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PROTECTING PLANTATIONS FROM PESTS AND DISEASES

Based on the work of

William M. Ciesla
Consultant

Edited by D. J. Mead

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For further information please contact:

Mr. Jim Carle, Senior Forestry Officer (Plantations and Protection),
Forest Resources Development Service
Forest Resources Division
Forestry Department
FAO
Viale delle Terme di Caracalla
I-00100 Rome (Italy)
e-mail: Jim.Carle@fao.org

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Contents

ABSTRACT

The effect of damaging pests and diseases on forest plantations, worldwide, is reviewed. The basic ecological concept of diversity leading toward stability in ecosystems would lead to the conclusion that mixed species, natural forests are less susceptible to pests and disease than single species plantations. However, both natural forests and plantations are known to be adversely affected by these agents. Case histories of pest occurrence in both exotic and indigenous species plantations are given as well as case histories of introduced vs. indigenous pests. The most frequently encountered situation is when plantations of exotic tree species are attacked by accidentally introduced pests or disease.

Both natural and plantation forests should be managed with the objective of keeping them in a healthy, productive condition, one in which pests and disease are kept at low levels and do not interfere with management objectives. Integrated pest management provides a framework of decision-making and action tools designed to maintain and improve forest health.

1. INTRODUCTION

Pests and diseases can damage trees in all stages of development and affect the ability of both natural forests and plantations to meet their management objectives. Some fungi and insects are pests of tree seedlings in nurseries while others attack older trees in a wide variety of ways. While invasive plants compete with seedlings and animals damaging forests are also sometimes problems, the focus here is on insects and diseases. Many examples exist of where one or more species of either indigenous or exotic pests or diseases have caused devastating losses to forests, requiring changes in management regimes or forcing forest managers to switch to alternative tree species. The purpose of this paper is to outline case histories of damaging insects and diseases in forest plantations and to describe the strategies and tactics available to reduce such losses.

2. PEST AND DISEASE OCCURRENCE

2.1. Plantations vs natural forests

Damaging pests and diseases are found in plantations and natural forests in both the temperate and tropical zones. A fundamental concept of ecosystem dynamics is that as diversity increases, so does stability. The greater the number of plants and animals that occupy an ecosystem, the greater are the checks and balances that prevent any one species from increasing to the point where other ecosystem components are threatened. With pests and diseases, the greatest single deterrent to population increase is the amount of available host material. For example, in a complex tropical rain forest, where as many as a thousand plant species might occupy a single hectare, a population of a host specific, phytophagus caterpillar will find only a limited amount of suitable host material. Therefore its numbers will remain fairly stable. On the other end of the diversity scale is the agro-ecosystem. Dominated by a single plant species, agro-ecosystems often cover large areas and provide a virtually unlimited amount of suitable host biomass. This can result in population explosions of organisms that use the plant as host material. Furthermore, the lack of ecosystem diversity will, at best, provide only a marginal habitat for the natural enemies of the organisms that are using the crop plant as host material.

In terms of diversity and stability, forest plantations tend to be more like agro-ecosystems than natural forests. This would lead one to conclude that plantation forests are more susceptible to damage by pests and disease than are natural forests. While this may be generally true, it does not necessarily mean that natural forests are immune to damage from these agents. The relative lack of pest outbreaks in mixed tropical forests is often cited as evidence for the importance of diversity in stabilizing plant communities (Speight and Wainhouse 1989). Many natural forests in the northern hemisphere boreal and temperate zones however, tend to be relatively simple ecosystems when compared to tropical forests and are susceptible to outbreaks of insects. Examples include:

- the spruce budworm, *Choristoneura fumiferana*, a defoliator of *Abies balsamea* and *Picea* spp in the boreal conifer forests of eastern Canada and adjoining states in the USA (Blais 1984),
- western spruce budworm, *Choristoneura occidentalis*, and Douglas-fir tussock moth, *Orgyia pseudotsugata*, in natural conifer forests of western North America (Furniss and Carolin 1977),
- the processionary caterpillar, *Thaumetopoea pityocampa*, in Mediterranean Europe and North Africa (Speight and Wainhouse 1989)
- and several species of conifer attacking bark beetles, *Dendroctonus* spp and *Ips* spp (Coleoptera: Scolytidae) in the forests of Canada, the United States, Mexico, Central America and the Himalayas (Drooz 1985, Furniss and Carolin 1977, Cibrián Tovar *et al.* 1995, Schmutzenhofer 1990).

