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Biosecurity and Forests: An Introduction

with particular emphasis on forest pests

by

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with inputs from

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Disclaimer

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EXECUTIVE SUMMARY

‘Biosecurity’ in food and agriculture describes the concept and process of managing biological risks associated with food and agriculture (in its broadest sense, i.e. including forestry). Biosecurity is emerging as one of the most important issues facing the international community. There is a growing need for countries to establish biosecurity systems, either to meet obligations under international agreements (for example, in the environmental sector) or to take advantage of opportunities (for example, in the trade sector).

In the forestry sector, biosecurity encompasses three main fields of activity: forest protection and phytosanitary issues; naturalization of introduced forestry trees and their impact on ecosystems or individual species; and the release of new genotypes, including genetically modified organisms.

Phytosanitary issues

‘Pests’ are defined by the Food and Agriculture Organization (FAO) as any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products, i.e. insects, mites, molluscs, nematodes, diseases and weeds. Indigenous pests may be chronic or occur in outbreaks, whereas introduced pests usually occur in an initial outbreak followed by continuous chronic damage. Both types of pest can cause severe losses, making them important factors in forestry.

Tropical and subtropical plantation forestry has often focused on a small number of fast-growing, pioneer species, normally planted as pure stands. Monocultures, especially of genetically similar trees, are associated with an increased probability of pest outbreaks and can also transform sporadic pests into permanent problems. Mixed planting of native (and exotic) trees is therefore increasingly preferred as a strategy for avoiding pest problems. Pest risks associated with a particular tree/location combination should be evaluated prior to planting and the results confirmed with test plots.

There is a growing trend towards adopting more sustainable management strategies for forest pests, particularly in developed countries. These changes are related to changes in the perception of the role of the forest, which is increasingly valued not just for economic reasons, but also for its ecological and social functions. Large monocultures are disappearing from many European and North American landscapes and are being replaced by smaller, mixed stands, which reduce pest risks as mentioned above.

Analysing and evaluating pest risk requires reliable information. As might be expected, more information is available on pests of trees grown in developed rather than in developing countries, and also for pests of trees grown in plantations rather than for pests in natural forests. Virtually nothing is known of the pests associated with those trees harvested from natural forests and not grown in plantations, at least in the tropics. There is an urgent need for surveys and identification of the pests and diseases associated with many important tropical timber trees, in both natural and plantation situations.

Alien invasive species

Alien species can be particularly damaging during plantation establishment, but can also have important impacts on forest biological diversity, especially in the tropics. An increasing number of accidental introductions can be expected as a result of the growing internationalization of trade, the increased movement of people and the resultant overstretching of quarantine services.

Some forest and agroforestry trees have the potential to become invasive when grown as exotics, particularly in the tropics, but it is difficult to predict which alien species are likely to cause serious damage if introduced. Species that are innocuous or minor pests in their area of origin can be devastating when introduced elsewhere. At present, the best guide to potential invasiveness is those species that have already caused problems when introduced into another part of the world. Thus, access to reliable information is critically important for assessing this risk. Studies are needed to determine why introduced trees become naturalized or invasive, and protocols for assessing the risks of introductions must be developed and validated. Pilot planting schemes should include monitoring for any indications of invasiveness. Safer options for introductions (e.g. sterile trees) may also be useful.

The longer an alien species remains undetected after its introduction, the less chance there is for successful intervention: there are fewer options for its eradication, containment or control, and the costs of intervention rise. Often the key to a successful and cost-effective solution is eradication, but this requires both early detection of an alien species and a rapid response. Once eradication is no longer feasible, the options for control of an alien species include biological control by the introduction of exotic natural enemies from the pest's area of origin. However, this approach should always be based on an appropriate risk assessment and risk–benefit analysis, following international protocols.

Invasive tree species tend to be multisectoral in their impact, and thus need to be addressed with a multisectoral approach. In some cases invasive trees provide useful products or services and, when eradication is not possible, management options should be identified in order to balance the positive and negative aspects.

New genotypes

The introduction of new tree genotypes could potentially have adverse impacts, e.g. through the displacement of indigenous taxa or genotypes, or the transfer of genes (leading to local evolution, hybridization and introgression), with the resultant development of new taxa with novel ecological characteristics. However, as yet, there are few records of such impacts in the forestry sector. Introductions of other species associated with forestry, including biological control organisms, pollinators, mycorrhizae, etc., should be considered with caution and on a case-by-case basis.

The development of genetic modification has created new challenges in risk assessment. Although the first generation of GM products was not particularly relevant to forestry, there are numerous ways in which the technology could be used in forestry, and research in the field is extremely active. There seems to be considerable potential for improving forest trees by developing new genotypes with useful biological traits. However, assessing risks in long-term crops such as forest trees is difficult, and uptake of GM technology is likely to be slow unless protocols that reliably assess the risks are developed, tested, and agreed upon.

Managing biosecurity issues

Forestry activities can contribute to the introduction of alien species in several ways, including the movement of forest reproductive materials and germplasm, solid wood packaging materials, trade in unprocessed timber, and contaminants of forest produce. The forestry sector needs to work with other relevant sectors to prioritize the risks associated with these various activities and to find ways of addressing them.

In establishing the objectives of a biosecurity programme, it is critically important to consider the full range of stakeholders and their various interests in order to identify areas where cooperation is necessary and where synergies and efficiencies may be sought. In doing so, the whole regulatory cycle and the full range of players must be considered. Several groups may need to contribute to the definition of objectives and to the assessment of risks. Raising awareness, training and capacity building should therefore be important components of any biosecurity programme.

1. INTRODUCTION

1.1. Definitions

Biosecurity is a relatively new concept and its meaning is still evolving: usage varies among different countries and even among different specialist groups. It also presents difficulties when translated into other languages, for example, in Spanish 'biosecurity' and 'biosafety' cannot be distinguished, while in French biosafety ('biosécurité') is used as the definition for the transboundary movement of living modified organisms under the Cartegena Protocol[1]. To add to the confusion, biosecurity has also been used to describe the organized response to bioterrorism.

Despite these ambiguities, some countries have established biosecurity policies. New Zealand passed a Biosecurity Act in 1993 and established a Biosecurity Minister and Council in 1999 to manage risks posed to the economy, environment and people's health by the movement of various organisms. Similarly, Biosecurity Australia, located within the Department of Agriculture, Forestry and Fisheries, deals with risks pertaining to the import of animals, plants and their products.

Broadly speaking, 'biosecurity' in food and agriculture describes the concept and process of managing – in a holistic manner – biological risks associated with food and agriculture (in the broadest sense, i.e. including agronomy, livestock husbandry, forestry, fisheries and related environmental aspects). This usage also implies that transboundary movements or the use of novel genotypes are involved in some way.

A separate, though related, concept is 'biosafety', which, as developed for the Cartagena Protocol on Biosafety, is used specifically in relation to the release and transboundary movement of living modified organisms (LMOs). In one sense, therefore, biosafety is more limited in scope than biosecurity (since it refers only to LMOs), but in another sense it is broader, since it also encompasses the use of LMOs in medicine. Biosecurity in food and agriculture must be developed in harmony with the provisions of the Cartagena Protocol, while keeping these differences in mind.

The FAO Expert Consultation on Biosecurity (September 2002) discussed terminology and concluded that the phrase 'biosecurity in food and agriculture' best describes the concept as used by FAO and was unable to identify a satisfactory alternative (FAO 2003a).

[1] The Conference of the Parties to the Convention on Biological Diversity adopted a supplementary agreement to the Convention known as the Cartagena Protocol on Biosafety on 29 January 2000, which came into force on 11 September 2003. The Protocol seeks to protect biological diversity from the potential risks posed by living modified organisms resulting from modern biotechnology. It establishes an advance informed agreement (AIA) procedure for ensuring that countries are provided with the information necessary to make informed decisions before agreeing to the import of such organisms into their territory (see http://www.biodiv.org/biosafety/).

1.2. Scope

The FAO has outlined the scope of biosecurity as follows:

"Biosecurity is composed of three sectors, namely, food safety, plant life and health, and animal life and health. These sectors include food production in relation to food safety, the introduction of plant pests, animal pests and diseases, and zoonoses, the introduction and release of genetically modified organisms (GMOs) and their products, and the introduction and safe management of invasive alien species and genotypes. Biosecurity thus has direct relevance to food safety, the conservation of the environment (including biodiversity) and sustainability of agriculture." (FAO 2001).

The aspects considered relevant to the forestry sector are:

- Plant (i.e. tree) health as affected by biological factors – i.e. all groups of both introduced and indigenous pests (including insects, mites, molluscs, nematodes, diseases and weeds).
- The use of alien plant species in forestry (trees, but also associated species such as cover crops) that could become invasive.
- The introduction and release of exotic genotypes, including living modified organisms (LMOs) and their products.
- Forestry activities that may provide a pathway for the accidental introduction of alien species.

Biosecurity in forestry seeks to identify, prevent and remedy harm in specific sectors. In this context, it may be worthwhile highlighting the differences between harm and risk: 'harm' is the damage done by something that might have been prevented through biosecurity, whereas 'risk' is the chance of that harm occurring. Where risk is involved, there can never be absolute protection or certainty. The aim should be to optimize possible benefits while minimizing the risk posed by exposure to a potential hazard. This inevitably involves financial, ethical and technical factors. Public perception is also of great importance, and facilitating public understanding of risk is not easy. Often, the public demands a level of risk protection that is difficult to justify on technical or economic grounds, while a perceived failure of biosecurity can destroy public confidence in the whole concept.

The decision to initiate and implement a biosecurity regime is often based on the concern that a known problem (such as the introduction of a forestry pest) may reoccur. However, there is also an increasing perception that the use and products of new technologies need to be regulated, particularly in view of the speed and power of technological advances, and their associated uncertainties (transgenic crops are a good example).

