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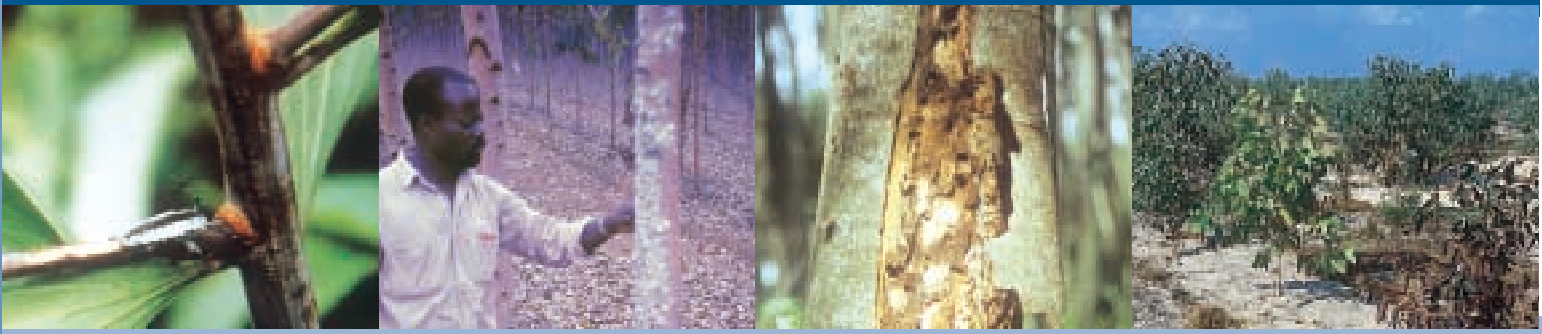

Pest Outbreaks in Tropical Forest Plantations:

Is There a Greater Risk for Exotic Tree Species?

K.S.S. Nair

PEST OUTBREAKS
IN
TROPICAL FOREST PLANTATIONS:

Is There a Greater Risk for Exotic Tree Species?

K.S.S. Nair

Visiting Scientist
Center for International Forestry Research

Cover photos (from left to right):
- *Acacia mangium* attacked by *Apomycera* sp. in Indonesia
(*by Forest Protection Laboratory, Gadjah Mada University*)
- Eucalypts attacked by *Gigantococus maximum* in the People's Republic of Congo
(*by C. Cossalter*)
- *Paraserianthes falcataria* attacked by termites, Central Java, Indonesia
(*by L. Santoso*)
- Young trees dying in an *Eucalyptus* plantation in Vietnam
(*by C. Cossalter*)

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Foreword

The world now has 50 million hectares of fast-growing timber plantations and the proportion of the world's wood supplies coming from plantations is increasing. It estimated that within 30 years the plantation area will have increased by 60% and plantations will dominate more and more of our landscapes. In the pulp and paper industry a few multi-national companies control vast areas of industrial monocultures – mainly of exotic species. Even the multitude of small plantations and woodlots in the developed and developing world are composed largely of exotic species.

The number of species exploited for industrial wood is decreasing and with the advent of genetically modified trees there will be further concentration on a few species and a few varieties of these species in plantation forestry. It is frequently claimed that vast areas of land dominated by a few species with an ever-narrowing genetic base is creating a risk of catastrophic pest and disease outbreaks. The risk increases as trade in logs is globalised and timber harvested on one continent may be found in log yards on another within a few weeks. Also, people who spend time in forests for work or recreation travel the world in a matter of hours. All this leads many people to argue against excessive use of exotic species and to urge foresters to concentrate on local species.

Dr K.S.S Nair's book is welcome because it contributes careful analysis and factual information to a debate that has been dominated by emotions, speculation and nostalgia. He demonstrates that the issues are far more complex than is commonly claimed. We now have several decades of information on the pest susceptibility of many different types of plantations. It is clear that just as it is often true that a species moved to an exotic location may be freed of its natural pests, it is also true that it may encounter new pests to which it has no resistance. Dr Nair provides much evidence that runs counter to the conventional wisdom of popular ecology and shows that broad generalisations in this complex arena are dangerous. By carefully evaluating pest problems in tropical forest plantations he has found that patterns do emerge and that many factors must be taken into account in assessing risk. He has assembled a body of evidence that will enable forest entomologists to make sensible predictions of the types of pest risk to which exotic plantations may be exposed. Some species have been widely planted and have not yet suffered from pest problems. Do we have massive pest problems just waiting to happen?

It makes sense to be cautious. My own hope is that the future will see different approaches to plantation forestry. I would like to see less emphasis on speed of growth and volume of yields. We need a diversity of approaches to plantation forestry designed to meet local production and environmental needs. Plantations and natural forests should complement one another in meeting both industrial needs for timber and the needs of local livelihoods and of the global environment. One of the attributes of such multi-functional landscapes is that they could be designed to minimise pest and disease risk. They could also provide a better environment for biological control of pest and disease outbreaks when this is feasible. This is an area of emerging concern and interest. This book provides an excellent overview of what we now know about insect pests in tropical plantations and gives guidance on where our research should focus.

Prof. Jeffrey A. Sayer,
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Abstract

In the context of the ongoing expansion of forest plantations of exotic tree species in the tropics, a critical assessment was made of the risk of insect pest outbreaks in exotics. To date, there have been two opposing views: that plantations of exotic species are at greater risk compared to indigenous species and conversely, that exotics are at lesser risk. Both views rest on theoretical arguments. In this study, an empirical approach was used to address the issue. For nine most commonly planted species in the tropics, the pest problems in natural forest stands, in countries in which the species are indigenous (native plantations), and in exotic plantations were compared. The species chosen were *Acacia mangium*, *Eucalyptus* spp., *Gmelina arborea*, *Hevea brasiliensis*, *Leucaena leucocephala*, *Paraserianthes falcataria*, *Pinus caribaea*, *Swietenia macrophylla* and *Tectona grandis*. The results showed that: (1) monoculture itself caused an increase in the pest problems; and (2) the pest risk of exotics was variable, for some species similar to that of native plantations, while greater or lesser for others. The risk of pest outbreak is therefore not solely dependent on the exotic or indigenous status of a species. Empirical results also showed that pest outbreaks occurred in native plantations. The theory relating to insect population dynamics and causes of pest outbreaks is discussed and based on a mix of empirical evidence and theory. It is concluded that the following factors determine the risk of pest outbreak in exotic monoculture plantations: (1) presence or absence of plant species closely related to the exotic; (2) extent of area under the exotic species; (3) genetic base of the planted stock; (4) distance from the native habitat of the exotic; (5) existence of serious pests in the native habitat of the exotic; (6) time elapsed since introduction; (7) chemical profile of the exotic species; and (8) innate biological attributes of the insects associated with a tree species. The overall conclusion from this study is that while all monoculture plantations are at greater risk of pest outbreaks than natural forests, plantations of exotics are at no greater risk than plantations of indigenous species. It should be possible to develop a pest risk rating system for different tree species for different locations, based on these criteria.

1. Introduction - The Problem and the Approach

1.1 Statement of the Problem

Over the past few decades there has been a steady expansion of forest plantations across the tropics. This is driven by two main forces: a dwindling supply of wood from natural forests and an increase in demand for various wood products as human populations grow and life styles change. The reasons for the decline in supply from natural forests are many, ranging from over-exploitation to increasing desire to conserve the forests for environmental benefits. The spectacular increase in recent times in the per hectare yield from plantations through genetic selection and intensive management, has also promoted reliance on plantations. Although some past expansion of tree plantations has been at the expense of natural forests, plantations are now regarded as a means to meet the wood requirements of the world without putting too much pressure on the shrinking natural forests in the tropics.

Plantations are a very small proportion of the total forest area although it is increasing rapidly. In 1995, the global plantation area totalled 123.7 million ha, constituting about 3.5% of total forests (Brown and Ball 2000), of which tropical and subtropical forest plantations accounted for nearly 45%, (about 55 million ha) (Pandey 1997). A substantial percentage is exotic species, notably eucalypts and pines, and more recently, acacias.

The success of exotic tree species in plantations has generally been attributed to the ability to match species from anywhere in the world to the site in question and their freedom, as exotics, from natural enemies, mainly insect pests and diseases. At the same time, there is a fear that catastrophic outbreaks of pests and diseases may occur suddenly in exotic plantations. Examples can be cited for both situations. Is the risk of pest outbreaks in plantations associated with the exotic status of the species? Or is it characteristic of monocultures, irrespective of whether a species is indigenous or exotic? Are the projected virtues of indigenous species an expression of an emotional attitude, similar to patriotism, rather than scientific truth? The uncertainty remains. The questions have become important in the context of the ongoing, rapid expansion of exotic plantations in the tropics, particularly large-scale industrial plantations aimed at production of pulpwood and medium-density fibreboard. This study was undertaken to critically assess the risk of pest outbreaks associated with exotic tree plantations. We need to examine the scientific issue, after disentangling it from a host of closely intertwined social, political, and other scientific issues connected with exotics, such as water use, biodiversity, etc. The focus is on insect pests; diseases are not covered. Evans (1999) reviewed evidence of sustainability of forest plantations, including pest and disease risk.

1.2 Exotics – Concept and Definitions

The term ‘exotic’ is generally used in relation to a country; in the case of plants, to indicate a species introduced into a country from outside, in contrast to ‘indigenous’ species that grow naturally within the country. Since the political boundary of a country is taken as the unit of area, a species is considered indigenous even if it occurs only in some parts of the country. Thus, teak is indigenous to India, Myanmar, Thailand and Laos although not occurring in all parts of these countries. This conventional definition of indigenous and exotic species is useful for quarantine purposes and to decide sovereign rights over biodiversity under the 'International Convention on Biodiversity'. However, it is a political concept and not scientifically rigorous, particularly when the natural distribution of a species is limited to small parts of a big country. For example, *Acacia mangium*, *Paraserianthes falcataria* and *Eucalyptus deglupta* occur naturally in very small pockets in the eastern part of Indonesia, but to say that they are indigenous to Indonesia is misleading, as they do not form part of the natural vegetation for most of the country.

Secondly, the exotic/indigenous status of a species can change with a change in the political boundary of a country. Also, for a country like Indonesia, where the Wallace Line separates a small part of the country into a different bio-geographical region, the terms 'indigenous' and 'exotic' lose their biological significance. It is more appropriate, therefore, to de-link the definition of indigenous and exotic from the boundary of country and make the terms applicable only to bio-geographical regions characterised by a more natural distribution of biota. Reliance on bio-geographical regions cannot be stretched too far either, as palaeontological records indicate that species' ranges are not static but in constant flux (Liebhold *et al.* 1995). The distribution range of a species is dependent on the geographical distribution of suitable habitats and the accessibility of such habitats to existing populations. In the past, this flux has occurred mainly due to temporal variations in climatic conditions that altered the habitat suitability, and more recently to population mobility, i.e., transportation of organisms by man past natural geographical barriers like oceans and mountain ranges.

In addition to the spatial dimension, being exotic or indigenous has a temporal dimension. It is obvious that many species have radiated widely from small centres of origin over a period of time and so, to decide whether a species is exotic or indigenous, the period during which it has been present in a given site as part of the naturally regenerating flora or fauna also assumes importance. A species can sometimes become naturalised in an introduced location. If an exotic species becomes well adapted and propagates itself in the new environment without human intervention it is considered naturalised. Many species we call indigenous, now occurring in a given location, must have become naturalised in this way in the past. We call them exotics in the early phase of introduction because we know that they are introduced, particularly when the introduction is man-made. Thus the spatial and temporal boundaries for recognition of exotics are difficult to define.

Definitions are useful only for specific purposes. For the purpose of this study, an exotic species is defined as 'one that does not occur naturally in a given geographical area delimited by visible natural boundaries'. Visible natural boundaries include landmarks such as mountains and seas. The term 'visible' is used because sometimes an invisible climatic boundary may delimit the distribution of an organism. For example, the northern limit of teak is about 24° latitude in India and so we say teak is indigenous to India. It does not mean teak occurs naturally throughout India. Some degree of ambiguity cannot be avoided in generalised statements. If we strictly follow the definition above, we cannot apply 'exotic' or 'indigenous' to India as a unit, because the country is not delimited by natural boundaries. When the context requires, more definite statements can be made. Thus we will say teak is exotic to the Andaman and Nicobar Islands and similarly, *Acacia mangium* is exotic to Java, Sumatra and Kalimantan although it occurs naturally in some parts of Indonesia, and so is indigenous to Indonesia. This is an operational definition useful for the context. The main difference from the conventional definition is that a species is considered exotic here, if it does not occur as part of the natural vegetation of a large area delimited by natural, not political or administrative, boundaries.

This definition is close to that of Zobel *et al.* (1987), except that the unit of geographical area covered is expanded and specified here. They used the term 'exotic' to apply to trees that are growing in an area in which they do not normally occur. They state, 'Every one will agree that *Eucalyptus* grown in Brazil is an exotic, as is *Pinus radiata* when grown in New Zealand. But is *Pinus elliottii*, which is indigenous to South Carolina, an exotic when grown in North Carolina, where it does not normally occur? By our definition, it is.' The difficulty with their definition is that the unit of area taken for consideration is narrow and not specified. In theory, we can narrow down the area further to absurd limits, and most tree plantations will then become exotic as they are growing in areas where they did not grow before.

In effect, we have two definitions: the conventional one in which the area is delimited by political boundaries and the one offered here in which the area is delimited by visible natural boundaries. The first is a political definition and the second, a scientific definition. Both serve their purposes. In this study, although the term is sometimes used loosely, the conclusions drawn are applicable to exotics as defined scientifically.

1.3 The Tropics

The geographical area lying between latitudes 23° 27' north and south of the equator is defined as the tropics. Yet, India, which stretches from 8° 4' N to 37° 6' N latitude, is known as a tropical country (by FAO definition, a country with more than 50% of its area in the tropics is a tropical country). Teak which is known as a tropical tree is grown in plantations as far north as 30°19' N in India. In addition, some of the common plantation species have a wide natural latitudinal range, e.g. *Eucalyptus tereticornis*: 9°S to 38°S. Evans (1992) points out that the geographical definition of the tropics is not of much value for delimiting land-use, and plantation forestry typical of tropical regions is not bound by strict latitudinal limits. He includes under 'tropics' a broad belt between 25°-27° north and south of the equator, comprising about 5000 million ha (40% of the Earth's land surface) for tropical forest plantations. This includes some subtropical areas. The term 'tropics' is used in a similar sense in this study.

1.4 Exotic Plantations in the Tropics

Exotics have always occupied a prominent place in tropical forestry. Teak was probably introduced into Indonesia (Java) from India as early as 1400-1600 AD (Phengklai *et al.* 1993) and successfully raised in plantations since 1829 (Evans 1992). Now there are about a million ha of teak plantations in Java (Perum Perhutani 1995). Teak was also introduced into Sri Lanka as early as 1680, to Trinidad in the 1880s, Nigeria in 1902, Ghana in 1905 and Côte d'Ivoire, Honduras and Panama between 1927-29 (Ball *et al.* 1999). Evans (1992) gives a good account of the historical development of plantation forestry in the tropics. Early introductions to India include eucalypts planted in Mysore in 1790 and wattles in Madras in 1832. However, extensive establishment of industrial plantations began only in the 1900s, initiated by European settlers, and included large plantations of pines in South Africa, black wattle (*Acacia mearnsii*) in South Africa and Kenya, eucalypts in Brazil and teak in several African and Caribbean countries (Evans 1992).

There was an increasing trend in the 1960s, mostly initiated by national Governments, to establish tropical forest plantations. Some international private companies also initiated huge plantation programmes in several countries. The Jari venture, initiated in 1968 in Brazil, with an ambitious target of converting 400 000 ha of Amazon forest to plantations of pines, eucalypts and *Gmelina arborea* is well known and about 120 000 ha were planted by 1980. Others included 28 000 ha of *Pinus caribaea* in Fiji, and several thousand hectares of eucalypts in Congo, Sudan and India. In the 1980s there was a steep rise in forest plantation' establishment, supported by international aid agencies. At the same time, increased environmental awareness stimulated the emergence of many voluntary agencies which promoted agroforestry and tree planting on degraded and waste lands with greater emphasis on native tree species.

Evans (1992) estimated tropical forest plantations covered about 6.7 million ha in 1965, about 21 million ha in 1980 and 43 million ha in 1990. A FAO study (Pandey 1997) gives the tropical (including subtropical) plantation area for 1995 at 55.4 million ha, representing 44.7% of the global area of forest plantations.

More than a hundred tree species are raised in plantations in the tropics and subtropics, but few dominate. Species-wise plantation area figures are not available for many tropical countries. Pandey (1997) gives statistics for 1995, which show that *Eucalyptus* spp. and *Pinus* spp. dominate, but 41.6% of the total planted area was grouped under 'other hardwoods' and 'other softwoods'. While it is beyond doubt that eucalypts and pines dominate the tropical plantations, area figures strictly applicable to tropics cannot be distinguished from the pooled figures for the tropical and subtropical regions. The 1995 figure for *Eucalyptus* spp. (Pandey 1997) is nearly 10 million ha, with India (3.1 million ha) and Brazil (2.7 million ha) accounting for about 58%. *Pinus* spp., particularly *P. caribaea*, are widely planted but the most extensive *Pinus* plantations are in the temperate regions of countries included in the pooled 'tropical and subtropical' classification (for instance, China, Chile, South Africa) (Brown 2000). In 1995, teak plantations covered 2.25 million ha; *Acacia mangium*, 454 000 ha; *Gmelina arborea*, 418 000 ha; and mahogany (*Swietenia macrophylla*), 151 000 ha (Pandey 1997). Teak is predominantly grown in India, Southeast Asia (Indonesia, Myanmar, Thailand), parts of Central America and the Caribbean, and mahogany, mostly in Indonesia and Fiji.

The annual rate of plantation establishment in the tropics was estimated at 1.7 million ha in 1995. There has been a recent shift in species choice, in favour of *Acacia mangium* in Southeast Asia and teak in Latin America. Several multinational commercial enterprises have taken interest in tropical tree plantations and international bodies under various schemes, including plantations for sequestering carbon, promote planting. A massive expansion of industrial plantations occurred in Indonesia recently, and there were about 500 000 ha of *Acacia mangium*, 48 400 ha of *Paraserianthes falcataria* and 47 800 ha of *Gmelina arborea* in 1999 (Cossalter and Nair 2000).

Plantation forestry is thus poised for great expansion in many tropical countries, particularly of exotic fast-growing species for production of pulpwood for paper manufacture and medium density fibreboard. Why do a few exotic species dominate plantation forestry in the tropics? Explanations vary. At a very simple level, some argue that in preliminary field trials, the chosen exotics have proved superiority in growth performance and ability to compete with and suppress noxious weeds. These species also yield good quality pulp. Others argue that indigenous species were not given a fair trial and were neglected for various reasons. The issues became more complicated when international or bilateral agencies made huge loans available to poor developing countries and decided what species to plant. Industrial monocultures with exotic species soon overtook the small-scale plantation efforts with diverse indigenous species. In many tropical countries large areas of pristine natural forests, as well as degraded natural forests, were planted with a few exotic species. This touched upon many interconnected social and economic issues. For example, large-scale planting programmes in Indonesia deprived the indigenous human populations of their common property resources, which became Government controlled assets. In all tropical countries where large plantation schemes were implemented, the livelihood of the tribals who depended on natural forests for their food, fruits, medicine, firewood, etc., was threatened, and often they were displaced. Each social group had different needs and expectations from the forests and converting them into plantations, whether exotic or otherwise, raised many issues. Some projected the benefits of the 'development' and others the negatives. It was alleged that eucalypt plantations consumed excessive water, causing drought, that acacia pollen caused allergy, etc. It was difficult to prove or disprove some of these claims. In some places, social activists resorted to burning exotic forest plantations. Sometimes the anger was against the ruling Government for encouraging large-scale planting by offering loans, tax concessions, etc. to plantation companies, which in some countries were foreign-owned or had foreign collaboration. The subject of exotics is still steeped in controversy and it is beyond the scope of this work to analyse the truths and myths, but the general situation portrayed above to indicate that pest susceptibility of exotics is also an issue used by both groups to argue their case. One group claims that exotics are more susceptible to pest outbreaks and the other, less. What is the truth? There is no clear-cut answer which adds to the ongoing controversy. Pest susceptibility of exotics is the only issue that will be addressed in this study.

1.5 Scope and Methods of Study

The scope of the study extended to all tropical forest plantations. The study was mainly empirical, based on a number of detailed case studies. However, after the case studies are presented and conclusions drawn, the conformity of the findings with theory is examined. The theoretical background relating to development of pest problems is discussed and final conclusions result from a blend of empirical findings and theory.

Nine tree species were selected for the case studies. This number was not pre-determined, but was the outcome of selecting species that are most widely planted in the tropics as exotics. In the absence of dependable plantation area figures, reliance on personal judgement was unavoidable. The list included the rubber tree, *Hevea brasiliensis*, which is not conventionally treated as a forest plantation species as it is primarily grown for latex production. It was included in the study for three reasons: (1) it represents one of the earliest tree plantations in the tropics, (2) it is one of the most extensively planted exotic tree species, and (3) it is now being grown also for timber production.

Although the focus of this study is on pest outbreaks in the tropics, it is neither feasible nor desirable to strictly restrict the coverage to the tropics. More emphasis is given to the tree species than the latitude as many of the common plantation species have a wide natural and planted latitudinal distribution. For example, the natural latitudinal ranges of some commonly planted species are: *E. tereticornis*, 9° S to 38° S; *E. camaldulensis*, 13° S to 38° S; *E. grandis*, 16° S to 33° S; *Tectona grandis*, 25° N to 9° N (CABI 2000). The planted latitudinal range of teak extends further, from about 39° N (Turkey) to 34° S (Uruguay)(CABI 2000).

The literature on pests of each selected tree species worldwide was examined. Relevant information was extracted from the abstracts in the Commonwealth Agricultural Bureau International's TREECD database (1939-1998). In addition, the full text of several papers, published and unpublished reports from various sources was read to extract relevant information. Some specific information was also gathered from personal communication with experts.

1.6 Presentation

There are nine case studies in the alphabetical order of species. For each species, following a brief plantation profile, there is a summary of available information on pest problems in three situations: (1) in natural forests, (2) in plantations in countries where the species is indigenous (native plantations), and (3) in plantations in countries where the species is exotic (exotic plantations). Wherever feasible, the main species of insects associated with the tree species are grouped appropriately and presented in tables, for easy reference. It was not possible to list all species of insects, which number hundreds in some cases. Instead, the emphasis is on the major pests and trends. Sometimes a species, although not a significant pest, is listed to indicate the variety of insects associated with a tree species. This is followed by a discussion comparing the pest problems in the three situations, and conclusions for each tree species. Section 3 gives general conclusions from the case studies, discusses them in the light of theory and answers the question, 'Is there a greater risk of pest outbreaks in exotic forest plantations?' Unfortunately, there is no simple answer, because a number of factors, other than the exotic status of a tree species, is found to influence the pest situation. References are listed in Section 4.

2. Case Studies

2.1 *Acacia mangium*

Plantation profile

Acacia mangium Willd. (Leguminosae, Mimosoideae) is currently a widely planted exotic in the tropics, particularly in Southeast Asia. Its natural distribution is limited to latitudes from 10°S to 19°S, in Queensland, Australia, the western province of Papua New Guinea, and two provinces in Indonesia viz., Irian Jaya (particularly the southeast district of Merauke) and Moluccas (three small islands of Sula, Ceram and the Aru) (Pinyopusarerk *et al.* 1993). The species commonly occurs in coastal lowlands up to 800 m altitude. The plantation history is short, being introduced into Sabah, Malaysia in 1966 using seed of a very restricted genetic base (Pinyopusarerk *et al.* 1993). In Asia, plantations have been raised in several countries including Bangladesh, China, India, Indonesia, Laos, Malaysia, the Philippines, Sri Lanka, Thailand and Vietnam, accounting for about 600 000 ha in total, of which 500 000 ha are in Indonesia, mostly in Sumatra and Kalimantan (Turnbull *et al.* 1998). *Acacia mangium*'s ability to compete with the grasses in the *Imperata cylindrica* grasslands and suitability for production of pulp for paper and medium density fibreboard has made it a preferred species in industrial plantations in Indonesia since 1986. Smaller plantations have been established in several countries in Africa, the Caribbean and Latin America.