Natural forests are also subject to damage by a variety of diseases caused by fungi, bacteria, virus or parasitic mistletoes (Manion 1991) and they are vulnerable to introductions of exotic pests and disease. The introduction of white pine blister rust, *Cronartium ribicola,* into North America (Manion 1991), the European gypsy moth, *Lymantria dispar,* into the mixed broadleaf forests of the eastern United States (Doane and McManus 1981), of two *Juniperus* infesting scale insects, *Carulaspis visci* and *Lepidosaphis newsteadi*, into Bermuda (FAO 1986, Waterston 1949) and the apparent introduction of the soil fungus *Phytophthora cinnamomi* into *Eucalyptus marginata* forests in Western Australia (Newhook and Podger 1972) are just a few examples. Moreover, the recent introduction of pitch canker disease, caused by the fungus *Fusarium subglutinans* f. sp. *pini*, into forests of *Pinus radiata*, along the California, USA coast, now is a source of concern (Storer *et al.* 1994, 1997). A more recent example is the discovery in 1994-5 of the pink or hibiscus mealybug, *Maconellicoccus hirsutus*, an insect capable of feeding on between 125 and 150 different plant species, in the Caribbean islands of Grenada, Trinidad and Tobago and St. Kitts-Nevis. This insect poses a severe threat to natural mixed tropical forests as well as vegetable crops and ornamental plants in the region (SCMA 1996).

2.2. Exotic vs indigenous tree species

2.2.1 Exotic species plantations

A typical scenario in the use of exotics in forest plantation programmes, both in tropical and temperate zones, is that they enjoy a pest free “honeymoon” for a period of time. During this period, management practices often evolve that make the plantations especially susceptible to pests and disease once they begin to appear. These include:

1. Failure to give proper attention to species/site matching.
2. Use of planting stock from a narrow genetic base.
3. Failure to maintain optimum stocking levels and tree vigor through intermediate cuttings.
4. Dependence on one or two species in a plantation programme, resulting in an unlimited supply of host material for potentially damaging organisms.

When pests and diseases do begin to appear, they may come from two sources. A complex of indigenous agents may adapt to the new host or exotic pests may be accidentally introduced.

2.2.1.1 INDIGENOUS PESTS AND DISEASES

A number of examples of indigenous insects adapting to exotic forest plantations are known. In Colombia, indigenous insects have been detected in that country's exotic *Cupressus*, *Eucalyptus* and *Pinus* plantations, with the most frequently encountered groups being defoliating caterpillars of the family Geometridae, leaf cutting ants and stem infesting insects (Madrigal C. 1993). Rodas P. (1998) reports 30 species of defoliating insects feeding on exotic forest plantations in the Andean region of Colombia. A similar situation exists in Chile, where several species of indigenous pests are now associated with exotic forest plantations including *Ormiscodes cinnamomea*, a large Saturniid that occasionally defoliates *Pinus radiata* (Ciesla 1997). Ohmart and Edwards (1991) report 96 indigenous insects feeding on various species of *Eucalyptus* in China, 94 in India, 223 in Brazil, 31 in New Zealand, 105 in Papua New Guinea and 62 on the island of Sumatra, Indonesia. Termites and leaf cutting ants are the major damaging agents.

Indigenous disease causing organisms are also capable of adapting to new hosts and causing severe damage. In Kenya, plantations of *Cupressus macrocarpa* have been severely damaged by *Monochaetia unicornis*, a stem canker causing fungus (Odera and Arap Sang 1975, 1980). During the early 1990s, several species of foliar and twig pathogens, including Cylindocladium leaf blight, Coniella leaf spot, Kirramyces leaf spot and pink disease, *Corticum salmonicolor,* damaged *Eucalyptus* plantings in Vietnam (Sharma 1994).