The geographical scope of biosecurity measures should also be considered. While most national food and agriculture biosecurity structures have been established on an ad hoc basis, many countries are increasingly establishing regulatory frameworks that aim to protect global common goods and to respond to increasingly globalized risks, either to meet obligations under international agreements (for example, in relation to health, food safety, pest control, zoonoses and bioterrorism) or to take advantage of trade opportunities (for example, through the World Trade Organization Sanitary and Phytosanitary Measures Agreement (WTO SPS)).

No country can afford to ignore transboundary risks, which can have catastrophic implications for human well-being, the environment and the economy. A biosecurity failure in one country will often cause problems in neighbouring countries, particularly where shared terrestrial boundaries are not protected by natural ecological barriers. In this context, regional coordination and mutual support could have very substantial advantages. Some examples of the economic consequences of failures in biosecurity systems are given in the case studies.

Subnational boundaries (based on geographical and ecological features) may also be highly significant, particularly in those countries that include islands or island groups. Biosecurity systems should also be developed to protect these boundaries. For example, the Hawaiian Islands have one of the highest invasion rates of alien organisms amongst oceanic islands; while there are legal barriers to slow down the rate of movement of organisms between mainland USA and these islands, they are comparatively ineffective: the postal system, for example, is not subject to inspection without a warrant. Similarly, the majority of invasive alien species arriving in the Galapagos Islands come from mainland Ecuador without crossing national boundaries. Even within a single conterminous country, movement of organisms can be very important, e.g. between the east and west coasts of Australia or the USA. At present, for example, one of the highest profile pest species in the USA is the glassy-winged sharpshooter (*Homalodisca coagulata* (Say); Cicadellidae), a pest of vines which has managed to spread from Florida (where it is indigenous) to California, where it is threatening the wine and table grape industry.

These examples show that, in most cases, biosecurity should be considered to be both national and international in scope.

It is clear, therefore, that implementing biosecurity can involve a number of integrated activities at regional and national levels, including:

- identifying biosecurity issues for each sector at a national level;
- ensuring coordination and cooperation among the relevant authorities and ministries in relation to both national policy and action, and in the definition of common international actions;
- harmonizing and integrating national legislation to rationalize sanitary, phytosanitary and zoosanitary measures, while protecting human health and the environment;
- harmonizing methods for risk analysis and standard-setting across sectors;
- establishing, rationalizing and optimizing national capacity, with the aim of avoiding duplication, inconsistency and disputes among the relevant national agencies;
- making optimal use of regional resources and capacities; and
- cooperating in the international exchange of relevant information.

1.3. Importance of biosecurity

Biosecurity is emerging as one of the most important issues facing the international community, for a number of reasons:

- Producers' livelihoods can be destroyed by animal and plant pests, diseases, or damage to the environment.

- Processors rely both on high-quality primary produce and on stable consumer demand, based on trust in their products. They are at severe economic risk if either is compromised, either through an external failure of biosecurity measures, or through internal risks, such as contamination in the course of processing.
- Ecosystem stability, and hence maintenance of ecosystem services to the environment and society, can be threatened by unwanted changes resulting from the introduction of invasive alien species or genotypes.

Two main factors have increased the perceived threat of these hazards, namely the increased global movement of biological materials and the rapid development of technologies associated with genetic modification. Over the past few decades, for example, the steady decline in the relative cost of transport, coupled with trade liberalization, have resulted in much wider movement of people, plants, animals and their products (including seed and reproductive material) than has previously been the case. This has severely strained the ability of quarantine and inspection services to prevent the unwanted introduction of alien species and genotypes of both plants and animals. Meeting this ever-expanding challenge will require cooperation across sectors, with optimal use of existing agencies and agreements. The Convention on Biological Diversity (CBD), for example, recognized the need to "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species" (CBD 2000). In relation to plant health and movement, the International Plant Protection Convention (IPPC) is the most important international agreement. Ideally, to achieve their individual aims, the CBD and IPPC should be applied in parallel in a cooperative manner. This type of cross-sectoral collaboration exemplifies the way in which biosecurity should develop.

As mentioned above, new technologies can also pose new potential risks to both human health and the environment, and as such require due consideration in any assessment of biosecurity. In this context, risk analysis is becoming increasingly important as a basis for regulatory decisions. Recognition of the risk implications of international trade in genetically modified organisms was the reason for the adoption of a new international agreement, namely the Cartagena Protocol on Biosafety, as part of the CBD.

2. THREATS TO FORESTS AND FOREST TREES

2.1. Importance of arthropod pests and diseases

The impact of invertebrate pests and plant pathogens is not always obvious or easy to calculate. Just because a pest is present does not mean it has either an immediate or a long-term impact. Furthermore, while the relationships between pests (in the broad sense) and their host plants are relatively well known in temperate regions, the impact of tropical pests is relatively poorly documented (Speight and Wylie 2001). In the case of the latter, the available economic assessments generally involve informed estimates rather than controlled scientific studies (see Case Study 1).

CASE STUDY 1: ASSESSING THE IMPACT OF INTRODUCED CONIFER APHID PESTS IN AFRICA

In eastern and southern Africa, pine and cypress trees are grown extensively in industrial plantation monocultures for wood-based industries such as sawn timber, paper and other products. In most countries in this region, cypress trees are also grown in village woodlots and by small-scale farmers for fuelwood, local timber, soil stabilization and wind breaks.

Three accidentally introduced aphid pests attack these trees: the pine woolly aphid, *Pineus boerneri* Annand (Adelgidae) (first found in 1968); the pine needle aphid, *Eulachnus rileyi* (Williams) (Aphididae) (first found in the 1970s); and the cypress aphid, *Cinara cupressivora* Watson and Voegtlin (Aphididae) (first found in 1986). The first two species attack *Pinus* spp. while the third attacks *Cupressus* spp. as well as indigenous cedars and junipers.

Since their introduction, these three aphids have spread throughout southern and eastern Africa; they were the first pests specific to conifers to invade the region and have subsequently become the most damaging pests of these trees.

In 1991, an attempt was made to estimate the losses caused by these pests, by collecting information on the area, growth and monetary value of softwood timber in the region, and on aphid distribution, feeding ecology and associated losses through tree mortality and reduced growth. It was estimated that, up to 1990, *C. cupressivora* had killed trees worth UK£27.5 million (approx US$44 million) and was causing an additional loss of a further UK£9.1 million (approx US$14.6 million) per year through reduction in annual growth increment (including that from dead trees). In addition, the two pine aphids caused a further loss of UK£1.5 million (approx US$2.4 million) per year due to reductions in the annual growth increment in the region's pine plantations. These figures are clearly conservative, since they do not include the impact of the aphids on indigenous junipers and cedars, or allow for any subsequent mortality due to *C. cupressivora*. A second study, conducted by the Kenya Forestry Institute, estimated that in Kenya the latter species might kill as many as 50 percent of all cypress trees during the 30-year harvest cycle.

These economic data were instrumental in securing the resources needed to mount a biological control programme against the three aphids, which has resulted in substantial reductions in the incidence of the cypress aphid and possibly the others, although this has not been established with certainty.

Sources: Murphy (1996). See also Watson *et al*. (1999).

Some pests cause obvious damage that can be readily quantified, for example damage by the mahogany shoot borer (*Hypsipyla grandella*) can cause loss of the leader and hence trunk distortion in attacked trees. In other cases (e.g. damage by sap suckers, chronic diseases, defoliators and weeds), effects on yield may be far less obvious. Furthermore, although the short-term effect of 'outbreak' pests is usually very obvious, data on the long-term economic impact of such damage (which occurs over a relatively limited period) tend to be sparse, particularly for tropical tree crops. The particular problems associated with outbreak pests are discussed in Section 2.1.1.

The impact of potential pests often differs in different regions. Thus indigenous pests may appear in sporadic outbreaks, or may cause more frequent problems, perhaps because of sylvicultural practices such as a tendency to grow a single species in monoculture (see Section 2.5). Newly introduced exotic pests, on the other hand, will often occur as an initial massive outbreak, but may become less damaging over time as the most susceptible trees die or, in some cases, the plants develop defensive responses against them. However, most alien pest species are likely to remain damaging at some level.

In severe cases, pests may set ecological limits to the areas in which trees can be grown. For example, in Fennoscandia, severe outbreaks of the lepidopteran defoliator *Epirrita autumnata* are believed to be responsible for the altitudinal displacement of the boreal tree limit (Nuorteva 1963; Seppälä and Rastas 1980; Virtanen 1998). In rare cases, introduced pests may even threaten endemic tree species with extinction (see Case Study 13).

In some cases, the impact of a particular pest or disease may be limited by using alternative, less susceptible, tree species. In contrast to agricultural systems, there are often several different tree species that can be used to produce very similar products. Hence, in the medium to long term, tree species or genotypes that are susceptible to the pests and diseases in a particular area can be phased out and replaced by other, less susceptible, alternatives. In such cases, the net effect of the pest over time is indirect (by restricting the choice of tree species), rather than direct.

However, replacement tree crops may also be damaged by new pests. For example, in eastern Africa, damage due to canker (*Rhyncosphaeria cupressi*) led to the replacement of *Cupressus macrocarpa* by *Cupressus lusitanica*, which subsequently came under threat from the introduced cypress aphid, *Cinara cupressivora*. This type of situation is particularly common in agroforestry, where new trees (both exotic and native) are constantly being adopted and abandoned because of new pest problems. This is a good indirect indication of the importance of forest pests in the tropics, despite the absence of precise data on economic losses.

In some cases, too, limitation of damage by substitution is not always practical. Some tree species will always be in demand and hence will be grown despite substantial losses due to pests or diseases. This is the case for mahogany, for example, which can suffer severe damage from the widely distributed mahogany shoot borer (*H. grandella*). The continuing demand for mahogany also explains why research on the shoot borer has continued for many years (Newton *et al.* 1993; Floyd and Hauxwell 2001), whereas little work has been done on equally intractable pests of trees that can be substituted. Similarly, the cultural and economic value of American chestnut (*Castanea dentata*) is such that efforts continue to be made to develop varieties resistant to chestnut blight (*Cryphonectria parasitica*), a disease that devastated this species during the first part of the twentieth century (see Case Study 2).