Pests in natural forests

No information is available on pests of *A. mangium* in indigenous natural stands.

Pests in native plantations

Some information is available on plantations in Queensland (Elliott *et al.* 1998).

Minor damage has been reported from leaf feeding insects. These include a chrysomelid beetle, *Rhyparida discopunctata* (known as a minor pest of banana), in small plantations in farmland and a buprestid beetle, *Cisseis cupripennis*. Caterpillars of a moth widely distributed in Australia, *Ochrogaster lunifer* (Lepidoptera, Thaumetopoeidae), commonly called 'bag shelter moth' or 'processionary caterpillar', cause occasional defoliation by gregarious feeding on the foliage at night. A tortricid caterpillar, *Cryptophlebia* sp., causes serious damage by tunnelling into the terminal shoot, causing dieback. Almost all trees were attacked in a 1-year-old seed orchard and the damage by this insect appears to be on the increase (Wylie *et al.* 1998).

A large scarabaeid beetle, *Xylotrupes gideon*, feeds on the bark of stem of young trees. Serious damage to stems and branches is caused by a cerambycid borer, *Penthiea pardalis*, which shreds the bark, lays eggs and the larvae tunnel into the wood producing copious amounts of frass. Another cerambycid beetle, *Platyomopsis* sp. nr. *albocincta*, ringbarks branches.

A thrips, *Scirtothrips dorsalis* (Thysanoptera), causes bunchy top in seedlings grown in glasshouses (Ashwath and Houston, 1990).

Pests in exotic plantations

Although *A. mangium* is native to some parts of Indonesia, its natural distribution is confined to three small islands in the Moluccas and small parts of Irian Jaya. As most *A. mangium* plantations in Indonesia have been grown in Sumatra and Kalimantan, these plantations are considered exotic.

Hutacharern (1993) and Wylie *et al.* (1998) have reviewed the information on pests of *A. mangium*. About 75 species of insects have been found associated with *A. mangium* planted as an exotic, most of them in Asia, but no wide-spread pest outbreaks have been encountered so far, although there are indications of potential problems. Most pest records represent incidental feeding by polyphagous pests and may not have present or potential economic significance. Hutacharern (1993) listed about 27 species of greater importance and Wylie *et al.* (1998) about 16 for Southeast Asia. In the absence of suitable guidelines, workers' perceptions are likely to vary. A list of about 20 of the more important species/species groups associated with *A. mangium,* although not pests in the economic sense, is based on the author's judgement (Table 2.1.1).

In general, *A. mangium* plantations are remarkably free of insect pests. Insects commonly found nibbling on the foliage in small numbers include several species of bagworms, curculionid beetles and some hairy caterpillars. Several generalist feeders can be found, as usual, in nurseries, such as jassid bugs, cutworms and other caterpillars. More specific pests in young plants include the following. The termite *Coptotermes curvignathus* killed 10-50% of <1-year-old field-planted saplings in central Sumatra in Indonesia (Wylie *et al.* 1998). The same species also attacked 4-8 years old *A. mangium* trees in Malaysia (Kirton *et al.* 1999). The scolytid beetle, *Xylosandrus* (= *Xyleborus*) *compactus,* which bores into the shoot of seedlings, can cause large-scale mortality of seedlings in nurseries in Malaysia. A few species of the sap-sucking bug, *Helopeltis* cause damage in Malaysia, the Philippines and Indonesia. The damage has assumed serious proportions in 6-18 months old plantations in north and central Sumatra (Wylie *et al.* 1998). The grasshopper, *Valanga nigricornis* which often consumes leaves and terminal shoots, has shown a tendency to build up into large numbers in nursery sites and young plantations in Indonesia.

In addition to *Helopeltis* spp., the noctuid, *Spirama retorta* has shown a tendency to develop into outbreaks. Infestation of the insect was noted from May to October 1992 in 800 ha of a year-old *A. mangium* plantation at Perak in Peninsular Malaysia. The number of infested trees ranged from 30% in May to 60% in June, 55% in July and 20% in August, before it declined, possibly due to the effect of parasitoids and predators (Sajap *et al.* 1997). In infested trees, the defoliation level per tree ranged from 20-30% of the foliage.

Discussion

No comparison of the pest problem in natural forests versus native plantations is possible due to lack of data for natural forests.

Comparison between native plantations and exotic plantations shows that while only eight species of insects were found associated with native plantations compared with about 75 in exotic plantations, the native plantations suffer greater damage. The shoot tip moth, *Cryptophlebia* sp., and the cerambycid stem borer, *Penthia pardalis,* cause serious damage. It must, however, be noted that the smaller number of species found in native plantations is due partly to the smaller area of plantation represented, compared to the millions of hectares under exotic plantations in various geographic locations.

In the exotic plantations, in spite of the large number of associated insects, pest problems have not become serious, although there are indications that the mosquito bugs, *Helopeltis* spp. and the noctuid caterpillars, *Spirama retorta* and 'caterpillar Plusia', could become serious pests in future.

Table 2.1.1 Main species/species groups feeding on exotic *Acacia mangium*

Type of damage	Insect species	Countries of occurrence	Remarks
Root and stem feeding	*Coptotermes curvignathus* (Isoptera, Rhinotermitidae)	Indonesia, Malaysia, Thailand	
	Other termite spp. (Isoptera, Termitidae)	Malaysia, Vietnam	
	Sternocera spp. (Coleoptera, Buprestidae)	Thailand	Larvae bore into the root collar
Leaf feeding	*Archips micacaena* (Lepidoptera, Tortricidae)	Thailand	On seedlings
	Pteroma plagiophleps and other bagworms (Lepidoptera, Psychidae)	Indonesia, Malaysia, India, Philippines	
	Dasychira mendosa (Lepidoptera, Lymantriidae)	Malaysia, Thailand, India	
	Eurema spp. (Lepidoptera, Pieridae)	Malaysia, Philippines, Vietnam	On seedlings
	Unidentified 'caterpillar Plusia' (Lepidoptera, Noctuidae)	Indonesia	
	Spirama retorta (Lepidoptera, Noctuidae)	Malaysia	On young saplings
	Spodoptera litura (Lepidoptera, Noctuidae)	Malaysia	
	Hypomeces squamosus (Coleoptera, Curculionidae)	Malaysia, India, Indonesia	
	Valanga nigricornis and other grasshoppers (Orthoptera, Acrididae)	Indonesia, Malaysia	
	Leaf cutter ants (Hymenoptera, Formicidae)	Costa Rica	
Sap sucking	*Helopeltis* spp. (Hemiptera., Miridae)	Indonesia, Malaysia, Philippines	
	Acizzia sp. (Hemiptera., Psyllidae)	Philippines	
Stem/twig boring	*Agrilus fisheri* (Coleoptera, Buprestidae)	Philippines	
	Xylosandrus (=*Xyleborus*) *compactus* (Coleoptera, Scolytidae)	Malaysia, Indonesia	Kills seedlings/ branches
	Sinoxylon anale (Coleoptera, Bostrychidae)	Thailand	On branches
	Xystrocera spp. (Coleoptera, Cerambycidae)	Indonesia, Malaysia	
	Oncideres saga (Coleoptera, Cerambycidae)	Brazil	On branches
	Zeuzera coffeae (Lepidoptera, Cossidae)	Thailand	
	Xyleutes sp. (Lepidoptera, Cossidae)	Philippines	

No pest from the native distribution range of *A. mangium* has invaded it in its new locations. However, the plantation history of *A. mangium* is comparatively short, with most expansion of planted area taking place during the past 10 to 15 years, in both native and exotic locations.

2.2 *Eucalyptus* species

Plantation profile

Eucalyptus spp. are the most widely planted exotics in the tropics. The genus comprises more than 600 species, most of them endemic to Australia. In Australia, they occupy various ecological niches from sea level to alpine zones and from moist to dry areas, with about 280 species occurring in the northern tropical zone (Wylie and Floyd 1998). A few species are native to the tropics outside Australia; e.g., *E. pellita*, *E. deglupta* and *E. urophylla*. *E. pellita* occurs in Australia, Papua New Guinea and Indonesia (Irian Jaya), *E. deglupta* in Papua New Guinea, eastern Indonesia (Sulawesi, Moluccas and Irian Jaya) and Mindanao Island in the Philippines, and *E. urophylla*, known as Timor mountain gum, is limited to Timor and the adjacent islands (CABI 2000).

Several species are now grown in large plantations in over 80 countries (Wylie and Floyd 1998). Species commonly planted in the tropics are *E. camaldulensis*, *E. globulus*, *E. grandis*, *E. robusta*, *E. saligna* and *E. tereticornis*, all of Australian origin and *E. deglupta* and *E. urophylla* that originate elsewhere. The latest estimate (Brown and Ball 2000) puts the global area under *Eucalyptus* plantations at 10 million ha, although some of it is in the subtropical zone. *Eucalyptus* thus provides a typical case study to examine the pest problems of exotic plantations. Strange as it may appear, Australia itself had only a small area under eucalypt plantations until recently, mainly because the wood requirements in the past were met by the vast natural estate. The plantation area was estimated at 92 000 ha in 1992 (Wylie 1992), 150 000 ha in 1998 (Elliott *et al.* 1998) and 500 000 ha in 2001 (F.R. Wylie, personal communication), most of it in the temperate zone. Tropical Australia has only a few thousand hectares of eucalypt plantations but they are increasing rapidly (Wylie and Floyd 1998).

Pests in natural forests

The diversity of insects associated with eucalypts in Australia's native forests is very large. Moore (1972) listed 180 species that attack *E. grandis*, *E. pilularis* and *E. saligna* alone. Carne and Taylor (1978), Wylie (1992) and Elliott *et al.* (1998) have discussed the pest problems of eucalypts in Australia. Based on the type of damage, the pests can be grouped into three major categories; leaf feeding, sap-sucking and stem-boring.

Leaf feeding insects constitute the majority of *Eucalyptus* pests. They include the grasshoppers (Orthoptera: Acrididae), stick insects (Phasmatodea), beetles (Chrysomelidae and Scarabaeidae), caterpillars (Lepidoptera), leaf miners (Diptera: Agromyzidae) and sawflies (Hymenoptera: Pergidae). In general, they occur in very low numbers, but population outbreaks have occurred occasionally. Outbreaks are particularly well known for phasmatids and leaf beetles. Three species of phasmatids, *Ctenomorphodes tessulatus, Didymuria violescens* and *Podocanthes wilkinsoni*, cause extensive and repeated defoliation, resulting in tree mortality. Many species of eucalypts are affected, including *E. tereticornis*, a species widely planted outside Australia. Between 1964 and 1983, over 22 000 ha of forests were sprayed with insecticides to control defoliation caused by *D. violescens* (Elliott *et al.* 1998). Chrysomelid beetles of the genera *Chrysoptharta* and *Paropsis* constitute another significant group of defoliators with occasional outbreaks. Susceptible hosts include *E. grandis*, also a species widely planted as an exotic.

Among sap-sucking insects, psyllids, particularly those of the genus *Cardiaspina* (known as lerps), are the most damaging. Their feeding causes necrosis of the leaf tissue, resulting in growth retardation and crown dieback (Carne and Taylor 1978). Natural stands of species such as *E.*

camalduensis, E. grandis and *E. tereticornis* are affected.

Among the trunk-infesting insects, several species of termites, notably, *Coptotermes* spp., *Porotermes adamsoni* and *Neotermes insularis*, cause serious damage by hollowing out the stem, particularly in older stands. Several species of the longicorn borer, *Phoracantha* (Coleoptera: Cerambycidae) tunnel into the trunk of eucalypts, but they are generally secondary pests attacking live trees weakened by other causes.

Decline and dieback of trees have been noticed in natural stands of eucalypts in some rural areas, in which the insect pests are thought to be a contributory factor along with several other factors (Landsberg and Wylie 1983).

A study in Queensland by Wylie and Peters (1993) on pests of native eucalypt forests, which comprised many commonly planted tropical species, is of particular interest. They listed nine species of defoliators, four sap-suckers and five stem-feeders as the most common and damaging. In addition to occasional outbreaks of some of these pests, some like the cerambycid borer, *Phoracantha* (*Tryphocaria*) *masteri*, caused consistent serious damage leading to death of vigorous saplings and older trees of *E. maculata*. Major pests recorded on *E. tereticornis* and *E. grandis* are listed in Table 2.2.2, which compares pests in natural stands and native plantations.

No information is available on insects associated with natural stands of *E. deglupta* and *E. urophylla* that occur outside Australia.

Pests in native plantations

Australia has only a few thousand hectares of eucalypt plantations in the tropical belt. Wylie (1992) reviewed the pest problems of eucalypt plantations in Australia. He listed 17 species as serious pests and Wylie and Floyd (1998) added some (Table 2.2.1).

Leaf feeding beetles of the families Chrysomelidae and Scarabaeidae are the most damaging. In Tasmania, severe defoliation caused by the adults and larvae of the chrysomelid, *Chrysophtharta bimaculata*, in plantations of *E. nitens* has required

Table 2.2.1 Most important pests of *Eucalyptus* plantations in Australia

Category	Order and family	Species
Defoliators	Coleoptera, Chrysomelidae	*Chrysophtharta bimaculata*
		Paropsis spp.
	Coleoptera, Scarabaeidae	*Anoplognathus* spp.
		Epholcis bilobiceps
		Heteronychus arator
		Liparetrus spp.
	Coleoptera, Curculionidae	*Gonipterus scutellatus*
	Lepidoptera, Nolidae	*Uraba lugens*
	Lepidoptera, Geometridae	*Mnesampela privata*
	Lepidoptera, Limacodidae	*Doratifera* spp.
	Lepidoptera, Tortricidae	*Strepsicrates semicanella*
	Orthoptera, Acrididae	*Phaulacridium vittatum*
	Hymenoptera, Pergidae	*Phylacteophaga* spp.
Sap-suckers	Hemiptera, Psyllidae	*Cardiaspina* spp.
	Hemiptera, Coccidae	*Eriococcus coriaceous*
	Hemiptera, Coreidae	*Amorbus obscuricornis*
Stem-borers	Coleoptera, Cerambycidae	*Phoracantha* spp.
	Lepidoptera, Cossidae	*Endoxyla cinerea* (syn. *Xyleutes cinereus*)
	Isoptera, Rhinotermitidae	*Coptotermes* spp.

Data from Wylie (1992); Wylie and Floyd (1998) application of control measures in some years. A stand of *E. regnans* protected from insects for 8 years by using insecticides had three times the average wood volume of unprotected trees (Forestry Tasmania 1999). Scarabaeid defoliators have caused serious damage to *E. camaldulensis, E. globulus, E. grandis, E. robusta* and *E. tereticornis*.

Among the sap-suckers, the psyllids, *Cardiaspina* spp., caused occasional severe defoliation in Queensland, New South Wales and Victoria. In Queensland, *E. grandis* plantations were badly affected by the psyllid, *C. fiscella* (Wylie and Peters 1993).

Among stem boring insects, the longicorn, *Phoracantha* spp. were important pests in plantations in Queensland, New South Wales, Tasmania and Victoria. The trunk-feeding termite, *Coptotermes acinaciformis,* infested 33.5% of trees in 26- to 29-year-old plantations of *E. pilularis* in Queensland.

In a specific study of eucalypt plantations in Queensland during the period 1985 to 1991, Wylie and Peters (1993) recorded 105 species of insect pests, of which 97 were leaf or sap feeders, and eight were stem borers. The majority of species (94) caused only minor damage, eight caused occasionally severe damage and three caused consistently severe damage. In a later study (Wylie and Floyd 1998), a further six species were added to the list of serious pests. The most severe pests were the cossid wood borer, *Endoxyla cinerea* (syn. *Xyleutes cinereus*) (Lepidoptera, Cossidae) which attacked 8-47% of *E. grandis* trees in the observation plots, the longicorn borer *Phoracantha solida* (Coleoptera, Cerambycidae) which attacked 13-16% of trees, and the leaf beetle *Epholcis bilobiceps* (Coleoptera, Scarabaeidae) which caused almost complete defoliation of several species including *E. camaldulensis*, *E. grandis* and *E. robusta*. Those that caused occasionally severe damage included some chrysomelid and scarabaeid beetles, some moth caterpillars and a sawfly.

All pests found in plantations are those that occur in natural forests, but only some of the latter are found in plantations. The most notable difference is the near absence of phasmatids and the preponderance of leaf feeding beetles in plantations.

Outside Australia, plantations of the indigenous *E. deglupta* have been raised in Papua New Guinea, Philippines and Indonesia. In Papua New Guinea, the larvae of a cossid moth, *Zeuzera coffeae*, bores into the cambium and sapwood of young trees, leaving them susceptible to breakage by wind; 3% of trees in one plantation were affected (CABI 2000). A buprestid stem girdler, *Agrilus opulentus,* also attacks suppressed trees in Papua New Guinea. In the Philippines, two unidentified wood borers (a hepialid and a cossid), a leaf folder, *Strepsicrates ejectana* and a flower bud fly, *Fergusonina* sp., have been recorded. In addition, seedlings are attacked by white grubs. No information is available on pests of *E. deglupta* in plantations in eastern Indonesia where the species is endemic.

No plantations of *E. urophylla* exist in its native islands; pests in plantations elsewhere in Indonesia are discussed under plantations of exotics.

Pests in exotic plantations

Exotic eucalypt plantations exist in over 80 countries and at least 20 species are grown on a commercial scale. The pest situation in Brazil, India, and China is examined in some detail below. Eucalypt plantations cover 3.1 million ha in India, 2.7 million ha in Brazil and 670 000 ha in the tropical south of China (Brown and Ball 2000, Wylie 1992). For other countries, the general trends will be examined.

India

Large-scale planting of eucalypts in India began in the 1960s. Commonly planted species are *E. tereticornis, E. grandis, E. camaldulensis, E. globulus and E. robusta.*

In 1986, Nair *et al.* (1986b) made a comprehensive review of pests of eucalypts in India and assessed the future risks. No major new pest has emerged since then and their conclusions remain valid. Pests of eucalypts in India have also been listed and reviewed by Mathur and Singh (1959) and Sen-Sarma and Thakur (1983).

The most notable pests of eucalypts in India are root-feeding termites, which can kill a large percentage of transplanted seedlings during the first year. At least 20 species have been recorded, of which *Odontotemes* spp. are the most common (Nair and Varma 1985). This has necessitated use of prophylactic soil application of insecticides. Root-feeding whitegrubs (larvae of some beetles) have also been recorded in some localities but are less important.

About 50 species of leaf feeding insects are known, of which over 40 are caterpillars belonging to 12 families (see Nair *et al.* 1986b). Others include beetles, crickets, grasshoppers and stick insects. However, no outbreaks of these insects have occurred. A few species of sap-sucking insects have been recorded, including aphids, psyllids (*Trioza* spp.) and the mirid bug, *Helopeltis* sp. nr. *antonii*. *Helopeltis* attack results in drying up of tender terminal shoots; Nair *et al.* (1986b) reported that in a 7-month-old, 95 ha *E. grandis* plantation in Kerala, about 2.5% of the saplings were attacked. Some saplings in 2-3 years old plantations in nearby areas were also attacked. Although a few stem borers have been recorded, none is considered serious. The cerambycid, *Celosterna scabrator* (Lamiidae), known primarily as a borer of *Acacia nilotica*, has been found to attack young eucalypt trees. In Kerala, they have been noticed particularly in plantations receiving fertiliser treatments. The lepidopteran borers, *Sahyadrassus malabaricus* and *Endoclita undulifer* (Hepialidae) also bore into the stem of saplings. A bark-feeding caterpillar, *Indarbela quadrinotata* (Metarbelidae) also causes minor damage.

One insect of Australian origin, the cottony cushion scale, *Icerya purchasi* (Hemiptera, Margarodidae), has been recorded on *E. globulus* in India. It is not a serious pest of eucalypts although outbreaks have occurred in *Acacia mearnsii* (wattle) in the cooler hilly regions of southern India. It is an unimportant pest of acacias in Australia and Elliott *et al.* (1998) in their book on insect pests of Australian forests do not even mention this species. In India it was first noticed during 1927-28, mostly on fruit trees; its association with eucalypts appears to be incidental.

Eucalypts of non-Australian origin, viz., *E. deglupta* and *E. urophylla*, have not been planted in India except for experimental purposes, and except for root feeding termites, no major pests have so far been reported.

Brazil

Fairly large-scale planting of eucalypts in Brazil dates back to the 1920-30s (Evans 1992). The programme received a boost in the 1960s owing to tax incentives and the success of the gigantic Jari plantation with *Gmelina arborea* and *Pinus caribaea*. Later, Aracruz plantations captured phenomenal increase in yield of eucalypts with genetic selection and clonal propagation. According to a latest update by Goncalves *et al.* (1999), Brazil now has over three million hectares of eucalypt plantations, most of them for pulpwood. The planted species include *E. camaldulensis*, *E. grandis*, *E. pellita*, *E. robusta*, *E. saligna*, *E. tereticornis* and *E. urophylla*.

Over 177 species of indigenous insects have been recorded on eucalypts in Brazil, but most of them are casual feeders. Numerically, the most dominant are the leaf feeding lepidopteran caterpillars; up to a dozen species have been rated as serious pests by different authors, and aerial application of insecticides had been made to control some of them. The most damaging include *Thyrinteina arnobia*, *Glena unipennaria* (Geometridae); *Nysala nyseus* (Notodontidae); *Sarsina violascens* (Lymantriidae); and *Eupsuedosoma aberrans* and *E. involuta* (Arctiidae). Balut and Amante (1971) reported that in May 1970, nearly 2000 ha of a plantation of *Eucalyptus* spp. at Mogi-Guaco, Sao Paulo, Brazil, were severely infested by larvae of the arctiid, *E. involuta*, causing premature leaf-fall and withering of the branches, necessitating aerial spraying of insecticide. Oda and Berti-Filho (1978) estimated that *E. saligna* saplings in the State of Sao Paulo totally defoliated by *Thyrinteina* lost 40% of volume increment.

Next in economic importance are the leaf cutting ants, characteristic of Central and South America. The most common are species of *Atta* and *Acromyrmex*. Damage caused by them has necessitated insecticidal control measures.

Several species of subterranean termites attack newly transplanted seedlings causing their death. This has also necessitated prophylactic application of insecticides. *Coptotermes testaceous* (Rhinotermitinae), which attacks the heartwood of older trees, has also been noted in some areas.

Other indigenous pests of importance include a few species of sap-sucking psyllids (Burckhardt *et al.* 1999); a cerambycid girdler, *Compsosoma perpulchrum* (Sousa *et al.* 1995); an Orthopteran (Proscopidae), *Tetanorhynchus leonardosi* which feed on the foliage and cut the top shoot of 3-6 month old *E. urophylla* (Flechtmann and Ottati 1997); and a lepidopteran (Stenomatidae) borer, *Timocratica palpalis* which killed over 65% of infested *E. saligna* trees (Zanuncio *et al.* 1990).

Some pests of Australian origin have also been recorded in Brazil; the leaf feeding curculionids, *Gonipterus scutellatus*, *G. gibberus* and *G. platensis*, and the cerambycid borer, *Phoracantha semipunctata*, but the extent of damage is not known.

To summarise, the important pests of eucalypts in Brazil are a few defoliating caterpillars, leaf cutting ants, and root-feeding termites. These groups of insects are not important pests of eucalypts in Australia.

China

Eucalypts were first planted in China more than 100 years ago, and the current extent of plantation is about 670 000 ha, mostly in the tropical southern provinces of Guangdong, Guangxi and Hainan (Wylie 1992). *Eucalyptus citriodora* and *E. exserta* were planted in the past and since the 1980s, large-scale plantings of *E. globulus, E. saligna, E. grandis, E. urophylla* and the hybrid between the last two have been made.

Wylie (1992) has made a detailed analysis of the pest problems of eucalypt plantations in China in comparison with Australia and the following details are essentially based on his work. Over 160 species of insects were found associated with eucalypts in China, of which 13 were rated as serious pests and eight as occasionally serious. The most economically damaging were the subterranean termites which attack newly transplanted seedlings and sever the taproot. Losses up to 73% of the planted stock have been reported. *Eucalyptus citriodora, E. grandis, E. saligna and E. urophylla* have all been attacked. The termites involved belong to the genera *Odontotermes*, *Macrotermes* and *Coptotermes* (*C. formosanus*). Root feeding white-grubs also caused death of young plants in some areas.