2.2.1.2. EXOTIC PESTS AND DISEASES

The greatest hazard of pest and disease damage to exotic forest plantations is from the accidental introduction of exotic pests and diseases. Exotic pests and diseases agents, in the absence of natural enemies, and provided with a large supply of suitable host material, that may have little resistance to the new pest or disease, can build up rapidly and cause devastating losses.

One of the best-documented examples of exotic pests and diseases causing damage to exotic plantations is to pine plantations in the Southern Hemisphere, especially *Pinus radiata*. *P. radiata* were first planted in the late nineteenth century in Australia, Chile, New Zealand and South Africa. The excellent growth and form of the tree in these locations encouraged additional plantings. These provided the basis for thriving lumber and paper industries, especially in Chile and New Zealand. One of the first exotic insects to appear in New Zealand's radiata pine plantations was the European wood wasp, *Sirex noctilio*, during the early 1900's. This insect was probably introduced on unprocessed pine logs imported from

Europe. Native to southern Europe and North Africa, where it causes little or no damage, *S. noctilio* normally breeds in recently killed pines. Plantations established in New Zealand during 1920-30 stagnated because there was no market for small logs from thinning operations. This made the plantations susceptible to *S. noctilio* and its associated fungus, *Amylostereum areolatum.* By 1947, high levels of tree mortality were occurring, primarily in the unthinned plantations (McLean 1998). However, today *S. noctilio* is not a problem because of biological control methods and better stand management.

S. noctilio subsequently appeared in *P. radiata* plantations in Australia in 1952 (Gilbert and Miller 1952; Taylor 1981). In 1980 infestations were detected in South America where this insect is damaging plantations of *P. elliotii* and *P. taeda* in Argentina, southern Brazil and Uruguay (Rebuffo 1990; Iede *et al.* 1988). In 1994, infestations of *S. noctilio* were discovered in *P. radiata* plantations in the Cape Peninsula of South Africa (Tribe 1995).

Other damaging insects that have been introduced into *P. radiata* plantations include the bark beetle, *Ips grandicollis*, a North American species, into Australia (Morgan 1989) and the European pine shoot moth, *Rhyacionia bouliana* into Argentina and Chile. The latter is now regarded as Chile's number one forest insect pest (Ramirez Grez 1993; Ciesla 1997). The European bark beetles, *Hyalstes ater* and *Hylurgus ligniperda* were introduced into Chilean radiata pine plantations during the late 1980s and are capable of killing young pine seedlings (Ciesla 1988).

Several introduced fungi have also caused severe damage to *P. radiata* plantations. In 1957, a needle fungus, *Dothistroma septospora (D. pini)*, became a major concern in *P. radiata* plantations in Chile, parts of East Africa and New Zealand, although there are records of its occurrence in these areas as early as 1940 (Manion 1991). The stem disease, *Sphaeropsis sapinea* (*Diplodia pini*) has also been introduced in a number of countries. This fungus has been especially damaging in Kenya, where it first appeared in 1973 and proliferated on *P. radiata*, a species adapted to a winter rainfall regime and is especially susceptible to fungal attacks during periods of rain and warm temperatures (Odera and Arap Sang 1975, 1980).

Another example of damage to exotic forest plantations by an introduced pest is that of the leucaena psyllid, *Heteropsylla cubana* (Homoptera: Psyllidae) on *Leucaena leucocephala*, a fast growing legume native to Mexico and Central America. This tree was introduced into the Philippines as early as 1565 and was quickly established throughout the tropics where local people found it an excellent fuelwood and later as shade under which crops such as coffee, cocoa, pepper and vanilla could be grown. Genetically improved varieties were eventually introduced into the tropics where it was regarded as having the widest range of uses of all of the tropical legumes. In 1983, leucaena psyllid, a somewhat obscure insect of *L. leucocephala* in its natural range, was detected in southern Florida, USA and during the following year it was found in the Hawaiian Islands. The insect spread rapidly across the Asia and Pacific Region between 1985 and 1988. In 1991, infestations were found on the southern Indian Ocean islands of Reunion and Mauritius and one year later in several eastern African countries, including Burundi, Kenya, Tanzania and Uganda. This insect feeds on the shoots and young foliage of Leucaena causing wilting and growth loss (Banpot Napompeth 1994).

