K. S. S. NAIR

Tropical Forest Insect Pests

Ecology, Impact and Management

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Tropical Forest Insect Pests

Forest entomology is rich in theory, but much of this is based on observations of temperate forest insects. This comprehensive volume, by a leading researcher in tropical forest entomology, aims to promote a more global theoretical understanding of pest population dynamics and the causes of forest insect outbreaks.

Covering pests of both natural forests and plantations, the book examines the diversity of tropical forest insects; their ecological functions; the concept of pests and the incidence of pests in natural forests, plantations and stored timber. It explores the circumstances under which insect populations increase and acquire pest status. General issues on which foresters and forest entomologists hold strong traditional views, such as the severity of pest incidence in plantations vs. natural forests, in plantations of exotics vs. indigenous tree species and in monocultures vs. mixed plantations are discussed. The final chapter looks in detail at specific insect pest problems of the common plantation tree species across the tropics, and provides recommendations for control.

Containing a wealth of information about tropical forest insects, this book will be valuable for graduate and postgraduate students of forestry, research scientists interested in tropical forest entomology and forest plantation managers in the tropics.

Dr K. S. S. NAIR obtained his PhD in Zoology, specializing in Entomology, from the M. S. University of Baroda in 1964. From 1976 to 1994 he headed the Entomology Division of the Kerala Forest Research Institute in India, and carried out pioneering research on the management of tropical forest insect pests. He was later made Director of the Institute and guided research on various aspects of tropical forestry. Since 1999 he has served as an Editor of the journal Entomon and President of the Association for Advancement of Entomology. Earlier, he also served as Chairman of the IUFRO (International Union of Forestry Research Organizations) Working Party on ‘Protection of Forest in the Tropics’, for nine years. Dr Nair is now retired and lives in Kerala, India.

Tropical Forest Insect Pests

Ecology, Impact, and Management

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Dedication

Dedicated to:
Late Professor J.C. George, who introduced me to research
and
Dr P.M. Ganapathy, who introduced me to forestry

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Illustrations

Preface

This book has grown out of my feeling that tropical forest insects have not received the research attention they deserve. Most books on forest entomology deal with only temperate forest insects and those few that deal with tropical forest insects cover only small regions of the tropics and mostly contain descriptions of pest biology. An exception is a recent book by M. R. Speight and F. R. Wylie (2001) which covers the entire tropics and lays stress on pest management, although their coverage of the subject is very general. Other books on tropical forest entomology covering parts of the tropics are mentioned in the introduction to Chapter 2: particular mention must be made of C. F. C. Beeson's (1941) excellent treatise on the ecology and control of forest insects of India and the neighbouring countries. This book, published some 65 years ago, contains much information that is valid and relevant even today, although it is not accessible to many. Extensive new knowledge has now accumulated on tropical forest insects across the world, but it lies scattered in innumerable journal articles and reports. I have made an attempt in this book to bring this knowledge together and present it in an ecological framework. Knowledge is seldom created by one individual and I have used the knowledge accumulated over time by the dedicated work of innumerable researchers. What is new here is a new framework on which the accumulated knowledge is organized to convey some central ideas relevant to the management of tropical forest insect pests. Facts or observations make sense only when arranged logically and interpreted. My attempt has been to provide an overview of tropical forest insect pests and discuss the basic principles of their ecology in the forest environment, using information about commonly encountered insects across the tropics.

Forest entomology is rich in theory. Much of this is based on observations on temperate forest insects. These theories, particularly, those on population dynamics, have not been static. For example, new theoretical alternatives to the conventional equilibrium viewpoint of population regulation have emerged in recent years. It is an open question whether the study of tropical forest insects might lead to modification of some of the existing theories, or reinforce them. Tremendous opportunities exist for using long-term observational and experimental data from tropical forests to test theories on insect population regulation. This is because the warm temperatures of the tropics permit year-round growth and multiplication of insects. While many temperate forest insects pass through only one generation per year, many tropical forest insects pass through 12–14 generations in the same period. Therefore testing theories should be easier in the tropical forests. Wider dissemination of knowledge about the tropical forest insects and the research opportunities they offer will promote collaborative work among scientists from developed and developing countries, for the benefit of both and the science of entomology in general. This thought has been one of my main motivations for embarking on this work.

The book is organized into 10 chapters. Chapter 1 gives an overview of the broad features of the tropical forests and their management. This is followed by an overview of tropical forest insects in which their structural and functional diversity and the concept of pests are discussed. Chapter 3 then discusses the several ecological functions the insects perform in the forest ecosystem, and how they influence plant succession. Against the background of these three chapters, the next three describe pest incidence in natural forests (Chapter 4), plantations (Chapter 5) and stored timber (Chapter 6). Characteristics of pest incidence in the three situations are described with examples (except for plantations, where the details are reserved for the last chapter) and generalizations drawn. Pest problems arise when insect numbers increase beyond a certain limit. Therefore, Chapter 7 examines the circumstances under which insect populations increase and how their numbers are regulated in nature.

In Chapter 8, some general issues on which foresters and forest entomologists hold strong traditional views are discussed critically in the light of available evidence. These include the severity of pest incidence in plantations vs. natural forests, in plantations of exotics vs. indigenous tree species and in monocultures vs. mixed plantations. With this background, Chapter 9 examines the pest management options, current practices and constraints in the tropical forestry setting, and suggests guidelines for practice. The last chapter, which occupies nearly half of the book, is devoted to detailed case studies of pest problems of the most common plantation tree species across the tropics. For each of the selected tree species, a tree profile is given which is followed by an overview of pests and detailed pest profiles of the major pests, including control options and knowledge gaps. This chapter contains the core of the data on which the generalizations made in the other chapters rest. But for the bulk, the information in this chapter should have been incorporated into Chapter 5. But placing it as a separate chapter at the end of the book will facilitate easy reference by practising foresters, planters and researchers who may want specific information on pest problems of particular tree species or details regarding specific pests.

Some observations on the general features of the book seem desirable here. Several changes have occurred recently in the scientific nomenclature of tree species, and the plant families in which they are placed. For example, the tree which was known as *Paraserianthes falcataria* until recently is now *Falcataria moluccana* and the teak tree which has been traditionally placed in the family Verbenaceae is now in the family Lamiaceae. Although these changes are not necessarily accepted by all, some standard is necessary. I have used the Forestry Compendium (2005, CD version) published by the Commonwealth Agricultural Bureau International as the standard for this purpose. Synonyms are given, both for plants and insects, when they are common in recent literature. On countries of occurrence of pests, only known information can be given; updating is necessary in many cases.

I have used the example of the teak defoliator *Hyblaea puera* at several places in the book, in several contexts, to illustrate some points. Also, the pest profile on this species is the longest. This is partly due to the knowledge available and partly to my personal familiarity with the insect. I hope the reader will bear with me for this indulgence.

This book is primarily intended for graduate and postgraduate students in forestry, and research students and research scientists interested in tropical forest entomology. Since its major focus is the researcher, I have included references to published scientific papers to substantiate the statements, at the cost of increasing the work's bulk, although many text books omit these while summarising the knowledge. Unfortunately, published literature is generally taken as truth, which need not always be the case. By including the references, I wish to encourage researchers to be critical and read the original article wherever possible, to understand the conditions under which the reported results were obtained. To stimulate further research, I have included comments on knowledge gaps under each pest profile.

A large part of the knowledge assembled in this book, from the field as well as from literature, was gathered during my career as a research scientist at the Kerala Forest Research Institute, Peechi, India, and I am indebted to the Institute, particularly to its former director, Dr P. M. Ganapathy, for creating an excellent work environment. Gathering of information was also facilitated by a short research assignment at the Center for International Forestry Research, Bogor, Indonesia, and from my association with the International Union of

Forestry Research Organizations (IUFRO) Working Group on 'Protection of Forest in the Tropics', founded by Dr Heinrich Schmutzenhofer. I am deeply indebted to my former entomologist colleagues at the Kerala Forest Research Institute – Dr R.V. Varma, Dr George Mathew, Dr V.V. Sudheendrakumar and Dr T.V. Sajeev – for help in various forms, including supply of photographs or specimens for photographing, reading and making suggestions on parts of the manuscript, providing literature and, above all, encouraging me to undertake this work. The draft of the book was prepared at the Department of Zoology, University of Kerala, Trivandrum, India, where Professor Oommen V. Oommen, Professor D. Muraleedharan and Dr Mariamma Jacob extended various kinds of help and made it pleasant to work. I thank Professor Alan Berryman, Dr Ronald F. Billings, Professor T.N. Ananthakrishnan, Professor A. Mohandas, Professor T.C. Narendran and Dr P.T. Cherian, who read parts of the manuscript and made helpful suggestions. Thanks are also due to Mr Sajan Bhaskaran who made the diagrams and Mr A.M. Shanmugam who processed some of the illustrations. A few of the illustrations were reproduced from other publications with the permission of the publishers, for which I am thankful to them; the sources are acknowledged in the respective legend. Some photographs used in the book were kindly provided by colleagues who are also acknowledged in the respective legend; others were taken by me at various places and times over the years, except a few taken by Dr T.V. Sajeev. This work would not have been possible but for the unstinted support rendered by my wife, Mrs Sathi Nair, in many different ways, including the long, lonely hours spent by her while I was engrossed in the work, particularly at the final stages of preparation of the document.