Important leaf feeding insects were four species of lepidopteran caterpillars (Geometridae, Noctuidae, Tortricidae, Psychidae), an acridid, a gryllid, and five species of beetles (Chrysomelidae, Curculionidae, Scarabaeidae). Of these, outbreaks have been recorded only for the caterpillar, *Buzura suppressaria* (Lepidoptera, Geometridae). In a forest farm at Wei Du, outbreaks of this insect have occurred annually since 1987 (Wylie (1992). In one of the worst outbreaks in 1990, each tree harboured 800 to 1000 larvae and about 1000 ha of *E. saligna, E. grandis, E. citriodora* and *E. urophylla* plantations were severely defoliated.

An exotic insect, *Strepsicrates* sp. nr. *semicanella* (Lepidoptera, Tortricidae), widespread in the Pacific region, is an important pest in China, attacking new leaves of young trees, causing multiple branching and growth retardation.

Although 36 species of sap-sucking insects were recorded on eucalypts in China, none caused serious damage. A stem borer, *Batocera horsefieldi* (Coleoptera, Curculionidae) caused the death of some plants in the Yunnan Province (Yonghi and Kuiguang 1996).

Wylie (1992) concluded that the range of pests and the severity of damage were much less in Chinese plantations than those in Australia.

Other countries

As in India, Brazil and China, several species of indigenous insects have adapted to feeding on eucalypts wherever they have been planted. The most common are subterranean termites that attack the root of young transplants. They are present in most tropical countries and several species, particularly of the genera *Odontotermes*, *Microtermes* and *Macrotermes* (Family Termitidae) are involved. Generally, they feed on the taproot of 1- to 2-year-old plants, causing death of the plant by severing the root system. In most African countries, larger termites of the genus *Macrotermes* attack plants up to 5 years old; the older saplings are killed by ring-barking due to termites feeding above ground. In addition, *Coptotermes* spp., belonging to the family Rhinotermitidae, also attack older standing eucalypt trees in some countries like Brazil and Malaysia. This is similar to the damage caused by termites in Australia, but the incidence is much less.

In most parts of Latin America, as in Brazil, leaf-cutting ants cause substantial damage to eucalypts. Fumigation or soil insecticide application is generally carried out to destroy ant nests before planting eucalypts.

In many countries, a few species of lepidopteran caterpillars have been found to feed on eucalypt leaves, although outbreaks are rare. The common indigenous defoliators include the leaf roller *Strepsicrates* sp. attacking eucalypt seedlings in Africa and Philippines, an unidentified tortricid leaf roller (? *Strepsicrates* sp.) in Malaysia, an unidentified pyralid leaf roller in Indonesia; *Buzura* sp. and *Neocleosa* sp. in several countries in southern Africa (both Geometridae); and *Narosa viridana* in Zambia (Limacodidae).

Among sap-sucking insects, as in India, *Helopeltis* spp. (Hemiptera, Miridae) have been found to cause dieback of shoots of saplings in Indonesia, particularly in Sumatra, where up to 57% of plants may be infested (Hardi and Intari 1990). In Solomon Islands, the coreid bug, *Amblypelta cocophaga* caused severe dieback of *E. deglupta* saplings. An unidentified pest causing shoot dieback of *E. deglupta* was also reported from Sabah, Malaysia.

Among the wood borers, a buprestid beetle, *Agrilus sexsignatus*, known as varicose borer, caused heavy mortality (28-63%) of saplings in *E. deglupta* plantations in the Philippines. The problem was associated with a Papua New Guinea provenance of *E. deglupta*; an indigenous provenance of the same species was found to be resistant (Braza 1987a). Infestation by an unidentified borer (? *Agrilus* sp.) also killed 1000 ha of 2-3 years old *E. deglupta* plantation in East Kalimantan, Indonesia (Soepangkat 1998). Two indigenous cerambycid borers, *Oxymagis horni* and *Hastertia bougainvillea,* have been reported from Solomon Islands. In Vietnam, the cerambycid borer, *Aristobia approximator,* has caused severe damage to young *E. camaldulensis* and *E. tereticornis* (Wylie and Floyd 1998). Saplings are attacked by the borers, *Endoclita hosei* (Lepidopter, Hepialidae) and *Zeuzera coffeae* (Lepidoptera, Cossidae) in Sabah, Malaysia, and by the latter in Indonesia.

A few pests of Australian origin have also reached the exotic *Eucalyptus* plantations in some countries. Most important is *Phoracantha semipunctata* (Coleoptera, Cerambycidae), known in Australia as the common eucalypt longicorn. Although a minor pest attacking damaged, stressed or newly felled trees in Australia, it has become a serious pest of planted eucalypts elsewhere, killing even healthy young trees (Elliott *et al.* 1998). It is now established in many regions of the world, including the temperate (New Zealand, Europe, North America) and tropical (Africa, Middle East, South America). A related species, *P. recurva,* has also reached several countries in Africa where it is a more serious pest of eucalypts than in Australia. Other introduced pests of eucalypts in the tropics (some of these and others have also spread to temperate regions) include the following. The leaf feeding curculionid beetle, *Gonipterus scutellatus*, a relatively minor pest in Australia caused severe damage to eucalypt plantations in South Africa until its native egg parasitoid was introduced and released in large numbers to control it (Elliott *et al.* 1998). The related species, *G. gibberus* is established in Argentina (FAO 1979). The Australian tortoise beetle, *Trachymela tincticollis* (Chrysomelidae), causes defoliation of several species of *Eucalyptus* in South Africa. The Australian scale insect, *Icerya purchasi,* has been found in *Eucalyptus* plantations in Angola and Malawi, as in India. A flower-associated fly, *Drosophila flavohirta* (Diptera, Drosophilidae) from Australia, has been recorded in Madagascar and South Africa.

Summary of pest status in exotic plantations for all countries

The pest problems of exotic eucalypt plantations can be summarised:

1. The most common problem of exotic eucalypts is damage caused to young plants by several species of subterranean termites during the establishment phase of plantations. This is a problem in all tropical countries where *Eucalyptus* is grown as an exotic. In Australia, on the other hand, subterranean termites do not cause such damage, with the exception of *Mastotermes darwiniensis* in the tropical north (F.R. Wylie, personal communication), although other species of termites attack older trees and hollow out the trunk.

2. Leaf feeding insects are not a major problem in exotic plantations, unlike in Australia. While periodic outbreaks of leaf beetles are common in native plantations (like periodic outbreaks of phasmatids in natural forests), defoliator outbreaks are uncommon and exceptional in exotic plantations. The outbreaks of an arctiid caterpillar, *Eupsuedosoma involuta,* in Brazil (in over 2000 ha at Sao Paulo in 1970) and of the geometrid caterpillar, *Buzura suppressaria,* in southern China (in over 1000 ha at Wei Du in 1990) stand out as exceptions.

3. Leaf-cutting ants are important defoliators of eucalypts in Central and South America. The high density of ant nests in the planting area necessitates soil treatment to prevent extensive damage.

4. In general, sap-sucking insects do not pose a major threat to exotic eucalypt plantations, although *Helopeltis* spp. have caused some concern in Indonesia and India. (Although the coreid bug, *Amblypelta cocophaga,* causes damage to *E. deglupta* saplings in Solomon Islands, since these islands lie close to Papua New Guinea, it is debatable whether *E. deglupta* can be treated as an exotic to Solomon Islands.)

5. Indigenous wood boring insects are not major pests of exotic eucalypts, although a few do occur. An exception is *Timocratica palpalis* (Lepidoptera: Stenomatidae), which caused mortality of 67.5% of infested *Eucalyptus saligna* trees in the state of Minas Gerais in Brazil in 1985, but more information is needed on the prevalence of such damage.

6. Some *Eucalyptus* pests from Australia have found their way to exotic plantations in some countries. These include the curculionids, *Goniperus scutellatus, G. gibberus* and *G. platensis*; the cerambycid, *Phoracantha semipunctata* and *P. recurva* (South Africa, Zambia, California and South America); the chrysomelid, *Trachymela tincticollis* (South Africa), the psyllid, *Ctenaryctaina eucalypti*, the flower feeding dipteran, *Drosophila flavohirta* and the scale insect, *Icerya purchasi*. Most cause more serious damage to eucalypts in exotic locations than in Australia, apparently due to absence of their natural enemies.

Discussion

The pest problems of natural forests, native plantations and exotic plantations can be compared. Such a comparison is ideal when data are available for the same species of eucalypts from the three different habitats, however such data are meagre. The work of Wylie and Peters (1993) and S. Lawson (personal communication) in Queensland, provides data for natural forests and native plantations for two species, *E. tereticornis* and *E. grandis*. The relevant data are assembled and presented in Table 2.2.2. Based on this and other more general information given above, the following conclusions can be made on the comparative pest situation in natural forests versus native plantations.

1. There is a greater number of pest species in natural forests.
2. Some pests cause serious damage both in natural forests and native plantations. These include the chrysomelid, *Chrysophtharta* and *Paropsis*; the psyllids, *Cardiaspina* spp.; the termite, *Coptotermes*, the cerambycid, *Phoracantha* spp. and the cossid, *Endoxyla.*
3. Some serious pests are prevalent only in natural forests, eg. the phasmatids and sawflies. Sawflies have been recorded from plantations but are not yet regarded as major pests (F.R. Wylie, personal communication).
4. Some pests, although present in both natural forests and native plantations, cause more serious damage in plantations. These include several species of scarabaeid defoliators, the tortricid leaf roller, *Strepsicrates semicanella,*

Table 2.2.2 Important pests of *Eucalyptus tereticornis* and *E. grandis* in natural forests and plantations in Queensland, Australia

Order and family	Species	*E. tereticornis*		*E. grandis*	
		Natural forest	Plantation	Natural forest	Plantation
Defoliators					
Orthoptera, Phasmatidae	*Ctenomorphodes tessulatus*	v			
Hymenoptera, Pergidae	*Phylacteophaga eucalypti*			v	
Coeoptera, Scarabaeidae	*Anoplognathus pallidicollis*	v	v		
	A. porosus	v	v		v
	Repsimus aeneus	v			
	Epholcis bilobiceps				v
Lepidoptera, Nolidae	*Uraba lugens*	v			
Lepidoptera, Pyralidae	*Agrotera amathealis*		v		
Lepidoptera, Limacodidae	*Doratifera casta*		v		
Sap-suckers					
Hemiptera, Eriococcidae	*Eriococcus coriaceous*	v		v	
Hemiptera, Psyllidae	*Cardiaspina artifex*			v	
	C. fiscella			v	v
	C. maniformis			v	
Wood feeders					
Coleoptera, Cerambycidae	*Phoracantha acanthocera*			v	
	P. solida				v
Lepidoptera, Cossidae	*Endoxyla cinerea*	v	v	v	v
Isoptera, Rhinotermitinae	*Coptotermes acinaciformis*			v	

Data from Wylie and Peters (1993) and S. Lawson (personal communication) and a few other lepidopteran caterpillars and the curculionid leaf feeder, *Gonipterus scutellatus*.

From published literature, it is difficult to judge whether the impact of pests is greater in natural forests or native plantations. Both have required insecticidal applications in the past, to control outbreaks of different insects. However, recent information from an expanded plantation programme in Queensland show that although defoliation by phasmatids, *Uraba*, etc., can be spectacular and widespread when they occur in natural forests, the frequency of such damaging pest outbreaks in natural forest is lower than in native monoculture plantations (F.R. Wylie, personal communication). Also, the experience in eucalypt plantations in the temperate regions of Australia show that the plantation damage is greater.

The preponderance of phasmatids in natural forests, and of chysomelids and scarabaeids in native plantations was noted earlier. The differences in pest status of different groups of insects between natural forests and plantations are understandable because the physical and biotic environments obtained in the two habitats are different. Most phasmatids have a two-year life cycle, compared to most leaf beetles which pass through several generations per year (Elliott *et al.* 1998). Perhaps, the phasmatids may require a more moist and stable physical environment than the plantations can offer. Population increase of some insects in plantations may also be due to release from their natural enemies, which may flourish better in the more heterogeneous natural forest environment. Generally, due to these reasons, monoculture plantations of most species in the tropics have more serious pest problems than natural forests. Native plantations of eucalypts in Australia do not appear to be an exception, although the full magnitude of the problems has not become manifested as the plantation history is too short and the planted area is still small in tropical Australia. The difference between native plantations and natural forests in the number of species present is expected to narrow down as the plantations mature and the area under plantation increases. Similarly, pests, like phasmatids and psyllids, may become more damaging in plantations in future.

A comparison of the pest problems between native and exotic plantations shows:

1. There is a greater number of pest species in native than in exotic plantations. Brazil may be an exception, with about 177 species of insects associated with eucalypts. In terms of damage caused, however, Brazil has fewer pests. A number of reports on insects associated with eucalypts in Brazil are based on trap collections of insects in plantations; a more critical study of damage caused is needed.
2. Exotic plantations suffer much less damage from pests than native plantations and pest outbreaks are very rare.
3. In exotic plantations of eucalypts, a new group of pests, viz., root feeding termites, not present in Australia, attack the young plants during the establishment phase of plantations.
4. A few pests of eucalypts from Australia have spread to plantations in other countries where they cause more serious damage than in Australia.

The general conclusion is that exotic plantations of eucalypts suffer much less pest damage than native plantations and natural eucalypt forests. Since exotic plantations of eucalypts have been grown extensively at least for the past 40 years, and on a smaller scale for almost a century, the future pest situation is unlikely to change drastically from the present, except perhaps, for the increasing importance of *Helopeltis* and possibly some lepidopteran defoliators in Brazil. Wylie and Floyd (1998), however, have listed the leaf feeding sawflies and psyllids as potential threats from Australia to Asia.

2.3 *Gmelina arborea*

Plantation profile

Gmelina arborea Roxb. (Verbenaceae) is indigenous to India, Pakistan, Bangladesh, Myanmar, Sri Lanka, Thailand, Laos, Cambodia, Vietnam, and the Yunnan and Guangxi provinces in China (CABI 2000). It occurs mostly in deciduous and moist deciduous forests, but sometimes also in evergreen forests, from latitudes 0°N to 25°N and usually below 1200 m altitude. *Gmelina arborea* is a fairly fast growing tree which produces a light weight hardwood suitable for construction, carving, as well as for production of good quality pulp.

In Asia, plantations have been raised within its natural distribution range as well as beyond, in Peninsular and East Malaysia, the Philippines and Indonesia. It has also been introduced into many countries worldwide. Large-scale plantations exist in tropical Africa as well as in Brazil (CABI 2000). Some of the available planted area figures for 1990, rounded to the nearest thousand ha, are: Nigeria 91 000 ha; Sierra Leone 4000 ha; Bangladesh 6000 ha; and Malaysia 11 000 ha (Pandey 1995). In 1999, India had at least 148 000 ha of *G. arborea* plantations (FSI 2000), the largest for the species, and Indonesia had at least 48 000 ha (Cossalter and Nair 2000).

Pests in natural forests

Although many species found in native plantations of *G. arborea* may be present in natural forests, albeit in small numbers, very little published information is available. In a rare systematic study carried out in natural, moist deciduous forests in Kerala, India, over a two year period, Nair *et al.* (1986a) recorded only one species, viz., *Diacrotricha leucomochla* (Lepidoptera, Pterophoridae), the caterpillars of which fed on the leaves, causing very little damage. Other insects recorded in plantations in Kerala were not encountered. While the damage caused by insects in natural forests may be low, failure to record the presence of many insects in natural forests is surely a reflection of the paucity of investigations rather than real absence of insects.

Pests in native plantations

A large number of insects have been recorded in native plantations of *G. arborea*; 101 species in India and at least 20 in Thailand (Mathur and Singh 1960, Mathew 1986, Hutacharern 1990). Most are occasional feeders; the more important species are listed in Table 2.3.1.

One serious pest, *Craspedonta leayana* (Latreille) (syn. *Calopepla leayana*) (Coleoptera, Chrysomelidae) has become a constraint in the expansion of plantations, particularly in northeast India, Myanmar and Thailand (Garthwaite 1939, Beeson 1941). The beetle and the larvae feed on the leaves voraciously, making holes and eventually leading to complete damage, leaving only the main veins intact. There are two to three generations a year, with each female laying up to 1000 eggs. Heavy attack causes the leading shoot to dry up. The trees may remain leafless for about four months during the growing season, and repeated defoliation may kill the trees. In the Northern Shan State of Myanmar, about 800 ha of plantations were written off in 1936 due to *C. leayana* attack. Although the trees often survive, they become bushy and severe growth loss occurs. *C. leayana* is also a serious pest in Thailand and Bangladesh (Hutacharern 1990, Baksha 1997).

The bug, *Tingis beesoni* (Hemiptera, Tingidae), causes serious damage to saplings. The bugs feed gregariously at the base of the leaf blade and soft shoots. Necrotic lesions develop, leading to defoliation and dieback of shoots. A fungus, *Hendersonula toruloidea* (*Nattrassia mangiferae*), was found associated with this attack and the dieback and death of saplings were attributed to the combined action of the insect and the fungus (Harsh *et al.* 1992). The damage is prevalent in India, Myanmar and Thailand (Day *et al.* 1994).

A third serious pest is the sapwood borer, *Glena indiana* (Coleoptera, Cerambycidae), which occurs

Table 2.3.1 Main species of insects causing damage to native plantations of *Gmelina arborea*

Type of damage	Insect species	Countries of occurrence	Remarks
Leaf feeding	*Craspedonta* (=*Calopepla*) *leayana* (Coleoptera, Chrysomelidae)	India, Bangladesh, Myanmar, Thailand	Major pest
	Craspedonta mouhoti (Coleoptera, Chrysomelidae	Thailand	
	Prioptera spp. (3 species) (Coleoptera, Chrysomelidae)	Thailand	
	Epiplema fulvilinea (Lepidoptera, Epiplemidae)	India	
	Pionea aureolalis (Lepidoptera, Pyralidae)	Thailand	
	Eupterote undata (Lepidoptera, Eupterotidae)	India	
Sap sucking	*Tingis beesoni* (Hemiptera, Tingidae)	India, Myanmar, Thailand	On saplings
Stem boring	*Glena indiana* (Coleoptera, Cerambycidae)	India, Myanmar, Thailand	
	Xyleutes ceramicus (Lepidoptera, Cossidae)	Thailand, Myanmar	
	Euwallacea fornicatus (Coleoptera, Scolytidae)	India	
	Alcidodes ludificator (= *Alcides gmelinae*) (Coleoptera, Curculionidae)	India, Myanmar, Thailand	On green shoots of seedlings

in India, Myanmar and Thailand. It has ruined plantations in northeast Thailand; the attack begins in year-old saplings and continues in the following years, often resulting in death of the trees at 8-10 years (Hutacharern 1990). The beehole borer, *Xyleutes ceramicus* (Lepidoptera, Cossidae), primarily a pest of teak, is another occasional borer of *G. arborea* in Thailand and Myanmar, but not in India. The shot hole borer, *Euwallacea fornicatus* (syn: *Xyleborus fornicatus*), has also been recorded on saplings in India (Nair and Mathew 1988). The small curculionid beetle, *Alcidodes ludificator* (syn: *Alcides gmelinae*), which lays eggs in galleries made in the green shoot of seedlings in nurseries, causing dieback or death of seedlings, is another occasional serious pest. Other insects recorded on native plantations of *G. arborea* are of minor importance.

Due to the serious damage caused by insect pests, *G. arborea* has been dropped from the planting list or is not favoured by Forest Departments in many countries where the tree is indigenous.

Pests in exotic plantations

Only a few pests have been recorded in exotic plantations of *G. arborea*; the main species are listed in Table 2.3.2. None is a major pest.

Root feeding termites have been found to attack saplings in Malaysia (Chey 1996) and Cuba (Menendez and Rodriguez 1990), but the damage caused is minor. Leaf feeding insects include the geometrid caterpillar, *Ozola* minor, which caused moderate defoliation of out-planted seedlings in the Philippines (Yamane 1990) and *Atta* spp. in Brazil. Most leaf feeders, except *O. minor,* are generalists and occur only incidentally. Stem boring insects include cossids, hepialids and a curculionid. The cossid, *Prionoxystus* sp., is common on *G. arborea* saplings in Indonesia. In East Kalimantan, Ngatiman and Tangketasik (1987) reported that 5-70% of the saplings might be infested. In a clonal multiplication nursery at Sebulu in East Kalimantan, about 80% of the saplings that were stumped to produce

Table 2.3.2 Main species of insects recorded in exotic plantations of *Gmelina arborea*

Type of damage	Insect species	Countries of occurrence	Remarks
Root feeding	*Coptotermes curvignathus* (Isoptera, Rhinotermitidae)	Malaysia	On saplings
	Nasutitermes costalis (Isoptera, Termitiae)	Cuba	On saplings
Leaf feeding	*Ozola minor* (Lepidoptera, Geometridae)	Philippines	
	Dichocrocis megillalis (Lepidoptera, Pyralidae)	Malaysia	
	Archips sp. (Lepidoptera, Tortricidae)	Malaysia	
	Pionea aureolalis (Lepidoptera, Pyralidae)	Malaysia	
	Atta spp. (Hym. Formicidae)	Brazil	
	Spilosoma maculosa (Lepidoptera, Arctiidae)	Nigeria	
Stem boring	*Xyleutes ceramicus* (Lepidoptera, Cossidae)	Malaysia	
	Prionoxystus sp. (Lepidoptera, Cossidae)	Indonesia	Mostly on saplings
	Endoclita gmelinae (Lepidoptera, Hepialidae)	Malaysia	On saplings
	Aepytus sp. (Lep., Hepialidae)	Central American countries	On saplings
	Alcidodes ludificator (= *Alcides gmelinae*) (Coleoptera, Curculionidae)	Indonesia	On green shoots of seedlings

multiple shoots were infested by this borer (Nair 2000). At the same site, damage similar to that caused by the seedling borer, *Alcides ludificator*, in native plantations (see above) has been reported in less than 1-year old field plants, in the year 2001 (unpublished information) where an unidentified borer was earlier found to damage shoot cuttings kept in the nursery for rooting (Nair 2000).

Discussion

Compared to trees in natural forests, native plantations of *G. arborea* suffer very severe damage from pests. Some plantations have been abandoned because of pest problems and the species is not favoured for planting in India, Myanmar and Thailand where the problems are serious.

Generally, exotic plantations of *G. arborea* have registered good growth because of the absence of major pests. The small number of problems associated with *G. arborea* planted as an exotic are mostly due to general feeders. Insects common to native and exotic plantations include the pyralid leaf feeder *Pionea* sp., the borer *Xyleutes ceramicus* and the green stem weevil *Alcidodes ludificator*, which have been found in countries closer to the natural distribution range of *G. arborea*. Since these species are not host specific, they cannot be said to have invaded from the native distribution range of *G. arborea*.

The overall conclusion from this case study is that exotic plantations of *G. arborea* do not suffer major pest damage, compared to native plantations.

2.4 *Hevea brasiliensis*

Plantation profile

The rubber tree, *Hevea brasiliensis* (Willd. ex A. Juss.) Muell. Arg. (Euphorbiaceae), is indigenous to South America and occurs between 12° N and 35° S latitudes (CABI 2000). Because it is cultivated primarily for tapping latex for rubber production, it is not conventionally classified as a forestry crop, but it is now becoming increasingly important for timber production. Being a tree crop with a long history and large extent of exotic planting, it is relevant to this study.

Commercial planting of *H. brasiliensis* began during the 1870s in Asia (Baulkwill 1989), and now there are about 9 million ha of plantations worldwide (CABI 2000). In terms of the total area planted, it is next to *Eucalyptus* but it has the longest history (more than 100 years) of large-scale exotic planting. About 80% of the plantations are in South-East Asia. Plantations exist in Bangladesh, Brunei, Cambodia, India, Indonesia, Malaysia, Myanmar, Philippines, Singapore, Sri Lanka, Thailand and Vietnam in the Asia-Pacific and Congo, Liberia, Nigeria, Sierra Leone, Tanzania and Uganda in Africa (CABI 2000). While most plantations cover large areas, there are many individually owned, small-scale plantations.