Ironically, attempts to introduce new genetic material into a country have occasionally resulted in introductions of damaging pests. In 1968, a pine woolly aphid, *Pineus borneri* (also reported as *P. pini),* was introduced into Kenya on *Pinus caribaea* grafts imported from Australia (Owour 1991). Twenty years later, a scale insect, *Oracella acuta*, was introduced into China on *P. elliotii* scion material introduced from the United States. By 1995, over 212,500 ha of *P. elliotii* plantations in Guangdong Province in southern China were infested by this insect (Jianghua Sun *et al.* 1996).

2.2.2 Indigenous species plantations

Throughout much of Asia, Europe and North America, forest plantations are typically established with indigenous species (e.g. *Pinus massoniana* in China, *Picea abies*, *Pinus sylvestris* and *Populus* spp in Europe, *Pinus taeda* and *Pinus elliotii* in the southeastern USA and *Pseudotsuga menziesii* in western Canada and the USA). These plantations are also susceptible to damage by a complex of both indigenous and exotic pests and disease.

2.2.2.1. INDIGENOUS PESTS AND DISEASES

In China and Vietnam, the defoliating caterpillar, *Dendrolimus punctatus*, is a major pest of indigenous pine plantations. This insect has two generations per year in east-central China where it defoliates *Pinus massoniana*. In Vietnam, *D. punctatus* has four generations per year and outbreaks have occurred in plantations of *P. merkusii*, often established on steep deforested slopes where they are an important source of lumber, pulpwood, fuel wood and resin (Dao Xuan Troung 1990).

Nun moth, *Lymantria monacha*, is a defoliating caterpillar of both *Picea abies* and *Pinus sylvestris* in central Europe. This insect was originally a major pest of natural *Picea abies* forests but readily adapted to the extensive pine plantations. In Poland, plantations of *P. sylvestris* are established on low nutrient, sandy soils or abandoned marginal agricultural lands. Between 1978 and 1983, a major outbreak of this caterpillar necessitated aerial spraying of 2.5 million ha, over 25% of Poland’s forests (Speight and Wainhouse 1989). In 1991, this insect again reached outbreak proportions and large areas of forest were treated between 1992 and 1994. Other defoliating insects of *P. sylvestris* plantations in Europe include *Bupalis piniarius, Panolis flammea*, *Dendrolimus pini* and sawflies, *Diprion* spp. (Speight and Wainhouse 1989, Ciesla 1994).

Fusiform rust, caused by the fungus *Cronartium quercuum* f.sp. *fusiform*, has become a serious pest of *P. elliottii* and *P. taeda* plantations in the southeastern USA. Prior to 1900, the disease was rare, but because of intensive cultural practices associated with plantation forestry, including planting of infected seedlings, fire management, genetic selection of fast growing trees and expansion of the range of susceptible hosts, this disease has become a major problem. Recent estimates indicate that $US130 million in damage is occurring annually and the disease is increasing at the rate of 2-3% per year (Manion 1991).

In China, species of *Paulownia*, are widely planted either as ornamentals in villages or in intercropping systems. Pawlonias are commonly infected by a mycoplasma-like organism (MLO), which produces large witches brooms in tree crowns. This disease causes significant reductions in increment, leading to a gradual decline and death of infected trees. The wood of infected trees is of reduced quality (Tsai *et al.* 1988).

2.2.2.2. EXOTIC PESTS AND DISEASES

The pine wood nematode, *Bursaphelenchus xylophilus* is the cause of pine wilt disease. This disease has been a major cause of tree mortality in pine plantations in Japan since the early 1900's. The nematode is probably native to North America and has been introduced into Japan and more recently China, where it is causing extensive tree mortality in plantations of *Pinus massoniana*. The nematode is spread from tree to tree by longhorn wood boring beetles, *Monochamus* spp, when the adult beetles feed on pine shoots (Manion 1991).

