**

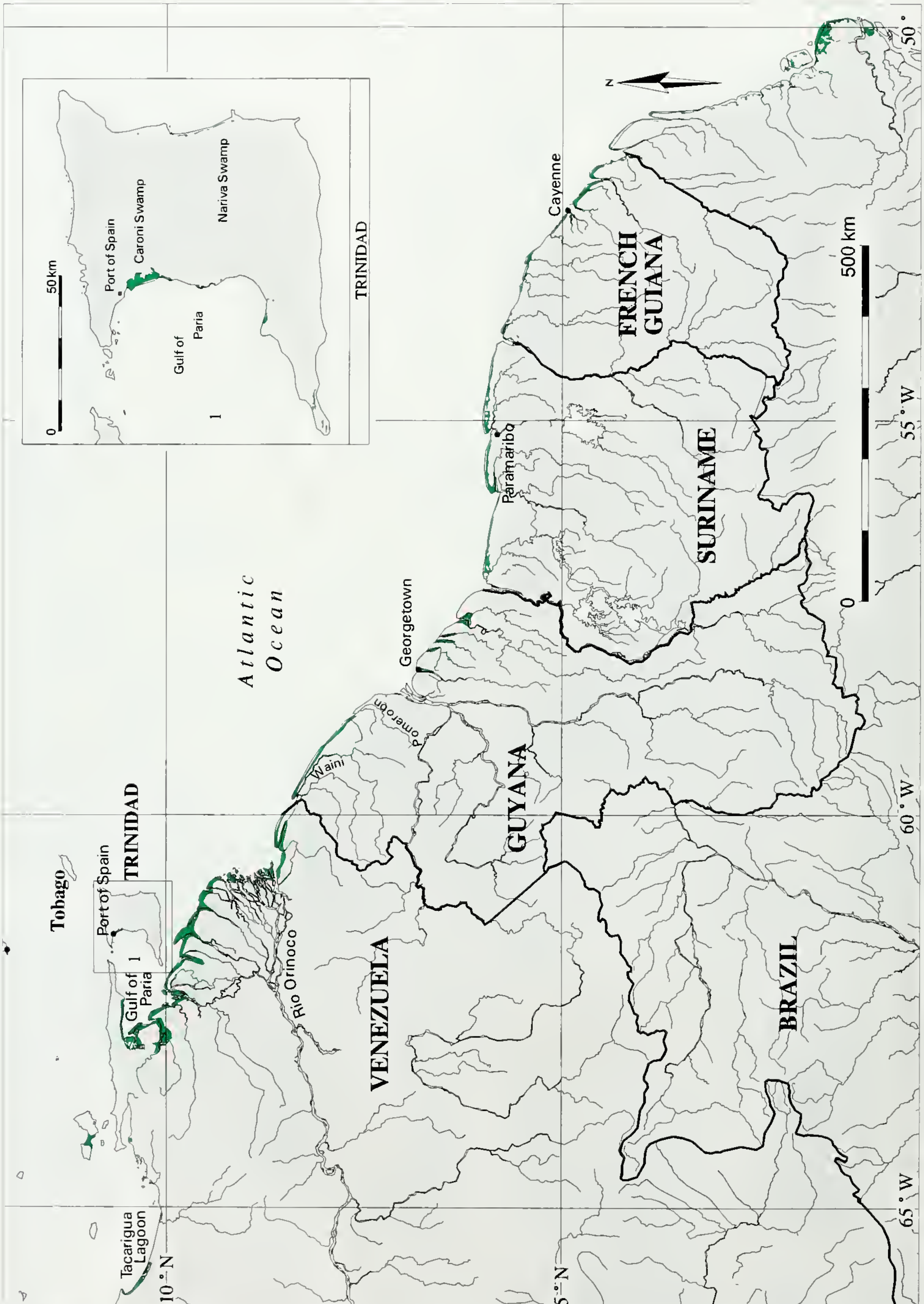


Map 7.2 Central America

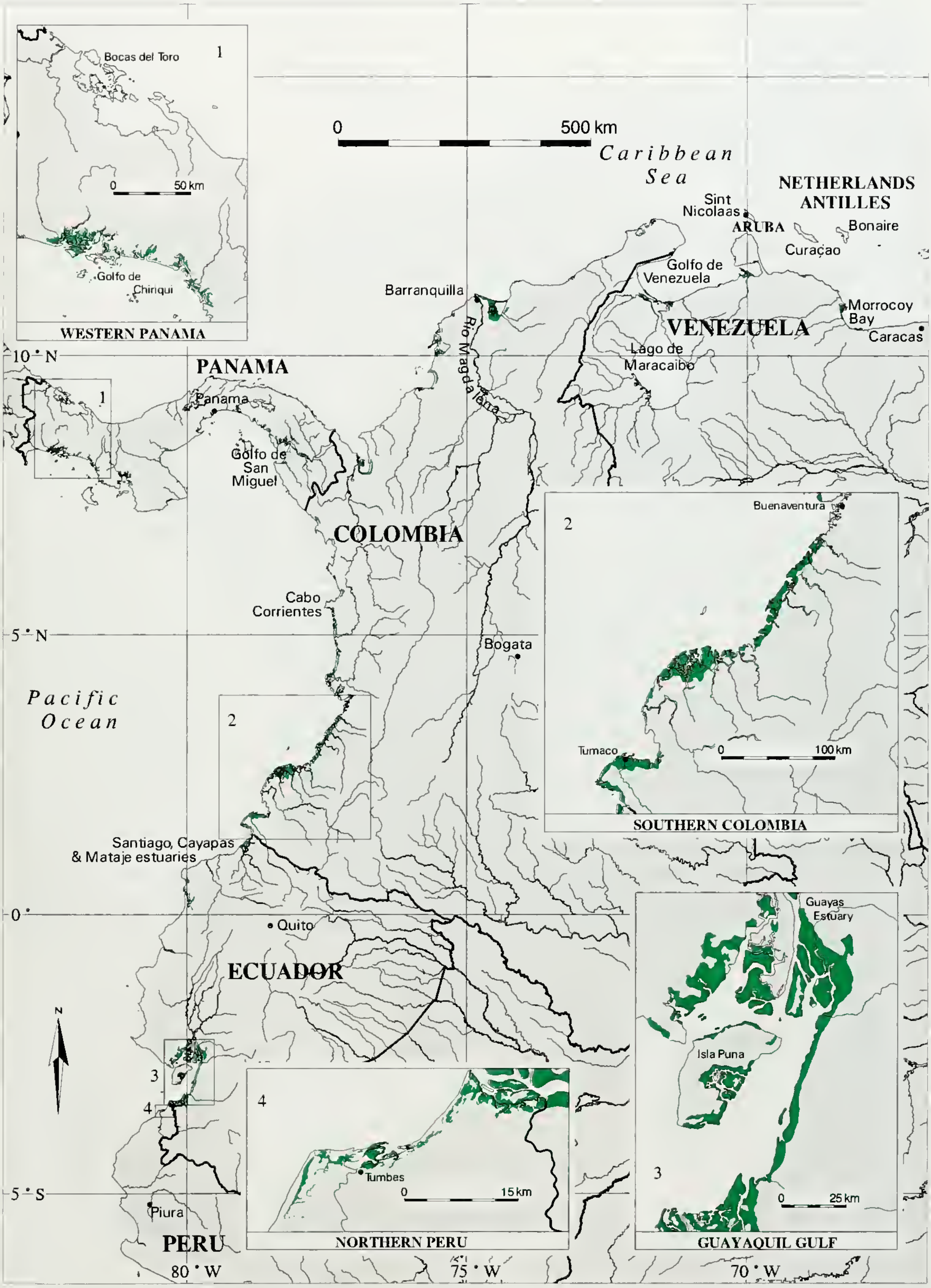


Map 7.3 Florida, Bahamas and the Greater Antilles

Map 7.4 **Puerto Rico and the Lesser Antilles**



Map 7.5 **Eastern Venezuela, Trinidad and the Guianas**



Map 7.6 **Northwest South America**

Map 7.7 Brazil

8

West Africa

Mangroves are found in all countries of West Africa from Mauritania in the north to Angola in the south. They are not found on the coast of Namibia or the west coast of South Africa. The mangroves of the region have been described by Hughes and Hughes (1992), Diop (1993) and Saenger and Bellan (1995). There are seven indigenous species of mangrove and one introduced species, *Nypa fruticans* on the Atlantic coast of Africa. All the indigenous species of mangrove on the Atlantic coast of Africa are shared with the Atlantic and Pacific coasts of America. The total area of mangroves in the region is some 27,995 sq km, representing some 16% of the total global area. Saenger and Bellan (1995) suggest that as a result of adverse sea level and climatic changes since the last significant geological transgression, the mangrove vegetation has contracted significantly in areal extent, with the remnants effectively confined to lagoons, embayments and deltas.

The northern limit of the occurrence of mangroves is the Ile Tidra (19°50'N) in Mauritania, while the southern limit of extensive mangrove vegetation is the Angolan estuary of the Rio Longa (10°18'S). The northern and southern limits of mangroves coincide with arid regions that are defined as areas having a yearly rainfall of less than 30 mm. It has been suggested (Saenger and Bellan, 1995) that mangrove distribution in western Africa is more limited by aridity than by temperature. Much of the western coast of Africa is uniformly mild to warm throughout the year but there is considerable variation in rainfall, with very high figures recorded in the coastal areas of Nigeria, Guinea, Guinea Bissau, Cameroon, Gabon and Zaire. In some places this can be in excess of 4,000 mm per year. Elsewhere, in countries such as Côte d'Ivoire, Ghana, Togo and Benin, the annual rainfall declines to between 1,000 and 2,000 mm per year and is broken by two short dry periods. Along the entire coastline of western Africa maximal rainfall generally coincides with the warmer months and, unlike many mangrove coastlines elsewhere, cyclone activity is absent.

Mangrove forests occur on all the coasts from Mauritania to Angola, but the best developed are those with the heaviest rainfall, namely the coasts and river estuaries of Gambia, Guinea, Guinea Bissau, Gabon and Nigeria. The extent of mangroves is also determined by the presence of suitable habitats. In Nigeria, mangroves can be found up to 50 km from the coast. Rivers are tidal for many kilometres in some countries, especially Senegal and Gambia, and in these places mangroves occur 160 km up river.

The people of the coastal regions of the countries of West Africa depend on the mangroves for firewood and timber for construction. Locally, mangrove wood is used extensively in the production of salt. There is also extensive use of the mangrove habitat for fishing and shellfish collection. Mangroves are threatened by over cutting, conversion of land for agricultural purposes and by pollution in areas where oil is being produced.

Table 8.1 Mangrove species list for West Africa

	Angola	Benin and Togo	Cameroon	Congo	Côte d'Ivoire	Equatorial Guinea	Gabon	Gambia	Ghana	Guinea	Guinea-Bissau	Liberia	Mauritania	Nigeria	São Tomé and Principe	Senegal	Sierra Leone	Zaire
Acrostichum aureum	•	•	•		•		•	•	•	•		•		•	•	•		•
Avicennia germinans	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Conocarpus erectus	•	•	•		•		•	•	•	•	•	•	•	•	•	•	•	•
Laguncularia racemosa	•	•	•		•		•	•	•	•	•			•		•	•	•
Nypa fruticans			I											I				
Rhizophora harrisonii	•	•	•				•	•	•	•	•	•		•	•	•	•	
Rhizophora mangle	•		•				•	•		•	•			•		•	•	•
Rhizophora racemosa	•	•	•	•		•	•	•	•	•	•	•	•	•		•	•	•

I Introduced

Country sources

Angola	Saenger and Bellan, 1995	Guinea	Saenger and Bellan, 1995
Benin and Togo	Saenger and Bellan, 1995	Guinea-Bissau	Saenger and Bellan, 1995
Cameroon	Saenger and Bellan, 1995	Liberia	Saenger and Bellan, 1995
Congo	Saenger and Bellan, 1995	Mauritania	Saenger and Bellan, 1995
Côte d'Ivoire	Saenger and Bellan, 1995	Nigeria	Saenger and Bellan, 1995
Equatorial Guinea	Saenger and Bellan, 1995	São Tomé and Principe	Saenger and Bellan, 1995
Gabon	Saenger and Bellan, 1995	Senegal	Saenger and Bellan, 1995
Gambia	Saenger and Bellan, 1995	Sierra Leone	Saenger and Bellan, 1995
Ghana	Saenger and Bellan, 1995	Zaire	Saenger and Bellan, 1995

Angola

Map 8.3

Land area	1,246,700 sq km
Total forest extent	52,950 sq km
Population	8,500,000
GNP	620 US$ per capita
Mean monthly temperature range	20-26°C
Mean annual rainfall	750 mm
Spring tidal amplitude (Luanda)	0.5-1.7 m
Alternative estimate of mangrove area (Saenger and Bellan, 1995)	1,250 sq km#
Area of mangrove on map	607 sq km
Number of protected areas with mangrove	2

In Angola, the mangrove flora is richest in the enclave of Cabinda but the number of species declines to the south. The coast becomes more arid to the south and inshore sea surface temperatures decline. An abrupt transition from a tropical to a temperate spectrum of species is seen in the vicinity of Cape Santa Maria. The most extensive stands of mangroves in Angola are found in the estuary of the Lubinda River, Cabinda and the estuary of the Zaire River, where they extend along the southern open coast. Other extensive mangrove communities occur at the mouths of the Chiluango, Bambongo, Longa and Cuanza Rivers. *Rhizophora racemosa* and *R. mangle* can reach heights of up to 30 m in north Angola but in the south they attain heights of less than a metre. In the south, *Avicennia germinans* also appears in stunted formations. A substantial proportion of the mangroves has either been cleared or severely disturbed by firewood collection. In Cabinda there has been some disturbance of the mangroves in the wake of oil exploration.

Map reference

Mangroves were annotated onto a 1:1,000,000 base map by R.H. Hughes, and are based on Hughes and Hughes (1992). Further mangroves were annotated by François Blasco for the Zaire estuary.

Hughes, R.H. and Hughes, J.S. (1992). *A Directory of African Wetlands.* IUCN, Gland, Switzerland and Cambridge, UK/UNEP, Nairobi, Kenya/WCMC, Cambridge, UK. 820 pp.

Benin and Togo

Map 8.2

In Benin, the mangroves are confined to brackish coastal lagoons as there are no active deltas and the shoreline is subject to significant wave action. The coastal lagoons occupy an area of 3,000 hectares and are subject to two rainy seasons and two dry seasons. There are six species of mangrove in Benin but *Rhizophora mangle* is absent and it has been suggested that this might be due to the irregular and hyposaline regime in the lagoon. *Laguncularia* and *Rhizophora harrisonii* are rare. In some parts of the lagoons mangroves can still be found reaching to heights of 22 m. The Benin Lagoon system extends into Togo and mangroves occur around the mouth of the Mono River and its western tributaries. The height of the trees rarely exceeds 10 m. There are only two species of mangrove found in Togo. The mangrove zone in Benin is densely populated by ethnic groups and the religious beliefs of these people often help preserve the mangrove. An important use of mangrove wood is for salt extraction and it has been estimated that one cubic metre of mangrove wood is required to produce one hundred kilograms of salt. In Togo, the use of mangroves appears to be less and at present there appears to be a balance between production and exploitation. The construction of a hydroelectric dam across the River Mono may affect mangroves in both Benin and Togo.

Benin

Land area	110,620 sq km
Total forest extent	35,200 sq km
Population	4,700,000
GNP	340 US$ per capita
Mean monthly temperature range	22-34°C
Mean annual rainfall	1,307 mm
Spring tidal height (Cotonou)	1.3 m
Alternative estimate of mangrove area (Saenger and Bellan, 1995)	69 sq km
Area of mangrove on map	17 sq km#
Number of protected areas with mangrove	0

Map reference

Prepared from a series of eight maps from Baglo (1989), based on aerial photographs plotting the mangroves of the entire coast at a scale of c.1:30,000.

Baglo, M.A. (1989). La mangrove du Benin: grands équilibres écologiques et perspecitves d'aménagement. PhD Thesis, Université Paul Sabatier de Toulouse, France.