Pests in natural forests

Hevea brasiliensis trees occur scattered in the forest in natural populations (Baulkwill 1989). No published information could be traced on pests of *H. brasiliensis* in natural forests. This partly reflects the absence of any serious pest problem in natural forests and partly the lack of attention given to such investigations in South America.

Pests in native plantations

There is very little planting of *H. brasiliensis* in countries in which it is indigenous. This is mainly because the devastating South American leaf blight disease, caused by the fungus *Microcyclus ulei* prevalent in Central and South America, precluded large-scale plantation development (Johnston 1989).

Very few pests have been recorded in the small extent of native plantations. A root feeding termite, *Coptotermes testaceous* (Isoptera, Rhinotermitidae), attacks newly transplanted seedlings in Brazil. Among the leaf feeding insects, a large polyphagous caterpillar, *Erinnys ello* (Lepidoptera, Sphingidae), is the most damaging pest of mature trees. In Brazil, it causes occasional severe defoliation. The young larvae feed on tender leaves and older larvae on mature leaves, often causing complete defoliation and reduction in latex yield. Aerial spraying of insecticide has sometimes been used to control this pest in Brazil (Johnston 1989). A caterpillar, *Premolis semirufa* (Lepidoptera, Arctiidae), has also been recorded in Para State, Brazil (Dias 1986). Sap-sucking insects recorded in Brazil include the lace bug, *Leptopharsa heveae* (Heteroptera, Tingidae), (Lara and Tanzini 1997) and two scale insects, *Selenaspidus articulatus* and *Aspidiotus* sp. (Hemiptera, Diaspididae) (Bergman *et al.* 1988, 1991). Some clones were more susceptible to *L. heveae* and *Aspidiotus* sp.; the latter was also heavily parasitised.

Among wood boring insects, 8 species of Cerambycidae, 2 of Platypodidae, 6 of Bostrichidae, and 30 of Scolytidae, have been recorded in surveys in plantations of Brazil (Dall'-Oglio and Filho 1997), but the damage caused by most of them is not known. The cerambycid borer, *Achryson surinamum* (Coleoptera, Cerambycidae), was found attacking 7-year-old trees in Sao Paulo, Brazil, causing partial or total drying of branches and trunks (Bergman *et al.* 1992).

Pests in exotic plantations

Exotic plantations of *H. brasiliensis* are remarkably free of pest problems. The few pests of minor importance are the following (Johnston 1989). Subterranean termites attack the root of recently transplanted seedlings and budded stumps in most countries, including Malaysia, Indonesia, India, Sri

Lanka, Cambodia, Vietnam and Papua New Guinea and Africa. In Nigeria, termites killed 50-72% of field-planted budded stumps (Omokhafe and Sagay 1996). The species causing damage are *Coptotermes curvignathus* in Malaysia, Indonesia and Vietnam, *C. elisae* in Papua New Guinea, *C. gestroi* in Thailand, and *Neotermes militaris* in Sri Lanka, all belonging to the family Rhinotermitidae, as well as *Odontotermes obesus* in India, and *Ancistrotermes guineensis* and *Macrotermes bellicosus* in Côte d'Ivoire, all belonging to Termitidae. Generally, *Coptotermes* species cause more serious damage. Many other species of termites may feed on dying or dead roots and stumps but they are not considered pests.

Whitegrubs, larvae of some groups of beetles, particularly of the family Melolonthidae, also feed on the taproot of seedlings, causing their death. They have been noted in Bangladesh, India, Malaysia, Vietnam and Papua New Guinea; the most common species belong to the genera, *Lachnosterna* (*Holotrichia*), *Leucopholis* and *Psilopholis*.

A few leaf feeding insects of minor importance have been recorded. These include the lepidopteran caterpillars *Tiracola plagiata* and *Spodoptera litura* (Noctuidae); *Thosea sinensis* (Limacodidae); *Orgyia postica, O. turbata, Euproctis scintillans* and *E. subnotata* (Lymantriidae); and *Antheraea paphia* (Saturniidae). The grasshopper, *Valanga nigricornis* (Orthoptera, Acrididae) has also been recorded. The cricket, *Brachytrupes portentosus* (Orthoptera, Gryllidae) cut off the top shoot of seedlings, and the weevil, *Hypomeces squamosus* (Coleoptera, Curculionidae), feed on tender leaves of nursery plants. A few species of sap-sucking scale insects and mealy bugs also infest the leaves, petioles and tender shoots. In Papua New Guinea, the bug, *Amblypelta lutescens papuensis* (Hemiptera, Coreidae), known as 'tip wilt bug', attacks young shoots, causing wilting of the shoot. It has often required application of control measures. In Malaysia, the thrips, *Scirtothrips dorsalis* (Thysanoptera, Thripidae), build up on the under-surface of young leaves during the dry weather but disappear with the onset of wet conditions.

A caterpillar, *Aetherastis circulata* (Lepidoptera, Yponomeutidae), that builds galleries with faecal matter and silk on the trunk and branches, and feeds on the bark has been noted as a minor pest in India. In Malaysia, a geometrid caterpillar, *Hemithea costipunctata*, as well as the lymantriid, *Euproctis subnotata*, have been found to feed on the flowers (Sujan *et al.* 1985).

Among borers, in trees damaged by other causes (fire, lightning, etc.), some species of small beetle borers (*Xyleborus* and *Platypus* of the families Scolytidae and Platypodidae) have been found. Two larger wood borers (Coleoptera, Cerambycidae) have also been recorded; *Batocera rubus* in Thailand (Hutacharern and Tubtim 1995) and *Ceresium pachymerum* in Papua New Guinea (Hawkeswood and Dauber 1990) but these are not major pests.

Discussion

Hevea brasiliensis is comparatively pest free, whether in natural forests, native plantations or exotic plantations. This is generally attributed to the latex production by all parts of the plant.

Native plantations appear to suffer greater damage from the defoliating caterpillar, *Erinnys ello,* than trees in natural forests.

Exotic plantations suffer little damage compared to native plantations, although a few pests have been recorded. The most significant is the damage caused by root feeding termites to recently planted seedlings and budded stumps, as in native plantations. The indigenous leaf feeding insects are of minor importance and most of them are casual polyphagous feeders that migrate from leguminous cover crops.

The overall conclusion from this case study is that exotic plantations of *H. brasiliensis* suffer much less damage than native plantations.

2.5 *Leucaena leucocephala*

Plantation profile

Leucaena leucocephala (Lamk) de Wit (Leguminosae, Mimosoideae) is a multipurpose tree species native to Mexico and Central America, with a latitudinal range from 30°N to 16°N. According to the PROSEA volume (López-Bellido and Fuentes 1997), its native distributional range is Mexico, Guatemala, El Salvador and Honduras. CABI (2000) has included Belize also in its native range, omitted Guatemala and El Salvador and observed,

> 'There is no doubt that *L. leucocephala* originates from Mexico. However, its true natural distribution is extremely difficult to ascertain in detail because it is cultivated throughout Mexico and Central America. No unambiguously natural populations have so far been located'.

Two major varieties are recognised; the 'common' or 'Hawaiian' shrubby variety that grows to 8 m tall and the 'giant', or 'Salvador' variety, that grows to16 m.

Due to its multiple uses for fodder, green manure, fuelwood, erosion control, nitrogen fixing, etc., as well as fast growth and ease of propagation, it has been very widely planted outside its native range. It was introduced to several countries in Latin America prior to 1500, to Philippines in the early 1600s, and to most other tropical countries in the late 1900s (López-Bellido and Fuentes 1997, CABI 2000). Most early introductions were of the shrubby variety; the giant variety has been introduced outside Central America only since 1960. The literature on *L. leucocephala*, particularly on its psyllid pest, is very extensive. A wealth of information is contained in the proceedings of an international workshop held in 1989 at Bogor, Indonesia (Napompeth and MacDicken 1990). A related species, *L. diversifolia*, some varieties of which are moderately resistant to the psyllid pest, has also been introduced to some countries and planted at a much smaller scale.

Pests in natural forests

Although the shrubby variety of *L. leucocephala* is believed to have originated in the Yucatan territory of Mexico and the giant form in the region of El Salvador, Guatemala and Honduras (López-Bellido and Fuentes 1997), both forms have been widely distributed and cultivated throughout Mexico and Central America for so long that it is difficult to distinguish natural populations (CABI 2000). However, some information on pests is available from natural stands of *L. leucocephala* in Mexico (McClay 1990, Waage 1990).

The most well known pest of the cultivated leucaena, the psyllid, *Heteropsylla cubana* (see below) is conspicuous by its absence in the fairly dense wild population of the shrubby variety of *L. leucocephala* in the Yucatan peninsula of Mexico, the suspected region of origin of the plant, although it is present elsewhere in Mexico (McClay 1990, Waage 1990). Typically, in lowland Mexico, dense populations of the psyllid were present in several places, e.g. Veracruz, Tempoal, Ciudad Victoria, Monterrey, but the insect was absent in others, e.g. Yucatan peninsula, Tehumantepec, Tampico. In most places examined, psyllids were present in varying density, from a few individuals to heavy infestations. From the exploratory studies of McClay (1990) and Waage (1990), it is obvious that in the natural stands of *L. leucocephala* in Mexico, the population density of *H. cubana* fluctuates widely in space and time, although the level of damage was not as severe as reported for Asia and the Pacific. Damage was always confined to the younger leaves, and general defoliation with the loss of older foliage was never observed (McClay 1990). The exact cause of the fluctuations in the psyllid population remains unclear (Waage 1990), but according to McClay (1990), factors other than natural enemies must be responsible. Systematic, long-term observations are needed to understand the dynamics of *H. cubana* populations in the native *L. leucocephala* habitat.

Other phytophagous insects recorded on *L. leucocephala* from Mexico include unidentified species of an arctiid caterpillar; a coreid bug that feeds gregariously on the shoot tips, causing them to wilt; a membracid bug; and a thrips commonly found feeding on young leaves, causing necrosis and loss of leaflets (McClay 1990). In addition, unidentified bruchid seed beetles and leaf and pod galling insects have also been recorded (Waage 1990). The full range of insects associated with *L. leucocephala* in natural forests has not been well documented.

Pests in native plantations

In the strict sense, *L. leucocephala* can be considered indigenous only to Mexico, Guatemala, Belize, El Salvador and Honduras. However, it has naturalised in the broader region of tropical America, including West Indies and Florida, for at least the past 500 years. As discussed earlier (Section 1.2), being exotic has a temporal dimension, and for all practical purposes, and from an ecological rather than terminological point of view, *L. leucocephala* must be considered native to the whole of the broader tropical American region rather than the small area where the species originated. When examined from this perspective, the following highlights of the pest situation are relevant.

Heteropsylla cubana has not been recognised as a major pest of *L. leucocephala* in tropical America, but significant damage to plantations has been reported from Florida, Cuba and Colombia (Schultze 1994, Austin *et al.* 1996, Valenciaga and Mora 1997). The first outbreak of *H. cubana* occurred in Florida in late 1983. A lepidopteran caterpillar, *Ithome lassula* (Cosmopterigidae), has also been recorded in plantations in Florida (Bullock 1989). There is no other published information on pests of *L. leucocephala* plantations in tropical America, indicating that pests do not pose a major problem.

Pests in exotic plantations

Leucaena leucocephala has been planted very widely in the tropics as an exotic in forestry and agroforestry planting programmes, especially after 1960. CABI (2000) lists over 130 countries where it is planted. Extensive areas have been planted, e.g. 1.2 million ha of plantations occur in Indonesia (Oka 1990) and 20 000 ha in central Queensland, Australia (Bray *et al.* 1990).

For nearly 25 years after large-scale exotic planting, it was free of major pest problems, but since the mid 1980s, the psyllid bug, *Heteropsylla cubana*, has emerged as a serious pest. Indigenous to tropical America, its other hosts are *Leucaena trichodes* (Jacq.) Benth., *L. pulverulenta* (Schlecht.) Benth., *L. diversifolia* (Schlecht.) Benth. and *L. salvadorensis* Standl. ex Britton & Rose (Geiger *et al.* 1995).

Its spread across the tropics has been dramatic and its initial impact devastating. It is a small bug (Heteroptera, Psyllidae), which builds up in large numbers and feeds on the terminal shoot, sucking the sap of developing leaves. As a result, the terminal shoots dry up and the growth of the tree is stunted. Plants usually recover, although initially they may have deformed and chlorotic leaves. Heavy infestation often results in complete defoliation, and rarely, in plant death. Secondary infestation with pathogenic organisms has been suspected (Napompeth 1990). Napompeth (1994) gives full details of the chronology of the spread. In summary, after the first outbreak in Florida in late 1983, the psyllid appeared in Hawaii in April 1994. Since then there has been a progressive westward movement across the globe. By 1985 it spread throughout several small islands in the Pacific and reached Philippines and Taiwan. In 1986 it was noticed in Indonesia, Malaysia, Thailand, southern Myanmar, southern China and neighbouring countries. In 1987, it appeared in Andaman Islands (India) and Sri Lanka and the next year in southern peninsular India. The westward movement continued, and in 1992 infestations were noticed in the African continent, in Tanzania, Kenya, Uganda, and Burundi, and by 1994, in Sudan (Geiger *et al.* 1995). Thus in less than 10 years, this pest has spread from its native range in tropical America, across the Pacific, to Asia and Africa; an unusual spread for an insect in recent history. According to Napompeth (1994), it is now likely to spread to the west coast of Africa

The onslaught of the leucaena psyllid has had economic, political and scientific impacts. In the Philippines, Thailand and Indonesia, which have vast areas under *L. leucocephala*, leaf meal production for cattle and fuelwood production were badly hit and many farmers became reluctant to pursue leucaena cultivation. The impacts are well documented in several country reports presented in the 1989 Bogor workshop (Napompeth and MacDicken 1990) and summarised by Napompeth (1994) and Geiger *et al.* (1995). Forage and fuelwood production losses varied from 28-56% in Indonesia. It was estimated that the monetary loss due to psyllid damage amounted to US$ 525 million in the first year of infestation in Indonesia, the Philippines, Thailand and Australia (Geiger *et al.* 1995). Indonesia which had 1.2 million ha under leucaena declared the psyllid damage as a national disaster and a Ministerial decree in 1986 established a National Task Force for its control (Oka 1990). Although large-scale forage production and fuelwood production units were affected, perhaps in all developing countries the most affected were the small-holders who utilised leucaena for various purposes at the subsistence level (Napompeth 1994). The psyllid problem triggered several international initiatives and meetings, and workshops were held to exchange views and draw up research and action plans. Research was initiated on breeding for pest resistance and biological control with introduced natural enemies. Screening of over 500 varieties of leucaena at the University of Hawaii identified some highly psyllid resistant varieties. Research at Taiwan Forestry Research Institute led to development of hybrids between *L. leucocephala* varieties and other species in the genus, which were resistant to the psyllid. These were propagated in many countries. Simultaneously, research by the Hawaii Department of Agriculture yielded potential biological control agents, notable among which are the coccinellid predators, *Curinus coerulus* and *Olla v-nigrum*, and an encyrtid (Hymenoptera) parsitoid, *Psyllaephagus yaseeni*. The first two are originally from Mexico, and the third, from Tobago (Napompeth 1994). These natural enemies were introduced to many countries in the Asia-Pacific to control the outbreak. *Curinus coerulus* and *P. yaseeni* have become successfully established in several countries and have exerted pressure on psyllid populations. In addition, over the years, several native predators, parasites and pathogens, originally present on other insect hosts, have also attacked *H. cubana* and checked its population increase. Fortunately, the threat of the exotic psyllid has not been as serious as it first appeared. A combination of several factors has put a brake on the escalating *H. cubana* populations and the crisis is now under control.

The outbreak dynamics of *H. cubana* show some interesting but unexplained features. In its native habitat in Mexico *H. cubana* populations show wide population fluctuations in space and time. As it depends on young leaves for its development, the seasonality is probably related to the synchronous flushing of the host plants and flushing depression during the flowering and fruiting season (Waage 1990). The seasonality is also exhibited in exotic locations, as observed in Thailand, Laos and Vietnam (Napompeth 1994). In Thailand, the population begins to increase during the cooler months at the end of the wet season, and during warm periods, they can be found only in 'pockets' with cooler microclimate or the cooler high elevation sites (Napompeth 1994). In Hawaii, with a generally cooler climate, it is prevalent throughout the year. In countries near the equator (Malaysia, Indonesia), the psyllid can be detected throughout the year, but at low population densities at times. These observations led Napompeth (1994) to suggest that the ups and downs of the psyllid populations are related to a definite optimum temperature range and availability of growing shoots. Although the reasons are not well understood, there has been a gradual reduction in the abundance of the leucaena psyllid over time in most exotic locations. This has been well documented in Thailand (Van Den Beldt and Napompeth 1992). During the seven years since the first invasion of *H. cubana* into Thailand in

September 1986, the relative level of damage during the peak infestation period in December-January had fallen to about 20% of the initial by 1993/94 (Fig. 11 in Napompeth 1994), although the economic loss during the period was substantial. The present status of the outbreak in the Asia-Pacific is neatly summarised by Napompeth (1994) as,

> 'The decline of the leucaena psyllid populations in Asia and the Pacific island countries cannot be explained scientifically. It is not known what the existing mortality factors are but most certainly some biological or density dependent factors are at work. The indigenous natural enemies, regardless of their generality or specificity, could be partially responsible for this decline. It was reported from several countries that the high populations of the leucaena psyllid are often infected with entomogenous [entomopathogenic] fungi at the epizootic level. Indigenous predators, such as various species of Coccinellidae, Hemiptera, spiders and other natural enemies, are almost always found associated with psyllid populations. The role of introduced natural enemies, particularly *C. coerulus* and *P. yaseeni*, could also be factors contributing to the decline of leucaena psyllid populations. In all situations, it is most certain that these factors have harmoniously and continually reduced populations of leucaena psyllid in the Asia-Pacific Region to their present low levels.'

In an update of the situation, Geiger *et al.* (1995) observed that the damage is generally heavy in about the first two years of infestation and then gradually weakens in duration and severity. They quote other reports indicating that: on one large Central Java coffee estate, 11% of trees died due to psyllid infestation in 1986, the first year of attack, but only 5.25% in 1987 and the percentage has decreased steadily since; in the Philippines, psyllid damage to forage production peaked at about 80% in the second year of infestation, but has declined gradually since and by late 1993 production had returned to normal; plantations in wetter areas of Indonesia are again green.

Two other leucaena insects of tropical American origin have also reached countries where the plant is grown as an exotic. One is *Semiothisa abydata* (Lepidoptera, Geometridae), a polyphagous pest of *Leucaena* spp. and other tree legumes, which has spread across the Pacific and into Southeast Asia recently (Waage 1990). It is not known to cause serious damage. An unidentified *Semiothisa* sp. was reported on *L. leucocephala* from Taiwan (Chang and Sun 1985), but it is not known if it is indigenous or exotic. The other is a microlepidopteran, *Ithome lassula* (Lepidoptera, Cosmopterygidae), reported from India (Pillai and Thakur 1990) and Australia (Beattie 1981). Its larva bores into the flower bud and feeds within. In irrigated plantations in Tamil Nadu, India, it was present throughout the year, and during most part of the year over 75% of the inflorescences were infested and a significant proportion of the florets destroyed (Pillai and Thakur 1990). However, these are not considered serious pests.

There are about 40 species of indigenous insects that feed on exotic *L. leucocephala* in various countries. These include leaf feeders (14 spp.), sap-suckers (18 spp.), root feeders (>3 spp.), flower and seed feeders (4 spp.) and stem/branch borers (Table 2.5.1), but none is considered a serious pest.

Discussion

A comparison of the pest problems between natural forests and native plantations of *L. leucocephala* is difficult because of insufficiency of data, lack of clear cut distinction between natural forests and plantations, and the long presence of the plant species in most parts of tropical America. Even at several places in Mexico, McClay (1990) found it difficult to distinguish between natural and planted stands as the local people cultivate the plant for its edible green seeds. However, it can be safely concluded that there is no major pest problem either

Table 2.5.1 Indigenous insects reported from exotic plantations of *Leucaena leucocephala*

Pest category	Species	[1]Country of occurrence	Remarks
Leaf feeders	**Coleoptera**		
	Curculionidae		
	Apogonia rauca	India	On new leaves
	Dereodus pollinosus	India	
	Myllocerus cardoni	India	
	M. discolour	India	
	M. undecimoustulatus maculosus	India	
	M. viridanus	India	
	Chrysomelidae		
	Diachus auratus	Vanuatu, New Caledonia, Australia	
	Aethiodactyla plagiata var. *minor*	India	
	Calasposoma aperatum	India	
	Diapromorpha turcica	India	
	Lepidoptera		
	Arctiidae		
	Amsacta lactinea	Taiwan	
	Orthoptera		
	Acrididae		
	Orthacris orthacris	India	
	Schistocera sp.	India	
Sap suckers	**Homoptera**		
	Aleyrodidae		
	Acaudaleyrodes rachipora	India	Highly polyphagous
	Bemisia porteri	Taiwan	
	Coccidae		
	Aonidiella sotetsu	China	Infests branches
	Asterolecanium pustulans	Taiwan	On branches and stem
	Coccus longulus	Australia, Taiwan	On branches and stem
	C. elongates	Taiwan	
	Hemiberlesia implicata	Taiwan	On branches and stem
	Pseudococcidae		
	Ferrisia virgata	India, Nigeria, Taiwan	
	Nipaecoccus viridis	Guam	On branches
	Eurybrachidae		
	Eurybrachys sp.	India	On stem, branches & leaves
	Membracidae		
	Leptocentrus taurus	India	On stem, branches & leaves
	Otionotus oneratus	India	On stem, branches & leaves
	Oxyrachis mangiferana	India	On stem, branches & leaves
	O. tarandus	India	On stem, branches & leaves
	Thysanoptera		
	Scirtothrips auranti	Reunion Island	

Table 2.5.1 *Continued*

Pest category	Species	[1]Country of occurrence	Remarks
	Hemiptera		
	Pentatomidae		
	Loxa deducta	Brazil	
	Nazara graminea	India	
	Chrysocoris purpureus	India	
	Coreidae		
	Homeocerus signatus	India	
Root feeders	**Isoptera**		
	Termitidae		
	Odontotermes sp	India	On 2-yr-old seedlings
	Microtermes sp.	India	
	Coleoptera		
	Scarabaeidae	Indonesia	On 1-2-yr old seedlings
	Whitegrubs		
Flower feeders	**Lepidoptera**		
	Momphidae		
	Ascalenia sp.	India	
	Thysanoptera		
	Thripidae		
	Frankliniella occidentalis	USA (Hawaii)	
Seed feeders	**Lepidoptera**		
	Tineidae		
	Spatularia mimosae	Philippines, Taiwan	
	Coleoptera		
	Curculionidae		
	Araecerus fasciculatus	Philippines	
Stem/branch borers	**Coleoptera**		
	Cerambycidae		
	Oncideres saga	Brazil	
	O. rhodosticta	USA (Texas)	Infests branches
	O. pustulatus	USA (Texas)	On small branches
	Lepidoptera		
	Cossidae		
	Zeuzera coffeae	Taiwan	

[1] Data from Braza (1987b, 1989); Chang *et al.* (1982); Chang and Sun (1985); Coutinho *et al.* (1998); Dubois and Quilici (1999); Elder *et al.* (1998); Felker *et al.* (1983); Intari and Natawiria (1973); Kadiata et al (1992); Nechols and Seibert (1985); Panizzi and Rossi (1991); Pawar (1986); Sagwal (1987); Pillai and Gopi (1990); Sundararaj and Murugesan (1996); Thakur and Pillai (1985); Wu *et al.* (1998); Yelshetty *et al.* (1998); and Yudin *et al.* (1986).

in natural forests or native plantations, although the psyllid, *H. cubana* is present in most places and their population fluctuates between low and high densities at small spatial scales. General defoliation with loss of older foliage does not occur.

In comparison, exotic plantations have suffered heavily, particularly during the early phase of invasion and colonisation of the psyllid. A fairly large native insect fauna is capable of utilising *L. leucocephala* for food, but none has become a serious pest.

The general conclusion from this case study is that exotic plantations of *L. leucocephala* suffer unpredictable and devastating pest outbreaks, the severity of which, however, lessens over time.