2.3 Mixed vs single species plantations

The concept of diversity leading to ecosystem stability would suggest that mixed species plantations would be more pest and disease resistant than single species plantation. Indeed, work by Klimetzek (1990) in Germany indicates that the inclusion of broadleaf trees in pine forests, either as a mixture or in the understory, tends to reduce the incidence of outbreaks of *Lymantria monacha.* On the other hand, planting *Picea abies* under a plantation of *P. sylvestris*, could intensify or prolong outbreaks of this insect since both trees are hosts.

Wormald (1992) indicates that data on relative susceptibility of mixed and pure species plantations in subtropical and tropical regions is, at best, inclusive and confusing. While examples of where pests and diseases have become problems in pure species plantations are cited, many result from accidental introductions or of indigenous pest species adapting to new conditions. Furthermore he cites examples where establishment of mixed species plantations has had little or no effect on reducing pest caused losses.

Some temperate zone pests and diseases have adapted to mixed-species ecosystems by having evolved life stages on alternate hosts. Many rust diseases fall into this category, including fusiform rust of *P. elliotii* and *P. taeda*, *Cronartium quercuum* f.sp. *fusiform*, which has alternate spore stages on oak, *Quercus* spp. Therefore, removal of oaks from the vicinity of pine nurseries in the southeastern USA is a common although not altogether effective practice (Manion 1991). Cooley spruce gall aphid, *Adelges cooleyi*, an insect indigenous to western North America, has alternating life stages on *Picea* and *Pseudotsuga menziesii*, trees that are often found growing in close proximity to one another in natural forests (Speight and Wainhouse 1989).

Perhaps a greater concern with regard to pests and diseases is not mixed vs. single species plantations, but the number of species used in a country's plantation programme. Reliance on one or two closely related species may meet a country's needs for wood products and foreign exchange. However, should a pest or complex of pests appear in these plantations, the results could be devastating. Yet, many countries have fallen into this dilemma. Examples include Kenya, where 46% of its industrial plantation area is composed of *Cupressus lusitanica* (Ciesla *et al.* 1995); Colombia with 66% of its plantations *Pinus patula* (Madrigal 1993); Poland with 70% of its plantation forests *P. sylvestris* (MEPNRF 1991); and Chile and New Zealand with 90% of their plantations composed of *P. radiata* (Ramierez Grez 1993; Ciesla 1997). New Zealand experience has been that deliberately planting a wide range of species to reduce risk from pests and diseases did not work (D. J. Mead pers. comm.). Rather, good site matching and silviculture, coupled with emphasis on disease prevention and control, backed by research, has been used as an alternative strategy.

1. MANAGING PESTS AND DISEASES

3.1 Healthy forests – the objective

The objective of managing pests and diseases in forests and forest plantations should be to keep them in a healthy, productive condition. What is a healthy forest? The concept of a healthy forest became a popular concept during the mid- to late 1980s. In economic terms, a "healthy" forest can be defined as "a forest in which pests and diseases remain at low levels and do not interfere with management objectives." In ecological terms, a healthy forest is "a fully functional ecosystem; one in which all of its parts can interact in a mutually beneficial way."

The healthy forest concept directs forest managers to focus on the forest rather than its pests and diseases and takes into account the natural role of insects, fungi, fire and other so called "damaging agents" and their interactions in forest dynamics. Under an overall policy of forest health protection, pests and diseases are looked upon as a symptom of an unhealthy forest rather than as the problem. This directs forest managers and forest protection specialists to address the underlying causes of the pest or disease – factors such as overstocking, over-maturity, poor site/species matching, excessive fuels and single species forests with little diversity. Striving for healthy forests also involves anticipating pests and diseases based on historical records of their occurrence and the knowledge of forest and climatic conditions that favour their abundance. This allows time to implement management practices that will make these forests inhospitable for build-up of damaging pests and disease (Ciesla 1998).