Togo

Land area	56 790 sq km
Total forest extent (1990)	13,530 sq km
Population (1995)	4,138,000
GNP (1992)	390 US$ per capita
Mean monthly temperature range	24-29°C
Mean annual rainfall	850 mm
Spring tidal amplitude	0.3-1.7 m
Alternative estimate of mangrove area (Saenger and Bellan, 1995)	26 sq km#
Area of mangrove on the map	No data
Number of protected areas with mangrove	0

Map reference

No data

Cameroon

Map 8.3

Land area	475,440 sq km
Total forest extent (1990)	203,500 sq km
Population (1995)	13,275,000
GNP (1992)	820 US$ per capita
Mean monthly temperature range	21-31°C
Mean annual rainfall	5,000 mm
Spring tidal amplitude (Point Olga)	0.4-2.3 m
Alternative estimate of mangrove area (Saenger and Bellan, 1995)	2,434 sq km
Area of mangrove on the map	2,494 sq km#
Number of protected areas with mangrove	1

About 30% of the coastline of Cameroon is occupied by mangrove swamps. Two major areas of mangrove lie on the coast east and west of Mount Cameroon and these are characterised by seasonally high rainfall and river flow. It has been estimated that 145 billion cubic metres of fresh water annually pour into the Gulf of Guinea. *Rhizophora racemosa* makes up 90-95% of the mangrove area in the tidal zone and it can reach heights of up to 25 m but is more often only 4-8 m in height further inland. Recently, *Nypa* has become distributed throughout some of the estuaries. The mangroves of Cameroon are relatively densely populated and are used for construction, food and medicinal purposes but over-exploitation is not marked, except for some over-cutting. There is an important fishing industry present off the coast of Cameroon. Pollution poses something of a threat to the mangroves. It arises from the pesticides and fertilisers from the rubber, oil palm and banana coastal plantations leached into the mangroves and from offshore oil operations.

Map reference

Letouzey, R. (1985). *Carte Phytogéographique du Cameroun.* 1:500,000 (mangroves on two sheets). Institut de la Carte Internationale de la Végétation, Toulouse, France and the Institut de la Recherche Agronomique (Herbier National), Yaoundé, Cameroon.

Congo

Map 8.3

Land area	342,000 sq km
Total forest extent (1990)	198,650 sq km
Population (1995)	2,590,000
GNP (1992)	1,030 US$ per capita
Mean monthly temperature range	21-27°C
Mean annual rainfall	1,500 mm
Spring tidal amplitude	0.4-1.3 m
Alternative estimate of mangrove area (Saenger and Bellan, 1995)	120 sq km#
Area of mangrove on the map	188 sq km
Number of protected areas with mangrove	1

There are relatively few mangrove forests in the Congo - most are restricted to coastal estuaries and lagoons - there are no mangroves on the sea-front. The best developed mangrove forests are located at Malonda and Conkouati Lagoons. The dominant mangrove is *Rhizophora racemosa*, though this becomes more scarce upstream and eventually the mangroves merge into freshwater palm-pandan swamps, backed by papyrus or freshwater swamp forest. Tidal influence can extend 10-30 km inland on several rivers. It has been suggested that a long dry season from June to September and the presence of a cold current not far off the Congolese coast may limit the development of mangroves. Oil exploration has occurred all along the coast of Congo and production occurs both onshore and offshore, as a consequence of which some coastal lagoons are polluted by petroleum waste. The mangroves are used by the coastal population for firewood and construction, but they are not over-exploited.

Map reference

Mangroves were annotated onto a 1:1,000,000 basemap by R.H. Hughes, and are based on Hughes and Hughes (1992).

Hughes, R.H. and Hughes, J.S. (1992). *A Directory of African Wetlands.* IUCN, Gland, Switzerland and Cambridge, UK/UNEP, Nairobi, Kenya/WCMC, Cambridge, UK. 820 pp.

Côte d'Ivoire

Map 8.2

Land area	322,460 sq km
Total forest extent (1990)	109,040 sq km
Population (1995)	14,401,000
GNP (1992)	700 US$ per capita
Mean monthly temperature range	24-27°C
Mean annual rainfall	2,800 mm
Spring tidal amplitude (Abidjan)	0.2-1.2 m
Alternative estimate of mangrove area (Saenger and Bellan, 1995)	150 sq km
Area of mangrove on the map	644 sq km#
Number of protected areas with mangrove	2

In Côte d'Ivoire, mangroves once occurred in most of the lagoons, river deltas and estuaries but many of the mangroves have been destroyed for firewood and urban development. Mangroves have also been disturbed by the construction of canals opening up the lagoons. There is very little variation in temperature along the coast and this means that any changes in the mangroves are likely to be due to differences in soil, salinity and water movement characteristics. There are significant differences of rainfall along the coast. The mangroves of Côte d'Ivoire can be divided into two main groups: the region between Assinie and Fresco, which is a series of lagoons into which rivers empty; and the region between Fresco and the border with Liberia at the Cavally River, which is a series of deltaic river mouth systems. The lagoon mangroves are relatively small but can reach heights of around 20 m at Grand Bassam. The lagoon systems contain *Rhizophora racemosa*, *Avicennia germinans* and *Conocarpus erectus*, while the deltaic systems are dominated by *A. germinans* and *R. racemosa*. *R. racemosa* occurs closest to the sea, followed by *A. germinans*, with *C. erectus* nearest the land.

Map reference

Map based on a 1:1,000,000 base map and more detailed sketch maps of specific sites contained in Egnankou Wadja (1985).

Egnankou Wadja, M. (1985). Etude des mangroves de Côte d'Ivoire: aspect écologique et recherches sur les possibilités de leur aménagement. PhD Thesis, Université Paul Sabatier de Toulouse, France.

Equatorial Guinea

Map 8.3

Land area	28,050 sq km
Total forest extent (1990)	18,260 sq km
Population (1995)	400,000
GNP (1992)	330 US$ per capita
Average temperature	26°C
Mean annual rainfall	3,000 mm
Spring tidal amplitude	0.3-1.7 m
Alternative estimate of mangrove area (Saenger and Bellan, 1995)	257 sq km
Area of mangrove on the map	277 sq km#
Number of protected areas with mangrove	0

Equatorial Guinea is the only Spanish-speaking nation in sub-Saharan Africa and one of the least developed. Extensive development of mangroves is confined to three estuaries: Mbini, Muni and Ntem Rivers. The Muni estuary is the combination of several rivers and it is 2 km wide over much of its length. Mangroves extend from just inside the mouth to the head of the estuary, 17 km inland. There are about 65 sq km of tidal forest on the estuary dominated by *Rhizophora racemosa* and *Avicennia germinans* in the more seaward regions. There are a number of villages in the mangroves which have subsistence economies. The mangroves have suffered little degradation though there has been some cutting for firewood.

Map reference

No recent data were available. Source did not include data for Bioko or Annobon.

Servicio Geográfico del Ejército (1960). Untitled. 1:100,000, 15 sheets. Servicio Geográfico del Ejército.

Gabon

Map 8.3

Land area	267,670 sq km
Total forest extent (1990)	182,350 sq km
Population (1995)	1,367,000
GNP (1992)	4,480 US$ per capita
Mean monthly temperature range	23-30°C
Mean annual rainfall	2,645 mm
Spring tidal amplitude (Libreville)	0.4-2.4 m
Alternative estimate of mangrove area (Fromard and Fontès, 1994)	2,500 sq km#
Area of mangrove on the map	1,759 sq km
Number of protected areas with mangrove	1

In Gabon, river mouths tend to be deflected northwards because of the prevailing currents and mangroves tend to develop in the folds where the rivers turn north. Mangrove forests occur in all estuaries, bays and lagoons along the coast and they are more extensive on the south banks than the northern banks. The main concentration of mangroves is at the mouths of the River Como, where Libreville is situated on the northern sand spit, and around the Ogooué River. *Rhizophora racemosa, R. harrisonii, R. mangle* and *Avicennia germinans* dominate the seaward areas, while *Acrostichum aureum, Conocarpus erectus* and *Laguncularia racemosa* are found in less inundated zones and in the dry fringes. The *Rhizophora* canopy can reach 30 m in height in the Bay of Cape Lopez. In Gabon an extensive freshwater swamp often appears to be associated with mangroves and this may have led to an over-estimation of the area of mangroves in the past. There does not appear to be much commercial exploitation of the mangroves.

Map references

High resolution data (1:150,000) were used where available from Fontès and Fromard (1993, 1994). Gaps in these coverages were filled from Maley (in press). Minor corrections were added by François Blasco.

Fontès and Fromard (1993). *Carte de la végétation Cap Lopez - Pointe Fétiche au 1:150,000.* One sheet. ICIV, CNRS/UPS pour ELF Gabon.

Fontès and Fromard (1994). *Carte de la végétation: Estuaire du Gabon; Nyonie; Gongue.* Three sheets. ICIV, CNRS/UPS pour ELF Aquitaine, Toulouse, France.

Maley, J. (1997). Histoire récente de la forêt dense humide africaine et essai sur le dynamisme de quelques formations forestières. In: *Paysages quaternaires de l'Afrique Centrale Atlantique.* Schwartz, D. and Lanfranchi, R. (Eds). Travaux et Documents de l'ORSTOM, Paris, France.

Gambia

Map 8.1

Land area	11,300 sq km
Total forest extent (1990)	970 sq km
Population (1995)	980,000
GNP (1992)	390 US$ per capita
Mean monthly temperature range	17-28°C
Mean annual rainfall	925 mm
Spring tidal amplitude (Banjul)	0.2-1.8 m
Alternative estimate of mangrove area (Saenger and Bellan, 1995)	497 sq km#
Area of mangrove on the map	747 sq km
Number of protected areas with mangrove	5

The country of Gambia forms an enclave within Senegal. It is essentially the valley of the navigable Gambia River and it extends 320 km inland from the coast. At the coast the country is about 45 km wide and this width decreases to some 10 km on either side of the river. An almost continuous belt of mangroves exists from the mouth of the river to about 160 km inland and it is the most pristine of the remaining natural habitats in the country. The mangrove and salt marsh species in Gambia are the same as those in Senegal. The height of the mangroves tends to increase after the first 25 km upstream and *Rhizophora* can attain heights of 20 m. The extent of the mangrove swamp tends to decrease in the lower parts of the river and is better developed at the mouths of small tributaries further upstream.

Map reference

This map (USGS, 1985) was kindly made available to WCMC by the EDC International Projects Department of the EROS Data Center, and was compiled from the interpretation of Landsat imagery of different dates and from extensive ground surveys. A considerable eastward extension of the mangrove coverage to Georgetown was made on the advice of François Blasco. This should be regarded as a crude approximation only.

USGS (1985). *Range and Forest Resources of Senegal.* 1:1,000,000 scale. Digital map prepared for the US Agency for International Development (USAID) by the US Geological Survey, National Mapping Division, EROS Data Center.

Case study

The mangroves of Gabon

Several physiognomic and ecological facts have recently been recorded by Fromard and Fontès (1994). Despite very favourable physical and human parameters, the mangrove forests of Gabon, where all West African species are found, are not extensive. With the exception of the narrow riverine *Rhizophora harrisonii* belt, where growth and regeneration are good, other mangrove stands show poor or very poor development. An *Avicennia* belt is observed in many areas and seems to be restricted to the limits of the daily tidal influence. An inner belt of dwarf *R. harrisonii* is also observed (Plate 8.1). Growth seems limited by chemical or physical (or both) parameters of the soil (Figure 8.1).

Deforestation is not a major threat in Gabon. The only major threat is from the oil extraction which is taking place in the mangrove areas and could potentially generate disastrous pollution.

Figure 8.2 is an aerial photograph of the deltaic mangroves in the Cape Lopez Bay area which shows clearly the sort of detail available. It is quite possible to determine both the forest extent and elements of the forest structure as well as the disturbances to the forest. Figure 8.3 provides a view of a wider area of mangroves on Cape Lopez Bay. This map was prepared from satellite data and used aerial photographs such as that shown in Figure 8.2 to aid interpretation.

The local topography determines small depressions or slightly elevated land where mangrove trees are absent. These 'equatorial tannes', often dominated by the succulent halophyte *Sesuvium portulacastrum*, are quite extensive throughout the Gabon mangroves. On the other hand, the salinity of the water table and that of the interstitial waters is usually high (twice that of the free water). The presence of empty corridors, about 10 to 15 m wide and 100 to 500 m long, can be observed in several mangrove areas of Gabon, such as the Mondah and Gabon estuaries. These are the result of seismic oil exploration activities. One of the major reasons why mangroves have not been re-colonised in these areas could be related to the compactness of the soil.

Environmental data

• Mean annual rainfall	2,000-3,400 mm/year
• Dry season	2-4 dry months
• Fresh water discharge	High and evenly distributed
• Temperature	Mean of coldest month >20°C (mean annual temperature variation <5°C)
• Air humidity	Constantly high (>80%)
• Mean water salinity	≤20-30‰
• Soil types	Usually clayey-loamy under the best mangrove stands (30 - 40% of clay and loam)
• Average tidal amplitude	1.5 m
• Total areal extent	2,500 sq km
• Average population density	<5 people/km
• Dominant mangrove types	- tall dense *Rhizophora harrisonii* and *R. racemosa* stands (>20 m in height) - extended tall heterogeneous *Avicennia germinans* communities - very extended dwarf *R. harrisonii* thickets (3-5 m in height)
• Extent of salt marshes	<5% of the total mangrove area

Plate 8.1 A conspicuous inner *Rhizophora harrisonii* belt

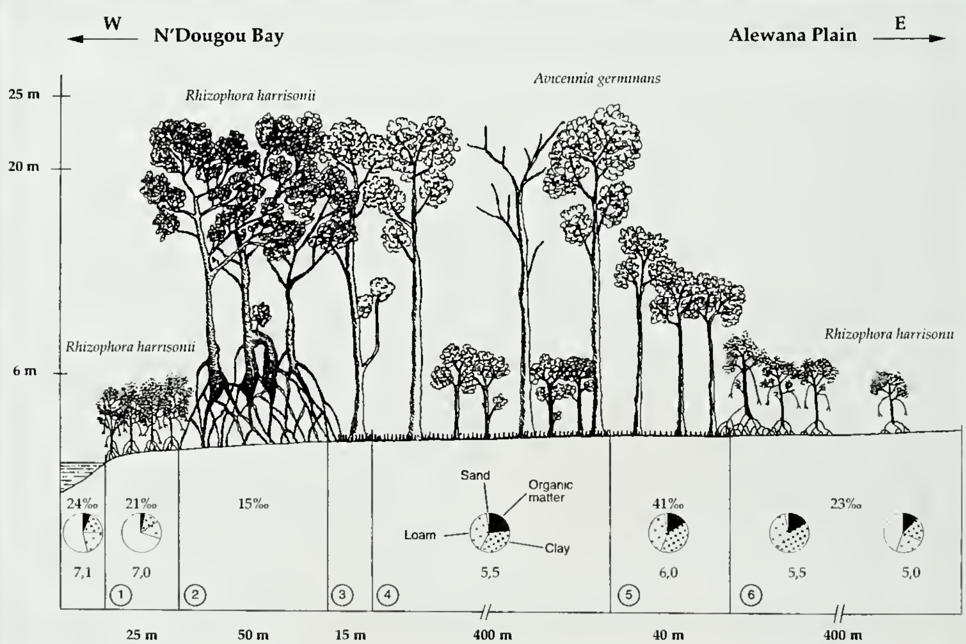


Figure 8.1 An east-west transect across the mangroves on the east coast of N'Dougou Bay

Figure 8.2 The deltaic mangroves of Gabon: Cape Lopez Bay

This is an aerial photograph at approximately 1:30,000 showing the seismic transects and oil pumping platforms in the mangroves of Gabon

Figure 8.3 The mangroves of Cape Lopez Bay, Gabon

Case study

The riverine mangroves of Gambia

The mangroves of Gambia were well documented in 1984 (Figure 8.4) when the Gambian-German Forestry Project (GGFP) undertook an accurate inventory and mapping project at 1:10,000 scale. This work began in October 1980 with the acquisition of a colour infrared aerial coverage. In addition to the mapping work, an extensive report on the mangroves of this small country was also published in 1981 (Checchi and Co., 1981). Figures 8.5 and 8.6 show recent SPOT satellite pictures of the mangroves in Gambia.

Beautiful mangrove stands, reaching to over 20 m in height, can be observed between 100 and 160 km upstream from the sea, especially near Tendaba, Elephant Island and Dan Kun Ku Island, where the average salinity of the water during the dry season is about 10‰.