CASE STUDY 2: CHESTNUT BLIGHT CHANGES A FOREST ECOSYSTEM

Chestnut blight entered the USA on nursery stock imported from China to New York around 1900. It is caused by a fungus that prior to 1978 was known as *Endothia parasitica*, but has subsequently been renamed *Cryphonectria parasitica*. The fungus is spread by wind, rain, birds and other animals; it enters through cracks or wounds in the bark and multiplies rapidly, causing sunken cankers which expand and girdle the stem, killing everything above the canker (usually in a single growing season).

Since it had never previously been exposed to this fungus, the American chestnut (*Castanea dentata*) was highly susceptible and was devastated throughout its natural range, which extended over the Appalachian hills and highlands from Maine to Georgia. By 1940, it has been estimated that three and a half billion American chestnuts had perished.

Prior to this, the American chestnut had been one of the most abundant hardwoods in the deciduous forests of the eastern USA, in some areas accounting for as much as 25 percent of all tree cover. In many eastern hardwood forests, it was not only the most numerous species, but also often the largest (30 m specimens were common). It was one of the most economically important trees in the eastern USA, with very durable wood that was highly valued for furniture and construction, and nuts that were both a cash crop and a staple food for wildlife. Now, American chestnuts survive mostly in the form of small understorey trees that sprout from the original root systems but which are continuously attacked by the blight. There have been attempts to produce hybrid chestnuts through cross-breeding, using Chinese species resistant to the disease as the parent line.

The demise of the American chestnut illustrates how an entire ecosystem can be fundamentally altered. Although as a species it still survives, it is ecologically extinct – no longer a functional part of the ecosystem. Its loss has permanently changed the ecology of the eastern deciduous forests.

Source: Stein and Flack (1996)

Rubber (*Hevea brasiliensis*), a species of South American origin, grown extensively in South-East Asia, is another example of a tree for which substitution is not an option, since it is still the only species from which rubber can be produced (in spite of the extensive evaluation of thousands of other plant species as potential sources of rubber).

For the moment, the extremely damaging leaf blight (*Dothiudella ulei*) that attacks this species is restricted to South America, where it prevents the establishment of commercial rubber plantations (Case Study 3). Africa and South-East Asia are currently free of the disease, which would be devastating if introduced. The disease-free status of countries in these areas is maintained almost entirely by preventing entry of the blight and, although early detection systems and emergency eradication plans may be in place, it would be optimistic to think that the disease could be contained if it was accidentally introduced (Case Study 4).

CASE STUDY 3: FORDLANDIA – A CLASSIC STORY OF INDIGENOUS PLANTATION FAILURE

In 1927, Henry Ford was making half the automobiles in the world. Then, as now, the car industry depended upon the rubber supply from South-East Asia to make tyres, and by the 1920s rubber accounted for an eighth of the value of all US imports. Seeking an alternative source of rubber, Ford set out to establish a Brazilian plantation to challenge the British and Dutch monopolies based in Malaya and Indonesia.

He bought 25,000 square kilometres of land on the banks of the lower Rio Tapajós, 100 km from Santarem. However, the area had very limited potential for plantations of any kind, since it depended on seasonal rather than regular rains, was hilly (and therefore awkward to mechanize), the soil was sandy and over-leached, and it was beyond the reach of ocean-going vessels for several months of the year. Nevertheless, Ford built Fordlandia, a town complete with miles of roads and railroads, a modern port, a factory, schools, churches, hundreds of brick and stucco bungalows and a fully equipped hospital that overlooked swimming pools, tennis courts and a golf course. Thousands of acres were cleared and planted with more than five million seeds of the finest, highest-yielding clones of rubber (*Hevea brasiliensis*), secured by botanists sent to Malaya and the Dutch East Indies. By 1934, 1.5 million rubber saplings were growing at Fordlandia. Initially, all went well. However, as the growing foliage began to form a continuous canopy over the fields, it was attacked by South American leaf blight (*Dothiudella ulei*). Within a year, the disease had ravaged the plantation.

Ford ordered his agronomists to try again, on an even larger scale. A second area of land was secured at Belterra, 20 km from Santarem; another town was built, more land was cleared and more rubber planted. The outcome was the same.

Although the plantations have persisted, they have always suffered from South American leaf blight, a loss of topsoil and poor labour relations (although the relative importance of these factors varies according to different sources). They have never made a significant contribution to the world's rubber supply. Ford never looked likely to recover his money, and by the late 1930s he had lost interest, finally selling out to the Brazilian Government in 1945 for US$500 000 – having already invested well in excess of US$10 million.

Sources: TAMU (2000); Evans (2002);
http://www.pacificislandtravel.com/south_america/brazil/about_destin/fordlandia.html.

CASE STUDY 4: THE THREAT OF SOUTH AMERICAN LEAF BLIGHT TO RUBBER IN MALAYSIA

The rubber tree (*Hevea brasiliensis*) is grown extensively in South-East Asia, especially in Malaysia, for the production of natural rubber and, increasingly, timber. Malaysia is one of the main South-East Asian rubber producers: in 1997, a total area of 1.564 million ha was planted with rubber, predominantly by smallholders. In 1999, the total rubber production for Malaysia was 0.9 million tonnes and its export value was 3115 million Malaysian Ringgit (approx. US$0.8 million; 2 percent of total Malaysian exports).

In Malaysia, rubber is relatively free from attack by indigenous pests or diseases, and no such species accompanied the plant from its area of origin in the Amazon. In South America, the most damaging disease of rubber is South American leaf blight (SALB, *Dothidella ulei*), which is so virulent that the commercial planting of rubber in the continent is not viable (see Case Study 3). Since resistant varieties are not available (see Case Study 5), Malaysia has a substantial programme aimed at preventing the entry of leaf blight, which R.E. Schultes, Director Emeritus of the Harvard Botanical Museum, has suggested would overrun the Asian plantations in five years, reducing yields, killing trees and compromising the entire industry.

The first and principal line of defence against the disease is prevention. Quarantine regulations in Malaysia, Thailand and some other rubber producing countries have been strengthened to prevent an accidental introduction of leaf blight. The importation of rubber tree planting materials directly from the American tropics is prohibited except for research purposes, and relevant national and industry research institutions and universities are well aware of the potential risks. Airport posters are used to alert airline passengers to the hazard and travellers from tropical South America are requested to stopover in another country en route for at least two days; those arriving on direct flights are required to complete plant quarantine declaration cards and upon arrival are subjected to quarantine treatments, e.g. showering and changing their clothing and exposing their baggage to ultraviolet irradiation.

In comparison, investment in early warning systems is quite limited. Staff from the Rubber Research Institute of Malaysia and the Department of Agriculture carry out regular surveys of rubber diseases every two to three years. These are primarily intended to identify indigenous disease problems, so that recommendations for suitable clones may be made for different areas. However, a watch is also kept for symptoms of other diseases, especially South American leaf blight. A contingency plan has been prepared in the event of leaf blight being found in Malaysia, but by that stage it may well be too late for the South-East Asian rubber industry.

Source: Wittenberg and Cock (2001).

From a global perspective, there is a great need to develop blight resistant varieties (Case Study 5) as insurance against the ever-present possibility of leaf blight escaping from South America. Disruption of the global rubber supply, on which automobiles and airplanes depend, would have a major economic impact on the world economy.

CASE STUDY 5: RUBBER – AN INDUSTRY UNDER THREAT

From Fordlandia (Case Study 3) emerged a sobering lesson: the rubber trees that were by far the most sensitive to leaf blight were the high-yielding strains from the Far East. In selecting for yield, the breeders in Asia had inadvertently produced strains that were especially susceptible to the blight. However, whilst millions of trees died at Fordlandia, a handful survived, all wild and native to the Amazon. Since trees with inherent resistance to the disease clearly existed, this suggested that standard plant breeding techniques could be used to produce resistant commercial varieties.

In 1943, in response to the need to secure rubber supplies during World War II, the US Department of Agriculture sent botanists into the Amazon to search for resistant trees. Some were found growing at the agricultural experimental station at Turrialba, Costa Rica (now CATIE), and by the end of the war many of the technical problems related to establishing high-yielding, disease-resistant varieties had been solved. However, shortly after the war's end, the work ceased, reportedly in the belief that a satisfactory synthetic alternative would soon be available, although also partly to protect the British rubber industry in Malaya. In Costa Rica, all records of the project were lost and the germplasm collections were abandoned and eventually destroyed.

Satisfactory synthetic rubber has yet to be produced and natural rubber still dominates the rubber market, being particularly important for vehicles and aircraft tyres. South-East Asia is the principal source of natural rubber and if South American leaf blight were to reach the region, the world's supply of natural rubber would be drastically reduced, causing considerable economic perturbations on a global scale. The need for disease-resistant cultivars seems obvious, but nevertheless is not being addressed.

Source: TAMU (2000)

2.1.1. Outbreak pests

Some forest pests are characterized by population cycles in which prolonged periods at relatively low (non-damaging) densities are interspersed with occasional ‘outbreaks’, during which their numbers grow rapidly to very damaging levels. These outbreaks persist for varying lengths of time. Pest outbreaks in tropical forest plantations are almost inevitable at some time during the rotation and can cause major economic losses (Wylie 2001). Since there will inevitably be some impact on tree growth during the outbreak, these pests may cause considerable concern while their populations are high. However, over the entire lifetime of the crop, the damage caused is not necessarily significant. Nevertheless, synchronized or successive outbreaks of different pests (e.g. a defoliating insect followed by a disease (Case Study 6)) can be particularly damaging, and may lead to tree mortality.