Last, but most important, the writing of this book was catalysed and supported by the Department of Science and Technology, Government of India, under its Utilisation of Scientific Expertise of Retired Scientists Scheme.

K.S.S. Nair
June 2006

Foreword

This book forms a comprehensive and thoroughly up-to-date text on tropical forest entomology written by an author who has spent his entire career working and living in the tropics. It is both a broad treatment of the principles and practice of tropical forest entomology, and a detailed and penetrating exploration of specific insect pests and the methods used to manage them. What is most significant about this work is its organization of an enormous body of information on tropical insect pests within a general theoretical framework. This is particularly important to students of forest protection, who need to understand the theory of population dynamics and pest outbreaks before they can intelligently manage insect pests.

Dr K. S. S. Nair is eminently qualified to write such a book. He has served as head of the Entomology Division of the Kerala Forest Research Institute in India for some 18 years, and as its director for a further five years, and has also worked at the Centre for International Forestry Research in Indonesia. He has been an active member of the International Union of Forestry Research Organizations (IUFRO) Subject Group 'Entomology' for many years, and has served as chairman of the Working Party on 'Protection of Forest in the Tropics' for eight years, and as deputy coordinator of the subject group 'Forest Health' for nine years. This has given him a broad experience in international forest entomology, both in tropical and temperate forests.

This book will be invaluable to teachers, researchers and forest protection specialists in the tropics. I expect it to become the major textbook in tropical forest entomology as well as an important reference for those involved in research and management of tropical forest pests. It should also bring tropical forest entomology to the attention of a broader audience and, as the author hopes, stimulate collaborative research between scientists in the developed and developing countries. Forest entomology evolved as a science in the Northern Hemisphere. Nair's book will help to correct this bias and thereby lead to a more global theoretical understanding of pest population dynamics and the causes of forest pest outbreaks.

On a personal note, I remember with pleasure my visit to Kerala in 1986 and, in particular, my walks in the teak plantations with K. S. S. where we contemplated the ways of that mysterious teak defoliator, *Hyblaea puera*. We once stumbled upon an aggregation of moths resting in the undergrowth of a natural forest. When the small shrubs were disturbed they emitted clouds of moths identified as *Hyblaea* by their orange wing-flashes. This discovery helped us to understand the sudden appearance of concentrated, single-aged populations of larvae that completely defoliate stands of teak trees, and made us think of this insect more like a locust than a moth.

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June 20, 2006

1

Forestry in the tropics

1.1 Introduction

Tropical forests have always attracted the world's attention because of their magnificence and potential for economic exploitation. For centuries, they catered to the people's livelihood needs for timber, fruits, firewood, medicinal plants etc., and also, indirectly, animal meat. The native people lived in harmony with the forest as their populations were small and their demands did not exceed the forest's capacity to regenerate. The situation changed drastically in the colonial era between the mid seventeenth and mid twentieth centuries. During this period, large areas of tropical forests were cleared for human settlement and large-scale cultivation of agricultural and estate crops like sugar cane, tea, coffee, rubber and wattle. Forests were also logged for selective extraction of valuable timbers such as teak and rosewood in Asia, mahogany in Latin America and khaya in Africa, mainly for export. By the mid eighteenth century, forest plantation technology had developed and the natural forests were increasingly replaced by plantations. After the Second World War, forest plantation programmes received a further boost in the newly independent nations due to international exchange of information and availability of international development funds (Evans, 1992). Exotic, fast-growing eucalypts and pines were raised in the tropics on a large scale during this period. As industrialization progressed, more extensive plantations were established, mostly with exotic fast-growing species, and on land cleared of natural forests. Most of these were intended to produce pulpwood for paper, rayon and fibreboard. As a result, vast stretches of natural tropical forests across the continents were destroyed or degraded.

While tropical deforestation was thus progressing steadily, the environmental value of tropical forests was also being slowly recognized worldwide, particularly after the 1960s. The role of natural forests in maintaining the climate, soil, hydrological regime, biodiversity, the global carbon balance and the overall security of the local people's livelihood was recognized. Campaigns against the indiscriminate destruction of tropical forests gathered momentum. A large number of local and international voluntary organizations were established to push the cause of conservation, with particular emphasis on tropical forests. Although many of them had a negative agenda, opposing all sorts of developmental activities, their dramatic and emotional campaigns helped to create wide public awareness of the ecological importance of tropical forests. As a result, national governments and international bodies such as UN agencies took initiative in conservation action. For example, roughly 10% of the world's tropical forests are now set aside as national parks or undisturbed reserves. In some places like the hilly State of Kerala in India, for instance, as much as 25% of about one million ha of forest has been designated as wildlife sanctuaries and national parks. In spite of this awareness, deforestation in the tropics continues, albeit at a slower pace, driven by the profit motive of pulpwood industries and the gullibility of the governments of economically stressed tropical countries. As Whitmore (1998) observed, 'logging proceeds as fast as ever and moves on to fresh countries'. The tropical forests of South and Southeast Asia have been heavily depleted and the timber lobby is now focussing on Latin America.

Although the progress of deforestation was concomitant with the growth of the human population, and some of it was essential to ensure civilization, recent decades have witnessed an unprecedented destruction of tropical forests with the growth of the pulp and paper industry. Can we continue to destroy the tropical forests at the current rate of 17 million ha annually, and degrade much of the remaining area, without endangering our own future survival? Can we manage the remaining tropical forest, or at least a reasonable chunk of it, in a sustainable manner so that we will continue to be sustained by it? What is unique about tropical forests? It is beyond the scope of this book to answer all these questions, on which there is a vast literature. For details on the state of the world's forests the reader is referred to the periodic reports of the Food and Agriculture Organization of the United Nations (FAO) (2005), which are updated every two years. Whitmore (1998) gives a balanced account of the tropical rain forests and discusses the key tropical forestry issues. What is attempted here is a brief overview of the broad features of tropical forests to facilitate an appreciation of the role and importance of the forest insects.

1.2 The tropics

Although the tropics can be easily defined as the geographical area lying between the tropic of Cancer and the tropic of Capricorn (latitudes 23° 27’ north and south, respectively, of the equator), it is not possible to discuss tropical forestry exclusively within these geographical limits. For one thing, the distribution of many tropical forest tree species does not coincide with the limits of the tropics; it often extends beyond. For example, the natural distribution of *Eucalyptus tereticornis* extends from 9° S to 38° S, and that of the dipterocarp *Shorea robusta*, from 18° N to 32° N, covering both tropical and subtropical zones. Teak (*Tectona grandis*) has a natural distribution mostly confined to the tropics (25° N to 9° N), but is also planted widely in the subtropics (e.g. Bhutan, Japan, Korea, Nepal, Pakistan, Turkey). Even the tropical rain forest, the most characteristic forest formation of the tropics, extends, for example, into southern China at 26° N, with ill-defined change into subtropical rain forest (Whitmore, 1998). Secondly, most information related to forestry is available according to country, and countries known as tropical countries do not fall neatly within the tropics either. According to the FAO definition, if more than 50% of the area of a country falls within the tropics, it is designated as a tropical country. Thus India, situated between latitudes 8° 4’ N and 37° 6’ N, is a tropical country but has a substantial area outside the tropics. And a non-tropical country such as China or Taiwan has areas that fall within the tropics. Thirdly, even within the tropics, temperate conditions are obtained on high mountains. For example, Honduras in Central America lies between latitudes 13° N and 16° N and the climate is tropical, but most forests lie in the cooler highlands (plateaus) where the mean annual temperature is about 21.1 °C. These forests are dominated by oak and pine, while the coastal regions are warmer, with a mean annual temperature of 26.7 °C (Simon and Schuster, 1999). Because of these overlaps, in general, the term ‘tropics’ is loosely used. The regions lying not only between but also *near* the tropics of Cancer and Capricorn are usually included under the tropics. In this book, we will use the term in a similar broad sense. This will allow us to deal with insects associated with predominantly tropical trees even when these trees’ natural or planted distribution extends into the subtropical zone. In fact, strict distinction into tropics based on the imaginary latitudinal lines is artificial, because the tropics merge imperceptibly into the subtropics, often termed ‘warm temperate’.