Along the almost flat topography of the Gambia River valley, several mangrove formations exist, from the estuarine formations found near the capital Banjul to the tall fluvial formations found some 160 km upstream from the ocean (lower river and MacCarthy Island divisions). A large water catchment and a high, almost constant, freshwater supply maintain some of the best mangrove stands presently found in West Africa. Direct human impact is limited, except near Banjul. However, the exceptional dryness that affected the African continent in the 1970s, caused deterioration of the mangroves of Gambia, especially those found near the river tributary, Bintang Bolon. A high mortality of the mangroves occurred, presumably due to deeper tidal penetration and accompanying increased water and soil salinity (Plate 8.2, Figure 8.7). About 20 sq km of mangroves were destroyed.

From an ecological point of view, the mangroves are probably extremely sensitive to minor changes in the tidal regime and in the volume and frequency of the freshwater input. The mangroves play an important role in the fisheries of the river and estuary. The tall mangrove areas of Gambia (height over 20 m) represent an important sustainable source of forest products. These systems are highly productive and it might be possible to utilise and manage the *Rhizophora* stands of the lower Gambia River basin on a 30 year rotation. Out of 497 sq km, which is the present area of mangroves in Gambia, tall forest probably covers 300 sq km.

Environmental data

• Mean annual rainfall	1,000-1,300 mm
• Dry season	6-8 consecutive dry months (November-May)
• Water salinity	Minimum 5‰ upstream, maximum 33‰ (mouth of the river)
• pH of the topsoil	5 to 7
• Dominant soil type	Clayey
• Mean tidal amplitude	1-2 m
• Areal extent	600 sq km in 1982, less than 500 sq km in 1995 (saltmarshes and blanks make up 3% of the total mangrove area, and crops less than 5%)
• Average population density	5 people/sq km
• Dominant mangrove type	Tall riverine mangrove type (>20 m height)
• Main mangrove species	Rhizophora *harrisonii*, *R. racemosa*, *Avicennia germinans*
• Average standing stock	100-150 m^3/ha

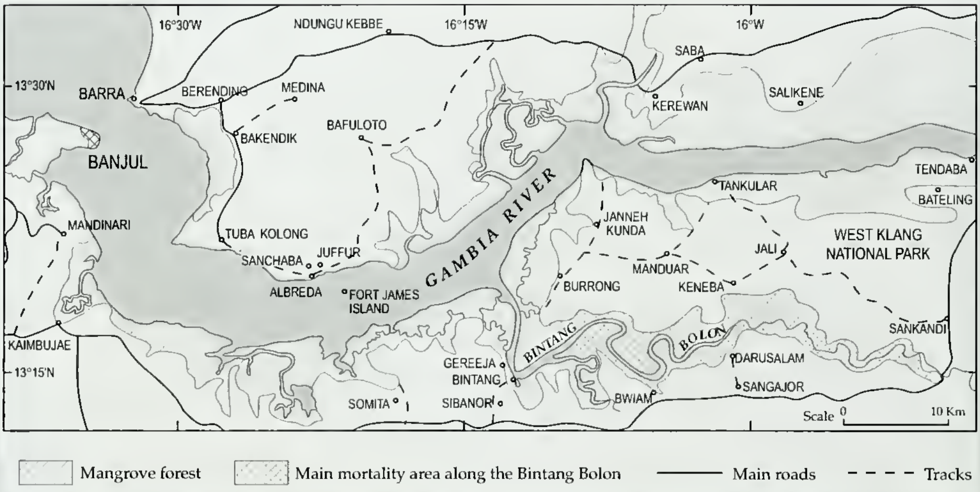


Figure 8.4 Distribution of mangroves in Gambia

Figure 8.5 SPOT satellite image. The mangroves along the lower Gambia River (in red) surrounded by savannah and crop land

White and black 'holes' in the vegetation cover are due to mangrove mortality either on dry soils (white) or on flooded areas (black)

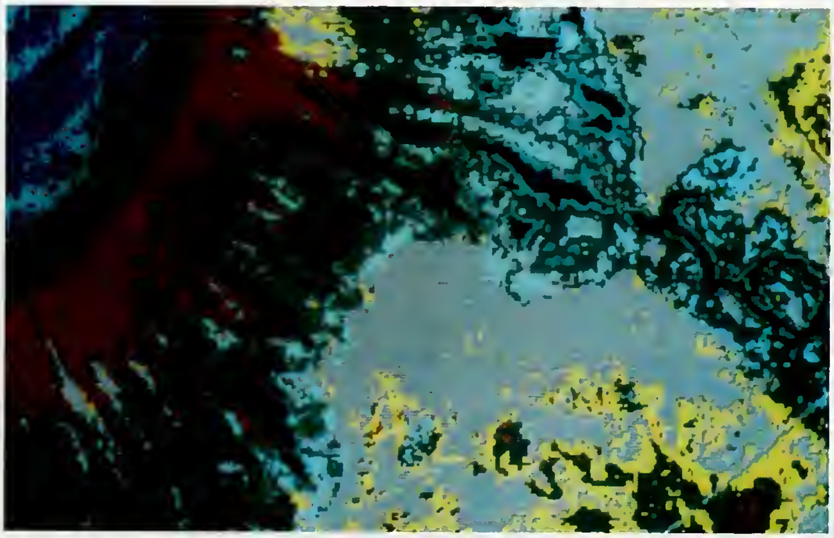


Figure 8.6 SPOT satellite image
As Figure 8.5, showing greater detail (prepared using Multiscope software)

Plate 8.2 A view of mass mortality in the mangroves of Gambia

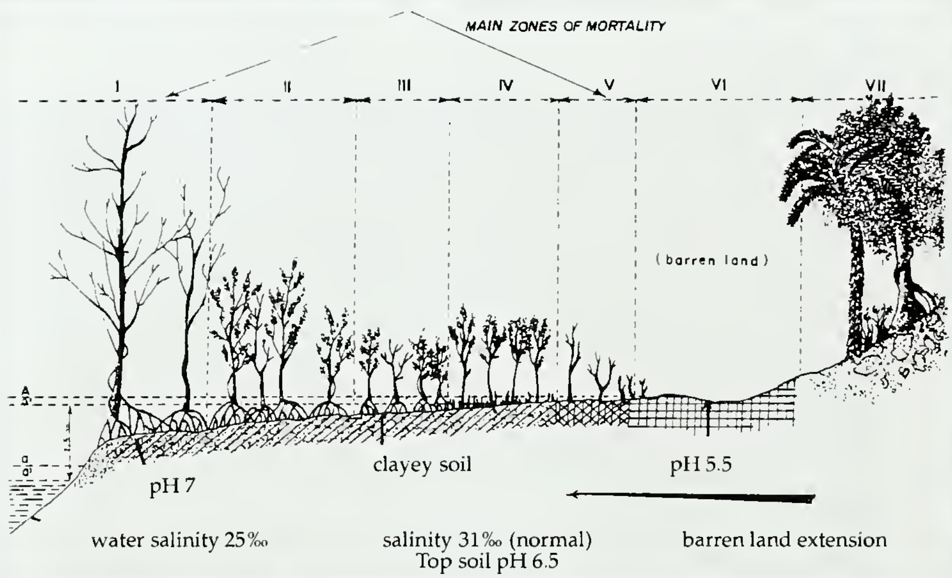


Figure 8.7 Mortality and distribution of mangrove plants at Darusalam, Bintang Bolon (Gambia)

A Previous mean high tidal level (twice a day)
A' Present mean high tidal level (twice a day)
a Previous mean low tidal level
a' Present mean low tidal level

I *Rhizophora harissonii* and *R. mucronata* dead or dying, practically no regeneration
II *Rhizophora mangle* almost monospecific, good regeneration, low mortality
III *Rhizophora mangle* and *Avicennia* intermingled, healthy, good regeneration
IV *Avicennia* only, healthy, good regeneration
V *Avicennia* zone totally destroyed without any regeneration
VI Barren, high soil salinity, arid conditions
VII Orchards (oil palm (*Elaei guineensis*), *Ficus* etc.) on well drained soils

Ghana

Map 8.2

Land area	238,540 sq km
Total forest extent (1990)	95,550 sq km
Population (1995)	17,453,000
GNP (1992)	440 US$ per capita
Mean monthly temperature range	24-30°C
Mean annual rainfall	1,250 mm
Spring tidal amplitude (Takoradi)	0.3-1.6 m
Alternative estimate of mangrove area (Saenger and Bellan, 1995)	100 sq km#
Area of mangrove on the map	214 sq km
Number of protected areas with mangrove	0

In Ghana, mangroves are mainly limited to stands around lagoons on the west coast of the country and bordering the lower reaches and delta of the Volta River. They are best developed on the west coast between Côte d'Ivoire and Cape Three Points. Open lagoons are often dominated by *Rhizophora*, while closed lagoons, which have an elevated salinity, contain *Avicennia germinans*, *Conocarpus erectus*, *Laguncularia racemosa* and *Acrostichum aureum*. The mangrove stands in most areas are secondary growth with degraded faunal composition due to intensive use of the mangrove for fuelwood to smoke fish and extract salt. Mangrove wood is also used for construction. Mangrove lands have been reclaimed for agriculture and urbanisation. There is a threat from oil pollution. The relatively dry climate of Ghana means that the coastal areas are dominated by savannah.

Map reference

Digital data set entitled West African Forest Data compiled by Henrik Olesen of UNEP-GRID from AVHRR imagery (1 km pixels), for the TREES (Tropical Ecosystem Environment Observations by Satellite) project of the EC Joint Research Centre, Italy. A crude estimate of the mangrove coverage in the Volta Delta has been added.

Guinea

Map 8.1

Land area	245,860 km
Total forest extent (1990)	66,920 sq km
Population (1995)	6,700,000
Mean monthly temperature range	23-32°C
Mean annual rainfall	4,500 mm
Spring tidal amplitude (Conakry)	0.5-3.7 m
Alternative estimate of mangrove area (Saenger and Bellan, 1995)	2,963 sq km#
Area of mangrove on the map	3,083 sq km
Number of protected areas with mangrove	0

Mangroves are located all along the coast of Guinea. The subsidence of the coastal region has favoured the deposition of sediment and the flooding of river mouths. The tide penetrates far upstream and forms many narrow inlets by partial submergence of river valleys. The mangroves stretch along these narrow inlets and into the bays at the river mouths. The mangroves are extensive for about 10 km inland and they can be found up to 40 km from the coast on the larger rivers. *Rhizophora* can be found growing to a height of 20 m in some areas but in other areas the trees rarely get above 8 m and are often much smaller. As in the other countries of this region rice growing is widely practised in the mangrove areas and this is often combined with fish farming. Salt extraction is a seasonal activity and mangrove wood is often used as fuel. It is estimated that 1,400 sq km of mangrove swamp has been converted to rice fields. By 1993, 620 sq km had been abandoned. Most of this area remains barren or has thin cover of saltmarsh plants.

Map reference

The data are derived from 1979-80 aerial photography, updated using Landsat MSS 1984-1985-1986 imagery.

CTFT/BDPA-SCET AGRI (1989). *Potentialités et Possibilités de Relance de l'Activité Forestière: Synthèse Régionale et Nationale.* 1:700,000. CTFT/BDPA-SCET AGRI.

Guinea-Bissau

Map 8.1

Land area	36,120 sq km
Total forest extent (1990)	20,210 sq km
Population (1995)	1,073,000
GNP (1992)	210 US$ per capita
Mean monthly temperature range	24-27°C
Mean annual rainfall	1,750 mm
Spring tidal amplitude (Caio)	2.30m
Alternative estimate of mangrove area (Saenger and Bellan, 1995)	2,484 sq km#
Area of mangrove on the map	3,649 sq km
Number of protected areas with mangrove	0

Guinea-Bissau is generally low lying, rising from sea level in the west to low mountains in the east. The coastal zone represents an important resource with its numerous estuaries surrounded by mangrove swamp forests. It is inhabited by numerous ethnic tribes and about 60% of the population live in this region. Guinea-Bissau has the same mangrove species as Senegal except that *Acrostichum aureum* is not found. Salt marshes or herbaceous 'tannes' exist and species of *Sesuvium* are dominant. The tidal influence is felt 150 km inland and defines the limit of the mangroves. The most extensive mangrove forests are in the north of the country. The area of mangrove may have declined by as much as 20% since 1973 mainly due to conversion for rice farming. The growing of rice on mangrove soils has a long tradition and sea water is allowed to enter the rice fields during the dry season to reduce the acidity of the soil. Fish and crustaceans collected from the mangrove estuaries are the main source of protein in the coastal villages. Firewood, construction timber and medicinal products are also obtained from the mangroves. The construction of numerous anti-salt barriers to extend commercial rice production is having an adverse affect on many mangrove areas.

Map reference

Information taken from a generalised map (c.1:1,000,000) hand drawn by Scott Jones in 1990, based on IGN (1981), but updated to show forest loss.

IGN (1981). *Guinée Bissau*. 1:500,000. Instituto Geográfico Nacional.

Liberia

Map 8.2

Land area	96,320 sq km
Total forest extent (1990)	47,900 sq km
Population (1995)	2,600,000
GNP (1992)	440 US$ per capita
Mean monthly temperature range	24-29°C
Mean annual rainfall	4,600 mm
Spring tidal amplitude (Monrovia)	0.2-1.3 m
Alternative estimate of mangrove area (Saenger and Bellan, 1995)	190 sq km#
Area of mangrove on the map	427 sq km
Number of protected areas with mangrove	0

Mangroves are not extensive in Liberia but they do occur at the mouths of the rivers and in some of the lagoons. Lake Piso, a very large open lagoon near the border with Sierra Leone, supports a series of mangrove swamps. The lagoon mangrove communities around Cape Palmas in southeastern Liberia can attain a height of 3 m and are dominated by *Conocarpus erectus* with only rare specimens of *Avicennia germinans* and *Rhizophora racemosa*. Thickets of *Acrostichum aureum* are also common. On the central Liberian coast estuarine mangroves occur, consisting of stunted *Rhizophora harrisonii*, *Avicennia germinans* and *Conocarpus erectus*. The mangroves of Liberia have suffered from road building, landfill and fuelwood collection. *Rhizophora racemosa* seems to have been eliminated in some places by extensive felling. At present, none of the mangroves are in a protected area.

Map reference

Digital data set entitled West African Forest Data compiled by Henrik Olesen of UNEP-GRID from AVHRR imagery (1 km pixels), for the TREES (Tropical Ecosystem Environment Observations by Satellite) project of the EC Joint Research Centre, Ispra, Italy. Further minor edits were provided by François Blasco.

Mauritania

Map 8.1

Land area	1,025,520 sq km
Total forest extent (1990)	5,540 sq km
Population (1995)	2,335,000
GNP (1992)	520 US$ per capita
Mean monthly temperature range	21-30°C
Mean annual rainfall	139 mm
Spring tidal amplitude (Port Etienne)	0.5-1.5 m
Alternative estimate of mangrove area (Saenger and Bellan, 1995)	10 sq km
Area of mangrove on the map	1.04 sq km#
Number of protected areas with mangrove	2

Mangrove communities are somewhat limited in extent in Mauritania, but those that do occur represent the northernmost and the most arid mangrove systems on the Atlantic coast of Africa. There are two centres of mangrove distribution, one along the Senegal River Delta, which has a sahelian climate, the other further north around Cape Timirist and the Banc d'Arguin National Park. These two areas are separated by a coastline consisting of sandy beaches backed by a high ridge and exposed to strong wave action. In the Senegal River Delta *Rhizophora racemosa* is dominant along the creeks and *Avicennia germinans* covers the back swamps, possibly with some specimens of *Conocarpus erectus*. The northern stands consist of a few hundred hectares of pure *Avicennia germinans*, and may well be relict from an estuarine past. Trees are dwarfed, rarely exceeding 2 m in height, and the stands may be in decline as levels of recruitment are very low. The mangroves have also declined considerably in the Senegal Delta, a fact which has been related to over-exploitation for firewood and boat construction by local populations; increased grazing pressure by camels and goats, combined with reduced flooding, both of which can be related to the sahelian droughts; and the increased salinity of the river basin as a result of the construction of the Diama dam near the Senegal River mouth. Since 1993 it appears that regeneration of mangrove communities may have occurred in some areas. (Main source: O. Hamerlynck, pers. comm., 1995.)

Map references

Mangroves were annotated from sketch maps in Gowthorpe (1993) and Yelli (1995), kindly provided by O. Hamerlynck, UICN Mauritanie.