2.6 *Paraserianthes falcataria*

Plantation profile

Paraserianthes falcataria (L.) Nielsen (Leguminosae, Mimosoideae) is an exceptionally fast growing tree native to the eastern islands of the Indonesian archipelago, Papua New Guinea and the Solomon Islands. It has been known earlier under the names *Albizia falcata*, *A. falcataria* and *A. moluccana*. According to CABI (2000), the current preferred name is *Falcataria moluccana* (Miq.) Barneby and J. W. Grimes, but *Paraserianthes falcataria* is used here for ready recognition.

Paraserianthes falcataria is widely planted in the humid tropics; in Bangladesh, India, Indonesia, Malaysia, the Philippines and Sri Lanka in Asia; Cameroon, Côte d'Ivoire, Malawi and Nigeria in Africa; Mexico in middle America; and Hawaii and Samoa in the Pacific (CABI 2000). In 1990, the plantation areas included 12 000 ha in Bangladesh and 11 550 ha in Malaysia (Pandey 1995). Indonesia, where it is planted in both industrial and smallholder plantations, had more than 48 000 ha in 1999 (Cossalter and Nair 2000).

Pests in natural forests

Very little information is available on pests of *P. falcataria* in native stands, except that a cerambycid stem borer, *Xystrocera festiva*, attacks live trees in natural pure stands (Alrasjid 1973).

Pests in native plantations

No information is available on pests in native plantations. Since the natural distribution of *P. falcataria* in Indonesia is confined to the eastern islands of the archipelago, plantations in the main islands of Java, Sumatra and Kalimantan are considered exotic for the purpose of this study (see Section 1.2 for definition).

Pests in exotic plantations

A large number of insects have been found associated with exotic plantations of *P. falcataria*. They include the root feeding whitegrubs, leaf feeders, sapsuckers, bark feeders, stem borers and seed feeders. About 40 species have been recorded in India alone (Mathew and Nair 1985, Pillai and Gopi 1991) although only a few cause serious damage. The main species in Asia are listed in Table 2.6.1; no published pest records are available for countries in other continents.

The cerambycid borer, *Xystrocera festiva*, has emerged as a major pest in plantations of *P. falcataria* in Indonesia. It is present in most areas where *P. falcataria* plantations have been raised in Indonesia, although most reports are from Java and Sumatra. The beetle lays eggs on fissures on the bark and the larvae that initially feed underneath the bark burrow deeper into the wood as they grow to maturity in about four months. The larvae are gregarious and severe infestation often leads to death of the tree. The infestation usually begins when the trees are 2-3 years old and the percentage of infested trees increase with age. In East Java, Notoatmodjo (1963) estimated yield loss of about 12% if the trees are harvested when 4-years old, and about 74% at 8 years. *Xystrocera festiva* is also a serious pest of *P. falcataria* plantations in Malaysia (Abe 1983).

Table 2.6.1 Main species of insects causing damage to exotic plantations of *Paraserianthes falcataria*

Type of damage	Insect species	Countries of occurrence	Remarks
Root feeding	Whitegrubs (several spp.) (Coleoptera, Scarabaeidae)	Philippines, Indonesia	On saplings
Leaf feeding	*Pteroma plagiophleps* (Lepidoptera, Psychidae)	India, Indonesia	Feeds also on bark surface
	Eurema blanda/hecabe (Lepidoptera, Pieridae)	India, Indonesia, Philippines, Malaysia	
	Archips micaceanus (Lepidoptera, Tortricidae)	India	
	Adoxophyes sp. (Lepidoptera, Tortricidae)	India, Malaysia	
	Semiothisa sp. (Lepidoptera, Geometridae)	India, Malaysia	
	Catopsilia pomona (Lepidoptera, Pieridae)	Sri Lanka	
Sap sucking	*Oxyrhachis tarandus* (Hemiptera, Membracidae)	India	
	Acizzia sp. (Hemiptera, Psyllidae)	Philippines	
Bark feeding	*Indarbela quadrinotata* (Lepidoptera, Metarbelidae)	Bangladesh, India, Indonesia	
	Sahyadrassus malabaricus (Lepidoptera, Hepialidae)	India	On saplings, larva bores into stem
Stem boring	*Xystrocera festiva* (Coleoptera, Cerambycidae)	Indonesia, Malaysia	Major pest
	Xystrocera globosa (Coleoptera, Cerambycidae)	Indonesia	Minor pest
	Unidentified (Coleoptera, Cerambycidae)	India	
	Callimetopus sp. (Coleoptera, Cerambycidae)	Philippines	Shoot pruner on saplings
	Euwallacea fornicatus (Coleoptera, Scolytidae)	Sri Lanka, India	On saplings
	Xylosandrus morigerus (Coleoptera, Scolytidae)	Indonesia	Twig boring
Seed feeding	*Spatularia mimosa* (Lepidoptera, Tineidae)	Philippines	
	Bruchidius bilineatopygus (Coleoptera, Bruchidae)	India	

The leaf feeders include caterpillars of several families of Lepidoptera, and chrysomelid and curculionid beetles. Most are general feeders but two have acquired pest status. First in importance is the bagworm, *Pteroma plagiophleps* (Lepidoptera, Psychidae). Nair and Mathew (1992) reported that in Kerala, India, in a 20 ha plantation, outbreaks of *P. plagiophleps* over a 3-year period killed about 22% of 3-6 years old trees and severely damaged another 17%. Repeated heavy infestation, causing dieback of trees has also been reported in Sumatra in Indonesia (Zulfiah 1998). Second in importance is the caterpillar of the yellow butterfly, *Eurema* spp. (mainly *E. blanda* and a small proportion of *E. hecabe* and others) that often build up in large numbers and cause locally widespread defoliation in nurseries and young plantations in India, Indonesia, the Philippines and Malaysia (Mathew and Nair 1985, Irianto *et al.* 1997, Braza, 1990, Abe 1983).

Discussion

A comparison between natural forests and native plantations is not possible as no information is available for the latter. For the same reason, no comparison can be made between native and exotic plantations.

The major pest, the live tree borer, *Xystrocera festiva*, occurs both in natural stands and exotic plantations. This insect has been recorded in species of *Albizia* grown as shade trees in tea gardens in Myanmar, Malaysia and Indonesia (Beeson 1941) and therefore does not represent a case of invasion of an exotic pest. The related *X. globosa*, a minor pest of *P. falcataria* and other leguminous trees, is widely distributed in the Oriental Region.

Although the plantation history of *P. falcataria* as an exotic is comparatively short, at least 47 indigenous species have been found to feed on it, of which the cerambycid borer, *Xystrocera festiva*, is a serious pest in Indonesia and Malaysia. The others are occasional feeders, but *Pteroma plagiophleps* and *Eurema blanda* have shown a tendency for sporadic outbreaks.

The general conclusion from this case study is that a fairly large number of indigenous insects are associated with exotic plantations of *P. falcataria*, of which at least one has become a serious pest in some countries and two have shown sporadic localised outbreaks.

2.7 *Pinus caribaea*

Plantation profile

Pinus caribaea Morelet (Pinaceae) is a fast growing conifer, suitable for a variety of sites in the tropics and subtropics. It occurs naturally between latitudes 12°N and 27°N and grows best from sea level to an altitude of about 700 m. Three varieties are recognised: *P. caribaea* var. *caribaea*, confined to Cuba and a small nearby island; *P. caribaea* var. *bahamensis* indigenous to certain islands of the Bahamas and the Caicos groups; and *P. caribaea* var. *hondurensis* found in the eastern half of Central America (Belize, Guatemala, Honduras, Nicaragua) (CABI 2000).

Pinus caribaea var. *hondurensis*, has been widely planted throughout the American, Asian, and African tropics and subtropics, covering over 65 countries. Although pine plantations rank as the most extensive along with eucalypts, many of these plantations are of subtropical pines and a species-wise split up of the areas planted is not available for most countries. Available figures for 1990 indicate about 300 000 ha of *P. caribaea* plantations in tropical America, about 40 000 in Fiji and 7000 in New Caledonia.

Pests in natural forests

Very little information is available on pests in natural forests of *P. caribaea*. In Honduras, a massive outbreak of the bark beetle, *Dendroctonus frontalis* (Coleoptera, Scolytidae), occurred from 1963 to 1966, killing about 25% of the infested pine stand consisting of *P. caribaea* var. *hondurensis*, *P. oocarpa* and *P. tenuifolia.* All three species were attacked equally by *D. frontalis* (Coyne and Critchfield 1974). Many insects found in the native plantations must have originated from the natural forests, but published information is lacking.

Pests in native plantations

The major pests noticed in native plantations of *P. caribaea* covering Nicaragua, Guatemala, Cuba, Honduras, Mexico and Bahamas are shown in Table 2.7.1.

Two major categories of pests are involved; shoot moths and bark beetles. The shoot moths bore into the shoot and cause growth retardation. *Rhyaciona frustrana* is a common shoot moth in all Central

Table 2.7.1 Major pests of *Pinus caribaea* in native plantations

Common name	Insect species	Remarks
Nantucket pine tip moth	*Rhyacionia frustrana* (Lepidoptera, Tortricidae)	Common
Shoot moth	*Dioryctria clarioralis* and *D. horneana* (Lepidoptera, Phycitidae)	Bores into the shoot
Sawfly	*Neodiprion insularis* and *N. merkeli* (Hymenoptera: Diprionidae)	In some countries
Aphids	*Cinara atlantica* and *C. pergandei* (Hemiptera, Aphididae)	In Cuba
Southern pine beetle	*Dendroctonus frontalis* (Coleoptera, Scolytidae)	Outbreaks occur
Bark beetles	*Ips calligraphus* and other *Ips* spp. (Coleoptera, Scolytidae)	

American countries, although it is not a serious pest in some. *R. subtropica* is seen in Guatemala and Cuba. The bark beetles, which usually breed on fallen trees infest living trees, usually when the trees are under stress (e.g. drought). Several species of the genera *Dendroctonus* and *Ips* are involved. In addition, there are sawfly larvae which feed on the needles; aphids which suck the sap from shoots; and many casual feeders which include other caterpillars, beetles, bugs, leaf cutting ants and resin feeding bees. Altogether about 26 species have been recorded on *P. caribaea* in Central America (CATIE 1992). Very little quantitative information on the impact of these pests is available, but control measures have been practised against the shoot borers in some countries, particularly in Cuba, suggesting their economic importance.

Pests in exotic plantations

Pests in exotic plantations are considered by region.

Other countries in tropical America

Exotic plantations in the Caribbean, Central American and South American countries that lie close to the natural distribution range of *P. caribaea*, have many species common to the native plantations. These include the tip moth, *R. frustrana* in Jamaica and Costa Rica; *Ips* spp. in Jamaica and Dominican Republic; leaf cutting ants in Costa Rica, Venezuela and Brazil, and *Cinara* sp. in Costa Rica. In some plantations at Turrialba, Costa Rica, 91% of trees in young plantations have been attacked by *R. frustrana* (Salazar 1984). While some of these species might have moved from the adjacent countries where *P. caribaea* is indigenous, others might occur on other hosts in the region. The invasive introduced aphid, *Eulachnus rileyi* was found in Venezuela (Rosales and Cermeli 1995). In addition, ambrosia beetles, *Xyleborus affinis* and *X. intrusus*, occur in Jamaica; needle feeding weevils, *Pantomorus* sp. (*Asynonychus*), were recorded in Brazil and *Pseudopantomorus latifrons* in Colombia; crickets and cutworms were recorded in nurseries.

Asia-Pacific

Several pests have been recorded on *P. caribaea* in the Asia-Pacific (Table 2.7.2). Shoot borers are the most economically important. They include two species of *Dioryctria*, and *Petrova cristata*.

Dioryctria rubella, like other species of *Dioryctria* in Central America, bore into the shoots. It is a

Table 2.7.2 Major pests of *Pinus caribaea* plantations in Asia-Pacific

Common name	Insect species	Countries of occurrence
Shoot borers	*Petrova* (=*Dioryctria*) *cristata* (Lepidoptera, Tortricidae)	Philippines
	Dioryctria rubella (Lepidoptera, Phycitidae)	Philippines
	D. sylvestrella (Lepidoptera, Phycitidae)	Vietnam
Wax scale	*Ceroplastes* sp. (Hemiptera, Coccidae)	Australia, Papua New Guinea
Bark beetle	*Ips grandicollis* (Coleoptera., Scolytidae)	Australia
Termites	*Coptotermes curvignathus* (Isoptera, Rhinotermitidae)	Malaysia
	Mastotermes darwiniensis (Isoptera, Termitidae)	Australia
	Odontotermes sp. (Isoptera Termitidae)	India

serious pest in the Philippines, where Lucero (1987) reported that 87% of saplings in 2-years old stands in Luzon were infested and 39% killed in 1980.This species also occurs on the native pines, *P. merkusii* in Philippines and Indonesia, and *P. kesiya* in Philippines. Another species, *D. sylvestrella*, attacks *P. caribaea* in Vietnam. Other species of *Dioryctria* also attack other pine species in Thailand and in northern India. The tortricid moth, *Petrova cristata,* is another shoot borer in the Philippines. These two moths have caused very serious damage to young *P. caribaea* plantations in the Philippines which led to the suspension or slowing down of planting programmes in Luzon (Lapis 1987). A sawfly, *Diprion* sp., has also been found in Vietnam.

The Florida wax scale, *Ceroplastes floridensis*, a pest of citrus introduced from Florida affected about 30% of the planted area of *P. caribaea* in northern Queensland in Australia (Elliott *et al.* 1998); the related *C. rubens* also occurs in Australia and from there was introduced to Papua New Guinea. Two species of diaspid scales have also been recorded in Fiji. Scale insects have also been recorded on *P. caribaea* in India.

A bark beetle, *Ips grandicollis*, accidentally introduced from North America has caused several outbreaks in *P. caribaea* plantations (also in the more common exotic *P. radiata*) in Australia, particularly when the trees have been exposed to stress by other factors like drought or fire (Elliott *et al.* 1998).

In Malaysia, the termite, *Coptotermes curvignathus*, attack pines over 5 years old, making tunnels inside the trunk and often causing death of trees by detaching the cambium (Abe 1983). Termites cause serious damage to trees in Australia also. Several species of lepidopteran larvae belonging to Psychidae, Geometridae, Lasiocampidae, Arctidae and Lymantridae have been recorded in plantations in India but most are not serious pests. Root feeding whitegrubs, cutworms and termites have also been recorded from nurseries in India

Africa

The invasive pine woolly aphid, *Pineus pini* (Homoptera, Adelgidae), was accidentally introduced to Kenya around 1968 from Australia. It spread rapidly to the pine growing areas in the highlands and frantic efforts were made to control it, with little success (Gichora and Owuor 1990). It infests the shoots in large numbers and sucks the sap, suppressing growth and contributing to, if not causing, death of the plants. A native of North America, it is now widespread in Africa and affects several other species of pines. Another invasive introduced aphid, *Eulachnus rileyi*, was found on

P. caribaea in Zambia (Loyttyniemi 1979) (as well as on other pine species in several other countries in Africa). While the introduced conifer aphids are widespread in Africa, they appear to be more prevalent on pines of European and Asian origin. Similarly, some wingless grasshoppers have become serious pests of exotic pines in Africa (Schabel *et al.* 1999), though not reported on *P. caribaea*; aerial application of insecticide has been carried out in Malawi to control the grasshopper outbreak on *P. patula* (MacCuaig and Davies 1972).

Discussion

Very little information is available on pests of *P. caribaea* in indigenous stands, to compare with native plantations. Bark beetle outbreak is common between the two and there are indications that stress such as water deficit or nutrient deficiency, or initial insect build up in trees fallen due to natural calamities such as landslides or hurricane, may trigger the outbreak.

Native plantations appear to suffer less pest damage than exotic plantations. Exotic plantations contain either the same pests or their ecological equivalents, depending on the distance of the countries from the native distribution range of *P. caribaea*, and they appear to be more damaging in the exotic locations. In addition, some new pests such as termites, grasshoppers and invasive pests from non-native regions of *P. caribaea* have acquired pest status. In effect, the exotic plantations of *P. caribaea* suffer greater damage than native plantations, although on the whole, the damage to *P. caribaea* plantations has not been severe or seriously threatening.

2.8 *Swietenia macrophylla*

Plantation profile

Swietenia macrophylla King, (Meliaceae) is a valuable timber tree, indigenous to tropical America, distributed from 20°N to 18°S latitudes. Commonly known as mahogany, it is also called big-leaved or broad-leaved mahogany to distinguish it from the small-leaved, *S. mahogoni*, which is more characteristic of the Caribbean region. A third species of mahogany, *S. humilis*, which is a smaller tree, 8-10 m in height, is also widely distributed in Central America. The natural distribution of the three species is shown in Table 2.8.1. The biological boundaries between the three species are not clear-cut and natural hybrids occur (CABI 2000). *Swietenia macrophylla* is the most widely distributed and the most widely planted, both in native and exotic locations. It is moderately fast growing and is grown in a 30-40-year rotation. *Swietenia mahogoni* is also grown in native and exotic plantations, although to a lesser extent as an exotic.

Swietenia macrophylla is grown as an exotic in over 40 countries across the tropics (CABI 2000). It is also grown in plantations to a smaller extent and since the pests are common to both, reference to *S. macrophylla*, should apply to both in this discussion. In 1995, *S. macrophylla* plantations covered 151 000 ha worldwide (Pandey 1997). Indonesia has about 55 000 ha (Cossalter and Nair 2000) and Fiji has 26 500 ha (Kamath *et al.* 1996).

Pests in natural forests

The shoot borer, *Hypsipyla grandella* (Lepidoptera, Pyralidae), is a well recognised pest in natural forests of mahogany. The larva bores into the growing shoot of saplings and destroys the terminal bud, causing retardation of growth and forking of stem. Yamazaki *et al.* (1990) observed that in Peruvian Amazon, the population of *H. grandella* increased rapidly in the rainy season when food availability increased with the growth of new sprouts. In southeast Mexico, the insect attacked the fastest growing seedlings in the logged over natural forest (Dickinson and Whigham 1999). It is generally believed that older trees are not attacked by *H. grandella,* (however, see the Section, Pests in exotic plantations, below). *Hypsipyla* has a number of alternative hosts in the family Meliaceae.

Leaf cutting ants, *Atta cephalotes* and *A.* cf. *sexdens*, damage 1-3 months old seedlings in Bolivia (Larrea 1999).

Table 2.8.1 Natural distribution of *Swietenia* species

Region	*S. macrophylla*	*S. mahogoni*	*S. humilis*
North America		Florida	
	Mexico		Mexico
Central America	El Salvador		El Salvador
	Guatemala		Guatemala
	Honduras	Honduras	Honduras
	Nicaragua		Nicaragua
	Panama		
South America	Bolivia		
	Brazil		
	Colombia		
	Ecuador		
	Peru		Peru
	Venezuela		
Caribbean		Bahamas	
		Cuba	
		Dominican Rep.	
		Haiti	
		Jamaica	
		Lesser Antilles	

Data from CABI (2000)

Pests in native plantations

Pest attack is a serious problem in native plantations of mahogany. The most damaging is the shoot borer *Hypsipyla grandella*. It causes severe damage in plantations throughout the native range of mahogany and has been a major limiting factor for the expansion of plantations. Saplings growing in the open in plantations are believed to be more prone to attack than naturally regenerating saplings with overhead shade. In spite of considerable research, no practical control measure has emerged and the shoot borer continues to be the main factor limiting the cultivation of mahogany which occurs in very low density in natural forests. In unlogged Mexican forests its average density is 1-2 mature trees ha^{-1}, and this may vary from 1 tree ha^{-1} in Brazil to 20-60 trees ha^{-1} in Bolivia (Mayhew and Newton 1998).

The following leaf feeding insects also cause damage. The mahogany webworm, *Macalla thyrsisalis* (Lepidoptera, Pyralidae) distributed throughout the natural range of mahogany, spins webs and feeds on newly flushed mahogany leaves (Howard and Solis 1989). Larvae of *Phyllocnistis meliacella* (Lepidoptera, Gracillariidae) mine in the leaves (Howard 1995). In Honduras, leaf cutter ants are reported to strip leaves of recently planted trees (Mayhew and Newton 1998).

A sap-sucking scale insect, *Conchaspis cordiae* (Homoptera, Coccoidea), was reported in the Dominican Republic (Panis and Martin 1976).

The following bark/stem boring beetles have been recorded. In Cuba, *Apate monachus* (Coleoptera, Bostrychidae) bore into the trunk and large branches of trees (Perez 1975). The scolytid ambrosia beetles (Coleoptera, Scolytidae), *Xyleborus morigerus* attacks young plantations in Mexico (Vazquez 1980) and *Hexacolus guyanensis* develops into outbreaks in declining trees in Guadeloupe (Gruer 1974).

Pests in exotic plantations

The shoot borer, *Hypsipyla* is the most serious pest in exotic plantations also. It has halted the expansion of plantations in many countries. While *H. grandella* is the problem throughout the North, Central and South American tropics and the Caribbean, the closely related *H. robusta* takes its place in Asia and Africa. It has been recorded in all countries where *Swietenia* has been planted, with the exception of some Pacific islands, such as Fiji, eastern Solomon Islands and Western Samoa, although it occurs in Australia and western and central Solomon Islands (Mayhew and Newton 1998). It has recently (2000) been found in the Pacific island of Vanuatu (F.R. Wylie, personal communication). While *H. robusta* attack has been reported only on young plants in most exotic plantations, in north Queensland, Australia, active attack by this species was found in the crowns of 50-year-old plantation trees, 45 m in height (F.R. Wylie, personal communication).

In terms of economic impact, the next in importance is the damage caused by some species of wood-dwelling termites in Fiji. Three species of the genus *Neotermes* (*N. samoanus, N. papua* and an unidentified species) (Isoptera, Kalotermitidae) are involved. They attack healthy trees of all ages and feed insidiously in galleries within the bole, hollowing out the tree and causing swellings on the bole at later stages of attack. Kamath *et al.* (1996) estimated that 7.7% of trees were attacked. The damage is similar to that caused by *Neotermes tectonae* to teak plantations in Indonesia. In Sri Lanka and Solomon Islands also, a species of termite of the genus *Coptotermes* is reported to feed on living wood of mahogany (Mayhew and Newton 1998).

Ambrosia beetles in Fiji cause another serious problem. Two species, *Crossotarsus externe-dentatus*, a pantropical species, and *Platypus gerstackeri*, a species endemic to Fiji, both belonging to the family Platypodidae (Coleoptera), infest living trees and tunnel into the wood, their galleries creating pin holes which are visible in sawn timber. Heavy infestations were reported in the 1970s. It is believed that such infestation was the result of large build up of the beetle populations in slow-dying natural forest trees, poison-girdled in preparation for establishment of the plantations. Both species are highly polyphagous; *C. externe-dentatus* has been recorded on 69 tree species and *P. gerstackeri* on 40 tree species in Fiji (Roberts 1978).

Some pests of lesser economic importance have also been recorded in exotic plantations. Some species of scolytid beetles bore into the stem of seedlings in nursery and lay eggs in galleries excavated in the stem, leading to collapse of the seedlings. The species responsible are *Xylosandrus compactus* (syn. *Xyleborus morstatti*) in Indonesia, Thailand and Sri Lanka (Day *et al.* 1994), *Hypothenemus eruditus* in Malaysia (Mayhew and Newton 1998) and an unidentified species in Fiji (Anon. 1954). *Xylosandrus compactus* also infests living twigs <25 mm in diameter, in saplings <3 years old, in Puerto Rico (Mayhew and Newton 1998). In Malaysia, a weevil, *Dysercus longiclaris* (Coleoptera, Curculionidae), ring barks and kills young trees, while in Puerto Rico, another weevil, *Diaprepes abbreviatus*, feeds on young leaves, with its larva feeding on the root stalk (Mayhew and Newton 1998). A coreid bug, *Amblypelta cocophaga*, causes dieback of terminal bud of saplings in Solomon Islands. Whitegrubs are reported to attack the root of seedlings in Indonesia (Intari and Natawiria 1973). Other minor pests in Indonesia include the leaf-feeding caterpillar, *Attacus atlas* (Lepidoptera, Saturnidae) and the leaf-cutter bee, *Megachile* sp. (Hymenoptera, Megachilidae) (Matsumoto 1994). The bark feeding caterpillar, *Indarbela quadrinotata* (Lepidoptera, Metarbelidae), was recorded on mahogany in India, although the damage was negligible (Mathew and Rugmini 1998).