CASE STUDY 6: CONCURRENT OUTBREAKS OF INSECTS AND DISEASES: MAPLE DEFOLIATORS AND MAPLE ANTHRACNOSE

Simultaneous or successive outbreaks of insect pests and disease can be very destructive to forests. For example, in Pennsylvania in 1994, the ability of sugar maple (*Acer saccharum* Marsh.) and red maple (*Acer rubrum* Linnaeus) to refoliate following outbreaks of forest tent caterpillar (*Malacosoma disstria* Hübner; Lasiocampidae) and elm spanworm (*Ennomos subsignarius* (Hubner); Geometridae) was limited by an anthracnose leaf disease caused by a fungal plant pathogen (*Discula campestris* (Pass.)).

The disease prevented many trees from refoliating and consequently prevented them from generating the sugar reserves in their roots needed to support new growth the following spring. Thus in 1995, the combination of the earlier defoliation and the anthracnose caused severe branch dieback and contributed to increased tree mortality: in a typical northern hardwood stand, tree mortality normally ranges from 1 to 3 percent, whereas in 1995 it reached 11 percent or more in many affected stands.

While such cases of insect outbreaks closely followed by disease outbreaks do occur from time to time (and can be very destructive), many trees do survive, and these genetically superior individuals then form the basis of a new and more pest-resistant forest community.

Source: Pennsylvania Department of Conservation and Natural Resources website (http://www.dcnr.state.pa.us/forestry/pests/maple.htm).

The causes of such outbreaks are not well known. Outbreaks of some species seem to occur in regular cycles, e.g. those of the larch budmoth, *Zeiraphera diniana*, and the birch looper, *Epirrita autumnata*, occur at intervals of 8–10 years in the Alps and Fennoscandia, respectively. Similarly, in Japan, the beech caterpillar, *Quadricalcarifera punctatella* (Motschulsky) (Notodontidae), often causes serious defoliation in beech forests at intervals of 8–11 years; furthermore, the outbreaks tend to occur synchronously in different areas (Kamata 1998).

Possible causes of outbreaks include:

- temporarily reduced resistance of host trees (e.g. in the case of larch budmoth);
- temporary abundance of a normally limited resource (e.g. bark beetle outbreaks after storms);
- synchronized populations enabling herbivores to escape natural enemies (or other cyclical interactions with natural enemies);
- control failure due to disruption of natural enemies by external factors (weather, fires, dust, insecticides, etc.).

Outbreaks of native pests are usually sporadic and collapse quite quickly, either due to starvation or to the action of natural enemies (predators, parasitoids or diseases). Newly introduced pests are more likely to increase until food is limited and then disperse, extending the outbreak to new areas, and possibly returning to the original outbreak area once regrowth is available. For example, the pine false webworm, *Acantholyda erythrocephala* (L.) (Pamphiliidae), usually develops outbreaks of short duration (mainly two to three years) in its region of origin in central Europe, whereas in North America, where it was introduced, persistent and severe outbreaks have been observed since the early 1980s (Kenis and Kloosterman 2001). If indigenous natural enemies can adapt to the new pest, they may break this pattern. Often, however, they are unable to do so, in which case biological control should be considered as a long-term solution (see Section 3.4).

2.2. Importance of weed pests

In forestry, weeds are principally a problem at the establishment stage of a plantation, creating difficulties in the preparation of sites for planting and through competition with young trees (particularly the smothering action of vines). They can also cause problems in the production of nursery stock and can affect forestry activities such as thinning and maintaining access, rights-of-way and road margins, as well as increasing fire risks.

Both indigenous and alien species can be involved, but in general they are early succession species that invade a site after disturbance and which would normally be displaced by forest anyway – but only after a much longer period of time than is typical of commercial forestry. Most weeds of forestry also affect other ecosystems, i.e. they are not specific to forestry systems. For example, *Mikania micrantha*, a South American vine, is an important weed in young plantations in the Asia-Pacific area (e.g. of *Pinus* plantations in Fiji), smothering young trees and easily growing into a 10 m canopy. However, it also affects arable crops, fruit crops, pasture, etc. (Case Study 7).

CASE STUDY 7: SOCIO-ECONOMIC IMPACT OF *MIKANIA MICRANTHA* IN KERALA, INDIA AND MALAYSIA

Mikania micrantha is an important invasive weed in several countries within the moist tropical zones of South-East Asia and the Pacific and is still expanding its range. In southwestern India (Western Ghats) it is a recent introduction (about 1985) but it is already a significant weed throughout Kerala and has started to invade neighbouring states.

The vine is able to invade degraded natural forest ecosystems, out-competing indigenous species. It is also an important weed of home gardens and agricultural systems, particularly of tea, bamboo, reeds (for thatching) and other plantation crops such as rubber, teak, eucalyptus and plantain. It grows up into the canopy and is capable of pulling plants over, or of smothering the crop. In tea plantations it seriously disrupts picking, since it grows amongst the tea shoots being harvested. Apart from depriving crop plants of soil nutrients and sunlight, it also has an allelopathic effect on their growth.

The Kerala Forest Research Institute recently assessed the socio-economic impact of *M. micrantha* in Kerala. The weed affects both subsistence and tree crops and intensive weeding is now necessary, resulting in an escalation of production costs and subsequent loss of income (KFRI, unpublished report).

In India, the most severely affected crops include banana, coconut, coffee, cocoa, cassava, pineapple, ginger and teak. Yield reductions can be substantial and infestations in some areas have resulted in the substitution of highly susceptible crops with more weed tolerant alternatives. In natural forests, the collection and extraction of non-wood forest products (e.g. reed, bamboo) have become more difficult and more time-consuming because of the creeping and twining habit of the weed.
In Malaysia, *M. micrantha* is considered to be a highly competitive weed in immature plantations of cocoa, coconut, rubber and oil palm; large potential yield losses have been estimated in the latter two crops, and the cost of controlling the weed has significantly increased overall production costs. In 1981, about 5 percent of the total weed control costs in rubber and oil palm plantations were directly attributable to control of *M. micrantha*; this amounted to about 10–12 million Malaysian Ringgit (approx. US$3 million at the 2002 exchange rate).

Source: Ellison and Murphy (2000) and Teoh *et al.* (1985)

In northern temperate regions, the main weeds affecting forestry tend to be indigenous, although there are some significant exceptions, e.g. Scotch broom (*Cytisus scoparius* (L.) Link.) and gorse (*Ulex europaeus* L.) in British Colombia (Petersen and Prasad 1997). Species which are weedy in their area of origin often cause worse problems when introduced elsewhere. For example, Old man's beard (*Clematis vitalba* L.) is a relatively minor forestry weed in its native Europe, but is extremely invasive in the natural forests of New Zealand.

An important but relatively little-studied aspect of alien weeds is their ability to displace indigenous vegetation and associated animal diversity in natural, disturbed and plantation forests. This effect may involve just the forest margins and trail edges, or clearings and the ground cover within the closed canopy; all are important in terms of the biodiversity associated with each habitat. This type of impact is generally poorly documented, particularly in developing countries. However, several examples of this effect have been reported in Hawaii. For example, the South American shrub *Clidemia hirta* (Melastomataceae), which was an important weed of grassland and pasture in Hawaii until biological control was implemented, is now found mainly along forest trails, where it dominates the ground cover. Similarly, the margins of many Hawaiian forests are dominated by South American wild passion fruit, *Passiflora tarminiana* (often incorrectly referred to as *P. molissima* – see Coppens d'Eeckenbrugge *et al.* 2001), and Afro-Asian ivy gourd, *Coccinea grandis* (Cucurbitaceae). These plants are also present on, or threaten, other Pacific Islands. *Clidemia hirta* has also been introduced to South-East Asia, East Africa (Usambara mountains), Madagascar and at least some of the Mascarene Islands where, although it is less dominant than in Hawaii, it is still a significant problem. Similarly, there are anecdotal reports that the neotropical weed *Chromolaena odorata* (L.) King and Robinson (Asteraceae) has come to completely dominate the ground cover in primary and secondary forest in parts of Ghana (H.C. Evans, personal communication, 2000). In the context of forest systems as reservoirs for biodiversity, this phenomenon merits further study.

The importance of forest weeds in developed countries is reflected by the fact that herbicide use generally greatly exceeds that of insecticides. This is partly a consequence of various sylvicultural practices (clear-cutting, monocultures, etc.) and may have negative environmental effects in terms of water contamination as well as the removal of indigenous flora and its associated fauna (Vanden *et al.* 1984). Alternative approaches may be appropriate in some circumstances, for example, the use of tree borders or buffers to protect planted and natural forests from invasive weeds (see Case Study 16). Such approaches warrant further testing and evaluation (including some assessment of the potential negative impact on the biodiversity associated with forest margins).

2.3. Alien versus indigenous pests and diseases

There is no doubt that newly introduced alien pest species can be devastating, particularly to plantation forestry (e.g. OTA 1993; Canadian Forest Service 1999; Pimentel *et al.* 1999; Wittenberg and Cock 2001) and to the biodiversity associated with forests (CBD 2000, 2002). Historical, recent and current examples abound (Case Studies 1, 2 and 8; Annex 1), and in future increasing numbers of accidental introductions can be expected as a result of the growing internationalization of trade, the increasing movement of people, and the consequent overwhelming of quarantine services.

CASE STUDY 8: THE ORIGIN AND SPREAD OF DUTCH ELM DISEASE

Evidence from pollen analysis in European peat sediments suggests that there were major fluctuations in elm (*Ulmus* spp.) populations in prehistoric times, related primarily to climate change but also perhaps to Dutch elm disease, caused by the fungus *Ophiostoma ulmi*.