Gowthorpe, P. (1993). Une visite au Parc National de Banc d'Arguin. 193 pp.

Yelli, D. (1995). Formations morphopédologiques et les unités floristiques de bas delta mauritanien. Paper presented at the Colloquium 'Biodiversité du Littoral Mauritanien', Nouakchott, 12–13 June, 1995.

Nigeria

Map 8.2

Land area	923,770 sq km
Total forest extent (1990)	156,340 sq km
Population (1995)	126,929,000
GNP (1992)	320 US$ per capita
Mean monthly temperature range	24-27°C
Mean annual rainfall	2,000 mm
Spring tidal amplitude (Escravos)	0.3-1.6 m
Alternative estimate of mangrove area (Saenger and Bellan, 1995)	10,515 sq km#
Area of mangrove on the map	11,134 sq km
Number of protected areas with mangrove	0

Nigeria has the largest area of mangroves in Africa and mangrove swamps stretch along the entire coastline, which is characterised by high rainfall and humid conditions. The largest expanse of mangroves is found in the Niger Delta between the region of the Benin River in the west and the Calabar, Rio del Rey estuary in the east. A maximum width of 30 to 40 km of mangroves is attained on the flanks of the Niger Delta, which is itself a highly dynamic system. Two large lagoons, Lagos and Lekki, dominate the coastal systems in the west of the country. Both are fringed by mangroves, backed, in turn, by swamp forests. In the far east of the country there is a second major delta/estuary system associated with the Cross River which also has a considerable area of mangroves extending in a belt of 7-8 km on either side of the estuary and up to 26 km in the deltaic zone at the head of the estuary. In the lagoons and deltas, *Rhizophora racemosa* is the most abundant mangrove, with *Avicennia germinans, R. harrisonii* and *R. mangle* only sparsely represented. In the estuaries the species composition may be different and *Nypa fruticans*, an introduced species, becomes more abundant. The mangroves rarely exceed more than 10-12 m in height but can on occasion reach more than 40 m. Fishing is an important activity in most mangrove areas. The major threats being experienced by mangroves are those resulting from oil pollution and uncontrolled wood exploitation. Oil and gas installations are spread throughout the central and western parts of the Niger Delta and there are four tanker ports at the delta face.

Map reference

Digital data set entitled West African Forest Data compiled by Henrik Olesen of UNEP-GRID from AVHRR imagery (1 km pixels), for the TREES (Tropical Ecosystem Environment Observations by Satellite) project of the EC Joint Research Centre, Ispra, Italy.

São Tomé and Principe

Map 8.2

Land area	960 sq km
Total forest extent (1990)	570 sq km
Population (1995)	133,000
GNP (1992)	350 US$ per capita
Mean monthly temperature range	23.9-26.1°C
Mean annual rainfall	951 mm
Spring tidal amplitude	0.5-1.9 m
Alternative estimate of mangrove area	No information
Area of mangrove on the map	No data
Number of protected areas with mangrove	0

No information on the presence of mangroves.

Map reference

No data

Senegal

Map 8.1

Land area	196,720 sq km
Total forest extent (1990)	75,440 sq km
Population (1995)	8,387,000
GNP (1992)	780 US$ per capita
Mean monthly temperature range	15-28°C
Average rainfall range (Casamance)	691-1,371 mm
Average rainfall range (St Louis)	95-342 mm
Spring tidal amplitude (Dakar)	0.3-1.6 m
Alternative estimate of mangrove area (Saenger and Bellan, 1995)	1,853 sq km#
Area of mangrove on the map	1,830 sq km
Number of protected areas with mangrove	2

The mangroves of Senegal are largely estuarine and occur in two main regions: the estuaries of the Saloum and the Casamance. These are both reverse estuaries as the salinity upstream in the dry season is often two to three times the salinity of the neighbouring sea water. There are often salt marshes behind the mangroves with species of *Sesuvium*, *Paspalum*, *Sporobulus*, *Scirpus* and *Philoxerus* present. Mangrove areas have been traditionally used for rice growing, fishing, fish culture, shell picking and wood. Senegal has been affected by drought since 1963 and this has had an adverse effect on the mangroves leading to a decrease in the total area. Intensification of agriculture and increasing population pressure have resulted in increased erosion and siltation.

Map reference

The main source map (USGS, 1985) was kindly made available to WCMC by the EDC International Projects Department of the EROS Data Center, and was compiled from the interpretation of Landsat imagery of different dates and from extensive ground surveys. A small northern extension to a Casamance tributary at the eastward end of that estuary was based on a sketch from François Blasco.

USGS (1985). *Range and Forest Resources of Senegal.* 1:1,000,000 scale. Digital map prepared for the US Agency for International Development (USAID) by the US Geological Survey, National Mapping Division, EROS Data Center.

Sierra Leone

Map 8.1

Land area	71,740 sq km
Total forest extent (1990)	18,890 sq km
Population (1995)	4,740,000
GNP (1992)	170 US$ per capita
Mean monthly temperature range	28-32°C
Mean annual rainfall	9,000 mm
Spring tidal amplitude (Freetown)	0.4-3 m
Alternative estimate of mangrove area (Saenger and Bellan, 1995)	1,838 sq km#
Area of mangrove on the map	1,695 sq km
Number of protected areas with mangrove	0

The rich mangrove forests of Sierra Leone have been heavily exploited due to rapid population increase and the poor economic performance of the country. The mangrove species and saltmarsh species found in Sierra Leone are the same as those found in Senegal. The most extensive mangrove stands are in the northern part of the country and major locations are Yawri Bay, the estuaries and islands behind Freetown and the complex of coastline and estuaries behind Sherbro Island which join into a wide waterway known as Sherbro River. The mangroves extend far up the rivers to the extent of the tides. *Rhizophora racemosa* is commonly found in association with *Avicennia* on mudflats, but in areas where the soil is well consolidated and there is an input of freshwater *R. racemosa* grows exclusively, sometimes to a height of 35 m. Large scale erosion in some mangrove areas has occurred due to deforestation, often to provide new areas for rice production. Fish smoking is a major way of preserving food and cheap fuel from the mangroves is used for this purpose. Similarly, mangroves supply cheap fuel for salt production. Siltation and pollution of estuaries pose a major threat to the mangrove communities.

Map reference

Digital data set entitled West African Forest Data compiled by Henrik Olesen of UNEP-GRID from AVHRR imagery (1 km pixels), for the TREES (Tropical Ecosystem Environment Observations by Satellite) project of the EC Joint Research Centre, Ispra, Italy.

Zaire

Map 8.3

Land area	2,345,410 sq km
Total forest extent (1990)	1,132,750 sq km
Population (1995)	43,814,000
GNP (1990)	220 US$ per capita
Average temperature	25°C
Mean annual rainfall	800 mm
Spring tidal amplitude	0.3-1.6 m
Alternative estimate of mangrove area (Saenger and Bellan, 1995)	226 sq km#
Area of mangrove on the map	374 sq km
Number of protected areas with mangrove	0

Zaire is Africa's third largest country, but has only a tiny coastline of less than 40 km at the mouth of the Zaire River. The coast is generally of high relief, but mangrove stands occur where the cliffs are breached by coastal rivers and streams. The main mangrove area occurs in the estuary of the Zaire River. The tidal forests are dominated by *Rhizophora racemosa* in the frontal zone and by *R. harrisonii* and *R. mangle* in the middle zones. The first two species can reach heights of 25-30 m. The *Rhizophora* forests merge into fresh water swamp forests some of which are weakly tidal. The Zaire River estuary is sparsely populated and there has been little degradation of the mangroves. There have been some reports of oil pollution from the oil terminals in the adjacent Cabinda enclave of Angola.

Map references

Digital data were provided by NASA/GSFC and the University of Maryland, USA (n.d.). Mangrove areas were estimated from the closed moist forest coverage by overlaying White (1983).

NASA/GSFC and the University of Maryland (n.d.). Derived from 1 km resolution NOAA/AVHRR 1988 data. Produced at NASA, Goddard Space Flight Center.

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Case study

Sahelian mangroves in Sine-Saloum, Senegal

The most northern mangroves presently found in West Africa are in Mauritania (Map 8.1) where a few stunted bushes of *Avicennia germinans* are still found in the Banc d'Arguin National Park, at about 20° north, growing in near-desert conditions and without noticeable freshwater supply. They are considered as remnants of moister climatic conditions. In this part of Africa, palaeontologists have described a continuous drying of the climate for the past 35,000 years. Most of the mangrove forests of Mauritania and northern Senegal disappeared during the Nouakchottian period, 6,500 years ago.

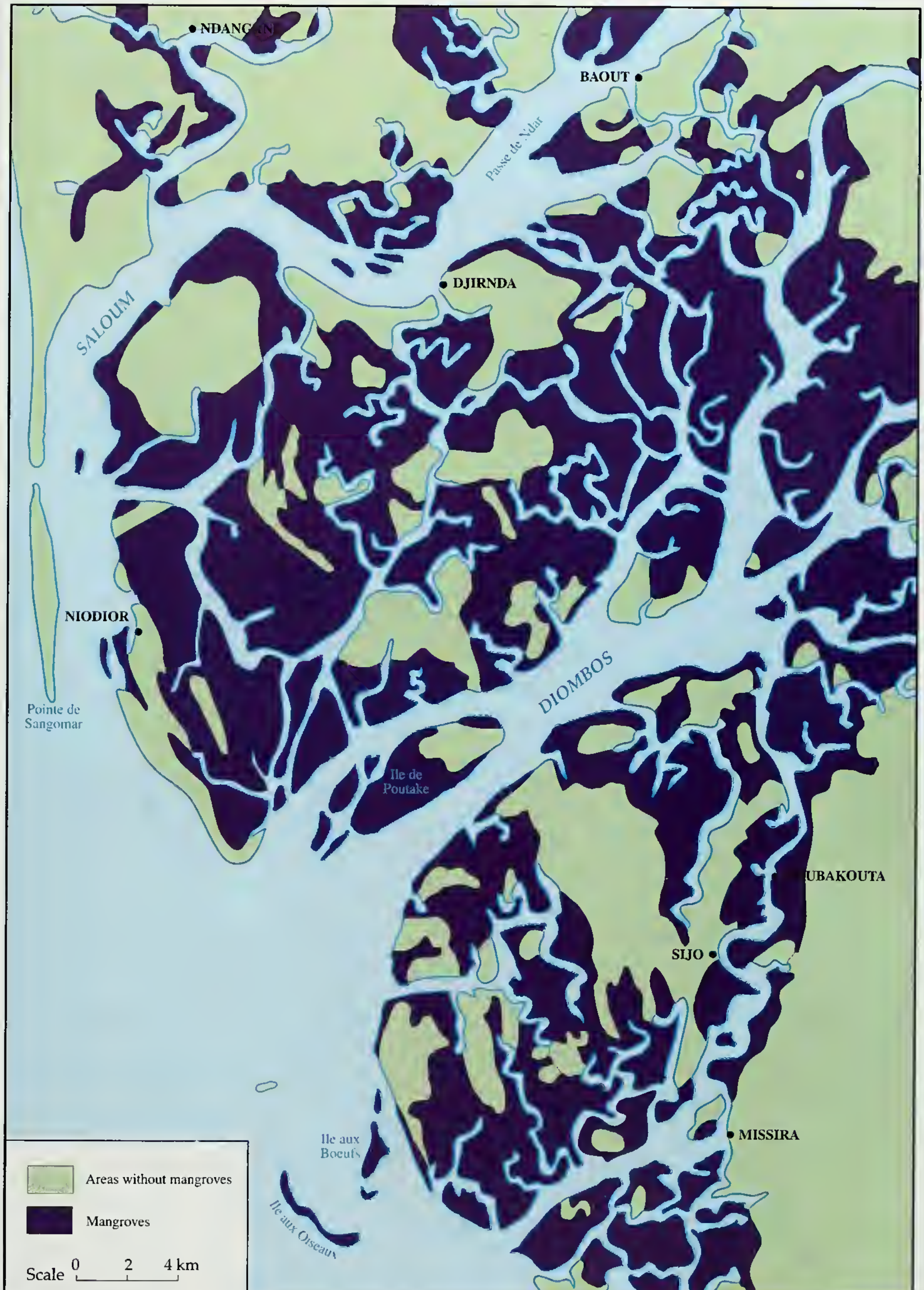
Several hundred kilometres further south, the mangroves of Sine-Saloum (Map 8.1, see insert 1) represent today the most northern of the large mangrove forests in the region. They are also the most exposed to the local climatic change and aridification. Figure 8.9 shows the classical zonation of these mangroves. The average annual rainfall (700-1,000 mm) and the eight consecutive dry months of the dry season create semi-arid conditions. The recent exceptionally dry years (300-500 mm rainfall per year) induced increased soil and water salinities and almost all woody halophytes have been affected. When the mean salinity of the water exceeds 40‰, *Rhizophora mangle* tends to disappear and the resulting mangrove community is limited to a low stand of scattered *Avicennia* bushes (Plate 8.3).

The general result of increasing salinity, due to worsening of climatic conditions and to freshwater diversion for human use, is reduced plant growth, lower organic matter production, the gradual substitution of mangrove species by other, more salt tolerant, species and the extension of salt flats (blanks or tannes) where the natural re-establishment of mangrove seedlings is impossible.

Between 1980 and 1991 the extent of barren soils in the Sine-Saloum increased by 3% and that of cultivated areas by 5% (Figures 8.8 and 8.11). The two maps illustrating the distribution of mangroves in the Sine-Saloum provide a useful comparison between the data obtained from Landsat MSS (Figure 8.8) and SPOT-HRV (Figure 8.11). While the former is generally considered highly accurate, SPOT provides the highest resolution and allows improved identification of mangrove types and related land uses. The average rate of deforestation in the mapped areas is about 8% per year which is quite high, especially as the mangroves are included in the National Park of Saloum Delta. The most affected areas are located between the Saloum and Diombos Rivers where large areas have been drained during the last decades to provide land for agriculture. Clearing land for agriculture (food crops, groundnuts, oil palms), wood extraction by the increasing local population and drastic climatic conditions seriously threaten the mangroves in this area (Figure 8.10) (Plate 8.4).