The healthy forest concept may sound like an idyllic approach to managing forest pests and diseases, especially in cases where an introduced pest is causing widespread damage in a simple plantation ecosystem in the absence of its normal complex of natural enemies. Yet even the most damaging of exotic pests and diseases respond to stand and site conditions and there is evidence that they focus their activities on "unhealthy" forests. A classic example is that of *Sirex noctilio* in exotic pine plantations in the Southern Hemisphere. In New Zealand, it was noted that stressed trees in unthinned plantations were the first to be attacked by this insect. Therefore, by its action, the plantations were effectively thinned (McLean 1998). Thinning is now an integral part of managing plantations threatened by *S. noctilio* in places where this insect has been introduced. In another example, when a cypress aphid, originally identified as *Cinara cupressi*, appeared in eastern and southern Africa, most severe damage occurred in plantations of *Cupressus lustianica* that were either overmature or had been established on low nutrient soils (Claude and Fanstin 1991, Ciesla *et al*. 1995, Obiri 1994).

3.2. Integrated pest management – the tools

The healthy forest concept provides the umbrella or objective for addressing damage caused by pests and diseases. Integrated pest management (IPM), on the other hand, provides the tools to accomplish this task.

The concept or philosophy of IPM as a "rational" approach to pest control was formalized during the 1960s. Crop protection specialists had become aware of the adverse side effects of dependence on chemical pesticides, including pesticide resistance, occurrence of secondary pests, environmental damage and human health hazards. This led to the realization that alternative approaches, including cultural, biological and genetic tactics, used either alone or in combination, were also needed to provide long-term, effective protection against damaging pests.

Numerous definitions of IPM appear in the literature. Smith *et al.* (1976) refer to IPM as "*a process based on ecological principles and integrates multi-disciplinary methodologies in developing agro-ecosystem management strategies that are practical and effective and protect both public health and the environment.*" Pimentel (1986) describes IPM as a "*pest control method that includes judicious use of pesticide and non-chemical technologies – all of which are based on sound ecological principles.*"

IPM can be looked upon as consisting of two basic elements; a decision process and an action process. The decision process establishes the basis for any subsequent actions to be undertaken, including no action. The action program may consist of one or more ecologically, economically and socially acceptable tactics designed to reduce pest populations to non-damaging levels (Ciesla 1982).

3.2.1 The decision process

The decision process is often the most time consuming and complex aspect of IPM. It requires careful consideration of the pest, its host, resource management objectives and the ecological, economic and social consequences of the various available tactics. Population levels of pests are estimated and anticipated resource losses are projected, as are the costs of treatment and its anticipated benefits. If treatment costs exceed losses, a rational decision may be to not treat and accept the losses. Other questions to address include: will natural controls take over within a short enough time so that artificial controls will be unnecessary; or will the effects of proposed treatments be so adverse that they would outweigh the benefits of treatment?

Monitoring of forest pests and diseases and their resultant damage is a critical input to the IPM decision process. Pest monitoring is becoming a sophisticated process that makes use of many technologies. Pheromones and other chemical regulators are often used to monitor insect population levels. Remote sensing technologies such as aerial sketch-mapping, aerial photography and airborne video are used to map and assess forest damage. Geographic information systems (GIS) can be used to relate the location of affected areas to key resource values, terrain features, land ownerships and environmentally sensitive areas. Mathematical models can predict resultant damage caused by certain levels of pest numbers and their consequences. In some cases, pest, growth and yield and economic models are linked to make projections of pest and disease impacts. Data visualization techniques can display the expected results of alternative action tactics.

3.2.2 The action process

IPM action programmes consist of two overall strategies: prevention or direct control (suppression). Specific pest management tactics exist under each of these strategies.

3.2.2.1. PREVENTION

Prevention consists of tactics designed to either reduce the probability of the occurrence of a pest or disease or to create environmental conditions inhospitable for its buildup into damaging numbers. Regulatory, cultural or genetic tactics are examples of prevention strategies.

Regulatory tactics are designed to prevent introductions of exotic pests and diseases and to prevent their spread once established. Examples include inspection of wood products and wooden containers at ports of entry to intercept pest species, conduct of pest risk analyses when new trade agreements are made and establishment of quarantine zones when a pest species is first discovered in a new location.