Discussion

A comparison of the pest problems between natural forests and native plantations shows that plantations suffer more heavily from pest attack. Although the main pest in both is the shoot borer, *Hypsipyla grandella*, the severity of damage is greater in plantations. It may be recalled that this insect preferentially attacks saplings. Most observations indicate that saplings growing under overhead or lateral shade are less frequently attacked than those growing in the open. There does seem to be a relationship between shade and level of attack, although this is yet to be properly quantified (F.R.

Wylie, personal communication). This may account for the difference in susceptibility between natural forest and plantations.

Impact of a greater number of pests is felt in plantations than in natural forest, although all the pests may be present in the latter. The greater prevalence of ambrosia beetles in plantations may be related to poorer tree health.

A comparison between native and exotic plantations also shows that the shoot borer *Hypsipyla* is the dominant pest in both, although the species may differ depending on the geographic region. The only exception is Fiji and some smaller islands in the Pacific where *Hypsipyla* has not reached, apparently due to geographic isolation. The intensity of damage is severe and similar in both native and exotic plantations. A notable additional pest in the exotic plantations is the wood-dwelling termite, but it is confined to Fiji, although wood-feeding subterranean termites of lesser importance occur in Sri Lanka and Solomon Islands. Ambrosia beetles attacking seedlings is also unique to exotic locations. Although of minor economic importance, the spectrum of species attacking *Swietenia* is greater in exotic plantations, apparently because of the much larger geographical area covered.

The general conclusion from this case study is that exotic plantations suffer equal pest damage as native plantations in most places, and greater pest damage in some.

2.9 *Tectona grandis*

Plantation profile

The teak tree, *Tectona grandis* L. f. (Verbenaceae) is indigenous to South and South-East Asia, more specifically, India, Myanmar, Thailand and Laos. Its natural distribution is from 25° to 9° North latitudes and 73° to 104° East longitudes, in two discontinuous patches, one in peninsular India and the other covering most of Myanmar, northern Thailand and a small part of northwest Laos (Kaosa-Ard 1995, Gyi and Tint 1998). Teak is also well established in the Indonesian island of Java and some of the smaller islands to the east of Java where it is believed to have been introduced from India about 400 to 600 years ago and become naturalised. A few patches of naturally regenerating teak have also been reported in the western part of the Yunnan Province in China, but whether these stands are indigenous or introduced is not clear (Kaosa-Ard 1995). The natural teak area totals about 28 million ha, with Myanmar accounting for 59% (16.5 million ha); India, 32% (8.9 million ha); Thailand, 8.9% (2.5 million ha); and Laos, < 0.1% (16 000 ha) (Teaknet 1995).

Teak has been planted extensively, both within its natural distribution range and elsewhere in the tropics and subtropics. Large-scale planting has a history of about 150 years, although the first introduction to many countries had taken place much earlier. Exotic plantations exist in the Asian, African and American continents as well as in many tropical islands. The global area under teak plantations in 1995 was estimated at 2.25 million ha, most of it in the Asian tropics (94%), followed by tropical Africa (4.5%) and Central and South America (1.5%) (Ball *et al.* 1999). The planted area for teak in some of the countries is given in Table 2.9.3. While the native plantations are grown at a rotation of 50 to 80 years, producing a mean annual increment (m.a.i.) of 3 to 10 m^3 of wood ha^{-1}, many exotic plantations, particularly in tropical America, are managed at shorter rotations of 20 to 30 years, with a m.a.i. of 10 to 20 m^3 ha^{-1}.

Pests in natural forests

About 187 species of insects have been recorded on the living teak tree in India and the adjacent countries (Table 2.9.1). While many of them have been collected from trees in natural forests, specific published information on their occurrence in natural forest and impact is lacking. Only a few are recognised as pests in natural forests. These include the leaf feeding lepidopteran caterpillars, *Hyblaea puera* (Hyblaeidae), commonly known as the teak defoliator, and *Eutectona machaeralis* (Pyralidae) commonly known as the teak leaf skeletoniser; the stem borer, *Xyleutes ceramicus* (Lepidoptera,

Table 2.9.1 Categories of insects associated with the living teak tree in India and adjacent countries

Category	Insect order	No. of species
Leaf feeders	Lepidoptera	79
	Coleoptera	50
	Orthoptera	18
Sap feeders	Hemiptera	16
Fruit and inflorescence feeders	Hemiptera	4
	Coleoptera	1
	Lepidoptera	1
Stem feeders	Coleoptera	6
	Isoptera	3
Root feeders	Lepidoptera	7
	Coleoptera	2
Total		187

Data from Mathur and Singh (1960)

Cossidae), and the gall insect, *Asphondyla tectonae* (Diptera, Cecidomyiidae).

In a specific study in the natural, moist deciduous forest of Kerala, India, Nair *et al.* (1986a) found four species of insects on teak; three of the above, viz., *H. puera*, *E. machaeralis* and *A. tectonae*, and the sap sucking bug, *Ricania speculum* (Hemiptera, Ricanidae). The damage caused by all species except *H. puera* was negligible. The mean annual leaf loss did not exceed 3.5%, but on some occasions, defoliation exceeded 50% as a result of *H. puera* infestation. Heavy defoliation by *H. puera* of isolated individual trees or small groups of trees in natural forests in Kerala and Karnataka States in India have also been recorded (Nair *et al.* 1985, Nair and Sudheendrakumar 1986). Unpublished personal observations by the author within the teak bearing natural forests in Myanmar (in September 1995, at Nagalaik Reserve Forest) showed that fairly high-density infestations of *H. puera* could also occur over larger patches within natural forests.

Periodic outbreaks of the skeletoniser, *E. machaeralis* also occur over large areas in Madhya Pradesh in central India where natural teak forests occur in almost pure stands, as understood from discussions with local forest staff. Again, published information is lacking.

The third pest of importance in the natural forest, the beehole borer *Xyleutes ceramicus* is prevalent in the teak forests of Myanmar (Beeson 1941) and the northern part of Thailand (Chaiglom 1990). It does not occur in India. Groups of the moth larvae that bore into the wood riddle the tree trunk with holes and degrade the timber. The severity of infestation may vary from place to place and increases with age of the tree. It also increases with increasing mean annual rainfall (Beeson 1941).

The twig gall midge, *Asphondyla tectonae*, noticed in the natural forest in Kerala and Karnataka in southern India, has also been found in poor class teak forests in central India (Beeson 1941). It attacks the new shoots of teak and causes formation of globular, multilocular galls that coalesce, harden and surround the stem of twigs.

There is little information on the pest status of other insects in natural forests.

Pests in native plantations

The first monoculture plantation was raised in India in the 1840s (at Nilambur in Kerala State), followed by Myanmar in 1856 (Gyi 1992), Thailand in 1906 (Kaosa-Ard 1995) and Laos in 1942 (Phengdouang 1992). Thus native plantations have been in existence for about 100 to 150 years. In India and adjacent countries, about 187 insects have been recorded on teak (Table 2.9.1). Most have also been recorded in Myanmar. In Thailand, 72 species have been recorded, which include 32 leaf feeders, 17 flower or fruit feeders, 11 sap feeders and 12 stem feeders (Hutacharern and Tubtim 1995). These include many species found in India and Myanmar. No information is available for plantations in Laos. The major pests are listed in Table 2.9.2; the following notes pertain to these and a few other notable pests.

Defoliators

Hyblaea puera, the teak defoliator, is the most serious pest. In India, almost every year, it causes one or more near-total and additional partial defoliations over extensive areas (Beeson 1941, Nair 1988). Annual outbreaks are also known to occur in Myanmar and Thailand. At Nilambur in southern India, this results in loss of 44% of the potential volume increment in young plantations (Nair *et al.* 1996). In India and Myanmar, outbreaks of *Eutectona machaeralis*, the teak leaf skeletoniser, also occur in most years, with exceptionally heavy population build up in some years. Although the insect is present throughout the year, outbreaks develop towards the end of the growth season before normal leaf shedding, unlike the outbreaks of *H. puera* that occur during the beginning of the growth season. *E. machaeralis* has also caused similar defoliation in Thailand, particularly in the southern peninsular region (Chaiglom 1990). In a recent paper, Intachat (1998) suggested that the species previously identified as *E. machaeralis* (syn: *Pyrausta machaeralis*, *Hapalia machaeralis*) in Thailand is probably the closely related *Paliga damastesalis* (Lepidoptera, Pyralidae) as in Malaysia and Indonesia. *P. dmastesalis* has also been reported on teak in the Andaman Islands in India (Veenakumari and Mohanraj 1996). There are no other major defoliators in spite of the large number of polyphagous leaf feeding insects

Table 2.9.2 Major pests of teak in native plantations

Pest category	Species	Countries of occurrence	Common name/Remarks
Defoliator	*Hyblaea puera* (Lepidoptera, Hyblaeidae)	Myanmar, India, Thailand	Teak defoliator
	Eutectona machaeralis (Lepidoptera, Pyralidae)	Myanmar, India	Teak leaf skeletoniser
	Paliga damastesalis (Lepidoptera, Pyralidae)	Thailand	Earlier identified as *E. machaeralis*
Stem borer	*Xyleutes ceramicus* (Lepidoptera, Cossidae)	Myanmar,Thailand	Beehole borer
	Alcterogystia cadambae (Lepidoptera, Cossidae)	India	
	Sahyadrassus malabaricus (Lepidoptera, Hepialidae)	India	Sapling stem borer
	Phassus signifer (Lepidoptera, Hepialidae)	Myanmar,Thailand	Sapling stem borer
	Zeuzera coffeae (Lepidoptera, Cossidae)	India, Thailand	On saplings
	Acalolepta cervina (syn: *Dihammus cervinus*) (Coleoptera,Cerambycidae)	Myanmar, India, Thailand	Canker grub
Root feeder	Whitegrubs (Coleoptera, many families)	Myanmar, India, Thailand	On seedlings

recorded. In systematic observations over 5 years, at Nilambur in Kerala, India, Nair *et al.* (1985) found that during the early flushing period, a chrysomelid beetle caused up to 2.5% cent leaf loss, and a curculionid beetle up to 15%.

Stem borers

The most serious among the stem borers is the beehole borer, *Xyleutes ceramicus* (Lepidoptera, Cossidae), that occurs in Myanmar and northern Thailand. In some plantations in northern Thailand, 87-100% of trees were infested, the proportion of infested trees increasing with age (Chaiglom 1990). It does not occur in India, but another cossid, *Alcterogystia cadambae*, of similar habits is present in southern India. Trees heavily infested by *A. cadambae* die in the course of time, possibly aided by associated pathogenic fungi (Mathew and Rugmini 1996). *Alcterogystia cadambae* is believed to attack trees with bark injury caused by lopping or other means, and is endemic to some localities.

Teak saplings are attacked by the large caterpillar (Lepidoptera, Hepialidae), *Sahyadrassus malabaricus* in India and the related *Phassus signifer* in Myanmar and Thailand. The caterpillar makes a tunnel in the central pith and emerging at night, feeds on the bark under cover of a mat of frass, silk and wood dust, causing a canker at which point the stem may break. The life cycle is annual. It is a conspicuous pest in some young plantations, although the overall damage caused is not serious (Nair 1987).

Another caterpillar, *Zeuzera coffeae* (Lepidoptera, Cossidae), has been found to bore into the stem of young, more succulent teak saplings in India and Thailand.

Adults of the beetle, *Acalolepta cervina* (syn: *Dihammus cervinus*) (Coleoptera, Cerambycidae), feed on the bark of teak saplings 2-8 years old, and lay eggs on the stem beneath the bark, near ground level. Feeding and tunnelling by the larva, known as teak canker grub, causes the formation of a bulging canker all around the stem, at which point the saplings may break. It occurs in northern India, Myanmar and Thailand, but is absent in peninsular India (Beeson 1941, Hutacharern and Tubtim 1995).

The larva of a weevil, *Alcidodes ludificator* (syn. *Alcides ludificator*) (Coleoptera, Curculionidae), bores into the pith of teak saplings from top downwards, causing dieback of the leading shoot, in India. The adult feeds by making punctures on the midrib of teak leaves. A related twig borer, *Alcidodes frenatus*, has been recorded in Thailand.

Flower and fruit feeders

In India and Thailand, the caterpillars, *Pagyda salvalis* and *Dichocrocis punctiferalis* (Lepidoptera, Pyralidae), and the bug, *Leptocentrus* sp. (Hemiptera, Membracidae), are main pests of flowering shoots and green fruits. *Mylabris phalerata* (Coleoptera, Meloidae) and *Machaerota elegans* (Hemiptera, Cercopidae) also cause serious damage in Thailand (Hutacharern 1990).

Root feeders

Larvae of some families of beetles, known as 'whitegrubs', feed on the fleshy taproot of teak seedlings grown in nurseries in some localities, causing economic damage.

Gall insect

In India, the gall midge, *Asphondylia tectonae* (Diptera, Cecidomyiidae), is abundant in some plantations, particularly of poor class (Beeson 1941). It is believed to retard growth when the infestation is heavy, but is not recognised as a serious pest.

Pests in exotic plantations

Exotic plantations of teak have been raised in many countries across the tropics; CABI (2000) lists 67 countries. In some of these countries (Bangladesh, Sri Lanka, China, Malaysia, Ghana, Nigeria), the first introduction was made at least 100 years ago and in most others, before or during the 1930s (Kaosa-Ard 1995). Therefore, exotic teak plantations have a history of 60-100 years. They comprise about 1.35 million ha in the Asia-Pacific (of which about 1 million is in Indonesia), at least 145 000 ha in Africa and at least 65 000 ha in Latin America. Pest incidence is best considered under the three major regions.

Asia-Pacific

Countries in the Asia-Pacific where teak is planted as an exotic include Bangladesh, Bhutan, China, Fiji, Indonesia, Malaysia, Nepal, Pakistan, Papua New Guinea, Philippines, Samoa, Solomon Islands, Sri Lanka, Taiwan, Turkey, Vanuatu and Vietnam.

In Indonesia, three major pests are encountered. The well-known teak defoliator, *Hyblaea puera* is believed to cause one or more defoliations every year in most teak plantations, but systematically gathered data are not available. The details of infestation outlined by Kalshoven (1953) indicate that the dynamics of infestation is similar to that noticed in India. The skeletoniser, identified as *Eutectona machaeralis* has also been reported in Java. Although Kalshoven (1953) mentions that it does not attack teak, several later authors listed it as a major pest of teak in Java (Nair 2000). No primary data are available on the frequency and intensity of its incidence. According to Intachat (1998) this species is *Paliga damastesalis*, as distinct from *E. machaeralis* present in India, although it has similar habits. A third notable pest in Indonesia is the termite, *Neotermes tectonae* (Isoptera, Kalotermitidae). This wood dwelling termite hollows out portions of stem and branches. Swelling of trunk and branches indicates infestation. The termites occupy crevices within the swollen stem. It is recognised as a serious problem in Central and East Java. In some districts in Central Java, 10-72% of the trees are attacked (Subyanto *et al.* 1992). Pests of lesser importance in Indonesia are the following (Nair 2000). An ambrosia beetle, *Xyleborus destruens* (Coleoptera, Scolytidae), attacks the trunk of the living tree, making branching tunnels that extend into the heartwood. It is prevalent in areas where there is no definite dry season. The grasshopper, *Valanga nigricornis* (Orthoptera, Acrididae), causes sporadic defoliation. The beehole borer, *Xyleutes ceramicus* (Lepidoptera, Cossidae), although not as prevalent as in Myanmar and northern Thailand, has been recorded in Central Java. Whitegrubs cause damage to seedlings in nurseries. Incidence of the red coffee borer, *Zeuzera coffeae*, has been observed in some intensively managed young plantations in Central Java.

Hyblaea puera also causes damage to teak in Bangladesh (Baksha 1990, Baksha and Crawley 1998), China and Taiwan (Chen and Wu 1984), Malaysia (Tee 1995), Papua New Guinea (Dun 1955), the Philippines (Quiniones and Zamora 1987), Solomon Islands (Bigger 1980) and Sri Lanka (Tilakaratna 1991). *Eutectona machaeralis* infests teak in Bangladesh (Baksha 1990), China (Li 1992), Sri Lanka (Bandara 1990b), and the Philippines (Quiniones and Zamora 1987) and the closely related *Paliga damastesalis* in Malaysia (Intachat 1998). Other minor leaf feeding insects on teak in Malaysia include the curculionid beetle, *Hypomeces squamosus* (Tee 1995) and *Acherontia lachesis* (Lepidoptera, Sphingidae) on seedlings (Pearce and Hanapi 1984).

Whitegrubs that feed on the tap root cause damage to seedlings in Bangladesh (Baksha and Islam 1990) and Sri Lanka (Bandara 1990a).

Among the borers, the canker grub, *Acalolepta cervina* has been noted in Bangladesh (Baksha 1990) and *Endoclita gmelina* (Lepidoptera, Hepialidae) in Malaysia (Dhanarajan 1976), on saplings. The beehole borer, *Xyleutes ceramicus*, is present in Sabah, Malaysia where 5-16% of trees were attacked (Tee 1995).

Africa

In Africa teak plantations exist in Benin, Congo, Côte d'Ivoire, Gabon, Ghana, Guinea, Kenya, Liberia, Madagascar, Malawi, Mozambique, Namibia, Nigeria, Senegal, Sierra Leone, Somalia, South Africa, Sudan, Tanzania, Togo, Uganda, Zambia and Zimbabwe.

Although teak plantations are long established in several countries in Africa, no major pest problem has so far been reported. Two small beetle borers, *Apate monachus* and *A. terebrans* (Coleoptera, Bostrychidae) were recorded on live trees in Ghana but the infestation is believed to have originated from cut sticks of some windbreak species stored at site (Atuahene 1976). Another small beetle borer, *Hypothenemus pusillus* (Coleoptera, Scolytidae) was also recorded on the shoot of *T. grandis* in Ghana (Cobbinah 1972).

Latin America

In Latin America, teak plantations exist in Belize, Costa Rica, El Salvador, Honduras, Nicaragua and Panama in Central America; Cuba, Dominican Republic, Jamaica, Puerto Rico and Trinidad and Tobago in the Caribbean; and Argentina, Brazil, Chile, Colombia, Ecuador, Peru and Surinam in South America.

Outbreaks of the teak defoliator, *Hyblaea puera*, have recently occurred in Costa Rica and Brazil. In Costa Rica, outbreak first appeared in 1995 in a commercial plantation and has progressively intensified, with about 600 ha infested in 1998, with some patches suffering total defoliation, necessitating helicopter application of insecticide (Camacho, personal communication). In Brazil, the first attack was reported in 1996, in a commercial plantation, in a small area within 16- to17-year-old teak plantations. In 1997, the outbreak spread to almost the entire 309 ha plantation, 16 to 24 years old. In 1998, the attack reached a small area of another plantation, located 150 km from the first one. No attack occurred in 1999 (Torres, personal communication).

Other pests of teak in Latin America include whitegrubs in nursery, leaf cutting ants, *Atta* spp., in nursery and older plants, and two cerambycid borers, *Neoclytus cacicus* and *Plagiohammus spinipennis*, on young plants (CATIE 1992). In addition, the small borer, *Xyleborus morigerus* (Coleoptera, Scolytidae), has been reported on young plantations in Mexico (Vazquez 1980). The damage caused by these insects is negligible.

Discussion

The most notable pest of teak in all the three habitats, viz., natural forests, native plantations and exotic plantations, is the defoliator, *Hyblaea puera*. Its status as a pest in teak plantations across the world is discussed in some detail below, as it is relevant to the general discussion in Section 3 on the origin of pest outbreaks.

Hyblaea puera is prevalent in India, Myanmar and Thailand, the natural home of teak, and outbreaks occur annually in plantations in these countries. The planted distribution of teak outside its home range and the geographic distribution of *H. puera* are shown in Table 2.9.3. The extent of area planted is given where recent data are available. The information was assembled from different sources and the years of data update vary; nevertheless, it gives an overall picture. It may be seen that both teak and *H. puera* are present in all the three regions, viz., Asia-Pacific, Africa and Latin America. However, until recently outbreaks of *H. puera* on teak have occurred only in some countries in the Asia-Pacific.

Hyblaea puera has a wider natural distribution than teak and occurs in both tropical subtropical regions. It can thrive on at least 30 host plants, mostly belonging to the families Verbenaceae and Bignoniaceae and at least one each in the families, Araliaceae, Avicennaceae, Juglandaceae and Oleaceae. No information could be obtained on its host plants in Africa but it has not been found on the exotic teak plantations there (Cobbinah 1997). In Australia, it occurs on *Vitex trifolia* (Verbenaceae), a common straggling shrub in the Northern Territory and coastal Queensland, but has not been reported on teak although there are a few private plantings and trial plots of teak (Wylie 2000). In Latin America, it occurs on *Vitex parviflora* and *Tabebuia pentaphylla*

Table 2.9.3 Exotic plantations of teak and occurrence of *Hyblaea puera*

Region	Country	[1]Planted area (ha)	[2]Occurrence of *H. puera*	[3]Recorded host plant of *H. puera*
Asia-Pacific		>1,345,447		
	Australia (Northern Territory & coastal Queensland)	A few private plantings and trial plots	Yes	Other
	Bangladesh	165,000	Yes	Teak
	Bhutan	Yes		
	Cambodia	Yes	Yes	?
	China	9000	Yes	Teak
	Fiji	Yes	Yes	?
	Indonesia	1,066,532	Yes	Teak
	Japan	Yes	Yes	?
	Korea	Yes		
	Malaysia	4328	Yes	Teak
	Nepal	Yes	Yes	?
	Oman	Yes		
	Pakistan	Yes		
	Papua New Guinea	4000	Yes	Teak
	Philippines	21,550	Yes	Teak
	Ryukyu Islands	?	Yes	?
	Samoa	?	Yes	?
	Solomon Islands	1000	Yes	Teak
	Sri Lanka	72,000	Yes	Teak
	Taiwan	Yes	Yes	Teak
	Turkey	Yes		
	Vanuatu	Yes		
	Vietnam	2037	Yes	?
Africa		> 144,500		
	Benin	15,000		
	Congo (Dem. Rep.)	Yes		
	Congo	Yes		
	Côte d'Ivoire	26,000		
	Gabon	Yes		
	Ghana	25,000		
	Guinea	Yes		
	Kenya	Yes		
	Liberia	1500		
	Madagascar	Yes		
	Malawi	Yes	Yes	?
	Mozambique	Yes		
	Namibia	Yes		
	Nigeria	40,000		
	Senegal	8000		
	Sierra Leone	Yes		
	Somalia	Yes		
	South Africa	Yes	Yes	?
	Sudan	15,000		
	Tanzania	3000		
	Togo	11,000		
	Uganda	Yes	Yes	?
	Zambia	Yes		
	Zimbabwe	Yes		

Table 2.9.3 *Continued*

Region	Country	[1]Planted area (ha)	[2]Occurrence of *H. puera*	[3]Recorded host plant of *H. puera*
Central America		22,290		
	Belize	Yes		
	Costa Rica	Yes	Yes	Other and teak
	El Salvador	1500		
	Honduras	400	Yes	?
	Mexico	Yes		
	Nicaragua	Yes		
	Panama	300		
Caribbean		>9250		
	Cuba	Yes	Yes	?
	Dominican Republic	?	Yes	?
	Jamaica	250	Yes	?
	Puerto Rico	Yes		
	Trinidad and Tobago	9000	Yes	?
South America		>33,000		
	Argentina	Yes		
	Brazil	20,000	Yes	Other and teak
	Chile	Yes		
	Colombia	10,000		
	Ecuador	Yes		
	Peru	Yes		
	Surinam	Yes		
	Uruguay	Yes		
	Venezuela	3000		

[1] Planted area is given where fairly recent information is available. 'Yes' indicates that teak plantations exist but the extent of planted area is not known. Question mark indicates lack of information on whether teak plantations exist although the defoliator is known to occur. Data from Ball *et al.* (1999); CABI (2000); Camacho (personal communication); Freitas (1973); ITTO (1997); Keogh (1996); Neil (1987); Pandey (1995); Perum Perhutani (1995); Rao (1997); Reis (1997); Teaknet (1995); Torres, (personal communication); Wylie (2000)

[2]Based on available information. Data from Camacho (personal communication); CIE (1982); Li (1992); Torres, (personal communication); Wylie (2000). CIE is the secondary source of information; for original sources see CIE.