What distinguishes the tropics more easily from other parts of the world is the consistently warm atmospheric temperature, with no drastic difference between seasons and all months without frost. Climatically, the tropical zone is characterised by annual and monthly average temperatures above 20 °C and a difference of not more than 5 °C between the mean monthly temperatures of the warmest and coolest months. This permits biological activity almost throughout the year except where seasonal drought limits the activity.

The tropics encompass many continents – parts of Asia, Australia, Africa, North America and South America, and several islands in the Pacific, Atlantic and Indian oceans. Conventionally, the tropical countries are grouped under three major regions, that is Asia-Pacific, Africa and Latin America. The countries that fall within the tropics are listed in Table 1.1. Together, these tropical countries cover a substantial portion of the earth's land surface, nearly 37%, comprising about 4800 million ha.

Table 1.1. *List of tropical countries/areas*[a]

Africa	Asia-Pacific	Latin America
Angola	Bangladesh	***Central America***
Benin	Brunei Darussalam	Belize
Botswana	Cambodia	Costa Rica
Burkina Faso	Fiji	El Salvador
Burundi	India	Guatemala
Cameroon	Indonesia	Honduras
Central African Rep.	Lao People's Dem. Rep.	Mexico
Chad	Malaysia	Nicaragua
Comoros	Myanmar	Panama
Congo	New Caledonia	
Côte d'Ivoire	Papua New Guinea	***The Caribbean***
Dem. Rep. Congo (Zaire)	Philippines	Antigua and Barbuda
Equatorial Guinea	Samoa	Bahamas
Ethiopia	Singapore	Barbados
Gabon	Solomon Islands	Cuba
Gambia	Sri Lanka	Dominica
Ghana	Thailand	Dominican Republic
Guinea	Vanuatu	Grenada
Guinea-Bissau	Vietnam	Guadeloupe
Kenya		Haiti
Liberia		Jamaica
Madagascar		Martinique
Malawi		Puerto Rico
Mali		St. Kitts and Nevis
Mauritania		St. Lucia
Mauritius		St. Vincent and the Grenadines
Mozambique		Trinidad and Tobago
Namibia		

Table 1.1. (cont.)

Africa	Asia-Pacific	Latin America
Niger		***South America***
Nigeria		Bolivia
Réunion		Brazil
Rwanda		Colombia
Senegal		Ecuador
Seychelles		French Guinea
Sierra Leone		Guyana
Somalia		Paraguay
Sudan		Peru
Togo		Suriname
Uganda		Venezuela
United Rep. Tanzania		
Zambia		
Zimbabwe		

[a]Countries more than 50% of whose area falls between the tropic of Cancer and tropic of Capricorn. It must be noted that smaller parts of other countries also fall within the tropics.

1.3 The tropical forests

As per recent estimates (FAO, 2001b), about 47% of the world's total forests (1818 million ha out of 3870 million ha) lie in the tropics and 8% (323 million ha), in the subtropics, together making up 55% of the total. Of the tropical forests, the largest portion is in Latin America (52%), centred on the Amazon river basin; followed by Africa (28%), centred on the Congo river basin; and the rest in the Asia-Pacific (19%), where it is more scattered (Fig. 1.1).

1.3.1 Characteristics of tropical forests

In general, tropical forests are characterised by high species diversity, in comparison to temperate and boreal forests. The composition varies considerably across the tropics, mainly depending on the temperature and moisture regimes, the soil and the geological history. The richest in species are those in Latin America, followed by those in Asia-Pacific and Africa. Between these three regions, there is very little similarity in the tree species present, although there are some common genera and similarities at family level. Some plant families are unique to certain regions. For example, Dipterocarpaceae, an important family of timber-yielding trees, is characteristic of Asia-Pacific where they are particularly abundant in Southeast Asia (Indonesia, Malaysia, Philippines). Similarly, Australian forests (excluding rain forests) are dominated by the tree

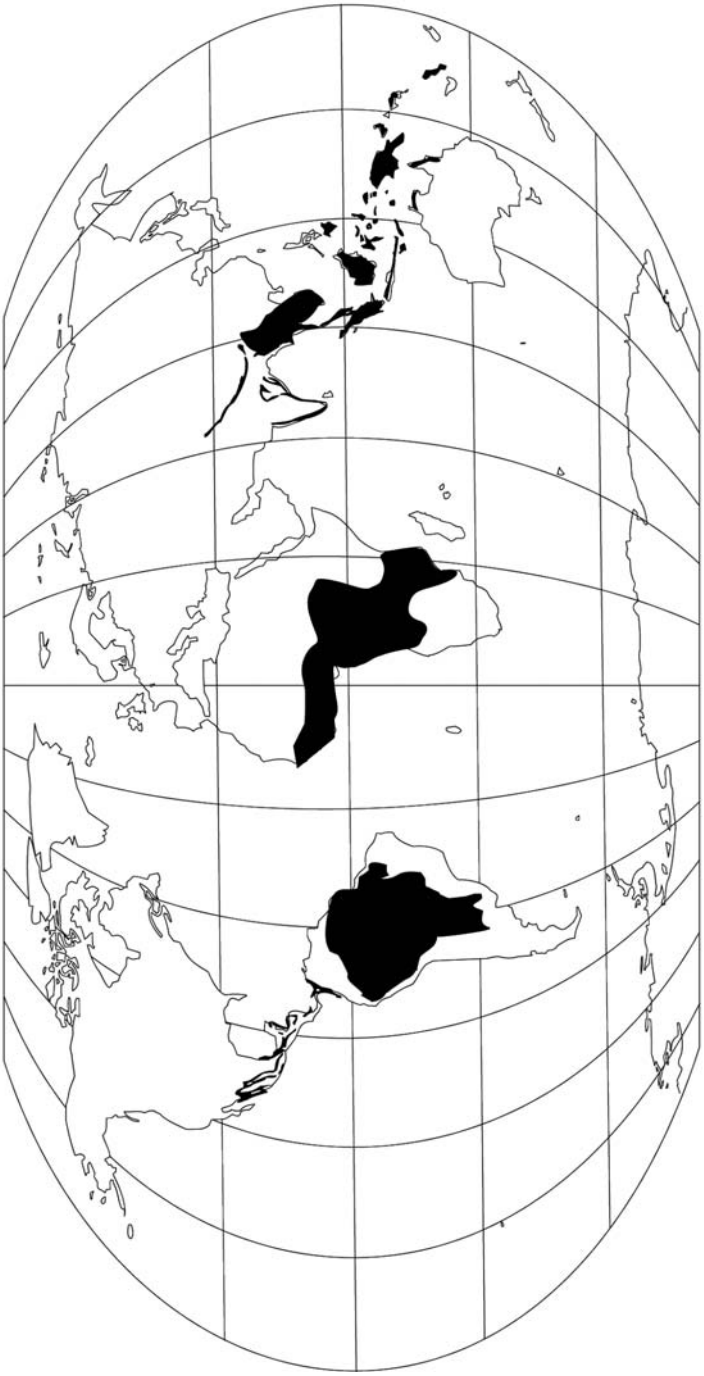

Fig. 1.1 Distribution of the world's tropical forests. The figure gives only a rough indication, as the scale does not permit depiction of small forest areas and the density of the forest cover is not represented. Based on FAO (2001b).

genus *Eucalyptus*. Africa is generally poor in flora. For instance, there are only four species of bamboos in mainland Africa (Whitmore, 1998), compared to 87 species in India alone within Asia-Pacific and about 1250 species worldwide. Africa is also characterised by the presence of savannas, plant communities dominated by grasses which may also contain scattered populations of trees that do not form a closed canopy. There are also differences within each region. For instance, within the Asia-Pacific, the natural distribution of teak is confined to two disconnected patches, one in peninsular India and the other covering most of Myanmar, northern Thailand and a small part of northwest Laos.