Cultural tactics are designed to create conditions inhospitable for the development of damaging numbers of pests and diseases. These include matching tree species selected for planting to suitable growing sites, controlling stocking through intermediate harvests to maintain tree vigor and timely harvesting of plantations when they reach maturity. A drastic but sometimes necessary cultural approach is to simply eliminate a tree species from a plantation programme because of its high susceptibility to certain pests and diseases. An example is Kenya’s policy to discontinue planting of *Cupressus macrocarpa* due to the stem canker fungus, *Monochaetia unicornis*, and *P. radiata* because of its susceptibility to *Sphaeropsis sapinea* (Odera and Arap Sang 1975, 1980).

Genetic tactics make use of varieties of host plants that are either more tolerant to damage or less palatable to the pest. Identification and testing of varieties of *Leucaena leucocephala* and hybrids with other species of *Leucaena* for resistance or tolerance to the psyllid, *Heteropsylla cubana*, was a major line of investigation following this insect’s introduction into the Asia-Pacific region (Banpot Napompeth 1994). In the southeastern United States, screening and development of pine seedlings resistant to fusiform rust is an integral part of the management of this disease (Manion 1991). Tree breeding programmes in Brazil address resistance to the canker *Cryphonectria cubensis* on eucalypts and breeding of *P. radiata* in New Zealand includes a rating for resistance to the needle fungus *Dothistroma pini* (McLean 1998).

3.2.2.2. SUPPRESSION

Tactics directed against the pest or disease are referred to as direct control or suppression tactics. Examples include various types of biological, mechanical or chemical methods.

Biological control involves the use of natural enemies of a pest or disease to help keep its numbers in check. Classic biological control, a technique widely used in agriculture, involves the importation of natural enemies to help control an exotic pest. In Colombia, the geometrid *Oxydia trychiata*, an indigenous species attacking pines and cypress, was successfully controlled by the introduction and release of an egg parasitoid *Telenomus alsophilae* (Bustillo and Drooz 1977). In another successful example of classic biological control, releases of a parasitoid, *Pauesia bicolor*, resulted in the collapse of an aphid, *Cinara cronartii*, a North American species accidentally introduced into pine plantations in South Africa (Kfir *et al.* 1985, Mills 1990). In Chile, state-of-the-art mass rearing facilities have been established by forest industry for production of the European pine shoot moth parasitoid, *Orgilis obscurator*. One such laboratory, *Controladora de Plagas Forestales*, was established in 1992. In 1996, this facility produced 1.2 million parasitized larvae and 22,600 adult female parasitoids for field release (Controladora de Plagas Forestales 1997).

A key concern about biological control is the possibility that the introduced natural enemy might also attack innocuous or beneficial insects in the ecosystem. Therefore it is necessary to thoroughly evaluate candidate species prior to release to ensure their relative host specificity. Another concern is the hazard of accidentally introducing hyperparasites, natural enemies of the biological control agents, which might eventually affect the agent's efficacy. For example, colonies of the leaucana psyllid predator *Olla v-nigrum*, released on the Indian Ocean island of Reunion, were subsequently discovered infested by three species of hyperparsites (Quilici *et al.* 1995). These could severely affect the ability of this predator to function as an effective biocontrol agent.

Augmentative biological control is a process designed to increase the efficiency of natural enemies already in place. Mass release of *Trichogramma dendrolimi*, an indigenous egg parasitoid of the defoliator *Dendrolimus punctatus* in pine plantations in China is an example of this tactic (Yan and Liu 1992). Another biological control tactic is the use of biological insecticides such as the bacterial agent, *Bacillus thuringiensis* (Bt), nuclear polyhedrosis viruses or fungal preparations to control insects. Bt is widely used for control of lepidopterous defoliators in both natural and plantation forests. In China and Vietnam, a fungus, *Beauvaria bassiana*, is used for control of the pine caterpillar, *Dendolimus punctatus* (Anon 1993).

Mechanical tactics include removal and destruction or rapid removal of infested or infected trees with the objective of destroying the pest. Examples include cutting and burning of trees infested by bark beetles or rapid salvage of infested trees and destruction of infested bark at the sawmill. When the pine woolly aphid, *Pineus borneri*, was first discovered in Kenya, the initial response was to destroy the infested pines. This insect is easily carried on air currents, however, and it was soon realized that the infestation had spread far beyond the designated area where trees were being destroyed (Owour 1991).