[3]Other indicates other than teak; question mark indicates lack of information on the host plant.

(Bignoniaceae) (CATIE 1992) and outbreaks on teak is of very recent occurrence, as noted earlier. Outbreaks first appeared in 1995 in Costa Rica and in 1996 in Brazil and have intensified progressively. It is understood that *H. puera* has been present in Brazil for a long time, causing damage to other crops and native vegetation (Torres, personal communication), but appeared on teak only in 1996, although commercial teak plantations have been raised since 1971. *Hyblaea puera* is also known to occur in Honduras, Cuba, Dominican Republic, Jamaica, and Trinidad and Tobago in Latin America (Table 2.9.3) but there is no report of its occurrence on teak in these countries, in spite of the long history of teak planting (for example, teak was introduced into Trinidad in 1913, Keogh 1996).

Conditions other than the mere co-occurrence of the host plant and the insect are necessary for development of outbreaks. The example of Costa Rica and Brazil suggests that plantation expansion is a factor favouring pest outbreaks. Perhaps outbreaks develop only on tall tree hosts; even on teak, young plants are seldom attacked during the initial wave of outbreak. The only other host on which large scale outbreak has been reported is the mangrove species, *Avicennia marina* (Avicennaceae, earlier included under Verbenaceae) occurring gregariously in natural stands over extensive areas on the Bombay coast in India (Chaturvedi 1995). Outbreak development of *H. puera* is intriguing and its dynamics are not fully understood. Even on teak, during most part of the year, *H. puera* population is very sparse, almost undetectable, and outbreaks occur all of a sudden, soon after the pre-monsoon showers. Outbreaks first appear over tree tops, in comparatively small, disconnected patches, before it spreads more widely over hundreds of hectares, again in discrete patches (Nair and Mohandas 1996). For a comprehensive summary of the state of knowledge on *H. puera* population dynamics see Nair (1988, 1998).

A comparison of the pest situation between natural forests and native plantations indicate:

1. There is a dearth of data on insects present in natural forests, but there appears to be no qualitative difference in the pest species present in natural forests and native plantations.
2. Three pests have assumed economic importance in both natural forests and native plantations; the leaf feeding *Hyblaea puera, Eutectona machaeralis* or its ecological equivalent *Paliga damastesalis*; and the stem boring *Xyleutes ceramicus* or its ecological equivalent *Alcterogystia cadambae*.

   All three species cause damage both in natural forests and plantations. However, outbreaks of the defoliators are more conspicuous and appear to be more frequent in plantations. Although there is very little quantified information on the intensity of damage in natural forests and the dispersed distribution of the host tree in natural forests may make the damage less visible, it is generally believed that the damage is greater in plantations.
3. At least two other pests have become prevalent in plantations; the whitegrubs and the sapling borer, *Zeuzera coffeae*. Whitegrub incidence may be facilitated by the greater attractiveness of the well-nourished nursery beds to the adult beetles for egg laying. As general observations indicate that *Zeuzera* attack is more prevalent in intensively managed plantations than conventional forest plantations, its incidence appears to be facilitated by the more succulent nature of the stem of fast growing saplings. Thus plantations appear to favour some pests.

In summary, the native plantations suffer greater damage than natural forests.

A comparison between native and exotic plantations reveals:

1. Compared to native plantations, the number of pest species present in exotic plantations is very small, with a greater number in exotic plantations in the Asia-Pacific, closer to its home range, than in Africa and Latin America.
2. Some pests are common to native and exotic plantations in some regions. These are *H. puera, E. machaeralis* (or its equivalent *P. damastesalis*), *X. ceramicus* (or its equivalent *A. cadambae*), and whitegrubs.
3. Some indigenous insects, not present in the home countries of teak, have developed pest status on exotic teak. These are the wood dwelling termite, *Neotermes tectonae* in Indonesia and *Atta* spp. in Latin America.
4. The African continent is conspicuous for absence of major teak pests, in spite of the long history of teak cultivation. *H. puera*, although present on other hosts has not been reported to attack teak. In exotic plantations in Latin America, *H. puera* appears to be building up.

The overall conclusion from this case study is that exotic plantations of teak are much less prone to pest damage than native plantations, at least for a long initial period after introduction.

3. Discussion - Is there a Greater Risk of Pest Outbreaks in Exotics?

Much of the discussion in the literature on the comparative susceptibility of exotic versus indigenous plantations to insect outbreaks has been based on theoretical considerations. In the past, reliance on theory was unavoidable because there was very little empirical data, and some guidelines were needed before embarking on large-scale cultivation of exotics. Unfortunately, in the absence of sufficient empirical data, opinion was sharply divided between the protagonists and antagonists of exotics, and the planting programme with exotics went ahead without regard to the scientific pros and cons. As indicated in the Introduction, a number of extraneous issues - social, political and environmental - entered into the debate, confounding the issue of pest susceptibility of exotics. Our task is to identify the real issues relating to pest susceptibility and draw conclusions.

Although we now have fairly good empirical data to draw conclusions, theoretical considerations cannot be dispensed with altogether. They provide a framework to organise and interpret the empirical data and are necessary for scientific understanding of the underlying cause-effect relationships. We will therefore first examine the empirical data and draw conclusions, and then examine whether the conclusions are consistent with contemporary theory. If they are not, it would mean that either the interpretation of the empirical data or the contemporary theory needs modification.

3.1 Conclusions from Empirical Data

What do the empirical data presented in Section 2 show? Since the influential review by Gibson and Jones (1977), pest problems of forest plantations have been primarily attributed to the practice of monoculture. When an exotic is grown in monoculture, the problem is confounded and it becomes hard to distinguish between the 'monoculture effect' and the 'exotic effect'. Because in the present case studies we have analysed the problems in three habitats, i.e., the natural forest, native plantations and exotic plantations, we have an opportunity to segregate the monoculture and exotic effects, at least in cases where data are available. Table 3.1 presents a summary of the findings.

In all five cases for which data are available, monoculture itself led to greater damage. The trees were *Eucalyptus* spp., *Gmelina arborea, Hevea brasiliensis, Swietenia macrophylla* and *Tectona grandis*. Data for exotic effect on pest susceptibility are available for eight species. Five of them, viz., *Acacia mangium, Eucalyptus* spp., *Gmelina arborea, Hevea brasiliensis* and *Tectona grandis* suffered lesser damage in exotic locations; two, viz., *Leucaena leucocephala* and *Pinus caribaea* suffered greater damage and one, viz., *Swietenia macrophylla,* suffered equal damage in some places

Table 3.1 Segregation of the monoculture effect and exotic effect in pest susceptibility of forest plantation species

Tree species	Monoculture effect[1]	Exotic effect[1]
Acacia mangium	No data	Lesser damage
Eucalyptus spp.	Greater damage	Lesser damage
Gmelina arborea	Greater damage	Lesser damage
Hevea brasiliensis	Greater damage	Lesser damage
Leucaena leucocephala	No data	Greater damage
Paraserianthes falcataria	No data	No data
Pinus caribaea	No data	Greater damage
Swietenia macrophylla	Greater damage	Equal damage in some places, greater in others
Tectona grandis	Greater damage	Lesser damage

[1]Monoculture effect indicates whether monoculture plantations in regions where the species is indigenous suffer greater or lesser pest damage compared to natural stands. Exotic effect indicates whether monoculture plantations in exotic regions suffer greater or lesser pest damage compared to monoculture plantations in regions where the species is indigenous.

Table 3.2 Comparison between the numbers of insect species associated with native and exotic plantations

Tree species	Score[1] for number of Native plantations	Insect species Exotic plantations	Whether exotic plantation has greater or lesser no. of insect spp.
Acacia mangium	1	8	Greater
Eucalyptus spp.	11	40	Greater
Gmelina arborea	10	2	Lesser
Hevea brasiliensis	6	3	Lesser
Leucaena leucocephala	1	4	Greater
Paraserianthes falcataria	-	5	-
Pinus caribaea	3	3	Equal
Swietenia macrophylla	1	2	Greater
Tectona grandis	23	2	Lesser

[1]Score 1 indicates 1 to 10 species, score 2 indicates 11 to 20 species, etc. See text for details.

and greater damage in others. This shows that pest susceptibility is not exclusively determined by the exotic or indigenous status of a tree species.

It is also interesting to look at the number of insect species associated with native and exotic plantations (Table 3.2). In the table, scores have been assigned for the number of insect species recorded. Although the approximate actual numbers could have been presented, scores are used to stress the fact that the numbers are only approximate and, of course, no weighting of potential threat is attached.

The number of insect species associated with exotic plantations was either greater or lesser than, or equal to that in native plantations; greater for four species (*Acacia mangium*, *Eucalyptus* spp., *Leucaena leucocephala* and *Swietenia macrophylla*), lesser for three (*Gmelina arborea, Hevea brasiliensis* and *Tectona grandis*) and equal for one (*Pinus* *caribaea*). The underlying causes will be discussed later.

To summarise the main conclusions from the empirical data, *neither the intensity of pest damage nor the number of pests associated with a tree species is determined by its exotic status*. The associated insects are called 'pests' for convenience; it does not imply that all cause economic damage.

Do these empirical findings conform to the conventional wisdom and theoretical expectations? To interpret the findings adequately, it is necessary to examine in detail the theoretical explanations available for the origin of pest problems,.

3.2 Theoretical Background

General beliefs

Some typical expressions of opinion on the susceptibility of indigenous and exotic species to pest outbreaks are:

> 'The world-wide distribution of forest trees is being continuously changed as exotic species are used more and more in plantation forestry….We should expect trouble from insects in these exotic plantations…' (Berryman 1986).

> 'The [indigenous] species is adapted to the environment and already filling an ecological niche. This may render it less susceptible to serious damage from diseases and pests since controlling agents (predators, viruses, climatic factors) are already present. …As a rule, where a native species meets the need there is no reason to choose an alternative. Indeed, for reasons of conservation, if the choice lies between two species of comparable growth and quality, one of which is native and one exotic, … the native species is to be preferred'. (Evans 1992).

> 'Utilization of indigenous species is preferable because native species are adapted to the local environment, …and have generally evolved considerable resistance to local pests and diseases'. (Sayer 1993).

> 'Some important biological advantages are present with indigenous species …They deserve more attention: it is possible to predict their performance in plantations based on their performance in natural stands; the species fills an existing ecological niche – it may therefore be less susceptible to diseases and pests, since the natural enemies are already present.…' (Appanah and Weinland 1993).

> '… the argument that establishing a species outside its natural habitat (i.e., as an exotic) increases its susceptibility to pests has not been proven. … Growing a species as an exotic may actually release that species from its natural pests and thus improve its health and performance.' (Zobel *et al.* 1987).

> 'Exotics in their new environments may initially enjoy freedom from insect attacks, leading to high productivity… For instance, *Eucalyptus* grows very well outside Australia and usually does not suffer from insect attacks. In Australia, however, most eucalypt species are so severely attacked by insects that it is often hard to find undamaged botanical leaf specimens.' (Pryor 1978 quoted by Zobel *et al.* 1987).

Based mainly on theoretical considerations, most authors argue that indigenous species are likely to suffer less damage from pests. Two main reasons are given: (1) they have developed resistance against the local pests through co-evolution; and (2) natural enemies of the pests are present to keep them under check. This implies, conversely, that exotics suffer greater damage because: (1) they have not had the evolutionary time to adjust with the new pests; and (2) pests invading from the native distribution range of the host tree inflict greater damage in the absence of their natural enemies. Empirical results neither support nor disprove these conclusions because some exotics suffer less and some suffer greater pest damage.

A minority has argued that exotics may enjoy freedom from pests, at least for a long initial period after introduction. Empirical data do not fully support this contention either. For example, *Swietenia macrophylla* suffers equal and *Pinus caribaea* greater damage right from introduction although initial freedom and delayed pest outbreak holds true in the case of *Leucaena leucocephala*, and for some regions, in the case of *Tectona grandis*. In the case of four other species (Table 3.1), delayed outbreak has not yet occurred.

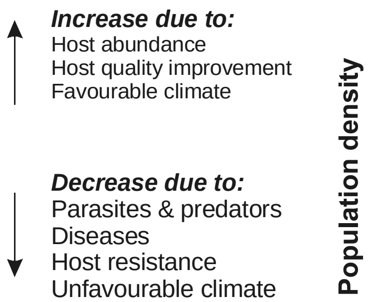
An explanation for pest incidence, or freedom from it, must also be sought in other factors.

The *raison d'être* of pest problems

Herbivorous insects are ubiquitous components of terrestrial ecosystems, including natural forests. They form a link in the energy cycle as one of the consumers of primary production, and in turn, serve as food for secondary consumers, ultimately contributing to the cycling of nutrients and energy in the ecosystem. Generally in the pristine forest, most species of insects remain in low numbers as their population size is regulated by a number of biotic and abiotic factors. This apparent constancy of numbers is the result of a dynamic equilibrium between production and destruction, i.e., increase in numbers due to growth and reproduction, and mortality inflicted by various factors (Fig. 3.1).

The factors which favour increase in population include host abundance, host quality improvement (for example, flushing favours insects that feed on tender foliage), favourable climate, etc., and those which cause decrease in numbers include parasites and predators, diseases, host scarcity, host resistance, unfavourable climate, etc. In natural ecosystems, each tree species and its associated insects have co-existed and co-evolved over millions of years. If either the host tree or its pests adversely affected the survival of the other, one or both would have been eliminated through the process of natural selection. The fact that they survive indicates that a balance has been struck between the adverse impact of the insect on the tree and of the tree defences on the insects, so that there is dynamic balance in the abundance of both. (Tree defences against insects include static defences such as hairs or spines on leaves, a vast array of unpalatable or toxic secondary chemicals, including waxes and resins or gum that can trap insects, as well as induced dynamic defences such as wound healing reaction, timely mobilisation of defensive chemicals to the sites of attack, etc.).

Figure 3.1 In natural ecosystems, the population size of a species remains in a dynamically steady state (i.e., fluctuates within a moderate range) due to the action of opposing forces



In rare cases, outbreaks of some insects occur in natural tropical forests. This is usually associated with a high density of the host tree. Examples are the outbreaks of the bagworm *Pteroma* sp. on *Pinus merkusii*, and the lasiocampid caterpillar, *Voracia casuariniphaga*, on *Casuarina montana*, in Indonesia (Kalshoven 1953) and of the cerambycid sal trunk borer, *Hoplocerambyx spinicornis*, on *Shorea robusta* (Day in press) and the defoliator *Hyblaea puera* on the mangrove, *Avicennia marina*, in India. These outbreaks in natural forests may well play an ecological role of regulating or stabilising the vegetation composition when one species tends to dominate (Huffakar 1970). Insect outbreaks, particularly of stem borers and sap feeders may also develop in natural forests when the tree defences are weakened by drought or other adverse conditions. An example is the outbreak of the scolytid bark beetle, *Dendroctonus frontalis,* on pine stands in Honduras.

A pest is defined as an organism which causes economic damage or other negative impact on human well-being. It therefore reflects a human viewpoint although all insects may have an ecological role in natural communities.

Although some insects may cause economic damage even when present in small numbers (e.g., a worm in an apple, a borer hole in wood), generally it is a large increase in the number of individuals of a species that creates a pest situation. In other words, a pest problem is a population dynamics problem. It originates when the dynamic equilibrium of insect numbers is disrupted, which can happen due to changes in a number of factors, broadly indicated in Fig. 3.1.

Negative feedback mechanisms are involved in maintaining the stability, i.e., the dynamic equilibrium, of insect numbers (Berryman 1986). For example, when an insect population increases, its parasite population also increases. The increased parasite population exerts greater pressure on the host population, reducing it to a lower level. Thus an initial stimulus (increase in the insect population which causes an increase in the parasite population) is fed back to the population, causing a negative impact, in the same way as increased temperature which expands a bimetallic rod of the thermostat regulates the temperature of an oven. Uncontrolled increase of population resulting in an outbreak can occur when either the negative feedback mechanism fails or when a positive feedback mechanism comes into operation. For example, an increase in the number of borers attacking a host tree can overcome tree defences such as resin flow more effectively than fewer borers. This causes a further increase of the population, creating a chain reaction which constitutes a positive feedback mechanism (i.e., every increase leads to further increase), leading to an uncontrolled increase in the number of borers, i.e., an outbreak.

The mechanisms which regulate insect numbers have been the subject of intensive theoretical debate since the 1930s, with two main schools of thought, one emphasising the importance of density-dependent factors (i.e., the direct or indirect negative feedback exerted by the increasing population) and the other, of density independent (abiotic, like weather) factors (Clarke *et al.* 1967, Turchin 1995). The debate still continues, but newer approaches to the study of insect population dynamics including application of mathematical theory has brought to light details of many forms that regulation can take, such as simple local regulation, metapopulation regulation and complex dynamics involving indigenous and exogenous factors (Cappuccino 1995, Turchin 1995, Berryman 1999). There is an emerging consensus that density dependent regulation may be very common although there are many 'counter-examples demonstrating that regulation does not always operate in all populations at all times' (Turchin 1995).

When trees are moved from their natural communities to artificial monoculture plantations, many of the checks and balances that operate between the host tree and the associated insect populations, often through the mediation of several other biotic and abiotic elements, are disrupted. Pest problems are thought to originate due to this disruption of ecological interrelationships. However, a number of other factors have also been postulated to precipitate pest outbreaks. It is often difficult to distinguish between proximate causes and the ultimate cause. The postulated causes of outbreaks include (Berryman 1987):

1. Dramatic changes in the physical environment.
2. Changes in the genetic composition of the pest population.
3. Qualitative changes in host plants, caused by environmental stresses.
4. Life history strategies characteristic of the species.

The case studies presented and other literature show that only very few phytophagous insects associated with trees (and other plants) become pests, that is, increase in large numbers to cause economic damage. For example, only a handful among 180 insects associated with eucalypts in Australia are pests, and only three are major pests among 187 insects associated with teak in India. This indicates that development of pest status is not necessarily a function (in the mathematical sense) of plantation conditions, but has something to do with the intrinsic characteristics of the insect species.

Based on life history strategies, insects have been categorised to fall within a scale of r-K continuum. At the r-end of the scale are species selected for ensuring maximum food intake in a short time in an ephemeral environment and at the K-end are species selected for harvesting food effectively in a crowded environment. Southwood (1977) has given a good discussion of the main points, which can be summarised as follows. The r-strategists tend to be small, with a short generation time. They increase enormously in number starting from small beginnings (e.g. a few colonisers) in the ephemeral habitats. Their population booms and busts (Southwood 1977), like that of the teak defoliator, *Hyblaea puera*, which booms into outbreaks on newly flushed teak plantations and then collapses. At the other extreme, K-strategists maintain a steady population at or near the carrying capacity of the habitat. They are in equilibrium with their resources, whose renewal they do not adversely affect (Southwood 1977). The r-strategists are devastating pests. They become very numerous at certain times in certain places (outbreak) and may destroy their habitat. On the other hand, K-strategists have a minimal impact on their host plant and do not become pests, except when man is sensitive to such low level of damage or he disrupts the natural regulation and causes an increase in the pest's density. The codling moth, *Cydia pomonella*, that attacks apple is an example of a K-strategist. In the tropics, subterranean termites could be cited as another example. In between, are the intermediate pests, which are normally held at a lower level than the carrying capacity of their habitat by the action of natural enemies, but will occasionally erupt into outbreaks due to environmental change.

The concept of r-K selection in the life history strategies of insects is an attempt to order the observed complexity of pest situations. However, there is no conclusive empirical proof for many of the traits like body size, fecundity, voltinism, etc., predicted for the outbreak and non-outbreak species according to the r-K selection model. The mechanisms driving the population dynamics of most insects remain unknown. The teak defoliator, *Hyblaea puera* satisfies most criteria attributed to r-strategists. Yet, these life history characteristics and the co-occurrence of the insect and the host tree are not sufficient to pecipitate outbreaks.

Principles governing population change

Pest problems are created by population increase. Are there principles governing the fluctuations of population over time, i.e., the dynamics of the population? Berryman (1999) has listed five basic principles of population dynamics. The first is exponential growth of populations, which he illustrates by the example of an amoeba which is assumed to reproduce by division once every day, producing two amoebas in two days, four in three days, then eight and so on, thus producing a million amoebas in 20 days. Some insects reproduce even faster than this. If unchecked, this leads to an unstable, exponentially increasing population. The second principle is cooperation among individuals of the same species, which can lead to higher rate of increase as populations become larger or denser. The third principle is competition or struggle between individuals to obtain the resources they need to survive and reproduce (struggle for existence). Mathematical simulations demonstrate that operation of this principle leads to a logistic population growth curve, random environmental disturbances caused saw-toothed oscillations, gradual change in the external environment caused trends, and sudden changes caused shifts in the population growth curve. According to the fourth principle, populations can affect the properties of their environment and thus create circular causal pathways linking the populations to elements of their environment such as resources, enemies or other components. Mathematical simulations show that circular causality can induce low frequency cycles in population dynamics, with environmental variability sustaining and amplifying these cycles. Circular causality can generate extremely complex patterns in time and space. The fifth principle recognised that a given population is embedded in complex webs of interaction with other biological populations and their physical environments, but that only one or a few of these interactions are likely to dominate the dynamics at any particular time and place. In other words, some of the feedback loops act as limiting factors. This is a simplifying principle, although the limiting factors can change in response to changing population density and environmental conditions. Simulations show that this can lead to unpredictable population dynamics including population explosion and collapses.

Populations governed by these five principles, viz., geometrical growth, cooperative and competitive interactions between members, circular causality between the population and its environment, and limiting factors can display a wide array of dynamic behaviour patterns. In two recent articles, Evans (2001a,b) has discussed how interactions with food plants, natural enemies and other habitat factors affect the diversity and abundance of forest insects.

Classification of outbreaks

Based on theoretical predictions and observed population behaviour, attempts have been made to develop a classification system for insect outbreaks (Berryman 1986, 1987, 1999). A classification system tries to organise the observed patterns of population fluctuations into groups or classes according to their common characteristics. In turn, it helps us to organise the observed phenomena and understand the cause-effect relationship. The rationale has been that if we know how a pest outbreak originates, we are better able to control the outbreaks. The observed spectrum of pest outbreaks is indeed very complex and each pest may be unique, but Berryman (1999) offers the following justification for attempting to classify the outbreaks. He says, ‘the fact that each person is unique does not prevent the physician from practising medicine’; in the same way, an entomologist can prescribe a treatment based on an understanding of the kind of outbreak.

Theoretically, population fluctuations have been classified into two basic kinds; those caused by endogenous factors (density induced feedback loops) and those by exogenous factors (weather, host condition, etc), each with several subclasses, based on trend parameters. However, different causes may lead to the same type of population growth behaviour, based on which three basic types of population behaviour have been recognised. These are: (1) relatively stable populations; (2) cyclical populations; and (3) eruptive populations. Most polyphagous forest insects belong to the relatively stable populations. Fast-acting, negative density dependent feedback mechanisms regulate their populations to relatively stable levels. Changes in the favourability of the basic environment may cause corresponding graded changes in the equilibrium density of the population. In the second category, the population goes through regular cycles of abundance, as exemplified by the 9-10 year cycle of larch budmoth populations in the Swiss Alps and may be caused by a delayed negative density dependent feedback mechanism mediated through the host plant. In the third type, populations remain relatively stable for long period of time, but erupt occasionally and spread over large areas. Examples are the spruce budworm, *Choristoneura fumiferana*, and several species of bark beetles in temperate climates and the sal borer, *Hoplocerambyx spinicornis*, in India. Subtypes have been recognised in each category (Berryman 1986) and a particular species may exhibit one or more of the types of population behaviour. Computer simulations have shown how each type of simple to complex behaviour can arise (Berryman 1999); and sophisticated analytical techniques have been developed to diagnose the causes of observed population behaviour based on time series data on population change. However, the challenge posed by the wide variability in the patterns of population change over time and space through the interplay of endogenous and exogenous causes continues to baffle the average entomologist and dampen the optimism suggested by the physician's example of practising medicine.