In spite of these differences between and within the tropical regions, in comparison to temperate forests, there are some broad features that can be considered as characteristic of tropical forests. These include high species diversity, year-round growth, existence of crown tiers, presence of lianas and understorey palms, development of buttresses on tree trunks and cauliflory (trunk-borne flowers). The major characteristic traits are discussed briefly below.

Species diversity

The diversity of life forms present in tropical forests, both of plants and animals, is staggering, and has not yet been fully scientifically documented. The number of species in a small spatial unit (generally one hectare or less) is usually referred to as ‘alpha’ diversity. It represents diversity within the community or local diversity, as compared to diversity among different communities on a larger spatial scale, referred to as ‘gamma’ diversity. The alpha diversity for tree species in tropical forests, particularly the tropical rain forests, is high. Typically, between 120 and 180 tree species (stems 10 cm or above in diameter) are present per ha in most tropical rain forest sites in the Far East (Whitmore, 1998). On the higher side, 307 tree species per ha were recorded at Cuyabeno in the western Amazon in Ecuador, while on the lower side, in Nigeria there may be only 23 per ha. Species numbers rise with increasing plot area. For example, 830 tree species were recorded in a 50-ha plot at Pasoh, Malaysia. Such high species diversity is in striking contrast to what is observed at higher latitudes.

In general, tree species diversity falls with increasing latitude (Fig. 1.2). Whitmore (1998) notes that the whole of Europe, north of the Alps and west of Russia has only 50 indigenous tree species and Eastern North America has only 171. Similarly Finland, a country with more than two-thirds of its land area under forest cover, lying between latitudes 60°N and 70°N in the boreal forest zone, has only 23 natural tree species in about 20 million ha of forest area, with Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and birch (*Betula pendula* and *B. pubescens*) accounting for 97% of the forest’s growing stock (Hakkila, 1995).

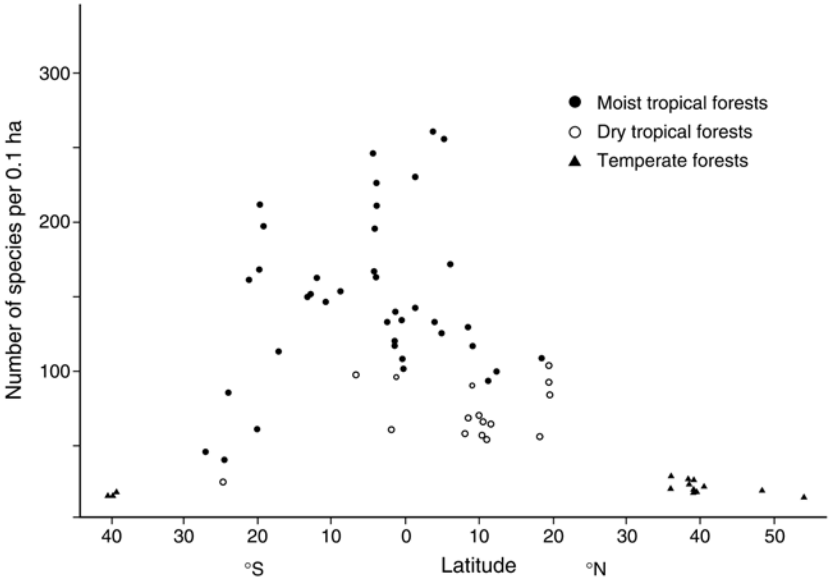

Fig. 1.2 Relationship between number of tree species and latitude. The number of tree species per standardized 0.1 ha plots at various latitudes is shown. Note that the species richness falls with increasing latitude on both sides of the equator. Reproduced, with slight modification, from *Annals of the Missouri Botanical Garden* (Gentry, 1988).

By comparison, the Kerala State in India, lying between latitudes 8°N and 13°N in the tropical zone, has 740 native tree species (Sasidharan, 1997) in about one million ha of forest. Gentry (1988) noted that in standardised 0.1 ha sample plots, temperate forests generally have 15–25 species, tropical dry forests 50–60 species and moist and wet tropical forests an average of about 150 species.

Some plant families like Myristicaceae are distributed only in the humid tropical climates while some others like Annonaceae, Musaceae and Ebenaceae are mostly concentrated there, with a few temperate outliers (Whitmore, 1998). The high species diversity of tropical forests is attributable mainly to environmental stability and possibly higher levels of speciation due to year-long biological activity. At higher latitudes, trees had to face great climatic variations during recurrent ice ages in the past and only a limited number of species were able to survive under such harsh conditions or recolonize from warmer areas.

Because of high species diversity, the number of individual stems of a species present per unit area (i.e. species density) is usually low. Often, the most abundant species do not make up more than 2.5% of all stems (He, Legendre and LaFrankie, cited by Kellman and Tackaberry, 1997) and many species are present at a density of less than one tree per ha. For instance, a density of one mature tree per ha represents the upper limit of density for mahogany (*Swietenia macrophylla*) in Brazil although its density may vary widely between regions. Thus, one to two mature trees of *S. macrophylla* per ha have been recorded in Mexico, four to eight trees per ha in Venezuela and 20–60 in Bolivia (Mayhew and Newton, 1998). There are exceptions to the general trend of low species density of tropical forests. As we proceed along the moisture gradient from wet evergreen to dry deciduous tropical forests and along the temperature gradient from lower to higher latitudes, some species become more abundant and in some cases lead to monoculture-like stands, as in higher latitudes. For example, teak (*Tectona grandis*) may constitute 10% to nearly 100% of the tree species present in the moist to dry deciduous forests in different parts of India. Similarly, sal (*Shorea robusta*) often occurs in high density stands in central and northern India. Many other dipterocarp species also occur in high densities in lowland evergreen forests of Southeast Asia. Monocultures tend to develop when competing species are eliminated mainly by climatic factors. For example, the northern limit of natural teak in India is 25° N latitude, beyond which sal takes over, because teak seedlings, unlike sal, cannot survive frost. In Finland, pure stands of spruce develop in areas prone to harsh winters. In winters with heavy snowfall, the load of ice and snow on trees can be as much as 100–150 kg/m of stem. Spruce withstands the load, but pine and birch are easily broken (Hannelius and Kuusela, 1995). Snow thus promotes the development of pure spruce stands. Tree species diversity and density have implications for pest outbreaks, as will be discussed later.

Forest structure

In tropical forests, tree growth is luxuriant and the stand is usually dense. The stem density (trees 10 cm or above in diameter) has been estimated at 497.4 ± 135.0 per ha for tropical lowland evergreen forests (Meave and Kellman, cited by Kellman and Tackaberry, 1997). Woody lianas are common and a few monocots such as canes and reed bamboos are sometimes present. Trees often harbour ferns, aroids, orchids, mosses and lichens, their presence and density varying with the moisture regime. At least three crown layers can often be distinguished. The chief, middle layer, may be between 15 and 35 m above ground, depending on the forest subtype. The top layer is formed by dominant species whose crowns may reach up to 40–45 m. Usually these trees are buttressed at the base, have unbranched, cylindrical boles and possess an umbrella-shaped top crown. The bottom layer consists of shade-tolerant trees, less than 15 m in height. A ‘profile diagram’ is generally used to depict the vertical layering of the trees in tropical forests (Fig. 1.3). Stratification of