O. ulmi is thought to have originated in Asia, primarily because Asian species of elm show at least a moderate level of resistance to this species. It is thought that, having coexisted for many generations with the fungus, susceptible Asian elms were slowly eliminated from the population and replaced by seedlings with greater resistance. In this way, the elms of Asia established a natural equilibrium with the disease. Dutch elm disease only reached epidemic proportions when the fungus reached Europe from Asia in the early part of the twentieth century.

A major pandemic spread across the Northern Hemisphere from the 1920s to 1940s. It was seen first in the Netherlands (hence the name, Dutch elm disease), then spread through continental Europe and into the USA, decimating the elm populations. The disease subsequently declined in Europe (though not in the USA) but re-emerged in an even more virulent form to affect Britain (in the mid-1960s) and most of Europe. The fungus isolated from this more recent outbreak showed some cultural and molecular differences from the older strains, and because it also failed to interbreed with them, was described as a new species, *Ophiostoma novo-ulmi*.

A range of molecular tools has been used to analyse the population structure of *O. novo-ulmi* in the current European pandemic. Based on comparisons of random DNA fragments and the abilities of strains to fuse with one another in culture (indicating cytoplasmic compatibility), the population at the advancing front of the pandemic seems to be genetically uniform. This is to be expected where an abundance of healthy host trees creates selection pressure for the most virulent component of the fungal population. However, behind the fronts, the population shows much higher diversity – the result of stabilizing selection where factors other than virulence are favoured.

Source: http://helios.bto.ed.ac.uk/bto/microbes/dutchelm.htm and
http://pine.usask.ca/cofa/departments/hort/hortinfo/trees/elm-1.html

It is not easy to predict which alien species are likely to cause serious damage if introduced. Many species are innocuous or minor pests in their area of origin, but can be devastating elsewhere. For example, of six of the most devastating forestry pests introduced into North America (including chestnut blight, Dutch elm disease, etc.), only the European strain of the gypsy moth was known as a pest in its indigenous range (Baskin 2002, quoting OTA 1993). Many ecologists have looked for predictors of invasiveness and pest potential, but at present, the best guide appears to be at least one previous record of causing problems when introduced elsewhere, especially in areas with similar climatic, geographic and ecological conditions to the area at risk. Close relatives of known invasive species are also suspect, although this is not an entirely satisfactory predictor of invasiveness. Access to reliable information is therefore critically important for assessing the potential risk of invasiveness.

2.4. Introduction of new tree genotypes

The introduction of new tree genotypes to areas where there are indigenous genotypes of the same species (or closely related species) could cause some specific problems, for example, through hybridization (see also Section 4), or by displacing indigenous genotypes, subspecies or closely related species. There are some examples of the latter situation from other systems, e.g. weedy genotypes of itch grass, *Rottboellia cochinchinensis*, replacing indigenous genotypes, but as yet there are few examples from forestry systems.

Alternatively, introduced genotypes may interbreed with indigenous genotypes (or closely related species/subspecies). Natural populations would then become a mixture of the two genotypes, although this is unlikely to be noticed unless the species was being monitored for such changes, or if it was linked to some evident change in appearance or ecology, e.g. a change in flower colour or a tree suddenly becoming more successful in a new habitat. In the larger scale of things, this change in the indigenous genotype may not be that important, although public concern could be an issue.

Hybridization between an introduced species and a closely related indigenous species is certainly a possibility. Generally, such crosses are likely to result in sterile or otherwise relatively uncompetitive F1 hybrids. However, unexpected and unusual things can also happen, e.g. doubling of the chromosome number of the F1 to create a new self-viable species (e.g. *Spartina* spp.). When congeneric species that normally occur on different continents are grown together, they are likely to hybridize successfully and indeed are often deliberately hybridized to produce plantation and amenity trees. *Populus* is an example of a genus whose species tend to hybridize very readily, and hybridization with introduced American species has become one of the main threats to England's endangered black poplar (*Populus nigra betulifolia* (Pursh) W.Wettst.) (see Case Study 9).

2.5. Monoculture versus mixed or natural plantations

Plantations provide an increasing proportion of the world's timber supply (FAO 2000). Tropical and subtropical plantation forestry has focused on a small number of fast-growing species, most notably in the genera *Acacia*, *Eucalyptus*, *Gmelina*, *Pinus*, *Populus* and *Tectona* (Evans 1987); perhaps as much as 85 percent of industrial plantations in the tropics use species from only three genera: *Eucalyptus*, *Pinus* and *Tectona* (Evans 1992). Furthermore, these species are normally planted as monocultures, which are often associated with an increased probability of pest outbreaks, particularly when they are composed of genetically similar trees (Gibson and Jones 1977). The underlying reasons for this include:

- the abundance of the host tree, especially when they are at a suitable stage for pest development;
- trees touching each other as the canopy closes, facilitating pest movement between hosts during dispersion;
- uniform planting, which may result in some trees being planted in unsuitable areas: such stressed plants typically favour localized pest outbreaks;
- adverse effects on pests' natural enemies due to the absence of alternative hosts, food sources, etc.; and
- low genetic variability, increasing the risk of disease epidemics (particularly since plant breeding tends to be aimed at increased yield rather than pest resistance).

CASE STUDY 9: HYBRIDIZATION THREATENS THE ENDANGERED BLACK POPLAR POPULATION IN GREAT BRITAIN

The black poplar, the most endangered native timber tree in Britain, is a segregated population of the Atlantic race of *Populus nigra* subsp. *betulifolia* (Pursh) W.Wettst. which is at the northwestern limit of its range in Britain. It was once a distinctive feature of Britain's lowland river valleys and appears in many of Constable's paintings. Now, however, it is sparsely distributed and the few remaining trees are coming to the end of their lives and do not appear to be regenerating from seed. In 1982, the British population was estimated at between 2000 and 3000, and it is now particularly rare in lowland England.

Several factors are thought to be contributing to the decline of black poplar in Britain:

- Drainage of farmland and loss of wetland habitats. The black poplar has slowly adapted over time to human impacts on the British countryside, but it remains a tree of wetland regions and land drainage has reduced the area of its preferred habitat.
- Most of the individuals remaining in the country have been propagated as cuttings from around 600 individuals, so genetic variation is low.
- The individuals selected for propagation were primarily male, for aesthetic reasons, leading to a lack of female trees.
- Male and female trees need to be in close proximity for pollination to take place.
- There is a predominance of old trees, which are not regenerating.
- Indiscriminate felling of 'unsafe' trees.
- Several poplar species have been introduced into Britain since the 1700s, some of which can cross-pollinate with the native black poplar, creating hybrid stock. Two American species in particular are implicated, namely *Populus deltoides* Bartr. ex Marsh. and *Populus angulata* Ait.
- The use of cultivated poplars all over the continental Europe has also created a potential threat to the remaining black poplar populations in the form of introgression (i.e. movement of genes from plantations to natural populations through hybridization).

Thus, although hybridization is recognized as a threat to black poplar, its relative importance has not been quantified.

Although black poplar lacks a direct commercial use, it is used as a parental pool in breeding programmes in many parts of the world. Therefore, active conservation and propagation by cuttings is needed to maintain the original stock. Genetic conservation is actively carried out through a dedicated network of the International Plant Genetic Resources Institute's (IPGRI) European Forest Genetic Resources Program (EUFORGEN), which has made considerable efforts to integrate *ex situ* and *in situ* conservation efforts for black poplar and has developed guidelines for *in situ* conservation. It has also generated a standardized list of descriptors for inventories of natural stands and established a database of black poplar clones.

Source: Wildlife Trust Action Plans http://www.wildlifetrust.org.uk/bcnp/northants-bap/Black%20Poplar.htm; http://www.wildlifetrust.org.uk/cheshire/bpoplbap.htm; and http://www.ipgri.cgiar.org/system/page.asp?frame=programmes/grst/FGR/home.htm.

Monoculture also tends to transform sporadic pests into more permanent problems. In Canada, for example, valuable trees such as Sitka spruce (*Picea sitchensis* (Bong.) Carriere (Pinaceae)) can only be planted in small areas and numbers because of damage by *Pissodes strobi* (Peck) (Curculionidae). Similarly, the pine shoot moth, *Rhyacionia buoliana* (Denis & Schiffermüller) (Tortricidae, Olethreutinae) is still an important pest where monoculture continues (e.g. Spain and Chile), although in central Europe it stopped causing substantial problems when pine monoculture declined.

Mixed planting of native (and exotic) trees is therefore preferred if pest problems are to be minimized.

2.6. Susceptibility of indigenous versus exotic trees in plantations

There has been considerable debate over the relative risks of pest outbreaks on exotic versus indigenous tree species, especially in plantation settings (e.g. Nair 2001). *A priori,* one might argue that since exotic trees will be introduced without their associated specialist diseases and herbivores, they should be largely free of pests (e.g. Case Study 4). Conversely, one might argue that exotic trees will be exposed to new pests to which they have no resistance and to which they may therefore be extremely susceptible. In practice, it is not uncommon for newly introduced exotic trees to experience an initial period with few pest problems, followed by a period in which indigenous pests gradually adapt to these new hosts (Nair 2001). In a similar way, it can be argued that since indigenous trees are already resistant to, or tolerant of, their indigenous pests, they should escape severe damage. However, converting mixed natural forest to monoculture might be expected to disrupt pest and natural enemy population dynamics and create outbreak situations.

Nair (2001) reviewed the empirical evidence from nine commonly planted trees, grown in both indigenous and exotic settings, and concluded that the only clear trend was that, in all cases, monoculture increases the chance of pest outbreaks. Several distinct factors influence the likelihood of an outbreak, amongst which Nair identified:

- Presence or absence of plant species closely related to the exotic – since these are more likely to harbour pests that can readily adapt to the new species.
- Extent of the area planted with the exotic species – the larger the area, the greater the chance of an outbreak, since the level of exposure to indigenous species will be higher, there will be more chance that some trees will be stressed (and hence more susceptible), and there will be more chance of an introduced pest finding suitable hosts and habitats.
- Genetic basis of the planted stock – the greater the diversity, the greater the chance that some of the population will be resistant to particular pests and diseases.
- Distance from the native habitat of the exotic – the shorter the distance, the greater the chance of pests arriving from the native habitat (in practice, however, the volume of trade between the two areas may be more important than physical distance).
- The existence of serious pests in the native habitat of the exotic – since these might eventually be introduced.
- Time elapsed since introduction – the longer a tree has been grown as an exotic, the more species from its area of origin are likely to have been introduced and the more native species are likely to have adapted.
- Chemical profile of the exotic species – novel chemical defences may deter indigenous pests.