Environmental data

• Mean annual rainfall	700-1,000 mm/year
• Dry season	8 consecutive dry months (November-June)
• Water salinity	Minimum 25‰ to maximum probably >90‰
• pH of the topsoil	7
• Dominant soil types	Mainly sandy on the seaward side, loamy-clayey upstream
• Average tidal amplitude	<0.5 m
• Total areal extent	About 55 sq km
• Average population density	65 people/sq km
• Dominant mangrove type	Estuarine. Low (3-5 m in height), dense formations
• Main mangrove species	*Rhizophora racemosa, R. mangle, Avicennia germinans*



 Realization : J.L. CARAYON

Figure 8.8 Mangroves of Sine-Saloum, Senegal, taken from Landsat MSS 1980

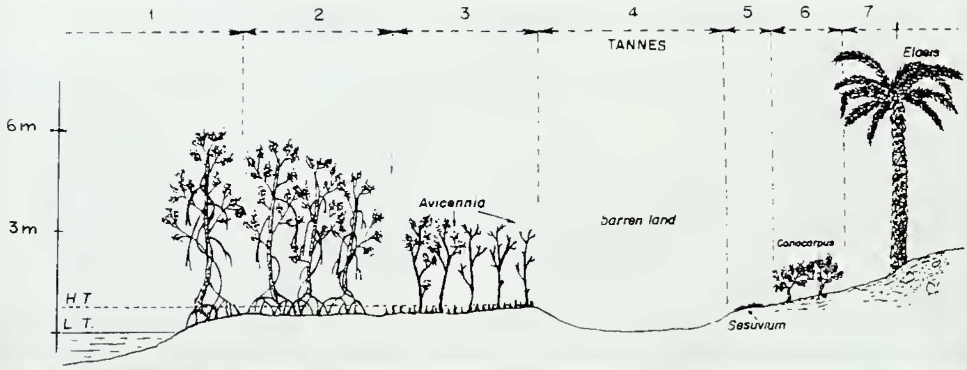


Figure 8.9 Classical zonation of Sahelian mangroves

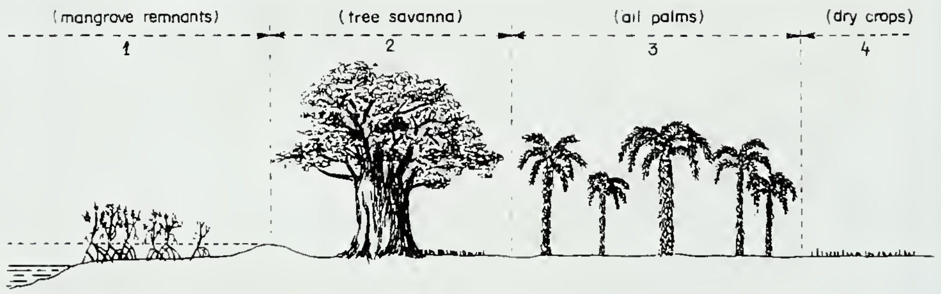


Figure 8.10 Landscape, near Niodor (Sine-Saloum), illustrating the extension of agriculture, notably groundnut and oil palm plantations

Main water bodies

Main dense mangrove areas

Areas with low mangroves, often degraded (mainly *Avicennia*)

Crops (mainly ground nuts) or plantations on sandy soils

Mosaics of crops and barren lands

Barren lands including salt flats

Cristallized sodium chloride

Mainly grassy halophytes

Tree savannas generally with *Adansonia digitata* (Baobabs) and shrubby *Acacia*

Realization: J.L. CARAYON

Legend to Figure 8.11

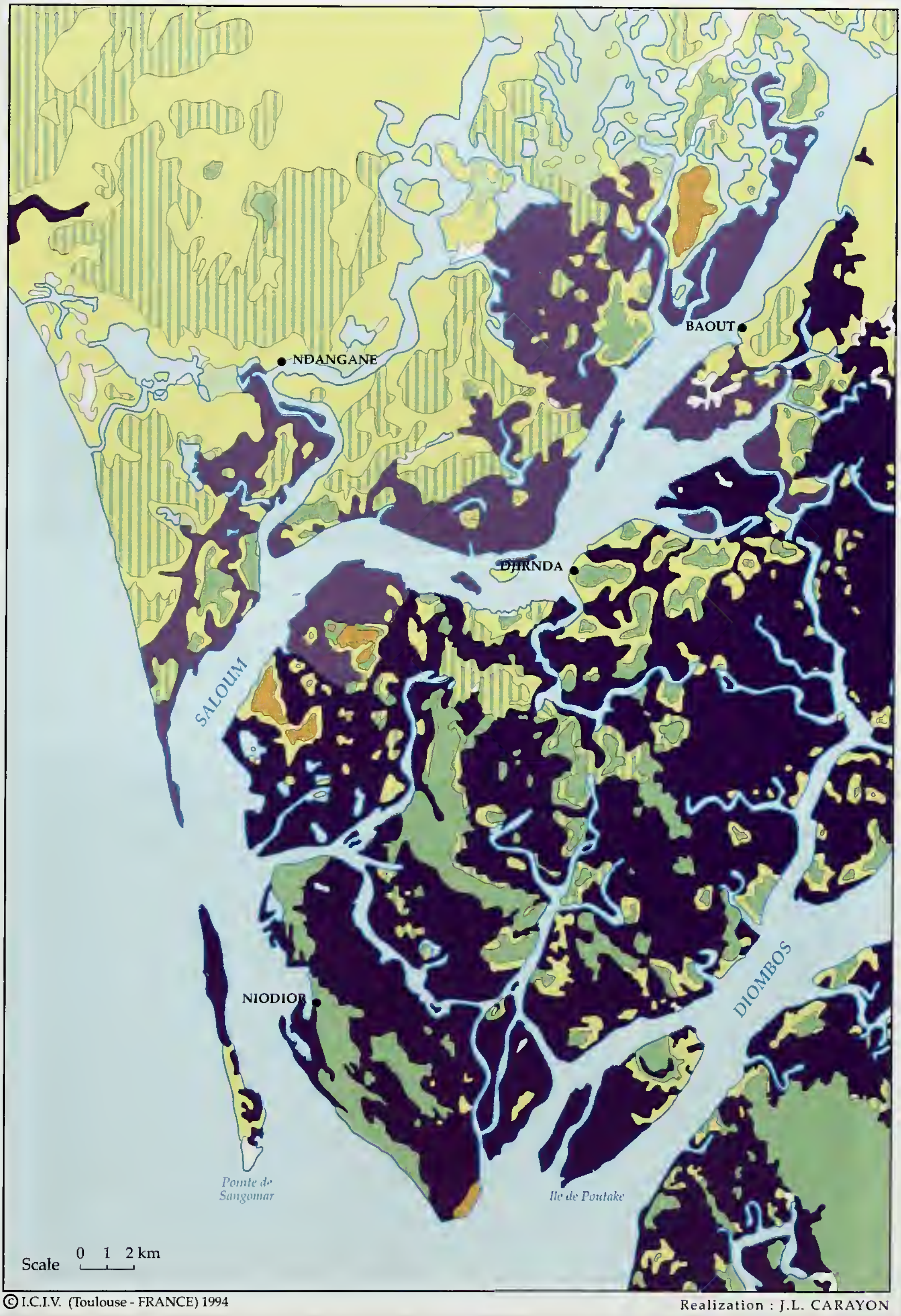


Figure 8.11 Mangroves of Sine-Saloum, Senegal, taken from SPOT data, 1991

Plate 8.3 Scattered dying stand of *Avicennia germinans*

Plate 8.4 Mangroves of Senegal badly affected by clearing for agriculture

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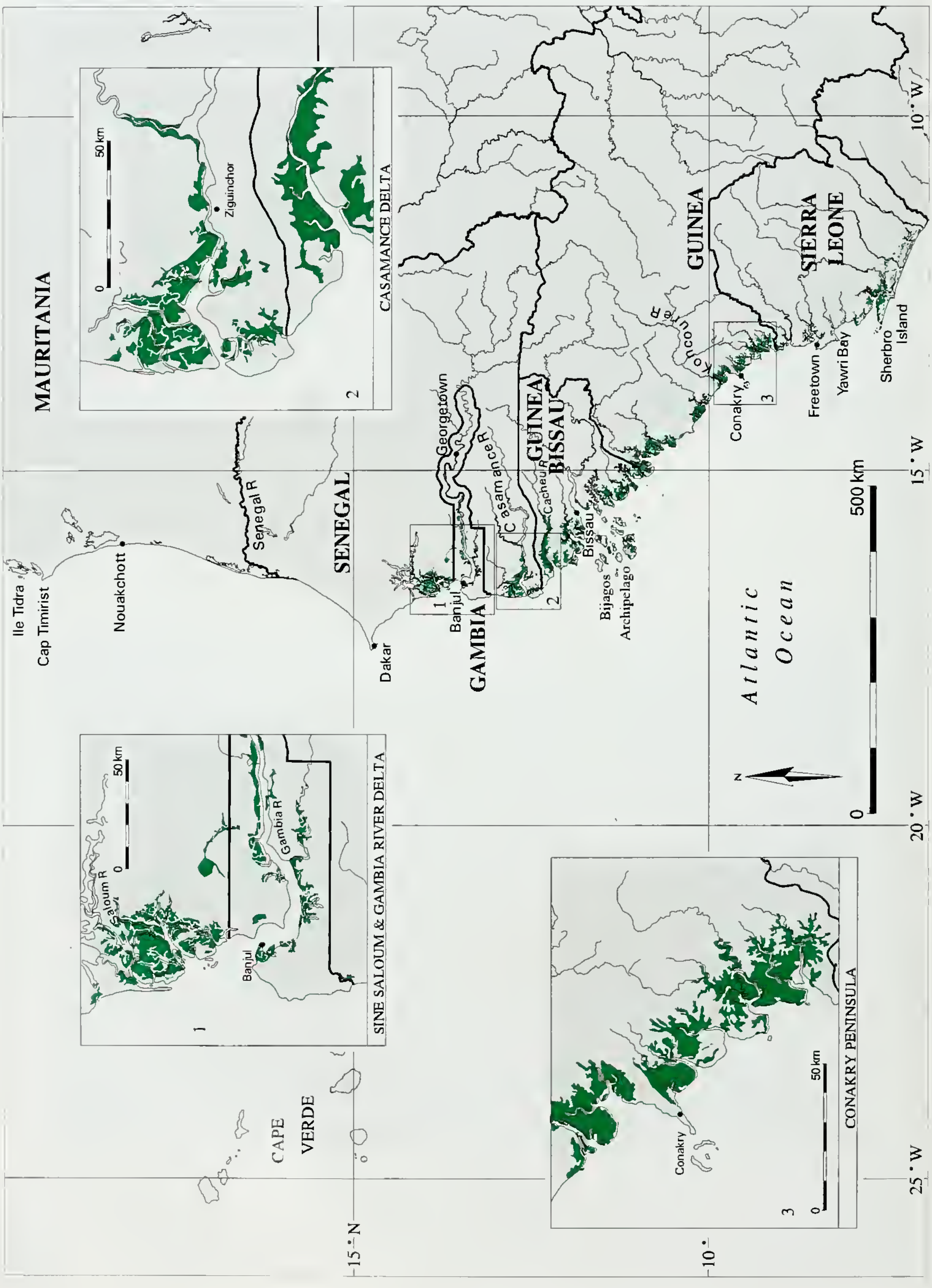
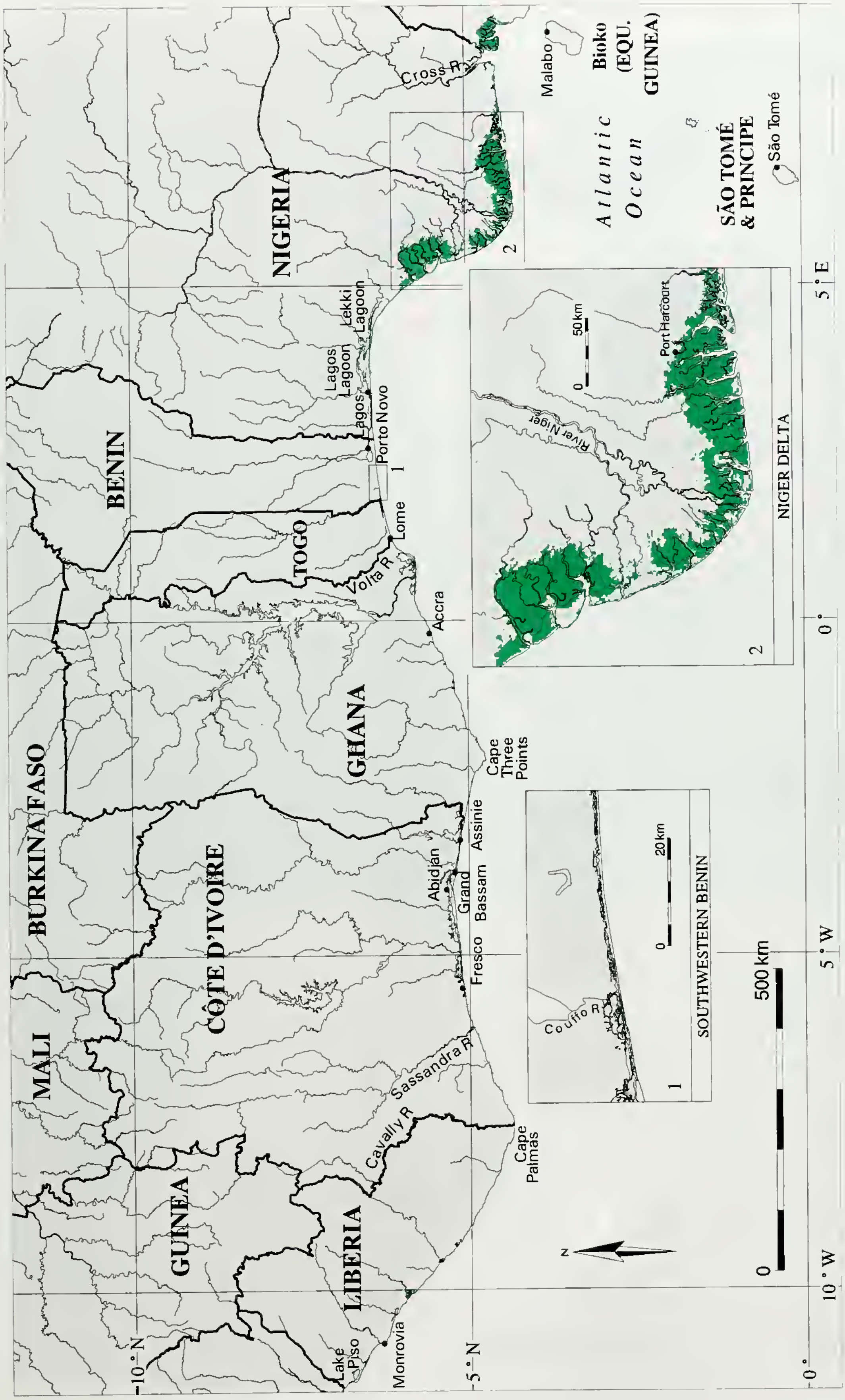
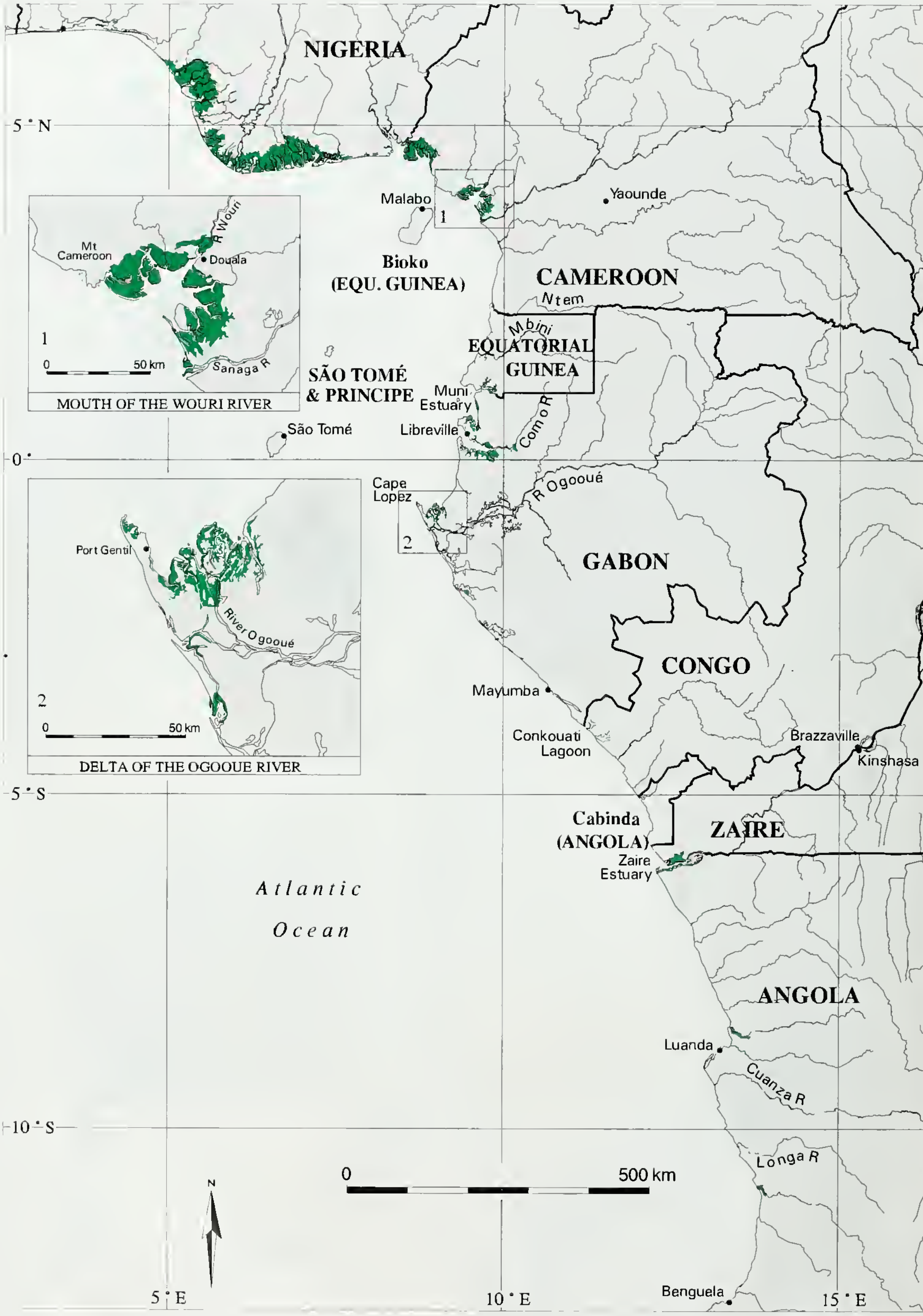


Map 8.1 Northwest Africa: Mauritania to Sierra Leone



Map 8.2 West Africa: Liberia to Nigeria



Map 8.3 **Southwest Africa: Nigeria to Angola**

9

East Africa and the Middle East

This region includes the entire east coast of Africa from South Africa to Egypt; it also includes the coasts of the Arabian Peninsula and Iran, together with the scattered mangrove communities of the Indian Ocean islands. This region is dominated by arid coastlines and so, despite having a long coastline, it has a relatively small area of mangroves. The total area of mangroves in the region is some 10,024 sq km, or 6% of the total global area. There are also relatively few species, which could be related to the harsh environmental conditions as much as to other historical and biogeographic factors.