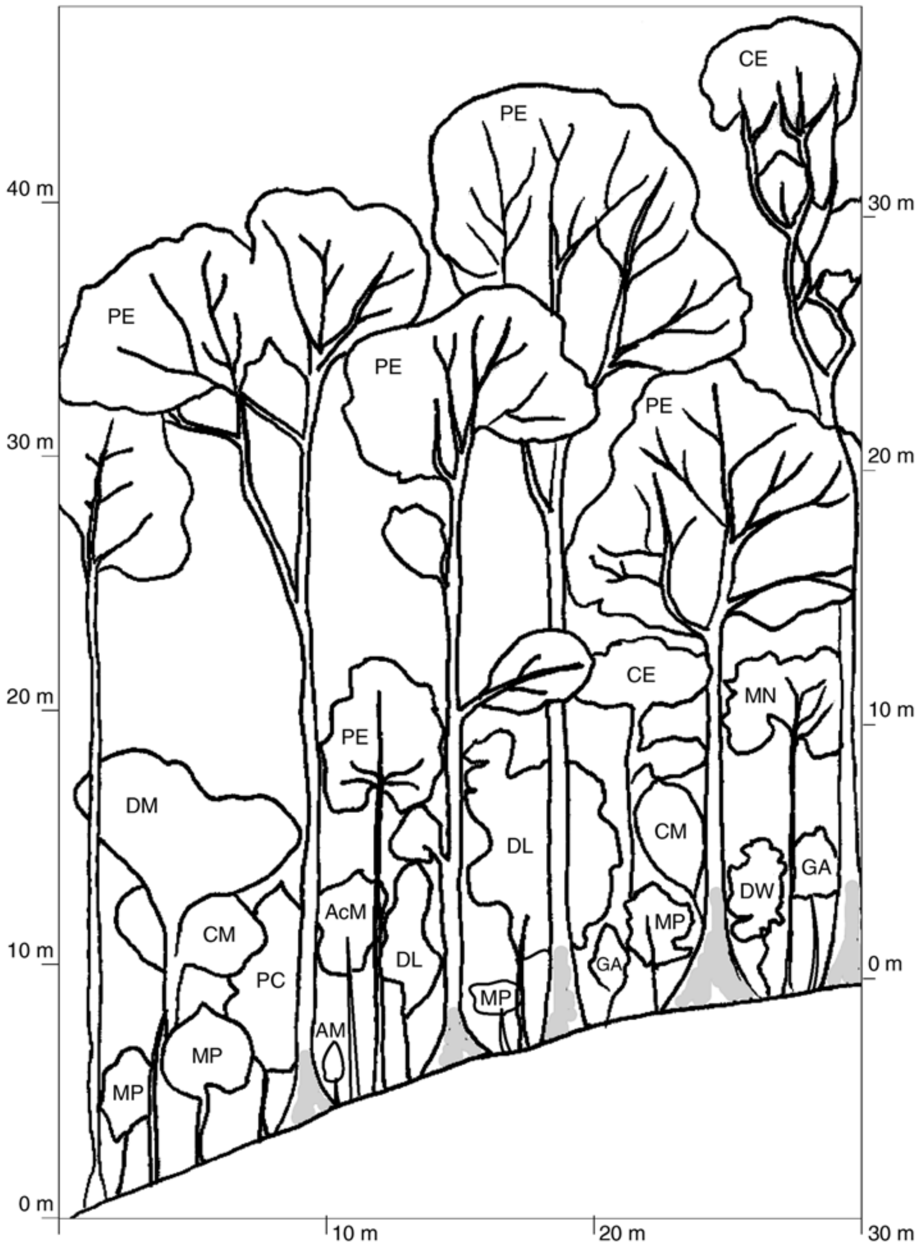

Fig. 1.3 Profile diagram of a tropical evergreen forest at Pothumala in Nelliampathy Forest Range, Kerala, India. Courtesy: U. M. Chandrashekara, Kerala Forest Research Institute.

AcM, *Actinodaphne malabarica*; AM, *Antidesma manasu*; CM, *Cinnamomum malabatrum*; CE, *Cullenia exarillata*; DL, *Dimocarpus longan*; DM, *Dysoxylum malabaricum*; DW, *Drypetes wightii*; GA, *Garcinia morella*; MN, *Mesua nagassarium*; MP, *Meiogyne pannosa*; PC, *Polyalthia coffeoides*; PE, *Palaquium ellipticum* tropical forest canopies into distinct layers is an abstraction and simplification of a complex structure that is in a dynamic state due to growth of the forest stand.

Growth dynamics

In contrast to the temperate climates where winter imposes an annual break in the growth of trees, in the tropics, growth is possible throughout the year, provided moisture is not limiting. In tropical forests, seasonality in growth is largely imposed by moisture availability. In general, the primary productivity of tropical forests is higher than in temperate forests due to the longer growth period, although part of this productivity is lost due to greater respiratory loss in the higher temperatures.

Although a climax tropical forest may appear uniform, on a larger spatial scale it is a mosaic with smaller parts in a continual flux. As Whitmore (1984) wrote, trees are mortal and eventually die of old age. This creates gaps in the forest canopy, initiating a forest growth cycle. Gaps of various sizes can also be created by other causes as when trees are killed by lightning strikes, fire, pest outbreaks, blown over by wind or swept aside by landslides. When the gap is small, pre-existing seedlings and saplings of shade-tolerant species (climax species) grow up to fill the gap and eventually become mature trees. When the gap is large, seeds of fast-growing, light-demanding species (pioneer species) germinate and colonize the gap, and as the short-lived pioneer species mature and decline, climax species take over. Three arbitrary phases, gap phase, building phase and mature phase, have been recognized in this growth cycle, and any stretch of forest is a mosaic of small and large patches in each of these three phases (Fig. 1.4). In drier tropical forests, fire often initiates the process of regeneration over larger areas and the stand dynamics may differ in detail from the gap phase dynamics.

1.3.2 Types of tropical forests

The structure and floristic composition of tropical forests varies from place to place according to latitude, altitude, amount and pattern of rainfall, nature of the underlying soil, past geologic and climatic history etc., and in transitional zones one kind of forest merges imperceptibly into another. Therefore classification of tropical forests into neat subtypes has been difficult and various schemes of classification have come into vogue in different parts of the world, causing some confusion. Forest stands that differ in overall vegetation structure (height of trees, crown tiers, presence of climbers and epiphytes), physiognomy (individual tree characteristics such as crown shape, presence of buttress, leaf shedding habit etc.) and floristic composition are often called **forest formations.** Examples of forest formations are lowland evergreen rain

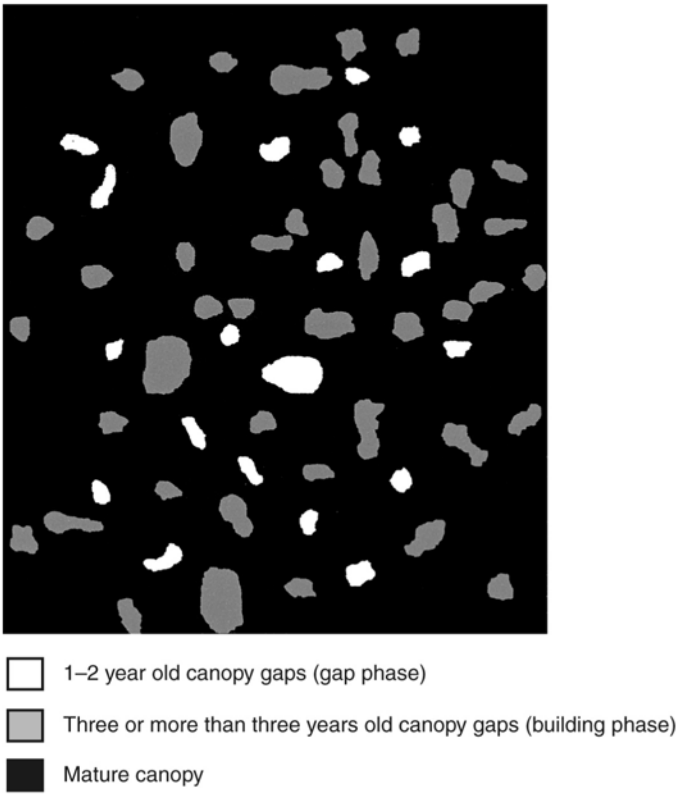

Fig. 1.4 Gap-phase dynamics. Map of the distribution of three phases of canopy development on a 10 ha block of tropical evergreen forest at Pothumala in Nelliampathy Forest Range, Kerala, India. The gap size varied from 86 – 665 m^2. A natural forest is a mosaic of patches in these three phases of development. Courtesy: U. M. Chandrashekara, Kerala Forest Research Institute.

forest, upper and lower montane rain forest, heath forest, mangrove forest, peat swamp forest, semi-evergreen rain forest, moist deciduous forest etc. For a detailed description of the various tropical forest formations the reader is referred to Whitmore (1984). Only the broad categories of tropical forests are discussed here.

As per FAO global ecological zoning, the tropical forests can be grouped into four broad categories – tropical rain forest, tropical moist deciduous forest, tropical dry forest and tropical mountain forest. Their extent and distribution in the three major tropical regions is shown in Table 1.2.