Factors favouring pest outbreaks in plantations

Tropical forests are characterised by high degree of tree species diversity. For example, the mature rain forest may contain 70-100 tree species ha^{-1} and usually a single species does not constitute more than 10% of the total number of trees, although some like dipterocarps may occur gregariously (Evans 1992). Plantations on the other hand, are usually monocultures. The following characteristics of plantations may favour the increase of pest populations. Gibson and Jones (1977), Evans (1992, 1999) and Evans (2001a) have also discussed some of these.

1. Plantation ensures an abundance of food supply. It creates a large extent of area under a single species and thereby an absolute increase in the abundance of food for an insect associated with the species. This large supply of food facilitates build up of pest populations since food supply is one of the basic determinants of population size for an exponentially growing population.
2. The closeness of host trees in a plantation, often with branch contact, facilitates easy spread of pest insects. This is particularly favourable to insects with limited power of dispersal. In natural forests where the 'host crop' is fragmented, dispersal mortality is an important limiting factor for many pests (Southwood and Way 1970). For example, in natural forests in Mexico, the average density of mahogany is one to two mature trees ha^{-1}.
3. Cultural operations in plantations causing plant injury may facilitate initial establishment of some insects.
4. Accumulation of wood residue during site clearance for planting may favour build up of some insects like borers.
5. When extensive areas are planted up uniformly, they may encompass some sites that are unsuitable for the species (rocky and drought prone, water-logged, acid or alkaline soil, etc.). Stressed trees in these poor sites may act as epicentres for build-up of some pests, which then attack healthier trees.
6. Absence of other plant species may make the environment unfavourable for survival of some of the parasites, predators and diseases that may normally keep a pest population under check. Survival of many parasitoids is dependent on presence of alternative host insects, and availability of pollen, nectar, etc., of other plants for their adult stage.
7. Absence of other tree species in a monoculture plantation may remove physical as well as chemosensory interference in host location by pests.
8. Irrigation and fertilisation may change the nutrient composition of trees and influence their attractiveness as well as promote the growth and development of some pests.
9. Natural populations of trees show high genetic variability in their susceptibility to pests. Most plantations are generally less diverse and may consist of genotypes more susceptible to some

pests. As noted by Zobel *et al.* (1987), it happens too frequently that seed used to make the planting comes from restricted sources or small numbers of parents. Breeding for increased yield is often without reference to pest resistance.

From the above, it is evident that several factors promote the increase of pest populations in plantations. It has often been argued that ecological stability is a consequence of diversity, and natural tropical forests have been cited as typical examples of the diversity-stability relationship which postulates, 'the more diverse, the more stable'. Conversely, it has been argued that simple systems like monoculture plantations are more prone to pest attack. Most of these have been theoretical arguments. There is general agreement that trophic diversity (i.e., greater number of links between different trophic levels) as distinct from interspecific diversity is likely to promote stability (Southwood and Way 1970), although Way (1977) argues that diversity *per se* does not prevent pest problems but on the contrary often creates them. According to Way (1977), the key functional links conferring stability are likely to be few and only small amounts of the right kind of diversity are needed to prevent pest problems. In a study of pest incidence in species of plantation value in natural forest stands in Kerala, India, Nair *et al.* (1986a) also emphasised the importance of appropriate diversity. There is no doubt that generally pest problems are greater in plantations than in natural forests, but this does not necessarily occur because of reduced diversity; it is also because of several other conditions in plantations as discussed above (see also Gibson and Jones 1977).

Factors controlling pest incidence in exotics

Insects that attack exotic plantations originate from two sources; (1) indigenous insects thriving on other hosts, and (2) exotic insects thriving on the same host in the native habitat of the host or elsewhere, which may invade or be accidentally introduced.

Indigenous insects are not adapted to feeding on the exotic host. Therefore we should expect only generalist feeders (polyphagous species) or species adapted to closely related tree species to accept a new exotic host. Host plant selection involves a series of sequential steps in which secondary plant chemicals play a crucial role. They act as token stimuli to guide the insects to the plant as well as in the acceptance or rejection of a plant for oviposition, initiation of feeding and its sustenance. Absence of deterrent chemicals and nutritional sufficiency are also important. Insects have well developed olfactory, gustatory and contact chemosensory mechanisms and host selection is usually dependent upon sensory recognition of unique qualitative and quantitative combinations of host chemicals. The first step in the chain of behavioural responses leading to the arrival of an insect on a host plant, either for ovipostion or feeding, may involve random landing as a result of exploratory behaviour or short range oriented movement elicited by the minute quantities of volatile chemicals emanating from the host plant. In the case of indigenous insects associated with an indigenous host tree, these interactions have been fine tuned by co-evolution and as a result, many insects are already adapted to most plants. Through the evolutionary process, what is a poison for one species may become an attractant for another because of development of suitable physiological mechanisms for detoxification, sequestration, etc. Even the celebrated neem tree, the source of many insecticidal chemicals, has its share of pests. Because of co-evolved insect plant interaction, the number of insect species attracted by a newly introduced exotic should be small. However, the few indigenous pre-adapted, polyphagous insects that successfully establish on the exotic can find an abundance of food and may adapt to them in course of time by the differential survival of those genotypes that utilise the exotics efficiently. Insects have a much shorter generation time than trees and so they adapt to them comparatively quickly. Development of host races is known in many insects.

On the other hand, some species of host-adapted insects invade or are inadvertently introduced into exotic plantations. Weather-aided aerial displacement often facilitates these invasions. Modern means of transportation and increased international commerce have increased the rate of spread in recent times. Quarantine measures are often inadequate, particularly in the less developed countries. When they arrive, the introduced insects find an abundance of resource free of competitors and so flourish, if the weather conditions are favourable. Sometimes a new location may be suitable for the host tree in terms of climate but not for its pests. In some cases, the pests may require a period of post introduction adaptation to the new environment as indicated by a delay in population outbreaks until several generations after the initial introduction. This is the case of insects intentionally introduced into new locations for biological control of exotic weed plants (Myers 1987). They also have the advantage of freedom from the specialised predators, parasitoids and diseases found in their native habitats. These factors lead to their quick colonisation and build up. However, over time, some generalised natural enemies catch up with these insects to exercise some control.

The factors favouring or hindering pest build up in exotics can be summarised:

Factors favouring pest build up in exotics:

1. Fewer competitors for the resource.
2. Absence of specialised natural enemies in the case of introduced pests.

In addition, most factors favouring pest build up in plantations *per se* as listed in the Section on Factors favouring pest outbreaks in plantations, are also applicable to exotic plantations.

Factors hindering pest build up in exotics:

1. Absence of specialised pests among indigenous insects in the new locations.
2. Uncertainty of the chance of introduction and establishment of specialised pests from the native habitats of the exotic host tree.

3.3 Re-examination of Empirical Findings in the Light of Theory

Can we explain the empirically observed inconsistency in the pest susceptibility of exotics in the light of the theoretical knowledge discussed above and answer the question, 'Is there a greater risk of pest outbreaks in exotics?'

First, a recapitulation of the definition of an exotic. We defined an exotic species as one that does not occur naturally in a given geographical area delimited by visible natural boundaries (Section 1.2). This differs from the conventional definition, where the spatial scale for considering a species exotic or indigenous is the political boundary of a country. Admittedly, in our definition, the boundaries of the area, although specified, can be narrowed or enlarged, depending on the purpose, just as in the case of the physical boundary of an ecosystem. The conclusions drawn here are applicable to exotics as defined above. However, for most practical purposes (i.e., with a few exceptions) it will also be applicable to exotics as defined conventionally.

Origin of pest problems in exotics

In the light of theoretical discussions and the empirical findings, we can now identify the ways in which pest problems of exotics originate. Obviously, when an exotic species is introduced into a new environment, it comes without its associated pests. Pests may originate from indigenous or exotic sources through the following mechanisms.

From indigenous sources

1. Generalist feeders.
   This category accounts for most of the insects associated with exotics in a new location. Many insects are polyphagous and their host selection mechanism permits acceptance of a wide variety of plants. Probably they arrive at a host plant by random exploratory movements and accept a host when they come into contact with it, more by absence of deterrents than by

presence of specific attractants. Thus a number of indigenous insects colonise an exotic.

Some examples of generalist feeders from our case studies are grasshoppers, cutworms and whitegrubs in nurseries of many species, leaf feeding curculionid beetles (*Myllocerus* sp., *Hypomeces* sp., etc.) on many species, the hepialid sapling borer, *Sahyadrassus malabricus*, on teak, eucalypts and *Paraserianthes falcataria*, and several noctuid, geometrid and lymantriid caterpillars on many species. Generally, they are incidental feeders and therefore, only minor pests.

Another category of generalist feeders causes economic damage to some exotics. These include several species of root feeding termites of young eucalypts and pines in many countries. It appears that the trunk dwelling termite *Neotermes tectonae* of teak in Indonesia, *N. samoanus* and *N. papua* of mahogany in Fiji and the bark beetles *Crossotarsus externe-dentatus* and *Platypus gerstackeri* on mahogany in Fiji may also belong to this category. Teak and mahogany do not suffer damage from similar pests in their native habitats, nor do these insects cause similar damage to native tree species. It appears that indigenous tree species have developed tolerance against these insects in evolutionary time so that the insects do not build up in large enough numbers to become pests although they may subsist on them, while the exotics are defenceless as they have not encountered similar pests in their native habitats.

2. Newly adapted insects causing delayed attack. Although there are no systematic records, the number of indigenous insect species attacking exotic tree species appears to increase over time through adaptation. Indigenous insects recorded on *Leucaena leucocephala* in India and on *Acacia mangium* in Malaysia are examples, although the confounding factor of additional research effort over time to explain the increasing number of pest records on these species cannot be ruled out. Wylie *et al.* (1998) also observed that the recent rapid expansion of eucalypt plantations in China has been accompanied by a substantial increase in the number of indigenous insect species feeding on these new hosts, and increased damage. In the case of the bagworm, *Pteroma plagiophleps*, in India, there is indication that from an insignificant insect on native *Tamarindus indica* and other hosts, it has over time developed into a major pest of the exotic *Paraserianthes falcataria* (Mathew and Nair 1986, Nair and Mathew 1992). This species appears capable of developing host races. Other examples of such host adapted insects causing delayed attack of exotics are the wingless grasshoppers on pines in Africa (Schabel *et al.* 1999); the bug, *Helopeltis* spp., on *Acacia mangium* in Indonesia, Malaysia and the Philippines and on *Eucalyptus* in India (Nair 2000); and the noctuid, *Spirama retorta*, in Malaysia (Sajap *et al.* 1997).

   These insects can become serious pests of exotics over time, because insects, with a shorter generation time than trees, can adapt quicker, and the trees in plantations have little chance of developing resistance mechanisms through natural selection, unlike those in natural stands. Insects can overcome the chemical defences of exotics through adaptive evolution using population genetics mechanisms, in the same way as they develop resistance to insecticides.

3. Specialised insects pre-adapted to closely related species.
   The examples of *Hypsipyla robusta* on mahogany and of the shoot moths *Dioryctria rubella, D. sylvestrella* and *Petrova cristata* on *P. caribaea* in Southeast Asia show that an introduced tree species may encounter insects already adapted to closely related tree species in the location of introduction. This leads to quick attack of the exotic by these specialised insects because the same or closely related host selection mechanisms developed over

evolutionary time may operate. This results in serious pest problem as soon as the exotic tree is introduced.

From exotic sources

1. Pests introduced from the native habitat of the exotic tree.
   Among the case studies, the psyllid *Heteropsylla cubana* on *Leucaena leucocephala* and the eucalypt beetles, *Phoracantha semipunctata* and *Gonipterus* spp., are examples of pests accidentally introduced from the native habitat of the exotic tree. The conifer aphids, *Cinara cupressi, Pinus pini* and *Eulachnus rileyi*, infesting several species of exotic conifers in Africa (FAO 1991, Murphy 1996) are other examples.

   These introduced pests can cause havoc as in the case of leucaena psyllid in Southeast Asia because they come without their natural enemies that often keep them in check in the pest's native habitat. However, the initial outburst may be tempered in course of time as the native generalist natural enemies catch up with the pest, as in the case of the leucaena psyllid. (The relative contribution of the native and artificially introduced natural enemies in the population regulation of the leucaena psyllid is, however, not clear.)

2. Insects introduced from regions other than the native habitat of the exotic.
   Although there is no example in the case studies, an insect which is not a pest in the natural habitat of a tree species may arrive from a third country and acquire pest status in an exotic location. The wood wasp, *Sirex noctilio* (Hymenoptera, Siricidae), on *Pinus radiata* in Australia is an example. *Sirex noctilio* is not reported as a pest of *P. radiata* in California where the tree is indigenous. It acquired pest status on exotic *P. radiata* plantations in New Zealand, from where it was later accidentally introduced to Australia. It caused extensive mortality of the widely planted, exotic *Pinus radiata* in Australia (Zobel *et al.*, 1987, Elliott *et al.* 1998). *Sirex noctilio* is not highly host specific and its successful establishment is dependent on mutualistic association with a basiodiomycetous fungus vectored by the insect (Madden 1988).

Factors determining the number of insect species associated with exotic trees and development of pest status

The empirical results showed that the number of insect species associated with an exotic varied considerably between tree species, from about 20 to 400 (Table 3.2). Trees growing in exotic locations may harbour lesser numbers of insect species than in their native habitat as in the case of *Gmelina arborea*, *Hevea brasiliensis* and *Tectona grandis* or greater number as in the case of *Acacia mangium, Eucalyptus* spp., *Leucaena leucocephala*, *Swietenia macrophylla* and possibly, *Paraserianthes falcataria*. The number of associated species is determined by several factors.

1. Distance from the native habitat.
   If the exotic tree is close to its native habitat, it is likely to have many species from the native habitat either because the insects are also naturally distributed there or can easily disperse there. This seems to apply in the case of exotic *Pinus caribaea* in many Latin American countries. Exotic teak in Bangladesh, Sri Lanka and Malaysia, closer to its native habitats, also contain more insects than exotic teak in Africa or Latin America.

2. The extent and diversity of the geographical area of introduction.
   The larger and more diverse the area into which a species is introduced, the greater is the chance of indigenous insects colonising it. This is because of the greater diversity of insects represented in the area. This is evident in the case of *Acacia mangium, Eucalyptus* spp., *Leucaena leucocephala* and *Swietenia macrophylla.*

Larger area and diversity of habitat also enhance the chances of landing and survival of exotic pests from the tree's native range.

3. Time elapsed since introduction.
As many indigenous species can adapt to an exotic host over time, time elapsed since introduction will also influence the number of colonising insect species. The larger number of insects associated with exotic eucalypts may be at least partly due to this factor.

   Time elapsed since introduction also enhances the chances of arrival of exotic pests from the tree's native range.

4. Chemical characteristics of the tree species
In spite of many other favourable factors, if the chemical composition of the tree is unique, it is likely to host a lesser number of insect species. Thus species that produce latex or resins or poisonous chemicals may have fewer colonisers. The rubber tree, *Hevea brasiliensis* (Euphorbiaceae), is a typical example, with about 60 species in its native habitat but only about 30 in exotic locations, in spite of the long period and large area of introduction. Other species in our case studies that had smaller number of associated insects in exotic locations are *Gmelina arborea* and *Tectona grandis*; the reason for this is not clear.

Area, distance and time have been recognised as major determinants of the number of plants and animals that colonise islands. For exotic pests, a plantation is like an island, that is, a suitable habitat patch isolated by a 'sea' of inhospitable environment. The theory of island biogeography (MacArthur and Wilson 1967) which postulated that the number of species inhabiting an island at any given time is determined by the dynamic equilibrium between immigration of new species and speciation within the island on the one hand and extinction of existing species on the other, has spurred much research into the relationship between these variables. Although the central dogma of the theory has not been substantiated, empirical data have shown that the number of species in an island is positively correlated with the area of the island and time elapsed since isolation, and negatively correlated with distance to the source of colonists (Cox and Moore 1993, Whittaker 1998). This relationship should be as applicable to habitat islands as to physical islands. In fact, studies on major tree genera in British forests indicate that the species-area relationship holds true in this case (Evans 2001a).

It can be concluded that the number of species associated with an exotic plantation depends, in the case of exotic insects, on the area of the plantation, habitat diversity of the area, distance from the native habitat of the planted species, time elapsed since planting, biological attributes of the pest insects and chance, and in the case of indigenous insects, on the area, habitat diversity, time and chemical profile of the tree species.

As noted earlier, only a few insects associated with a tree species become pests of economic importance. For example, in spite of the large number of indigenous insects associated with exotic eucalypts (about 400), there is no notable pest, although some like the arctiid caterpillar, *Eupsuedosoma involuta*, in Brazil, the geometrid caterpillar, *Buzura suppressaria*, in China and *Helopeltis* spp. in Indonesia, India and Malaysia are probably evolving into that status. It is obvious that development of pest status is an evolutionary process. In the case of exotics in their alien environment, this is still an ongoing process. As explained earlier, this happens through differential survival of certain genotypes which have access to a virtually unlimited and unclaimed food source. In the case of the same tree species in its native environment, this evolution has already taken place and therefore serious pests occur, as in eucalypts in Australia. Although the trees can also evolve defensive mechanisms, the insects are always one step ahead in this continuing evolutionary struggle because they have a shorter generation time. In the exotic plantation environment, insects have still better edge over the trees because unlike in the natural forests, trees cannot evolve here except through human intervention, while insects can. Factors that determine the number of species that acquire pest status are not fully understood in the case of exotics as in the case of all plants in general. Some kind of limiting factor seems to be operating to restrict the number of species that can acquire pest status on a particular tree species in a given location, in a given time. It may result from plant herbivore interaction involving many insects. This appears logical in the light of the fifth principle of limiting factors (Berryman 1999) in which it is recognised that populations are embedded in complex webs of interaction with other biological populations and their physical environments, but that only one or a few of these interactions are likely to dominate the dynamics at any particular time and place. If we think of pest outbreak as a mechanism of regulating the host density, it is logical to imagine that out of a complex network of feedback loops acting on a particular host population, only one will dominate under normal circumstances to ensure a stabilising equilibrium, but if that one fails, others will take over the role of population regulation. However, as exemplified by the teak defoliator population dynamics in the different continents, our understanding of the factors and conditions that lead to development of pest status is still poor.

Are there examples of newly evolved serious pests of exotics from among indigenous insects in trees represented in our case studies? It appears that there are none yet, although many seem to be in the making, as discussed above. Outside our case studies, wingless grasshoppers of pines in Africa may be an example. The risk of such pests in future appears to be very real.

3.4 Conclusions

This study sought to answer the question, 'Is there a greater risk of pest outbreaks in exotic forest plantations?' Based mainly on theoretical considerations, to date, there have been two opposing views; that exotics are at greater risk of pest outbreaks than indigenous species and conversely that exotics are at lesser risk, at least for a long initial period after introduction. The case studies vindicate both views as some are at greater and some at lesser risk. The conclusions drawn from the case studies cannot be disputed although we may argue on the underlying causes. No generalisation is possible for exotics as a group although more species in our case studies seem to be at lesser risk, at least for a long, though uncertain, period of time after introduction. The risk is not determined only by the exotic or indigenous status of a species, which is also a matter of definition. The factors that determine the risk of outbreaks are:

1. Presence in the location of introduction, of other closely related tree species.
   Closely related species, particularly of the same genus, may harbour pre-adapted insect pests. In some cases, plants of closely related genera may serve the same purpose (e.g. *Toona* and *Swietenia*). Similar phytochemical profiles is the deciding factor.

2. Extent of area occupied by exotic plantations. The risk of pest problems increases with increase in the extent of planted area for the following reasons: (1) greater number of indigenous insects from diverse habitats come into contact and interact with the exotic species and adapt to it; (2) the greater the area of planting, the greater is the chance of mismatched planting sites which lead to plant stress. This could promote outbreak of some pests like bark beetles that build up on stressed trees and then spread; (3) increased habitat heterogeneity increases the chances of matching with the habitat requirement of exotic, pre-adapted pests which arrive by chance; and (4) larger planted area offers a larger receptacle for randomly dispersing pre-adapted pests from the exotic's native habitat.

3. Genetic base of the introduced planting stock. Narrow genetic base increases the risk of pest outbreaks. An example is the heavy mortality caused by the buprestid borer *Agrilus sexsignatus* to a provenance of *E. deglupta* from Papua New Guinea, but not to other provenances in Malaysia. The risk increases over time due to inbreeding.

4. Distance between location of introduction and the native habitat of the tree species.
   The shorter the distance, the greater is the risk of pest problems as shown by the example of exotic teak in Asia, Africa and Latin America.

5. Existence of serious pests in the native habitat.
   This is important in two ways. Their absence indicates that the tree species has innate resistance to most insects and therefore indigenous insects in the new location are unlikely to adapt to it easily and become pests (e.g., *Hevea brasiliensis*). Secondly, the existence of serious pests in the native habitat indicates the chance of its unintentional introduction through one of several means.

6. Time elapsed since introduction.
   The risk of pest outbreak increases with time due to adaptation of indigenous insects and the greater chance of invasion by exotic pests.

7. Chemical profile of the exotic species.
   Some species are less prone to pest attack due to presence of toxic chemicals.

8. Innate biological attributes of the insects associated with a tree species.
   Populations of some insect species characteristically display outbreak dynamics while others display non-outbeak dynamics.

It should be possible to develop a pest risk rating system for different tree species for different locations, based on the criteria identified above, similar to that employed for quarantine pests (FAO 1996, 1999, Evans *et al.* 1996).

This study also shows that the argument that indigenous tree species have already developed substantial resistance to local pests through co-evolution and therefore are at lesser risk of pest outbreaks is not fully valid. It is valid to the extent that an indigenous tree species will not be wiped out by a pest because it has evolutionarily outlived such an eventuality. However, this is of little value in the plantation system of tree management because economic damage can still occur. The empirical data show that pest outbreaks do occur in plantations of indigenous tree species also.

It is also generally believed that pest problems are lesser in indigenous species because specialised natural enemies of the pest are already present in the environment. This implies that natural enemies exercise appropriate ‘checks and balances’ to keep the pest population in equilibrium and that pest outbreaks occur because of the absence of natural enemies or their inadequacy. Although natural enemies constitute an important factor regulating the population increase of many insects and decisively so in some cases, empirical observations show that pest outbreaks do occur in spite of them, sometimes even in natural forest stands. This shows that outbreaks occur due to other reasons as well. The theoretical principles of population dynamics discussed earlier show the possibility of complex patterns of outbreak behaviour through interplay of endogenous and exogenous factors. Unfortunately, the concept of ‘balance of nature’ and the few successful examples of applied biological control using introduced exotic natural enemies have over emphasised the importance of parasitoids as regulators of pest populations. While parasitoids do regulate population outbreaks in some cases, outbreaks occur in spite of them as in the case of the teak defoliator (Nair 1998), and in many cases the exact causes of outbreak still remain unknown.

This study also brings out the lacuna in our knowledge about insect pests in natural forests even for comparison with plantation pest problems. More research is needed on the dynamics of insect populations and the circumstances under which they become pests.

The overall conclusion from this study is that while plantations are at greater risk of pest outbreaks than natural forests, plantations of exotics are at no greater risk than plantations of indigenous tree species because the exotic status is only one among the many determinants of pest outbreak.

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The success of exotic tree species in plantations has generally been attributed to effective species-site matching and their freedom from insect pests and diseases. Nevertheless, there is a fear that catastrophic outbreaks of pests and diseases may occur suddenly in exotic plantations. There are two opposing views: that plantations of exotic species are at greater risk compared to indigenous species and conversely that exotics are at lesser risk. This report provides a critical assessment of the risk of insect pest outbreaks in exotic plantations using an empirical approach. Nine commonly planted species in the tropics, *Acacia mangium*, *Eucalyptus* spp., *Gmelina arborea*, *Hevea brasiliensis*, *Leucaena leucocephala*, *Paraserianthes falcataria*, *Pinus caribaea*, *Swietenia macrophylla* and *Tectona grandis*, were selected and their pest problems in natural forest stands, in indigenous species plantations and in exotic plantations were compared. Growing trees in monoculture increases the pest problem but the risk of pest outbreaks is not solely dependent on the exotic or indigenous status of a species. Pest outbreaks also occur in native plantations. The theory relating to insect population dynamics and causes of pest outbreaks is discussed and several factors are identified that determine the risk of pest outbreaks in exotic monoculture plantations.

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