In the Red Sea and the Gulf, despite the low diversity and relatively low total areas, the mangroves are of considerable interest and often represent the only forest habitats in the coastal areas of these countries. Furthermore, many of these mangroves are growing in areas of high seawater salinities, minimal freshwater input, and both hot and cold temperature extremes. Typically, these mangroves are stunted and cannot be used for timber. However, they are used for grazing and firewood. Fisheries, within the mangroves and offshore, are often very important. Arab, Somali, Persian and Indian traders export mangrove timber, primarily for boat building, from Kenya, Tanzania and Mozambique, in a trade that dates back to the ninth century.

On the Indian Ocean islands, the development of mangroves is very variable. The variation can often be related to either the morphology of particular islands, or to their isolation. The very steeply shelving rocky shores of some islands provide little space for mangroves to develop, and the most remote islands are perhaps too isolated for large-scale mangrove establishment, especially if they are regularly affected by tropical cyclones. East Africa, particularly Kenya, Tanzania, Mozambique and the western coast of Madagascar, has the best developed mangroves in terms of area, species diversity and forest structure.

In general, mangroves in this region appear to be less threatened by man than elsewhere, although detailed information is scarce for a number of countries. The harsh environmental conditions in many areas mean that coastal populations are not large and there is little pressure to convert mangroves to other uses. Aquaculture has not become widespread as it has in other regions. Some mangrove areas have been lost to urbanisation. Other areas have been severely degraded by salt extraction, overgrazing, unsustainable collection of fuelwood or pollution from oil or urban sources. Population growth in some areas will increase these pressures.

Although there are no general texts describing the mangroves of the region as whole, certain countries are described by Hughes and Hughes (1992) and by Sheppard *et al.* (1992).

Table 9.1 Mangrove species list for East Africa and the Middle East

	Bahrain	British Indian Ocean Territory	Comoros	Djibouti	Egypt	Eritrea	Iran	Kenya	Madagascar	Maldives	Mauritius	Mozambique	Oman	Qatar	Saudi Arabia	Seychelles	Somalia	South Africa	Sudan	Tanzania	United Arab Emirates	Yemen
Acrostichum aureum									•	•		•				•		•		•		
Avicennia marina	•			•	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•
Bruguiera cylindrica										•												
Bruguiera gymnorrhiza								•	•	•	•	•				•	•	•	•	•		Ex
Ceriops tagal						•		•	•	•		•				•	•	•		•		
Excoecaria agallocha										•												
Heritiera littoralis								•	•			•								•		
Lumnitzera racemosa		•						•	•	•		•				•	•	•		•		
Pemphis acidula		•								•		•				•						
Rhizophora mucronata					•	•	•	•	•	•	•	•			•	•	•	•	•	•		•
Rhizophora racemosa															I							
Sonneratia alba								•	•			•				•	•			•		
Sonneratia caseolaris										•												
Xylocarpus granatum								•	•			•				•				•		

Ex Extinct in that country
I Introduced

Country sources

Bahrain	Sheppard *et al.*, 1992	Mozambique	Hughes and Hughes, 1992
British Indian Ocean Territory	Bellamy, 1979	Oman	Sheppard *et al.*, 1992
Comoros	No data	Qatar	Sheppard *et al.*, 1992
Djbouti	MEPA, 1987	Saudi Arabia	Sheppard *et al.*, 1992
Egypt	MEPA, 1987	Seychelles	various WCMC files
Eritrea	MEPA, 1987	Somalia	Hughes and Hughes, 1992
Iran	Khosravi and Motalebi, 1994	South Africa	Hughes and Hughes, 1992
Kenya	Ruwa, 1993	Sudan	MEPA, 1987
Madagascar	Marguerite, 1993	Tanzania	Semesi, 1993
Maldives	NIO, 1991	United Arab Emirates	Sheppard *et al.*, 1992
Mauritius	Blasco, pers. comm., 1995	Yemen	MEPA, 1987 and M. Rands, pers. comm., 1992

The Gulf and the Gulf of Oman **Map 9.1**

The Gulf, variously known as the Arabian Gulf and Persian Gulf, is a wide, shallow body of sea to the north of the Indian Ocean, separated from the latter by the Gulf of Oman and the Straits of Hormuz. The Gulf of Oman represents a relatively narrow northern extension of the Indian Ocean. The countries under consideration are Bahrain, Iran, Iraq (no mangroves), Kuwait (no mangroves), Oman, Qatar, United Arab Emirates, and the east coast of Saudi Arabia. The coastlines in the region are all arid or hyper-arid and there is very little freshwater input other than that in the far north from the Shatt al Arab and associated rivers. Seawater salinities are higher than in the open ocean. Tidal ranges are generally less than 1 m, although they can reach 2 m in some areas. Temperature ranges are considerable and cool temperatures, together with high salinity, may be responsible for restricting mangrove distribution.

Only one species of mangrove is found in the Gulf, *Avicennia marina*, which is very tolerant of the highly saline conditions, while *Rhizophora mucronata* is reported from the Cyrich estuary on the Iranian coast of the Gulf of Oman. The northernmost natural limit for mangroves is about 27°N, which is close to the most southerly occurrences of ground frost in the region. Interestingly, there have been efforts to grow *Rhizophora racemosa* on the Saudi Arabian coast to the north of this (28°30'N) at Ras al Khafji. Mangroves are largely restricted to sheltered locations behind reefs or in creeks or embayments, and are not widespread, for example covering only 1% of the Gulf coastline of Saudi Arabia. In most areas they are unproductive, and are typically stunted, reaching only 1-2 m in height. The best developed stands of mangrove are found in Iran and Oman, the former notably in the Kuran Strait and on the coast of Qeshm Island, the latter in scattered but fairly dense stands on the northeast coast and some small stands with trees reaching 6 m in height on the southeast coast. Despite their limited extent, mangroves in the Gulf were the first to have been recorded anywhere in the world literature, described by Nearchus and Theophrastus over 2,000 years ago. There is very little human use of the mangroves themselves, although they are used in some areas as fodder for camels, for fuel, and in providing stakes for fishing. These uses are probably decreasing in many countries in line with increasing wealth in the region. Conversely many areas are increasingly threatened by pollution, especially oil pollution, which is widespread in many areas of the Gulf and the Straits of Hormuz. Landfill associated with urban and industrial development also threatens mangroves in many areas.

Bahrain

Land area	680 sq km
Population (1995)	578,000
GNP (1991)	7,150 US$ per capita
Mean monthly temperature range	19-36°C
Mean annual rainfall	130 mm
Spring tidal amplitude	1-2 m
Alternative estimate of mangrove area (Sheppard *et al.*, 1992)	1 sq km#
Area of mangrove on the map	3 sq km
Number of protected areas with mangrove	1

Map reference

Abbott (1995). Coral Reefs of Bahrain (Arabian Gulf). Unpublished report prepared for ReefBase and the World Conservation Monitoring Centre, including sketch map showing mangroves at 1:350,000.

Iran

Land area	1,648,000 sq km
Population (1995)	66,720,000
GNP (1992)	2,080 US$ per capita
Mean monthly temperature range (Abadan, northern Gulf)	12-36°C
Mean annual rainfall (Abadan, northern Gulf)	204 mm
Spring tidal amplitude	1-2 m
Alternative estimate of mangrove area (Khosravi and Motalebi, 1994)	207 sq km#
Area of mangrove on the map	749 sq km
Number of protected areas with mangrove	3

Map reference

Generalised data for the entire coastline were taken from Mobayen and Tregubov (1970). Further details for the mangroves of Qeshm Island were added from an unreferenced high resolution map provided to WCMC by M. Khosravi, Department of the Environment.

Mobayen, S. and Tregubov, V. (1970). *Carte de la Végétation Naturelle de l'Iran*. 1:2,500,000. Centre National Cartographique de l'Iran.

Oman

Land area	212,460 sq km
Population (1995)	1,822,000
GNP (1992)	6,490 US$ per capita
Mean monthly temperature range (Muscat)	22-33°C
Mean annual rainfall (Muscat)	99 mm
Spring tidal amplitude	1.5-2.5m
Alternative estimate of mangrove area (Sheppard *et al.*, 1992)	20 sq km#
Area of mangrove on the map	34 sq km
Number of protected areas with mangrove	1

Map references

Mangroves have been added to a 1:1,000,000 base map from IUCN (1986, 1988, 1989) which plots mangroves as points or polygons on maps at 1:312,500. These maps only cover approximately half of the coastline between the Yemen border and the centre of Sawqirah Bay and from Ras ad Daffah to Sarimah.

IUCN (1986). *Oman Coastal Zone Management Plan: Greater Capital Area*. Prepared for Ministry of Commerce and Industry, Muscat, Oman. IUCN, Gland, Switzerland. 78 pp.

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IUCN (1989). *Oman Coastal Zone Management Plan: Dhofar: Volume 2: Resource Atlas*. Prepared for Ministry of Commerce and Industry, Muscat, Oman. IUCN, Gland, Switzerland. 41 pp.

Qatar

Land area	11,000 sq km
Population (1995)	490,000
GNP (1991)	13,380 US$ per capita
Mean monthly temperature range	17-37°C
Mean annual rainfall	62 mm
Alternative estimate of mangrove area (Sheppard *et al.*, 1992)	<5 sq km#
Area of mangrove on the map	No data
Number of protected areas with mangrove	0

Map reference

No data

United Arab Emirates

Land area	83,600 sq km
Population (1995)	1,785,000
GNP (1991)	20,200 US$ per capita
Mean monthly temperature range (Dubai)	23-42°C
Mean annual rainfall (Dubai)	60 mm
Alternative estimate of mangrove area (Khan, 1982)	30 sq km#
Area of mangrove on the map	No data
Number of protected areas with mangrove	0

Map reference

No data

Indian Ocean Islands

Maps 9.2 and 9.3

There are a number of small islands scattered throughout the Indian Ocean. Notable among these are the British Indian Ocean Territory (UK), the Comoros, the Maldives, Mauritius, Mayotte (France), Réunion (France) and the Seychelles. With the exception of the Seychelles and Mayotte, mangroves are not well developed in any of these islands and they are not recorded from Réunion. There is also very little documentation describing the mangroves in these countries. In Mauritius there are some scattered mangrove thickets and on Rodrigues a few scattered bushes are found near Mathurin Bay. Despite the large number of islands in the Maldives (over 1,000) none are very large in total area, and there are no rivers or freshwater bodies. The commonest types of mangrove formation in these islands are closed communities in brackish lagoons, often only connected to the sea by underground links. The largest and most diverse stands occur on the northernmost atolls, and there is some cultivation and management, particularly of *Bruguiera*. This is an economically important species, providing timber particularly for boat-building. Only two species have been recorded from the Chagos Archipelago (British Indian Ocean Territory), and there is a small stand of *Lumnitzera racemosa* on Eagle Island on the Chagos Bank. The only significant stands of mangroves in the Comoros are a single stand on the southeast of Grande Comore and a few small areas on the southern shore of Moheli. The mangroves of Mayotte are well developed, probably as a result of the shelter provided by the barrier reef which encircles the island. Finally, in the Seychelles, fringing coastal communities are found on the coasts of Mahé, Curieuse, Praslin, La Digue and Silhouette and there are some fairly large areas in the lagoons of Aldabra and Cosmoledo, with most of the species found in the region being represented.

British Indian Ocean Territory

Land area	60 sq km
Population (1995)	Military and administrative personnel only (about 3,000)
Mean annual rainfall	3,700 mm

Map reference

No data

Comoros

Land area	2,230 sq km
Population (1995)	653,000
GNP (1992)	510 US$ per capita
Mean monthly temperature range	22-28°C
Mean annual rainfall	2,000 mm
Alternative estimate of mangrove area	No information
Area of mangrove on the map	26 sq km#
Number of protected areas with mangrove	0

Map reference

UK Hydrographic Office (1978). *Comoros Islands.* 1:300,000. British Admiralty Chart 563.

Maldives

Land area	298 sq km
Population (1990)	213,215
GNP (1990?)	436 US$ per capita
Average temperature range (daily)	26-30°C
Mean annual rainfall	1,500 mm
Spring tidal amplitude	0.9 m
Alternative estimate of mangrove area	No information
Area of mangrove on the map	No data
Number of protected areas with mangrove	0

Map reference

No data

Mauritius

Land area	2,040 sq km
Population (1995)	1,130,000
GNP (1992)	2,740 US$ per capita
Mean monthly temperature range	23-27°C
Mean annual rainfall	1,000 mm
Alternative estimate of mangrove area	No information
Area of mangrove on the map	No data
Number of protected areas with mangrove	0

Map reference

No data

Mayotte

Land area	373 sq km
Population (1991)	85,000
Alternative estimate of mangrove area	No information
Area of mangrove on the map	10 sq km#
Number of protected areas with mangrove	0

Map reference

Mangroves were estimated from a base map from a source at approximately 1:250,000 taken from Frazier (1985).
Frazier, J. (1985). *Marine Turtles in the Comoros Archipelago.* North Holland Publishing Company, Amsterdam, The Netherlands.

Seychelles

Land area	280 sq km
Population (1995)	74,000
GNP (1992)	5,450 US$ per capita
Mean monthly temperature range (Victoria)	25-27°C
Mean annual rainfall (Victoria)	2,375 mm
Alternative estimate of mangrove area	No information
Area of mangrove on the map	29 sq km#
Number of protected areas with mangrove	4

Map references

Mangroves for most islands have been prepared from a D.O.S. (1978) six-map series, themselves compiled from air photography, June 1960. Vegetation data for Aldabra were annotated onto these maps by R.N. Jenkin.

D.O.S. (1978). *Aldabra Island East.* 1:25,000 Series Y852 (Department of Overseas Surveys 304P) Ed.3.
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D.O.S. (1993). *Providence Group (North).* 1:25,000 Series 304P Ed.3-OS.
D.O.S. (1993). *Providence Group (South).* 1:25,000 Series 304P Ed.3-OS.

Red Sea and Gulf of Aden

Map 9.1

The Red Sea and Gulf of Aden represent a continuous geological feature, which is an oceanic-type rift system separating the African and Arabian continental plates. Countries bordering this region include: Djibouti, Egypt, Eritrea, Israel (no mangroves), Jordan (no mangroves), Somalia, Sudan and Yemen (including Socotra Island). There has been little research into the mangroves of most of the countries in the region, although the mangroves of the Saudi Arabian coast have been well surveyed and preliminary work is now under way in Eritrea and other countries. The coastlines are arid to hyper-arid and there is no permanent freshwater input into the sea. Four mangrove species have been recorded, *Avicennia marina, Ceriops tagal, Bruguiera gymnorrhiza* and *Rhizophora mucronata. Avicennia marina* is the best adapted to the harsh environmental conditions. While positive historical records exist, there is some question as to the continued existence of both *Ceriops tagal* and, more especially, *Bruguiera gymnorrhiza* in the region. *Rhizophora mucronata* is found at a number of sites but is not recorded from the northernmost parts of the Red Sea. High salinity may limit mangrove occurrence in all areas, while in northern areas low temperatures may further restrict development. In most areas, mangroves are found in sheltered embayments and behind reefs. When mangroves are found behind the reef-flat in many areas there is often only a thin veneer of substrate overlying fossil reef structures and this may further contribute to their reduced size and restricted distribution. The best developed stands occur in the southern parts of the Red Sea. These are often associated with 'soft-bottom' substrates in sheltered embayments. These southern areas are further characterised by a wider shelf area, better protected shorelines, and higher nutrient concentrations. In such areas stands of 100-500 m width are found, with the tallest trees reaching 5-7 m in height. There is little information describing the mangrove communities along the Yemen coast on the Gulf of Aden, although mangroves are well developed in a number of areas along this sector of the Somali coast. Small mangrove communities have been reported from the Yemeni island of Socotra, while the Indian Ocean coastline of Somalia (not strictly within the geographic limits described above) has some significant areas of mangrove, particularly associated with estuaries close to the Kenyan border. *Lumnitzera racemosa* and *Sonneratia alba* have been recorded from this area.