Of the total tropical forests, tropical rain forest constitutes the largest proportion (60%), followed by tropical moist deciduous forest (23%), tropical dry deciduous forest (11%) and tropical mountain forest (9%) (Table 1.2).

Table 1.2. *The major types of tropical forests and their distribution*

	Area in million ha			
Forest type	Total[a]	Africa	Asia-Pacific	Latin America
Tropical rain forest	1083 (60%)[b]	260	184	639
Topical moist deciduous forest	426 (23%)	170	86	170
Tropical dry forest	193 (11%)	75	44	76
Tropical mountain forest	155 (9%)	17	45	94
Total tropical forest	1818 (100%)	509 (28%)	345 (19%)	945 (52%)
Total subtropical forest	323	7	170	146

[a]The totals may not tally exactly as the individual values were calculated from rounded percentages from the source.
[b]Percentage of total tropical forests.
Source of data: FAO (2001b)

Tropical rain forest

The rain forest is unique tropical forest, well known for its extreme richness in species of plants and animals. Although it occupies only about 8% of the world's land area, it is believed to harbour about half the world's species (Whitmore, 1998). It occurs in all three tropical regions, with the largest proportion in Latin America, constituting about 59% of the global total. Brazil has more rain forest than any other nation. The second largest area (24%) of tropical rain forest is in Asia-Pacific, where Indonesia tops the list, with substantial areas also in Malaysia, Thailand, Myanmar, Cambodia, Laos and Vietnam. Africa has the smallest extent of tropical rain forest; it is centred on the Congo basin with extension into western Africa as a coastal strip and small patches on the eastern coast of Madagascar.

Rain forest develops in places where every month is wet, with 100 mm or more rainfall (Whitmore, 1998). Different climate, soil characteristics, soil water conditions and altitude have led to various rain forest formations. The major tropical rain forest formations are lowland evergreen rain forest, lower or upper montane rain forest, heath forest, peat swamp forest, freshwater swamp forest and semi-evergreen forest.

Tropical **lowland evergreen forest** is the most magnificent tropical forest formation, with lofty trees reaching 45 m or more in height at the top tier, over a main stratum between 20–35 m, and with smaller shade-tolerant trees below that. As the name indicates, it occurs at low elevations. In Indonesia, Malaysia and the Philippines, species of Dipterocarpaceae, many of which are of high commercial value, dominate the lowland rain forests. The **semi-evergreen rain forest** contains an intimate mixture of deciduous trees in the top canopy and the tree heights are smaller. It develops in places where there is a regular annual dry period of at least a few weeks. **Heath forest** is the name given to stunted forests that develop on sites of extreme infertility, with limited flora showing high specialization such as leathery leaves. Most often they occur on podzolic soil originating from siliceous sand that degrades quickly when the trees are removed. A variant of heath forest that occurs on peat swamps that are very rich in organic matter but highly deficient in mineral nutrients, formed as a result of incomplete decomposition of plant remains under wet anaerobic conditions, is known as **peat swamp forest. Fresh water swamp forests** develop where the underlying land is subject to inundation by fresh water, as on the coasts of the Amazon and its main tributaries, while **mangrove forests** develop where the underlying land is inundated by salt water, such as shorelines not subject to severe wave action and saline river mouths where large quantities of sediments are deposited. Each of these specialized forest types has its characteristic tree flora, generally species poor, capable of withstanding the harsh conditions.

The rain forests contain a large number of commercially valuable broad-leaved tree species, yielding timber of various qualities useful for a variety of purposes. Because of the large number of species it is not feasible to enumerate them here but the important ones will be referred to at appropriate places in connection with their pests.

Tropical moist deciduous forest

Tropical moist deciduous forest, sometimes called monsoon forest or seasonal forest, develops in places where several dry months regularly occur in a year. In general, these forests are less tall than rain forests and have a lower biomass. The dominant trees in these forests are mostly deciduous, with evergreen trees occupying the lower level. Characteristically bamboos are present.

Tropical moist deciduous forest occurs extensively in the Asia-Pacific countries of India, Myanmar, Thailand and Indonesia (Java) and in Africa and South America. Many valuable commercial species like teak (*Tectona grandis*), rosewood (*Dalbergia latifolia*), mahogany (*Swietenia macrophylla*), *Terminalia*, *Pterocarpus*, *Lagerstoemia* and *Albizzia* which yield construction wood as well as many species like *Ailanthus triphysa* and *Bombax ceiba* which yield plywood and matchwood timber occur in this forest type.

Tropical dry forest

Tropical dry forest, also called dry deciduous forest, occurs in areas receiving less rainfall. It is less species-rich than moist deciduous forest but has many valuable species like sandal (*Santalum album*), *Terminalia* spp., bamboos etc. Many species like teak and mahogany also occur in dry forest, forming a continuum with the moist deciduous forest.

Tropical mountain forest

Tropical forests that lie on mountains above a level of approximately 1000 m altitude constitute tropical mountain forests. On these mountains, which experience lower temperatures and other altered atmospheric conditions such as barometric pressure, solar radiation, moisture, wind and oxygen concentration, the forests take different forms that vary according to the altitude. Mountain rain forests have been further categorized into lower montane, upper montane and subalpine forests. There is a progressive diminution in the height and biomass of trees as the elevation increases. The leaf sizes decrease. There is an increase in the volume of epiphytes, particularly at medium heights as the cloud zone is reached. Floristic composition also changes drastically, with the flora becoming poorer as the height increases. Many plant families common to lowland tropical forests such as Anacardiaceae, Burseraceae, Capparidaceae, Combretaceae, Connaraceae, Dilleniaceae, Dipterocarpaceae, Flacourtiaceae, Marantaceae, Myristicaceae and Rhizophoraceae are replaced by families common to temperate regions such as Aceraceae, Araucariaceae, Clethraceae, Cunoniaceae, Ericaceae, Fagaceae, Lauraceae, Myrtaceae, Pentaphylacaceae, Podocarpaceae, Symplocaceae and Theaceae (Whitmore, 1984).

In drier forests, fire occurs often, resulting in the replacement of trees by tall grasses.

1.4 Management of tropical forests

Traditionally, the tropical forests have served as the source of wood and other building materials, and a variety of non-wood products such as fruits and tubers, dyes, resins, gums and medicines. With the progress of industrialization, exploitation of forests for wood increased, both for domestic use and national and international trade. Selective logging, that is, cutting and removal of selected species, was the initial practice. Among the large variety of tree species present in a tropical forest, only some had properties suited to meet constructional requirements and these were selected and removed. For example, in India, teak (*Tectona grandis*) was selectively logged from natural forests to meet the demands of the British shipbuilding industry. By the middle of eighteenth century, the once plentiful teak was becoming scarce on the Malabar coast (Western Ghats), as natural regeneration was not able to cope with the heavy extraction of logs. Eventually this led to the establishment of teak plantations during the 1840s, and the extent of teak plantations has grown steadily since then. Initially plantations were raised after the clear-felling of natural forests, but as a result of increasing environmental awareness since the 1960s this practice is now discouraged in most tropical countries. In most countries, large forest areas are now set aside for conservation purposes. They range from national parks, wildlife reserves, biosphere reserves etc., where limited management actions are permitted, to simple nature reserves where no management is carried out. The remaining forests are managed for timber production. This involves selective logging of desired tree species, although the logging intervals and methods used to promote the growth and regeneration of the residual trees vary. These silvicultural systems are summarised below.

Polycyclic selective logging

This involves removal of selected trees in a series of felling cycles. Usually, a large forest area is divided into smaller units called working 'coupes' and the well-grown trees of the desired species are removed from the coupes in a cyclic operation. That is, the logging is repeated in the same coupe after a fixed interval of, say, 10 to 30 years, by which time new trees will have reached maturity. For example, in the evergreen forests of the Western Ghats in Kerala, India, the felling cycle is 30 years and only 8 to 12 trees of girth above 180 cm at breast height can be felled. Damage to juvenile trees is kept to a minimum and when necessary obstructive climbers are cut down to remove crown competition.