Use of chemical pesticides applied either from the ground or by low flying aircraft is still considered to be an integral part of IPM. However these materials are used more sparingly, are applied at reduced intervals and with greater precision. In IPM, chemical pesticides are often considered to be the tactic of last resort.

3.2.3 Integration of new technologies

An important part of IPM is that no matter how advanced, sophisticated or effective an IPM system for a specific pest or pest complex may be, there is always room for the introduction of new technologies. These may include more accurate pest monitoring, prediction of new pest management tactics, and more efficacious treatments with fewer undesirable side effects.

3.2.4 Integrated pest management systems

IPM systems consist of a combination of decision-making and pest management tools directed against a pest or pest complex and are in various stages of development. An example of an evolving IPM system is the approach being taken to manage the European wood wasp, *Sirex noctilio*, in pine plantations in southern Brazil. Early detection of this insect is accomplished by baiting suppressed trees in plantations with an herbicide, a procedure that attracts attacking wasps. Infestations are treated either through inoculation of a parasitic nematode, *Daladenus siricidola*, which renders the female wood wasps incapable of producing eggs, or thinning plantations to reduce stocking and maintain tree vigor (Iede and Ciesla 1993). Damage assessment technologies such as aerial sketch-mapping and aerial photos (Disperati *et al.*1998, Ciesla *et al.* 1999) are currently being evaluated. Landsat satellite imagery is being tested to determine its capacity to map the location of small, non-industrial private pine plantations that might serve as reservoirs for populations of this damaging insect. Introduction of additional parasitic insects is another potential tactic for managing this insect (Iede *et al.* 1998).

2. CONCLUSIONS

The basic ecological concept of diversity leading toward stability in ecosystems would lead one to conclude that mixed species natural forests are less susceptible to damaging forest pests and diseases than single species plantations. However, both natural forests and plantations are known to be susceptible to a variety of damaging pests and diseases. Some northern temperate natural forests tend to be relatively simple ecosystems. These forests have a history of periodic outbreaks of bark beetles, defoliators and other insect pests. Moreover both natural forests and plantations are damaged by a variety of fungi, bacteria, parasitic plants and other disease causing agents. Consequently, effective monitoring and protection of forests against damaging pests and diseases must be an integral part of forest management regardless of whether the forests are natural or plantations, composed of exotic or indigenous species, single species or mixed.

Many records of devastating pest losses are reported in forest plantations. Plantations of exotic tree species can be attacked by indigenous pests, which have adapted to the new host, or introduced pests, which, in the absence of natural enemies, can build up into large numbers. Inadequate plantation management of either exotic or indigenous species will increase the susceptibility of plantations to pest and disease damage. These including poor species-site matching, planting stock with low genetic variability, failure to maintain tree vigour through intermediate cuttings, and reliance on one or two species in a national plantation programme.

While logic might dictate that mixed species plantations are less susceptible to damaging pests and diseases, and cases exist that support this notion, it is by no means certain this is a good tactic. Mixed species plantations may not necessarily meet management objectives. There are also cases where pest species have evolved that can survive on several closely related hosts or have alternative life stages on two unrelated hosts. These agents are best adapted to mixed-species situations.

Both natural and plantation forests should be managed with the objective of keeping them in a healthy, productive condition, one in which pests and disease are kept at low levels and do not interfere with management objectives. Integrated pest management (IPM) is a framework of decision-making and action tools designed to maintain and improve forest health. Pest and disease monitoring ensures early detection of potential problems. Combined with analysis of the economic, social and ecological impacts of pests, a sound basis on which to decide for or against control is derived. Two basic strategies, prevention or direct suppression, each with a range of tactics, can be applied. Prevention consists of actions taken to make trees and forests less hospitable to the build-up of pests and diseases and/or preventing new introductions. Direct suppression consists of biological, chemical or mechanical tactics designed to reduce pest and disease populations and subsequent losses. IPM systems consist of a combination of monitoring and action tools designed to reduce pest-induced losses. These systems are continuously evolving and are capable of accepting new technologies, as they become available.

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