In Saudi Arabia and several of the other countries of the region, the grazing of mangroves by camels has had a significant impact and is likely to continue or increase. Loss of mangrove areas has also occurred in Saudi Arabia due to coastal engineering and landfill projects, together with pollution from urban and industrial areas. Localised impacts are also likely to occur as a result of the high salinity and high temperature effluents associated with desalination plants.

Djibouti

Land area	23,200 sq km
Total forest extent (1990)	220 sq km
Population (1995)	511,000
Mean monthly temperature range	26-36°C
Mean annual rainfall	130 mm
Alternative estimate of mangrove area	No information
Area of mangrove on the map	10 sq km#
Number of protected areas with mangrove	0

Map reference

Map based on 1985 Landsat MSS.

Forgiarini, G. and Cesar, J. (1987). *Végétation et Ressources Pastorales.* 1:250,000. Institut d'Elevage et de Médecine Vétérinaire des Pay Tropicaux, France.

Egypt

Land area	1,001,450 sq km
Population (1995)	58,519,000
GNP (1992)	630 US$ per capita
Mean monthly temperature range (Ismailia, northern Red Sea)	13-29°C
Mean annual rainfall (Ismailia, northern Red Sea)	37 mm
Alternative estimate of mangrove area	No information
Area of mangrove on the map	(861 sq km)#
Number of protected areas with mangrove	2

Map reference

Data are of very low resolution and likely to be inaccurate, based on a regional sketch map in Sheppard *et al.* (1992).

Sheppard, C., Price, A. and Roberts, C. (1992). *Marine Ecology of the Arabian Region: Patterns and Processes in Extreme Tropical Environments.* Academic Press, London, UK.

Eritrea

Land area	93,679 sq km
Population (1994)	3,530,000
GNP (1993)	77 US$ per capita
Mean monthly temperature range (Massawa)	26-34°C
Mean annual rainfall (Massawa)	193 mm
Alternative estimate of mangrove area	No information
Area of mangrove on the map	(581 sq km)#
Number of protected areas with mangrove	0

Map reference

There are no accurate published maps showing the distribution of mangroves in Eritrea. Data were very kindly provided, annotated onto an approximately 1:1,000,000 base map using aerial photographs combined with detailed personal knowledge of the region, by Dr Chris Hillman, Ministry of Marine Resources, Eritrea and by Dr Liz Ross, Department of Earth Sciences, University of Oxford, UK.

Saudi Arabia

Land area	2,149,690 sq km
Population (1995)	17,608,000
GNP (1992)	7,940 US$ per capita
Mean monthly temperature range (Jeddah)	23-31°C
Mean annual rainfall (Jeddah)	81 mm
Alternative estimate of mangrove area (Sheppard *et al.*, 1992)	204 sq km
Area of mangrove on the map	292 sq km#
Number of protected areas with mangrove	3

Map references

Maps have been prepared for the Red Sea from IUCN/MEPA (1984,1985) unpublished reports with detailed data at 1:250,000, and for the Gulf from MEPA (1987) maps which simply mark small linear sections of the coast as having mangrove (1:2,000,000).

IUCN/MEPA (1984). Report on the Distribution of Habitats and Species in the Saudi Arabian Red Sea: Part 1. Saudi Arabia Marine Conservation Programme, Report No. 4. IUCN, Gland, Switzerland/Meteorology and Environmental Protection Administration, Jeddah, Kingdom of Saudi Arabia. 123 pp., numerous tables, photos, maps.

IUCN/MEPA (1985). Distribution of Habitats and Species along the Southern Red Sea Coast of Saudi Arabia. Saudi Arabia Marine Conservation Programme, Report No. 11. IUCN, Gland, Switzerland/Meteorology and Environmental Protection Administration, Jeddah, Kingdom of Saudi Arabia. 61 pp., numerous tables, photos, maps, annexes.

MEPA (1987). *Arabian Gulf. Saudi Arabia: an assessment of biotopes and coastal zone management requirements for the Arabian Gulf.* MEPA Coastal and Marine Management Series. Technical Report No. 5, December 1987 (printed January 1992). Meteorology and Environmental Protection Administration, Jeddah, Kingdom of Saudi Arabia/IUCN, Gland, Switzerland. 248 pp.

Somalia

Land area	637,660 sq km
Total forest extent (1990)	7,540 sq km
Population (1995)	10,173,000
GNP (1990)	120 US$ per capita
Mean monthly temperature range (Berbera)	24-36°C
Mean annual rainfall (Berbera)	51 mm
Alternative estimate of mangrove area	No information
Area of mangrove on the map	(910 sq km)#
Number of protected areas with mangrove	0

Map reference

Mangroves were annotated onto a 1:1,000,000 base map by R.H. Hughes, and are based on Hughes and Hughes (1992). Further small areas were added by François Blasco.

Hughes, R.H. and Hughes, J.S. (1992). *A Directory of African Wetlands*. IUCN, Gland, Switzerland and Cambridge, UK/UNEP, Nairobi, Kenya/WCMC, Cambridge, UK. 820 pp.

Sudan

Land area	2,505,810 sq km
Total forest extent (1990)	429,760 sq km
Population (1995)	28,960,000
GNP (1990)	400 US$ per capita
Mean monthly temperature range (Port Sudan)	23-34°C
Mean annual rainfall (Port Sudan)	94 mm
Alternative estimate of mangrove area	No information
Area of mangrove on the map	(937 sq km)#
Number of protected areas with mangrove	0

Map reference

Data are of very low resolution and likely to be inaccurate, based on a regional sketch map in Sheppard *et al.* (1992).

Sheppard, C., Price, A. and Roberts, C. (1992). *Marine Ecology of the Arabian Region: Patterns and Processes in Extreme Tropical Environments*. Academic Press, London, UK.

Yemen

Land area	527,970 sq km
Population (1995)	13,897,000
GNP (1991)	520 US$ per capita
Mean monthly temperature range (Aden)	24-32°C
Mean annual rainfall (coastal areas)	46 mm
Alternative estimate of mangrove area	No information
Area of mangrove on the map	81 sq km#
Number of protected areas with mangrove	0

Map references

Data for the former Yemen Arab Republic (North Yemen) obtained from IUCN (1987), which comprises four maps covering the coast at 1:500,000, based on field surveys. A small area for the coast of former South Yemen was added from Sheppard *et al.* (1992) and areas were annotated for the Island of Socotra from RGS (1978). This is reported to be the most accurate data available for the island and has a symbol which describes 'coastal marsh and mangrove'.

IUCN (1987). *The Distribution of Habitats and Species along the YAR Coastline*. IUCN, The World Conservation Union, Gland, Switzerland.

RGS (1978). *Socotra*. 1:125,000. Royal Geographical Society, London.

Sheppard, C., Price, A. and Roberts, C. (1992). *Marine Ecology of the Arabian Region: Patterns and Processes in Extreme Tropical Environments*. Academic Press, London, UK.

Kenya

Map 9.2

Land area	580,370 sq km
Total forest extent (1990)	11,870 sq km
Population (1995)	27,885,000
GNP (1992)	330 US$ per capita
Mean monthly temperature range	21-32°C
Average rainfall range (Lamu)	750-1,000 mm
Average rainfall range (Mombasa)	1,000-1,500 mm
Spring tidal amplitude	3.5 m
Alternative estimate of mangrove area (Ruwa, 1993)	530 sq km#
Area of mangrove on the map	961 sq km
Number of protected areas with mangrove	3

The coastline of Kenya is semi-arid, becoming more humid to the south. Mangroves are well developed in many areas, being particularly concentrated in creeks, bays and estuaries. There are only two large permanent rivers reaching the coast, the Tana and the Sabaki (Galana), both of which support mangroves. There are also a large number of seasonal rivers, and in many of these there is an associated ground water discharge which reduces salinities even when the rivers themselves are dry. To the north of the country, mangroves are well developed in the lee of several islands, notably Lamu, and on the corresponding sheltered coastlines. In the far south, offshore islands and fringing reefs also provide a more protected coastline suitable for the development of mangroves. Two basic formations have been described: fringe communities which do not show patterns of zonation; and creek mangrove formations found in low energy, more sheltered environments, which are often larger in aerial extent and may show zonation patterns.

There is a long tradition of using of mangrove areas in Kenya. Fishing villages are typically located close to mangrove areas, perhaps because of the freshwater associated with adjacent shallow water-tables. Mangrove timber has traditionally been used for building of houses, furniture and boats. The mangroves have been also used for fuel and used, to a lesser extent, for honey production, while some fishing for crabs and oysters takes place. The traditional export of mangrove timber from Lamu and elsewhere to the Middle East has been forbidden by law, in an effort to reduce degradation and loss of mangroves. Establishment of salt pans and shrimp farms has led to the loss of small areas of mangrove. Wider scale degradation is likely to be caused by pollution from sewage effluents, the dumping of solid waste, and increasing salinity as a result of the damming of rivers. The areas around Mombasa are further likely to be threatened by the development of the port and the risk of oil pollution. An oil spill in 1988 caused the loss of a considerable area of mangroves.

Map reference

Delsol, J.P. (1995). *A Vegetation Map of Kenya.* 1:1,000,000. Institut de la Carte Internationale de la Végétation, Toulouse, France.

Madagascar

Map 9.3

Land area	587,040 sq km
Total forest extent (1990)	157,820 sq km
Population (1995)	14,155,000
GNP (1992)	230 US$ per capita
Mean annual rainfall range (Antseranana to River Manambolo)	950-2,000 mm
Mean annual rainfall range (River Manambolo to River Mangoky)	500-900 mm
Mean annual rainfall (River Mangoky to Cap Sainte Marie)	350 mm
Spring tidal amplitude (west coast)	3.5 m
Spring tidal amplitude (east coast)	0.75 m
Alternative estimate of mangrove area (Marguerite, 1993)	3,270 sq km
Area of mangrove on the map	3,403 sq km#
Number of protected areas with mangrove	1

In Madagascar, mangroves are almost entirely limited to the western coast facing the Mozambique channel, with only about 50 sq km of mangroves found along the eastern coast. The most significant mangrove stands are found in the northwest, at Mahajamba Bay, Bombetoka, South Mahavavy and Salala, and Maintirano, where the climate is semi-humid. Many of the stands are in sheltered river mouth areas, but linear formations also occur in Mahavavy and Maintirano. Trees in this area may reach 20 m in height. Further to the southwest, the climate becomes more arid, with a dry season of seven to nine months in duration, and extensive mangrove areas are less common. In this region, wide areas of bare saline soils are often found behind the mangroves, known as 'tannes' or 'sira-sira'. Typically, trees in this area rarely reach 6 m in height. Human uses of the mangroves are limited in extent, although may be considerable in the areas around Tuléar and Mahajanga, particularly for charcoal and timber. Fishing occurs in mangrove areas, particularly for prawns, but there has been no clearance for aquaculture. This lack of human disturbance can be largely related to the relatively low population densities in most mangrove areas, combined with the availability of other timber and fuelwood sources. Demographic trends suggest that pressure on mangrove areas could increase considerably in the future. The generally quoted area of mangroves (3,270 sq km) is based on a 1966 estimate, but it has been suggested that the total area may not have decreased, or may have even increased since that time, resulting from the colonisation of rapidly advancing alluvial deposits.

Map references

Main source was Faramalala Miadana Harisoa (1996), with minor corrections from CI/DEF/CNRE/FTM (n.d.). Both these are drawn from the same source, 1972-79 Landsat imagery. The former appears to give higher precision, but the latter includes some additional mangrove areas in the far north of the country.

CI/DEF/CNRE/FTM (n.d.). *Formations Végétales et Momaine Forestier National de Madagascar.* 1:1,000,000. Conservation Internationale/Direction des Eaux et Forêts/Centre National de Recherches sur l'Environnement/ Foiben-Taosarintanin' l Madagasikara.

Faramalala Miadana Harisoa (1996). *Carte des Formations Végétales de Madagascar.* 1:1,000,000, 3 sheets. I.C.I.V., Toulouse, France.

Mozambique

Map 9.3

Land area	801,590 sq km
Total forest extent (1990)	173,290 sq km
Population (1995)	16,359,000
GNP (1992)	60 US$ per capita
Mean monthly temperature range (Beira)	21-28°C
Average rainfall range	800-1,500 mm
Spring tidal amplitude (Beira)	5.6 m
Alternative estimate of mangrove area (Hughes and Hughes, 1992)	850-1,000 sq km#
Area of mangrove on the map	3,459 sq km
Number of protected areas with mangrove	5

Mangroves are widespread and are located in all river mouths and in many sheltered bays and lagoons, although they are less widespread towards the south of the country. The coastline is the wettest part of the country, although most areas receive only about 800-900 mm rain per year with some pockets receiving up to 1,400 mm. The coast is warmed by the southward flowing Mozambique current. The full diversity of mangrove species from the region is found in the country, although some of these have their southern limits in Mozambique. In the far north mangroves form a near-continuous narrow strip along the many sheltered bays and river mouths. Between Moçambique and the Zambezi Delta, the sheltering fringing reef disappears, but mangroves are found in the many small deltas all along this stretch where alluvial deposits are considerable. These rivers may be tidal for many kilometres upstream and the mangrove communities typically grade into swamp forest. Mangrove swamps are extensive throughout the lower delta of the Zambezi, along the deltaic coast that extends to Beira and in the many river mouths and sheltered bays to the south. Floristically, the mangroves between Beira and the Save River are probably the best developed in the country, and perhaps on the entire eastern seaboard of Africa. In many areas they reach inland for 5-15 km and extend up to 50 km inland along the Save. In these areas, and in the Zambezi Delta, the canopy may reach 25 m or even 30 m in height. Northward pointing spits, formed by eddies from the southward flowing offshore current, protect a number of mangrove-filled bays, including the 200 sq km mangrove forest behind the spit of São Sebastião. In the far south of the country mangroves are not well developed except along the southern shore of Maputo Bay.

Most areas of mangroves have been utilised by man, although this is most pronounced closer to centres of high population density, notably in the north of the country and close to ports. Trees, especially *Rhizophora mucronata*, are widely used for timber, firewood and charcoal. Traditional Arab trade along the East African coast was mostly with Kenya and Tanzania, but also occurred as far south as Beira. There is some artisanal fishing in mangroves and permanent fish traps are a feature of many areas. The mangrove area given by Hughes and Hughes (1992) of 850-1,000 sq km is thought to be conservative.

Map reference

Ministerio da Agricultura (1980). *Mapa Florestal.* 1:2,000,000 (reduced from 1:1,000,000). Projecto UNDP-FAO MOZ/76/007. Ministerio da Agricultura, Dto Florestal e de Fauna Bravia, República Popular de Moçambique.

South Africa

Map 9.3

Land area	1,221,040 sq km
Population (1995)	42,741,000
GNP (1992)	2,670 US$ per capita
Mean monthly temperature range (Durban)	17-24°C
Average rainfall range (St Lucia)	1,200 mm
Spring tidal amplitude	0.75-1.5 m
Alternative estimate of mangrove area (IUCN, 1983)	11 sq km#
Area of mangrove on the map	(335 sq km)
Number of protected areas with mangrove	8

Due to the warming effect of the Mozambique current, mangroves occur on the east coast of Africa as far south as 32°59' latitude and, therefore, along the northeast coast of South Africa. On the west coast of Africa, the southernmost extent of mangroves is in Angola, nearly 20 degrees of latitude further north than on the east coast. In the south, mangroves are monospecific stands of *Avicennia marina*, with the southernmost stand being in the Nahoon River mouth just north of East London. *Bruguiera gymnorrhiza* is found as far south as 32°14' and *Rhizophora mucronata* joins the assemblage soon after. The Mngazana estuary is the first significant stand of mangroves, with about 1.6 sq km of peripheral mangrove and saltmarsh communities. Further north, most mangrove areas are much smaller, while the once extensive swamps around Durban have been almost entirely cleared. To the north, mangroves are found in the St Lucia estuary, which connects to Lake St Lucia, the Mfolozi River mouth and around the lower tidal basin and lake system of Kosi Bay. At this latter site two further species are found: *Ceriops tagal* and *Lumnitzera racemosa*. Coastal development has destroyed the mangroves in some areas but they have legal protection within a number of protected areas.