Polycyclic selective logging is carried out in the moist deciduous forests of India and Myanmar for teak (*Tectona grandis*) and rosewood (*Dalbergia latifolia*); in dry to wet tropical forests of Latin America for mahogany (*Swietenia macrophylla*) and in the rain forests of west Africa for African mahoganies (*Khaya* spp.), among others. In Bolivia, where 20–60 mature mahogany trees may occur per ha, a 25-year cutting cycle is prescribed for mahogany and 10% of commercial-sized trees must be left behind as seed trees (Mayhew and Newton, 1998).

Monocyclic selective logging

In this system, practised in natural forests with a high density of commercially valuable tree species as in the dipterocarp forests of Malaysia, all marketable trees are harvested in a single operation at an interval that approximates to the rotation age of the trees. This is also known as the Malayan Uniform System. When all the marketable trees are removed, the canopy is opened up and a more or less uniform crop of seedlings/saplings is left behind, which is expected to grow to maturity by the next cutting cycle (70 years for dipterocarp forests of Malaysia). Less valuable trees are poisoned to 'release' the valuable dipterocarp seedlings/saplings that are in an advanced stage of regeneration. Climber-cutting and canopy opening are carried out at 10-year intervals.

A number of variants of selective logging exist in different tropical countries, with modifications made to suit local demands and stand characteristics. In the forests of West Africa, canopy opening is carried out several years prior to the logging operation to encourage advance regeneration, and several weeding and thinning operations are done following logging. In some places, an inventory is made prior to logging to ascertain the size–class distribution of trees, based on which the girth limits for felling are determined.

Clear-cutting in strips

A common practice in the Amazon region is to carry out clear-cutting in strips, 30–40 m wide, and allow natural regeneration to take place. The cutting cycle is 30–40 years and silvicultural treatments are carried out intermittently.

Multiple-use management

Increasing environmental and biodiversity considerations have led, in recent years, to attempts to manage tropical forests with minimal disturbance, for multiple benefits. It has been increasingly recognized that forests produce not only wood but also many other goods and services, such as a variety of non-wood forest products (see section 1.6 below), and environmental benefits such as soil protection and regulation of the hydrological regime. Multiple-use management of forests envisages management for two or more of these benefits simultaneously. The concept of multiple-use management has received wide acceptance but practical implementation is still elusive. Attempts range from 'reduced-impact logging' of natural forests by using aerial lifting of logs to reduce the damage to standing crop caused by large falling trees, to management of forest with people's participation at local level, including sharing of benefits. Some simple systems like cultivation of the shade-loving cardamom as an undergrowth in natural forest, with necessary shade regulation by lopping of trees, is already in practice in the evergreen forests of the Western Ghats in India. Here there is economic gain from cardamom cultivation, the soil and water regimes are reasonably protected and timber production is also ensured. However, while established trees continue to grow, natural regeneration of trees is hindered, affecting the long-term sustainability of the forest. Such trade-offs seem inevitable in multiple-use forest management. Suitable models of multiple-use management are still being developed.

1.4.1 *Problems of natural forest management in the tropics*

In spite of the best intentions at policy level, management of natural forests in the tropics is beset with practical problems in implementation. Apart from the minor floristic alterations over the years that may be caused by selective removal of some tree species, incidental damage caused by logging operations can be substantial. Damage is caused by building an often extensive road network in the hilly forest terrain to transport logs and by the unintentional breakage of residual trees caused by the falling crowns of large trees when felled. In most tropical countries, the natural forests are government owned but the felling operations are carried out by private contractors. Inadequate supervision and/or collusion between unscrupulous government officials and contractors often results in excessive over-cutting of trees which destroys the capacity of the forest to regenerate adequately, leading to degeneration and formation of secondary forests.

Indonesia provides a typical example where, in the past, rules and regulations have been grossly violated with the patronage of corrupt politicians (Cossalter and Nair, 2000). Management of the vast Indonesian tropical forests has traditionally been vested with forest concessionaires. In the forest-rich outer islands of Kalimantan (Indonesian Borneo) and Sumatra, concession right was granted to private and state-owned enterprises to exploit and manage natural forests. In 1979, the management of about 50 million ha of forest was entrusted to the concessionaires. Although the concessionaires were required to rehabilitate the logged areas, the net result was large-scale clearing of natural forests and degradation of vast areas into unproductive grasslands. In 1987, such grasslands were estimated to occupy about 30 million ha. In another government programme initiated in 1980, additional areas were allotted to domestic and foreign concessionaires in order to establish industrial forest plantations, with liberal assistance such as capital in the form of government equity, interest-free loans etc. Although some plantations were established, many forest concessionaires catered only to their own short-term financial interests rather than the long-term ecological, economic and social prosperity of the country. In a review after 20 years of the 35-year concession right, the rights of over 60% of the 359 concession holders were revoked for not conforming to the prescribed rules and regulations (Cossalter and Nair, 2000), which is indicative of the level of mismanagement. Substantial damage to forests had already been caused by that time. The Indonesian scenario may be an extreme case, but it is indicative of the problems in many of the economically stressed tropical countries.

1.5 Plantation forestry

For timber production, plantations offer many advantages over natural forests. In mixed-species tropical forests, the low density of usable trees limits timber productivity. In plantations, the species composition can be changed according to requirements. There is also large inter-tree variation in growth rate in a natural forest due to genetic variability, soil properties, exposure to sunlight, competition among trees etc. These factors can be controlled to our advantage in a plantation, by genetic selection, fertilization, suitable spacing etc., thereby enhancing the growth rate. Whitmore (1998) observed that mixed-species tropical rain forests will yield 3.6–12 tons above-ground dry weight of bole timber/ha per year. In comparison, plantations of broad-leaved trees on moderately good soil will yield 6–17 tons and conifer plantations, as well as some eucalypts, 12–35 tons of timber/ha per year. Suitable spacing in plantations also facilitates silvicultural operations, including mechanical thinning and harvesting.

Due to these advantages, over the past few decades there has been a steady expansion of forest plantations across the tropics. Plantation expansion has also been driven by increasing demand for various wood products and the dwindling supply of wood from natural forests, as environmental concerns imposed increasing restrictions on the cutting of natural forests.

The beginnings

Trees have been planted and protected in the tropics since ancient times, for both religious and aesthetic reasons and to provide shade along the roadsides. However, planting trees over large contiguous areas to create plantations was largely initiated in the mid-nineteenth century by the colonial governments. Evans (1992) and Bass (1992) give detailed accounts of the historical development of plantation forestry in the tropics. The Dutch in Indonesia tried planting teak on a small scale around 1650. In India, teak plantations were first raised in the 1840s, mainly to cater to the needs of the British navy for shipbuilding. The success of teak plantations in India led to their subsequent extension throughout the tropics – Bangladesh, Myanmar, Indonesia, Philippines, Sri Lanka and Vietnam in Asia; Tanzania in Africa; and Trinidad in tropical America. During this period, plantations of eucalypts were also raised in India, Brazil, Peru and Tanzania. Wattle (*Acacia mearnsii*) was planted in India and Tanzania to produce tannin from its bark.

The expansion

Much of the expansion in forest plantations took place during 1900–2000. While plantations of teak in India and of eucalypts in Brazil, Ethiopia etc. had been built up steadily during the first half of the century, since the 1960s there has been a boom in the establishment of tropical forest plantations. As noted earlier, this was triggered by international exchange of information and the availability of international development funds following the Second World War. In addition, some transnational private entrepreneurs, supported by liberal incentives from local governments, took an interest in plantation development in some tropical countries. The ambitious Jari venture in Brazil, initiated in 1968 by an American entrepreneur to convert 400 000 ha of Amazon forest to plantations of pines, eucalypts and *Gmelina arborea* to produce pulpwood, is well known. Due to several problems (labour management, social strife, poor performance of *Gmelina* etc.) only about 120 000 ha were actually planted up by 1980, but eventual transfer of ownership to a Brazilian consortium and the choice of more suitable tree species such as *Pinus caribaea* var. *hondurensis* and *Eucalyptus deglupta* made it one of the most successful commercial plantations in the tropics (Bass, 1992). The later Aracruz plantation of eucalypts in Brazil is also well known for the high growth rates achieved through genetic selection and vegetative propagation. Other notable examples of plantations established between 1960 and 1980 are about 2.8 million ha, mainly of teak, eucalypts and other species in India; 28 000 ha of *Pinus caribaea* in Fiji; and about 15 000 ha of eucalypts in Congo (Evans, 1992).