- Innate biological characteristics of the insects associated with a tree species – for example, some species show a predisposition to occur in outbreaks.

It is worth noting that any such review is likely to be biased in favour of those tree species which have managed to avoid substantial damage and which have therefore been widely planted: those tree species which have proved to be highly susceptible to local or exotic pests will not have been widely grown and hence will have been excluded from the analysis. It is therefore appropriate to evaluate the pest risks associated with a particular tree/location combination on a case-by-case basis, and to establish pilot plots before scaling up production.

3. MANAGING THREATS TO FORESTS AND FOREST TREES

3.1. Alien species: prevention

This section is based largely on Wittenberg and Cock (2001).

Prevention is the first and most cost-effective line of defence against invasive alien species. For unplanned introductions, the benefit/cost ratio for exclusion is undoubtedly high. Even if only a small fraction of inadvertently introduced species become established and only a small fraction of those become invasive pests, the enormous cost of some of the latter can far outweigh any unexpected benefits that unplanned introductions may confer. For example, in the USA, the estimated cumulative potential losses from the Asian strain of the gypsy moth (*Lymantria dispar*) and the nun moth (*L. monacha*) between 1990 and 2004 are in the range of US$35 billion to US$58 billion (net present value in 1991 dollars). Thus, while the ongoing cost of preventing the introduction of the moths and of treating potentially contaminated goods is not negligible, it is far lower than the potential losses resulting from their establishment (OTA 1993).

The costs of establishing and maintaining the exclusion apparatus can be quite high, although mechanisms exist for apportioning fees to the users and beneficiaries of the system. For example, in New Zealand, private parties pay all costs associated with risk analysis and port inspection for imported alien species. In contrast, in the USA, while the commercial interests advocating Siberian timber imports (Case Study 22) spent about US$200 000 on developing Russian contacts and promoting the products, the US Government spent approximately US$500 000 more on analysing the associated risks (OTA 1993).

On average, it has been estimated that approximately 1 percent of introduced species are likely to become invasive (Williamson 1996); this estimate, coupled with the fact that eradication or control of well-established species is both difficult and costly, suggests that the precautionary principle should be adopted, i.e. that all species should be treated as potentially harmful until the contrary is proven (Case Study 10).

CASE STUDY 10: THE PRECAUTIONARY PRINCIPLE

The precautionary principle, while subject to varying interpretations and having over 12 different definitions in international treaties and declarations, is fast becoming a fundamental principle of international environmental law. In the late 1980s and 1990s, the principle was quickly incorporated into numerous multilateral treaties and international declarations, including the 1992 Convention on Biological Diversity. In essence, the principle implies that where an activity raises threats of harm to the environment or human health, precautionary measures should be taken even if certain cause and effect relationships are not fully established.

Variations in terminology have emerged, reflecting the considerable controversy surrounding the principle. To avoid the more extreme versions of the precautionary principle that press for absolute environmental protection, some prefer to use the term 'precautionary approach'.

James Cameron, Director of the Foundation for International Environmental Law and Development (FIELD) at King's College, London, has articulated the conceptual core of the principle as follows:

"The precautionary principle stipulates that where the environmental risks being run by regulatory inaction are in some way a) uncertain but b) non-negligible, regulatory inaction is unjustified."

A number of fundamental elements or key directions have also been identified, including:

- being proactive – a willingness to take action in advance of formal scientific proof;
- any action taken should be cost-effective, that is, some consideration should be given to the proportionality of costs;
- ecological margins of error should be included;
- the intrinsic value of nonhuman entities should be considered;
- the onus of proof should be placed on those who propose change;
- decisions should be made with concern for future generations; and
- strict/absolute liability regimes should be used to identify ecological debts.

Source: Wittenberg and Cock (2001), edited from VanderZwaag (1999)

Targeting individual species is the most common approach to preventing the introduction of invasive organisms. However, a more comprehensive strategy is to identify the major pathways through which harmful invasions occur and then manage the associated risks. Pathways as well as individual species can be subjected to risk assessments, and exclusion methods based on the latter would probably be more efficient, since efforts could then be concentrated where pests are most likely to enter. At present, while international trade and travel are believed to be the leading cause of harmful unintentional introductions, in most countries there is a lack of solid evidence concerning the actual pathways. In the case of forestry pests, for example, forestry products such as packaging materials (Case Study 20) can be particularly important in facilitating the worldwide movement of pest species.

It has been argued that, because some pathways have been used for decades (or even centuries) without any prevention methods, all invasive species have probably already spread to most areas. However, it is now obvious that establishment rates can vary over time, with some alien species known to have been introduced to a particular area decades ago only recently becoming established. Reasons for this delayed establishment include alterations of the alien species itself, changes in the pathway, climatic changes and changes in human impact in the area of introduction (e.g. growing forests near entry points). The accelerating rate of establishment of alien species demonstrates that the concern over accidental introductions is still valid. Furthermore, new pathways will be created with increased mobility and trade.

One such example, relevant to forestry, is the international trade in bonsai trees. China is now a major source of bonsai trees, exporting nursery stock to many countries. Pests can accidentally be transferred on the plants or in the soil. For example, the citrus longhorn beetle, *Anoplophora chinensis* (Forster) was introduced from China to Italy on bonsai and the USA quarantine service often intercepts beetles on bonsai nursery stocks (American Lands Alliance 2002; USDA-APHIS 2002)

The responsibility for preventing the introduction of alien species is normally a function of the government agricultural administration rather than the forestry sector itself. Thus, while the latter should be an important partner in these efforts (particularly in contributing to pest risk assessments), prevention should be managed, prioritized and implemented on a broader scale to address all risks, not just those posed by the priority pathways. For this reason, prevention is not considered further here, except inasmuch as forestry activities may provide a pathway for the introduction of alien species (Section 6.3).

3.2. Alien species: monitoring and surveillance

The longer an alien species goes undetected once introduced to a new country, the less opportunity there will be to intervene if it becomes a problem: the options for its control will become fewer and any intervention will become more expensive. For example, eradication (see Section 3.3) will rapidly cease to be an option once an alien species is left to reproduce and disperse. The opportunity for eradication or early control of a new colonizer therefore makes investment in detection worthwhile. More specifically, priority should be given to detecting and monitoring those species known to be invasive elsewhere, especially those spreading within a region.

Surveys aimed at detecting new invasive species should be carefully designed and targeted to answer specific questions as economically as possible (e.g. Case Study 4). Usually all that is needed from such surveys is an indication of presence or absence. However, some invasive species are more easily detected than others: cryptic species may require special efforts to locate or identify, particularly when present in low numbers. For certain groups of pests, surveys by experts should be made to permit a rapid response before the species becomes well established. For a detailed treatment of this subject see IPPC (1997).

The biosecurity surveillance programmes in New Zealand provide a useful model: although they specifically target invertebrate pests and diseases, there is also a generic surveillance programme of “high risk” sites (e.g. ports of entry, unpacking facilities, car import yards and industrial premises where machinery is unloaded). Staff from the Biosecurity Ministry (or contractors) also visit parks and other urban forest stands and monitor for symptoms of invertebrate pests or diseases. Public involvement is also encouraged and as a result some newly established exotics have been detected at an early stage (Case Study 11). Surveys are undertaken in a “walk through” manner and samples are taken where signs of ill health or feeding damage are observed. In this way, several plant pathogens are detected each year. Some are studied further, e.g. pine pitch canker, but in general the MAF response will be to follow the guidelines stated in their biosecurity policy (MAF Biosecurity Authority 2001).

CASE STUDY 11: EARLY DETECTION AND ERADICATION OF WHITE-SPOTTED TUSSOCK MOTH IN NEW ZEALAND

The very distinctive caterpillar of the white-spotted tussock moth (*Orgyia thyellina*, Lepidoptera, Lymantriidae) was first collected by a member of the public from a peach tree in suburban Auckland in April 1996. Native to Japan, Taiwan and Korea, this insect had adapted to conditions in the subtropical northern region of New Zealand following its accidental introduction one or two years before and had the potential to cause severe damage to a wide range of trees and other plants.

Surveys by New Zealand's Forest Health Advisory Services showed that this new pest was confined to an area of about 100 ha. The New Zealand Ministry of Forestry led a multiagency contingency response to eradicate the pest using Foray 48B (*Bacillus thuringiensis* var. *Kurstaki*). Foray 48B was applied in the period from October 1996 to early March 1997, using ground and aerial techniques, initially over 4000 ha, but subsequently over progressively smaller areas, so that the final applications were confined to only 300 ha. In all, 23 aerial and associated ground-spraying treatments were applied to the infected and buffer areas.

At all times, the eradication operations were fully supported by a team of relevant research and technical experts working alongside operational and media specialists. Spray efficacy was monitored with a variety of methods. For example, in order to attract males, female moths were confined in sealed traps at secure locations throughout the region. Six males were trapped in April 1997, but no live stages of *O. thyellina* have been intercepted in the field since then.

By mid-1997, a parallel international initiative instituted by the Ministry of Forestry had led to the isolation and synthesis of the pheromone used by female moths to attract males. This enabled the Ministry to set out 7500 pheromone-baited traps during the summer of 1997/98. No moths were trapped, and the project was wound up in July 1998. A sentinel pheromone trap array was maintained during the summer of 1998/99, again without capturing any moths, and the programme is considered to have eradicated the species in New Zealand.