Map reference

Small areas have been annotated onto a base map, using the textual descriptions of these locations from Hughes and Hughes (1992). While these may be indicative of mangrove locations they should not be regarded as providing a full or accurate areal coverage.

Hughes, R.H. and Hughes, J.S. (1992). *A Directory of African Wetlands.* IUCN, Gland, Switzerland and Cambridge, UK/UNEP, Nairobi, Kenya/WCMC, Cambridge, UK. 820 pp.

Tanzania

Map 9.2

Land area	945,090 sq km
Total forest extent (1990)	429,760 sq km
Population (1995)	30,742,000
GNP (1992)	110 US$ per capita
Mean monthly temperature range (Dar es Salaam)	23-28°C
Mean annual rainfall (Dar es Salaam)	1,064 mm
Spring tidal amplitude	3.2 m
Alternative estimate of mangrove area (Semesi, 1993)	1,155 sq km#
Area of mangrove on the map	2,456 sq km
Number of protected areas with mangrove	6

There is a long history of the use of mangroves in Tanzania, dating back to at least the ninth century when they were used as a major timber supply to the non-forested countries to the north, particularly on the Arabian Peninsula. Mangroves remain relatively widespread despite the exploitation. The largest mangrove area is on the Rufiji River Delta, but other large areas are found at Tanga, Kilwa and the estuaries of Ruvu, Wami, Pangani and Ruvuma Rivers. Most mangrove areas remain heavily exploited for timber and firewood and in many areas trees fail to reach their full stature. Uses include timber for fences, houses, boats, fish traps and fuelwood. Some poles are cut for export and the local markets, though much of this is illegal. Fishing, and particularly prawn fishing in mangrove areas is very important. In the Rufiji Delta, some areas have been cleared for rice cultivation. The remainder of the delta is now protected although it is still under considerable pressure from local populations, despite the observed declining yields on the existing farms. Further areas have been cleared for the construction of salt pans. The importance of mangroves to Tanzania has been recognised and all mangrove areas are legally protected. The key to their protection lies in the wise management and use of mangrove areas, and in the enforcement of existing regulations.

Map reference

Areas taken from summary map of a more detailed mangrove forest inventory supported by NORAD, based on aerial photography taken in 1988/9.

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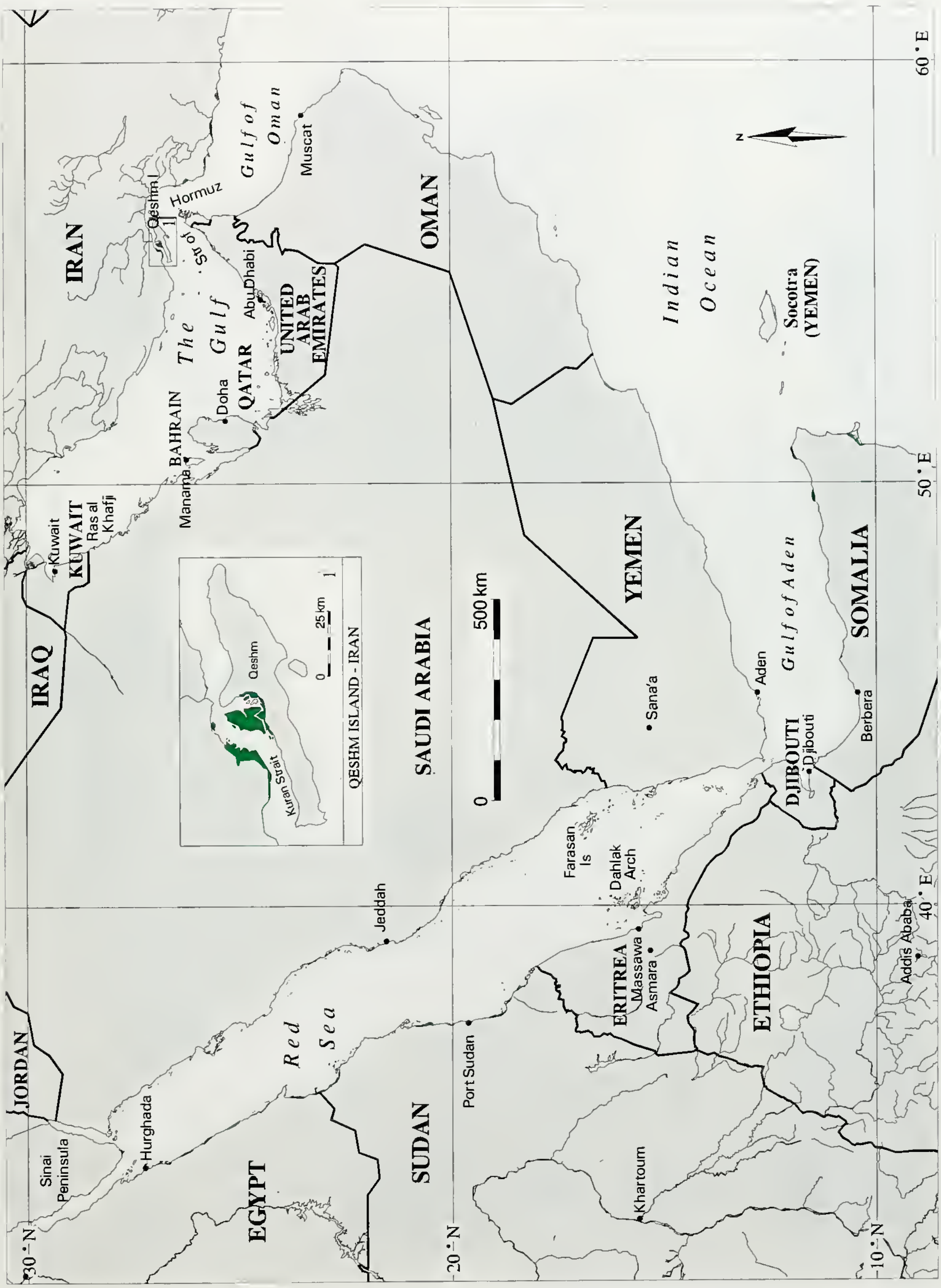
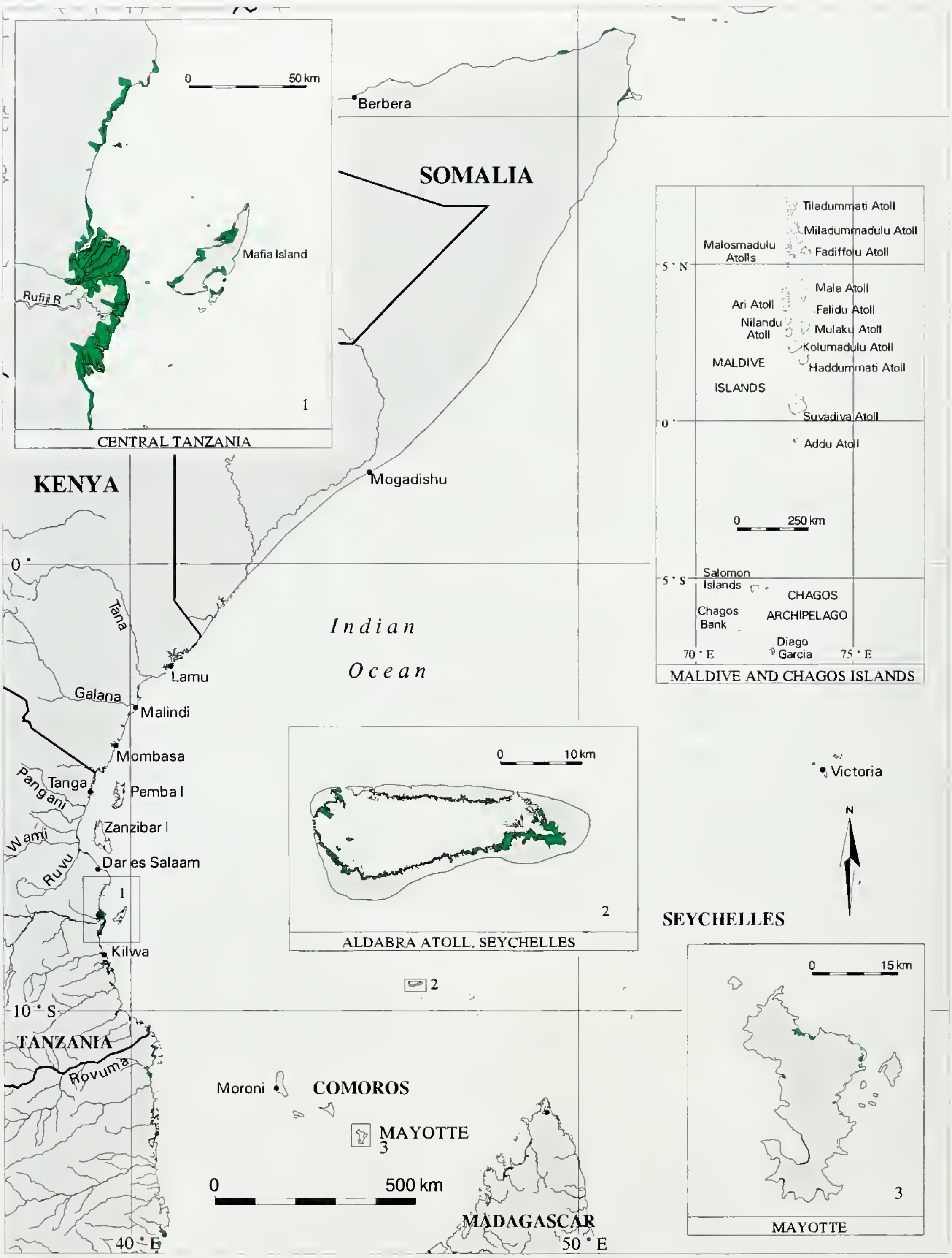
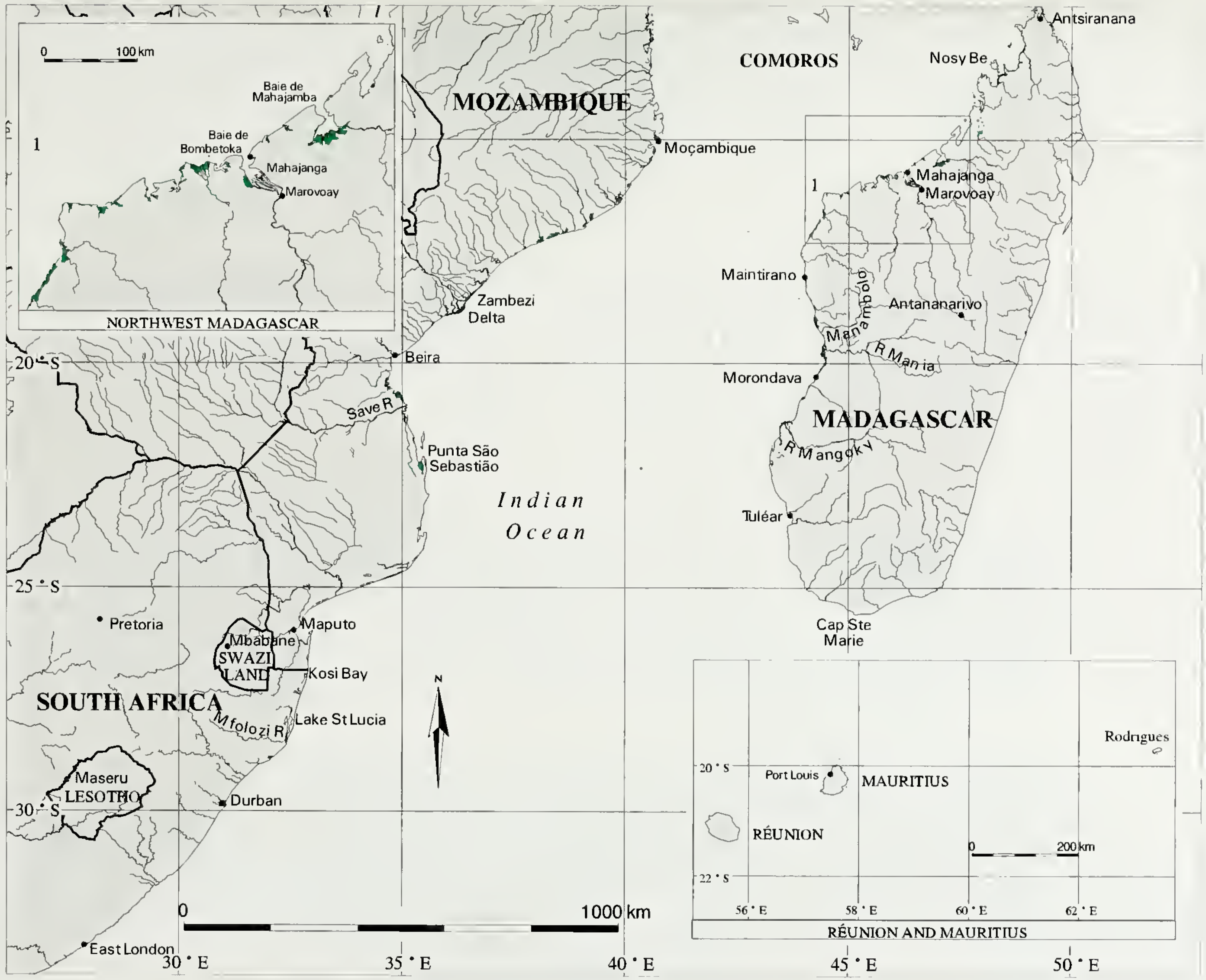


Map 9.1 Arabian Peninsula, Red Sea and the Gulf



Map 9.2 East Africa: Somalia to Tanzania



Map 9.3 Mozambique, Madagascar and South Africa

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Note: Page numbers referring to maps are given in bold

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ISME - International Society for Mangrove Ecosystems

ISME was founded in 1990 as a Society to promote the study and research of mangrove ecosystems. It aims to bring together scientists and interested organisations with the purpose of promoting the conservation, rational management and sustainable utilisation of mangroves. It also provides an international databank on mangrove ecosystems. ISME is a non-governmental organisation with members from sixty-six countries. Its secretariat is located in Okinawa, Japan. ISME has produced a Charter for Mangroves and has carried out projects in Southeast Asia, Africa and Latin America. It is currently promoting a mangrove afforestation project in Pakistan and it recently produced educational literature on mangroves in Vietnam. ISME seeks above all to work with people around the world to enhance the appreciation of mangroves.

ITTO - International Tropical Timber Organization

ITTO is an intergovernmental organisation established by a United Nations Conference with a mandate of ensuring the implementation of the provisions of the International Tropical Timber Agreement (ITTA) concluded in November 1983, but currently being renewed. At the present time, the ITTO membership consists of 24 tropical timber producing countries covering more than 75% of the world's tropical forest resources, and 27 consuming member countries, accounting for more than 95% of tropical wood imports in the world. ITTO encourages dialogue and action to improve forest management and the sustainable use of tropical forests. It recognises that tropical forests are vitally needed for their wealth of genetic diversity, conservation and environmental values, but maintains that sustainable tropical forest industries can generate social and economic benefits in many developing countries, so ensuring the survival of the forests. It is with this background that ITTO supports projects on mangroves.

WCMC - The World Conservation Monitoring Centre

The World Conservation Monitoring Centre, based in Cambridge, UK is a joint-venture between the three partners in the *World Conservation Strategy* and its successor *Caring for The Earth:* IUCN - The World Conservation Union, UNEP - United Nations Environment Programme and WWF - World Wide Fund for Nature. The Centre provides information services on the conservation and sustainable use of species and ecosystems and supports others in the development of their own information systems. WCMC has developed a considerable database of forest and other habitat distribution within its Biodiversity Map Library. It was responsible for the preparation of the three-volume *Conservation Atlas of Tropical Forests* and has a number of continuing projects relating to tropical forests and coastal habitats and species.

The International Society for Mangrove Ecosystems
The World Conservation Monitoring Centre
The International Tropical Timber Organization