Much of Indonesia's industrial forest plantations of eucalypts and acacias were established in the 1980s. Another significant development in the late twentieth century was the emergence of a large number of voluntary agencies worldwide who promoted tree planting in degraded and waste lands, for environmental protection. Agroforestry, that is, cultivation of forest trees along with agricultural crops, also became popular during this period.

Present status

Evans (1992) estimated that tropical and subtropical forest plantations covered about 6.7 million ha in 1965, about 21 million ha in 1980 and 43 million ha in 1990. A recent study by the FAO (Pandey, 1997) puts this figure at 55.4 million ha for 1995, representing nearly 45% of the global area of forest plantations. In 1995, the annual rate of plantation establishment in the tropics was estimated at 1.7 million ha. As noted above, there has been a rapid increase in the tropical forest plantation area since the 1960s (Fig. 1.5). Much of this expansion took place in Asia-Pacific, particularly in Indonesia, India and Malaysia. In 1990, the distribution of plantation area by region was Asia-Pacific (including southern China, Australia and the Pacific Islands) – 29.7 million ha (71%); Latin America – 8.2 million ha (20%) and Africa – 3.8 million ha (9%). Several countries in Asia-Pacific (Bangladesh, Myanmar,

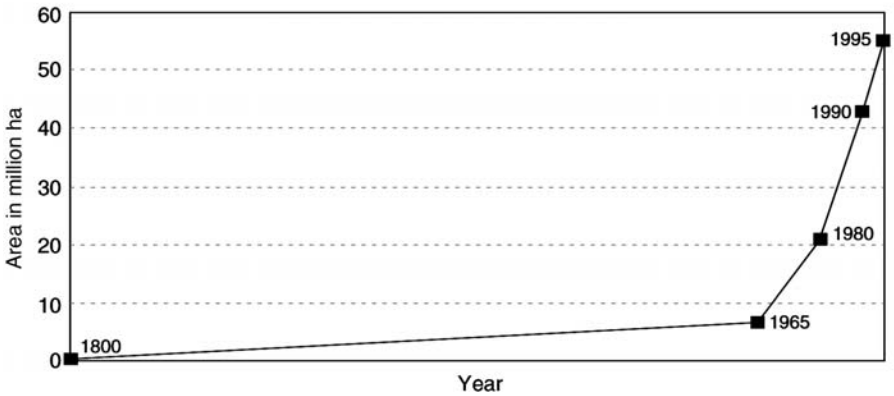

Fig. 1.5 Growth of tropical forest plantations.

India, Indonesia, Philippines, Sri Lanka, Thailand, Vietnam), Latin America (Cuba, Mexico, Brazil, Colombia, Peru, Venezuela) and Africa (Angola, Ethiopia, Kenya, Madagascar, Nigeria, Sudan, Zimbabwe) had more than 100 000 ha of forest plantations by 1990 (Evans, 1992). Thus plantation forestry in the tropics, under both commercial ventures and social forestry programmes, is poised for great expansion in the coming years.

1.5.1 Tree species planted

Over a hundred tree species are raised in plantations in the tropics, but a few dominate. The choice of species is determined by the purpose for which the plantations are raised and the nature of the site. The different categories of plantations include the following.

Plantations for constructional timber

Many species traditionally obtained from native forests and found valuable for use as constructional timber have been raised in plantations in the respective countries. An added criterion is comparatively faster growth rate. For example, rosewood (*Dalbergia latifolia*) may take about 300 years to yield a good commercial log while teak (*Tectona grandis*) can produce the same volume of wood in 60–80 years. Teak is one of the most valuable constructional timbers grown in plantations in the tropics. Its success in native plantations in India and exotic plantations in Indonesia has led to its cultivation in many tropical countries across the world; CABI (2005) lists about 50 countries (including subtropical ones) where it is grown. The global area under teak plantations in the year 2000 was estimated at 5.7 million ha, most of it in the Asian tropics (92%), followed by tropical Africa (4.5%) and Latin America (3%) (Ball *et al.*, 2000; FAO, 2001a). Some of the important plantation species for constructional timber and the major countries in which they are grown are given in Table 1.3. Mahogany (*Swietenia macrophylla*) from Central and South America and *Khaya ivorensis* from West Africa (known as African mahogany) need special mention as they are well-known, all-round timber species of the tropics. Together with teak, they share common properties of medium density, medium strength, good workability, medium to high durability, good dimensional stability, fine finish and a red–gold lustrous brown colour (Appanah and Weinland, 1993).

In addition to the species listed in Table 1.3, there are many that are locally important, such as *Manglietia conifera* (Magnoliaceae) in Vietnam, *Hopea odorata* (Dipterocarpaceae) in Bangladesh, *Pterocarpus macrocarpus* (Fabaceae) in Thailand, *Peronema canescens* (Verbenaceae) in Indonesia and several species of dipterocarps in Malaysia. Plantations of these species are on an experimental scale and little information is available about areas planted in the different countries. Cossalter and Nair (2000) reported 4963 ha under *Peronema canescens* and 4456 ha under *Octomeles sumatrana* in Indonesia as of 1999, based on information supplied by plantation companies. Appanah and Weinland (1993) give a long list of species under plantation trial in Peninsular Malaysia.

Plantations for pulpwood

Australian eucalypts are the most widely planted for pulpwood. Species commonly planted include *E. camaldulensis*, *E. globulus*, *E. grandis*, *E. robusta*, *E. saligna* and *E. tereticornis*, all of Australian origin, and *E. deglupta* and *E. urophylla* of Southeast Asian origin. The global area under tropical and subtropical eucalypt plantations in 1995 was 10 million ha (Brown and Ball, 2000). India had 3.1 million ha and Brazil 2.7 million ha (Pandey, 1997), but the exact total figure for the tropics is not available. Tropical pines, especially *Pinus caribaea* and *P. merkusii*, have also been planted extensively in the past, but they have not done well in some places due to the absence of mycorrhiza. Moreover, most pine plantations are in the subtropical or montane zones of the tropical countries. In recent years, *Acacia mangium* has taken over second place, with plantations in Bangladesh, China, India, Indonesia, Laos, Malaysia, Philippines, Sri Lanka, Thailand and Vietnam, accounting for about 600 000 ha of which 500 000 ha are in Indonesia (Turnbull *et al.*, 1998). Its fast growth rate and ability to compete with grasses in degraded secondary forests, combined with the suitability of its pulp for medium density fibreboard, has made it a preferred species for industrial plantations. *Gmelina arborea* which produces good quality timber has also been planted extensively as a short rotation crop for pulpwood in Brazil, West Africa and Indonesia. With recent improvements in pulping technology, plantations of many other fast-growing tree species such as other species of

Table 1.3. *Major plantation tree species for constructional timber*

Species	Common name	Major countries where grown
Tectona grandis (Lamiaceae)	teak	India, Indonesia, Myanmar, Thailand, Bangladesh, Sri Lanka, Nigeria, Côte d'Ivoire, Ghana, Trinidad, Brazil
Swietenia macrophylla (Meliaceae)	mahogany	Indonesia, Fiji
Khaya ivorensis (Meliaceae)	African mahogany	Nigeria, Côte d'Ivoire, Costa Rica, Trinidad and Tobago, Malaysia
Gmelina arborea (Lamiaceae)		India, Indonesia, Thailand, Malaysia, the Philippines, Nigeria
Agathis spp. (Araucariaceae)	damar	Indonesia, Malaysia
Araucaria cunninghami (Araucariaceae)	hoop pine	Papua New Guinea, Kenya
Dalbergia spp. (*latifolia, sissoo, cochinchinensis*) (Fabaceae)	rosewood, shisham, Siamese rosewood	India, Indonesia, Thailand, Vietnam, the Philippines, Sri Lanka, Kenya, Nigeria, Ghana, Sudan
Shorea spp. (*robusta, leprosula, parviflora* etc.) (Dipterocarpaceae)	sal, red meranti	India, Malaysia
Terminalia ivorensis (Combretaceae)		Many West African countries, many South American countries, Fiji, Solomon Islands
Triplochiton scleroxylon (Sterculiaceae)		Cameroon, Ghana, Nigeria, Solomon Islands
Eusideroxylon zwageri (Lauraceae)	ironwood	Indonesia, Malaysia
Koompassia spp. (Fabaceae)		Malaysia, Indonesia
Xylia xylocarpa (Fabaceae)	irul	India, Myanmar, Laos, Malaysia, Thailand, Vietnam, Nigeria, Uganda