The NZ$12 million (approx. US$6 million) spent on the programme is justified by the undoubted impact that the moth would have had on the urban forest environment, horticulture and, to a lesser extent, the exotic and indigenous forests of New Zealand.

Source: Wittenberg and Cock (2001).

Many pest species become invasive only after a considerable lag time during which they persist in small numbers until outbreaks occur. Several causes for this delay are discussed in the literature (e.g. Crooks and Soule 1996; Williamson 1996; Kowarik 2003), including alteration to ecosystems caused by land use changes, or changes in agricultural and forestry practices which may favour some species over others, or create new pathways linking habitats, etc. Other suggested causes include a process of adaptation to the new habitat, perhaps through a genetic bottleneck. Some species may simply be going through a long period of exponential growth and may therefore appear to suddenly increase in population size and become invasive. Since this type of delay is most likely to be associated with long generation times, many species of exotic trees planted around the world are likely to be "sleeper" invasive alien species, a fact which will only become apparent in years to come.

Contingency plans should be prepared to deal with any alien species found during surveys. Such plans are usually a carefully considered outline of the action that should be taken when a new invasive species is found. However, given the diversity of potentially invasive alien species, and the variety of options for their control, plans will initially have to be either very broad – perhaps identifying general principles, responsibilities and likely stakeholders – or targeted towards specific high risk species or groups. Over time, more specific components for different groups or species may be added to the overall plan to provide a detailed contingency plan for more general use. Of equal importance to formulating the contingency plan is securing the involvement and commitment of all those involved in caring for the area at risk. Not only must they all understand the plan, they must also put into immediate effect those parts of it relating to the prevention and early detection of alien species.

3.3. Alien species: eradication[2]

When preventative methods fail, an eradication programme is usually the preferred method of action for species that pose a significant risk. Eradication is the elimination of the entire population of an alien species, including any resting stages, within the managed area. Where it is feasible, eradication is often a successful and cost-effective solution. However, because eradication programmes often appeal to politicians and the public, there is often a temptation to implement them even if they are unlikely to succeed. In reality, containment may be a more realistic alternative (Case Study 12). A careful but rapid analysis of the risk posed by a new species, the probable costs (including indirect costs) and the likelihood of success must be made; even then, eradication should only be pursued when the necessary funding and the commitment of all stakeholders (including the public) have been secured. Eradication of mammals, particularly those with which humans can identify, is particularly prone to opposition. Methods of killing these targets are rightly the subject of discussion and are often the cause of disagreement. However, resolving such conflicts takes time, and eradication is more likely to succeed if the initial response is rapid. Decision-making in such cases is not easy and must take these conflicting viewpoints into account.

[2] The following discussion of eradication options and criteria is based substantially on Wittenberg and Cock (2001).

The best chances of successful eradication are during the early phase of invasion, while the target populations are small and/or limited to a small area; well-established populations and large areas of infestation are usually unsuitable for eradication programmes. Furthermore, once an alien species is well-established and has become a major element of the ecosystem, its eradication (or control) may influence that ecosystem in unpredictable ways. The relationships between the target species and others (both indigenous and alien) then have to be carefully considered. Elimination of a dominant alien plant may lead to its replacement by one or more other alien species, perhaps with more damaging characteristics.

Eradication efforts have been most successful in island situations, including ‘ecological islands’ isolated by physical or ecological barriers, e.g. forest remnants surrounded by agricultural fields. However, the target species may survive in small populations outside an ecological island and, depending on the degree of isolation, could rapidly reinvade after an eradication campaign. The same may be true of real islands, especially coastal islands and archipelagos.

CASE STUDY 12: CONTAINMENT VERSUS ERADICATION: *MICONIA CALVESCENS* IN HAWAII

In formulating strategies for combating *Miconia calvescens* in Hawaii, it has been difficult to decide between eradication and containment. *M. calvescens* takes 45 years to reach maturity and commence fruiting: hence eradication is clearly possible for some small, localized populations and may be possible for entire islands. On the other hand, the longevity of the seed bank (thought to be 3+ years, but not fully assessed) means that an eradication programme has to be continued for several years to ensure success. Eradication will clearly require sustained commitment and funding for many years, but so, too, will containment. The control programme in Hawaii aims for eradication at a local or island level, whilst recognizing that complete eradication of the weed may not be achieved. Unfortunately, as long as there is a seed source of *Miconia* in the state, there will always be a strong possibility that new areas will be invaded, or that cleared areas will be reinvaded.

Source: Loope (1996)

Eradication programmes can involve several control methods, either alone or in combination. The methods used vary with different species, but may include:

- mechanical control (e.g. hand-picking of snails or hand-pulling of weeds);
- chemical control (e.g. herbicides for weed control);
- biopesticides (e.g. *Bacillus thuringiensis* (Bt) against insect pests);
- habitat management (e.g. grazing and prescribed burning);
- mass trapping (e.g. against fruit flies); and
- sterile male technique (used against several dipteran pests).

Some groups of organisms are more suitable for eradication efforts than others. Each situation should be carefully evaluated to determine the best method under the given circumstances. Ideally, the methods chosen should be as specific as possible, but the rather rigorous nature of concentrated eradication efforts will often inflict incidental casualties on nontarget species. In most cases, however, these losses are acceptable when balanced against the long-term economic and biodiversity benefits.

In general, plants are best eradicated by a combination of mechanical and chemical treatments, e.g. cutting woody weeds and applying herbicide to the cut stems. Amongst land invertebrates, only some snails and insects have been successfully eradicated (Case Study 11). Snails can be hand-picked, whereas the commonest options for eradicating insects are insecticides or biopesticides, usually by aerial application and/or in the form of baits. Mass releases of sterile males have been effective on several occasions (e.g. for fruit flies and the screw-worm fly) but have not been used in forest systems.

The advantage of eradication as opposed to long-term control is the possibility of complete reversion to the conditions prevailing prior to the invasion of the alien species. There are no long-term control costs (although precautionary monitoring may be appropriate) and the ecological impacts and economic losses fall to zero immediately after eradication.

The major drawback of eradication programmes is that they may not succeed, in which case the entire investment is largely wasted – at best, the spread of the target species will have been slowed. Many failed attempts have been both costly and have had significant adverse effects on nontarget species (e.g. the attempt to eradicate South American fire ants in the southern states of the USA, which ultimately had to be abandoned).

In summary, the basic criteria for a successful eradication programme are as follows:

- The programme needs to be scientifically based. Unfortunately, the traits that render species invasive make eradication efforts more difficult, e.g. high reproductive rates and good dispersal ability.
- Eradication of all individuals must be possible, bearing in mind that it becomes progressively more difficult and more costly to locate and remove the final individuals at the end of a programme.
- Support by the public and all stakeholders must be obtained beforehand.
- Sufficient funding must be secured for an intensive programme (allowing for contingencies) to ensure that eradication can be pursued until the last individual is removed.
- Small, geographically limited populations of alien species are easiest to eliminate. Thus, immediate eradication is the preferred option for most species found in detection surveys. Therefore, it is crucial that the early warning programme has sufficient funds available.
- Ideally, the management area must be completely isolated from other infested areas to prevent subsequent immigration of the alien species (as is the case for islands, particularly oceanic islands). Potential reinvasion pathways between infested areas and the management area must be carefully monitored and control measures implemented when necessary.
- All individuals of the population must be susceptible to the eradication technique. A combination of methods that are successful at either high or low population densities may be the most successful approach.
- A monitoring phase should be part of the eradication programme to make sure that eradication has been achieved.
- A suitable technique (e.g. pheromone traps) must be available for monitoring the species at very low densities at the end of the programme. Organisms that have less obvious stages that can survive for long periods (e.g. seed banks of weeds) will need monitoring for comparatively long periods.

Species currently considered unsuitable for eradication may be targeted in the future as new technologies are developed. For example, genetically engineered micro-organisms are currently being evaluated for the eradication or control of introduced foxes and rabbits in Australia. Such approaches may become more widespread in the future if public concerns over their safety can be satisfactorily addressed.

3.4. Alien species: biological control

Once an alien species has become established and eradication is no longer an option, a particularly useful management tool is biological control by the introduction of exotic natural enemies from the pest's area of origin (e.g. Case Studies 13 and 14). This approach (so-called 'classical' biological control) is particularly appropriate for the control of alien pests and has been carried out successfully for more than a century (Greathead and Greathead 1992; Julien and Griffiths 1998).

CASE STUDY 13: BIOLOGICAL CONTROL OF AN INSECT TO SAVE AN ENDEMIC TREE ON ST HELENA

Gumwood (*Commidendrum robustum* (Asteraceae)), the endemic national tree of St Helena, once formed much of the extensive woodland that used to cover the higher regions of the island, but is now restricted to two stands comprising around 2000 trees. It is a typical example of the remarkable indigenous flora of St Helena.

In the 1990s, gumwood was in danger of extinction as a result of attack by an alien insect, the Orthezia scale, *Orthezia insignis*. The latter is a polyphagous species native to South and Central America, but now widespread throughout the tropics. It damages its hosts primarily through phloem feeding, although the growth of sooty mould on its honeydew also has the effect of reducing photosynthesis by restricting the amount of light reaching the leaves. The scale was accidentally introduced into St Helena in the 1970s or 1980s and large populations built up on hosts such as lantana before it spread to the relatively rare gumwood trees in 1991. Thereafter, an increasing number of gumwood trees were killed each year and by 1993 at least 400 had been lost. If the pest had been allowed to continue unchecked, it is probable that gumwood would have become extinct in its natural habitat.

However, the Government of St Helena sought the help of the International Institute of Biological Control (now CABI Bioscience) in conducting a biological control programme against the pest. A suitable predator was already known: between 1908 and 1959, the predatory coccinellid beetle, *Hyperaspis pantherina,* had been released against *O. insignis* in Hawaii, four African countries and Peru. Substantial control was reported in all cases.

A sample of *H. pantherina* was therefore obtained from Kenya and studied under quarantine in the UK. Reproduction of the beetle was found to be dependent on *O. insignis*, with *H. pantherina* normally laying its eggs directly onto adult host females. The first two larval instars of the beetle are typically passed inside the ovisac of the host, after which the whole body is generally consumed. An assessment of the St Helena fauna showed that although there were several exotic pest scales in addition to *O. insignis*, there did not appear to be any related indigenous species; it was therefore concluded that introduction of the predator would be safe (in terms of possible effects on non-target organisms), and would also be effective against the orthezia scale.

Hence in 1993, *H. pantherina* was imported, cultured and released in St Helena. It rapidly became established and did indeed control orthezia scale on gumwoods, saving the latter from extinction in its natural habitat. This is probably the first case of biological control being implemented against an insect in order to save a plant species from extinction.

Source: Booth *et al.* (1995); Fowler (1996)

CASE STUDY 14: BIOLOGICAL CONTROL OF EUCALYPTUS WEEVIL IN SOUTH AFRICA

The Eucalyptus weevil, *Gonipterus gibberus* Boisduval (= *scutellatus* Gyllenhal) (Curculionidae), is a native of Australia that was first found in Cape Town, South Africa, in 1916. It spread slowly within Cape Province until 1925, when it was found in Johannesburg, after which it spread very rapidly through the Transvaal and Orange Free State.

Both larvae and adults of this weevil feed on the leaves of *Eucalyptus* spp., causing severe defoliation that, if unchecked, leads to the death of susceptible varieties and severely damages others. The preferred host is *Eucalyptus viminalis* Labill, but *E. punctata* DC., *E. globulus* Labill. and *E. maideni* F. Muell. are also severely damaged. Consequently, planting of these species in South Africa was greatly curtailed from the late 1920s onwards.

In Australia, this weevil is of little importance as a pest of eucalypts since it is kept in check by various natural enemies; an entomologist sent there in 1926 to look for potential biological control agents sent back three parasitoids to South Africa: a mymarid egg parasitoid *Anaphoidea nitens* (Girault), a tachinid and an eulophid. The mymarid was cultured and released in late 1926 near Johannesburg. The first recoveries were made in this area in January 1927 and by then releases had been made in about 20 plantations throughout the infected area. Establishment and dispersal (probably wind assisted) was rapid and by 1931 all affected areas were colonized. By 1935, economic control had been achieved in all areas except the High Veld, where sporadic damage continued, particularly to *E. viminalis*. Since then, *Gonipterus gibberus* has been reduced to the status of a minor pest causing low-level chronic damage and occasional outbreaks, but its economic impact has been greatly reduced. *Anaphoidea nitens* has since been distributed to other countries invaded by the weevil, including New Zealand, Kenya, Mauritius and the USA (Florida), with good results. This is now an often-quoted example of successful biological control.

Sources: Clausen (1978); Greathead (1971); Hanks *et al.* (2000); Nuttall (1989)

Despite the undoubted success of some biological control programmes, practitioners have become increasingly aware that introduced biological control agents may themselves have undesirable side effects. Initially, this concern was limited to the possible impact of introduced biological control agents on economically important plants and insects (notably honey bees and weed biological control agents). More recently, increased attention has been given to the potential danger to all indigenous fauna and flora, particularly rare and endangered species.

All biological control projects should therefore have a sound scientific basis and be subjected to proper risk assessments, with all stakeholders being involved in the decision-making process. Nevertheless, it should be remembered that any introduction is a permanent decision and that a successful biological control agent may sometimes spread to unanticipated areas (Case Study 15). Biological control agents are normally quarantined upon importation to screen for parasites and diseases, and to check the purity of the material.

In response to these concerns, some countries (mostly in the developed world) have developed their own legislation, whereas others depend on the IPPC (1996) Code of Conduct for the Import and Release of Exotic Biological Control Agents. The latter was an attempt to formalize current good practice and to set standards in terms of the information needed for decision-making without being over-restrictive (Kairo *et al*. 2003).

CASE STUDY 15: SPREAD OF A BIOLOGICAL CONTROL AGENT, *CACTOBLASTIS CACTORUM*, IN THE CARIBBEAN

The very successful introduction of the moth *Cactoblastis cactorum* from Argentina to Australia in the 1920s to control the cactus *Opuntia* is a classic example of biological weed control, which has since been repeated in South Africa and other countries.

In 1957, *C. cactorum* was introduced into the Caribbean island of Nevis, resulting in outstanding control of alien *Opuntia* species. Subsequently, the moth spread two miles to the island of St Kitts, and it was later introduced into the Cayman Islands, Antigua and Montserrat.

The moth subsequently spread more widely in the Caribbean and in 1989 it reached Florida. The mechanism of introduction is unknown, but is thought to have been via infested *Opuntia* sp. carried by man from the Dominican Republic.

In Florida, the moth is now attacking indigenous *Opuntia* species and is threatening the remaining populations of endemic semaphore cactus (*O. spinosissima*), already brought to the edge of extinction by habitat destruction. The threat to indigenous *Opuntia* spp. in Mexico has yet to be evaluated, but commercial cultivars of *Opuntia* are a significant local crop, grown both for their pads and fruits.

Apportioning responsibility for this situation is not straightforward. While some might blame the original biological control introduction into Nevis, others might implicate the breakdown in quarantine that allowed *C. cactorum* to spread to the areas where it is now considered a pest. One major problem is the lack of consultation between the USA, Mexico and the Caribbean islands regarding their proposed releases of biological control agents. It is worth noting that the issue in this case is not an unforeseen impact on nontarget organisms (since *C. cactorum* was known to attack a range of *Opuntia* species), but rather the limitations of both the decision-making process and the various quarantine services.

The importance of this case study lies in its highlighting of the irreversibility of biological control and the fact that the values and concerns of society change over time, so that yesterday's correct decision can look questionable today.

Source: Wittenberg and Cock (2001).

3.5. Other management options

There are various other management options for the control of insects, diseases and weeds, although many are unsuitable for use in forest systems on the grounds of practicality, effectiveness, economics or environmental risk. Ideally, all relevant and appropriate techniques should be integrated to meet the pest management objective in an optimum manner (e.g. maximizing yield and profit while minimizing adverse environmental and aesthetic impacts). Suitable approaches include cultural techniques (e.g. seedling management, planting patterns, buffer zones (Case Study 16), ecoclimatic matching, resistance/ tolerance to pests), mechanical methods (e.g. cutting, bulldozing, shading), chemical control (pesticides), and biological control (classical, augmentative, or conservation). The principles and use of integrated pest management (IPM) are considered beyond the scope of this report, although an overview is presented in Table 1 and Figure 1. For more information, see relevant texts from forestry (e.g. Speight and Wylie 2001) and agriculture (e.g. Dent 2000; Matthews 1984; Mengech *et al.* 1995; Metcalf and Luckman 1994; Morse and Buhler 1997; Norton and Mumford 1993).

CASE STUDY 16: BUFFERS TO KEEP INVASIVE PLANTS OUT OF FOREST FRAGMENTS

Fragmented forest habitats are vulnerable because they have proportionately more edges through which alien species can invade. The obvious solution of minimizing the amount of edge is not always feasible, but there may be another effective approach: intact edges can help keep seeds out of the forest interior.

Cadenasso and Pickett (2001) quantified aspects of this phenomenon in New England, USA. They compared the number of seeds blowing from an old field into an adjacent deciduous forest patch through two types of edge: intact and thinned. The thinned edge was created by removing all trees, shrubs and branches that were less than half the height of the forest canopy. This thinned edge extended 20 m into the forest patch and resembled that created by logging or a large blow-down. Four times as many wind-borne seeds crossed the thinned edge than the intact edge, and seeds penetrated 2.5 times further into the thinned forest edge than the intact edge – 45 m vs 17 m. Cadenasso and Pickett therefore recommended protecting forest fragments from invasive weeds by "sealing" the edges – removing non-native plants and planting with dense native shrubs, vines and understorey trees.

A similar result was obtained in New Zealand, where a buffer of *Pinus radiata* (planted for timber production) effectively protected an adjacent native podocarp-broadleaf forest from invasion by exotic species. The vegetation at the interface of the two zones was a mixture of light and shade-tolerant species, reflecting its history (i.e. an 'open' edge both prior to the planting of the *P. radiata* and during its early growth phase, and a 'sealed' edge once the pine reached a certain height and density). Very few exotic plants were found in the native forest adjacent to the mature pine, although such species were found both under the pine and within the first 10 m of the native forest where it was adjacent to pasture. The edge of the native forest area adjacent to 75-year-old pines (with diameters up to 70 cm) was indistinguishable in species composition from the interior of that area of forest. At the edges of a stand of 25–30 year old pines, the vegetation was similar in composition to that found 25 m into native forest adjacent to pasture (Karen Denyer, unpublished report).

In addition to reducing the spread of invasive alien plants (especially those with wind-borne seeds), such buffer zones can provide new habitats and increase local species diversity. They can also limit other adverse effects from adjacent land. Specific benefits include reducing fire risk, reducing the risk of pesticide spray damage, protecting forest edges from wind penetration, protecting sensitive plants and animals in the interior, and limiting the movement of sediments and nutrients (particularly in areas adjacent to wetlands and riparian habitats).

Sources: Cadenasso and Pickett (2001); Davis and Muerk (2001); Denyer (2000); http://www.canr.uconn.edu/ces/forest/invasives.htm

TABLE 1: COMPONENTS OF A GENERALIZED IPM SYSTEM.
Stages A and B are entirely preventative, Stage C involves monitoring and prediction, while Stage D covers control strategies should prevention fail or monitoring reveal high risk (adapted from Wylie 2001; Speight *et al.* 1999).

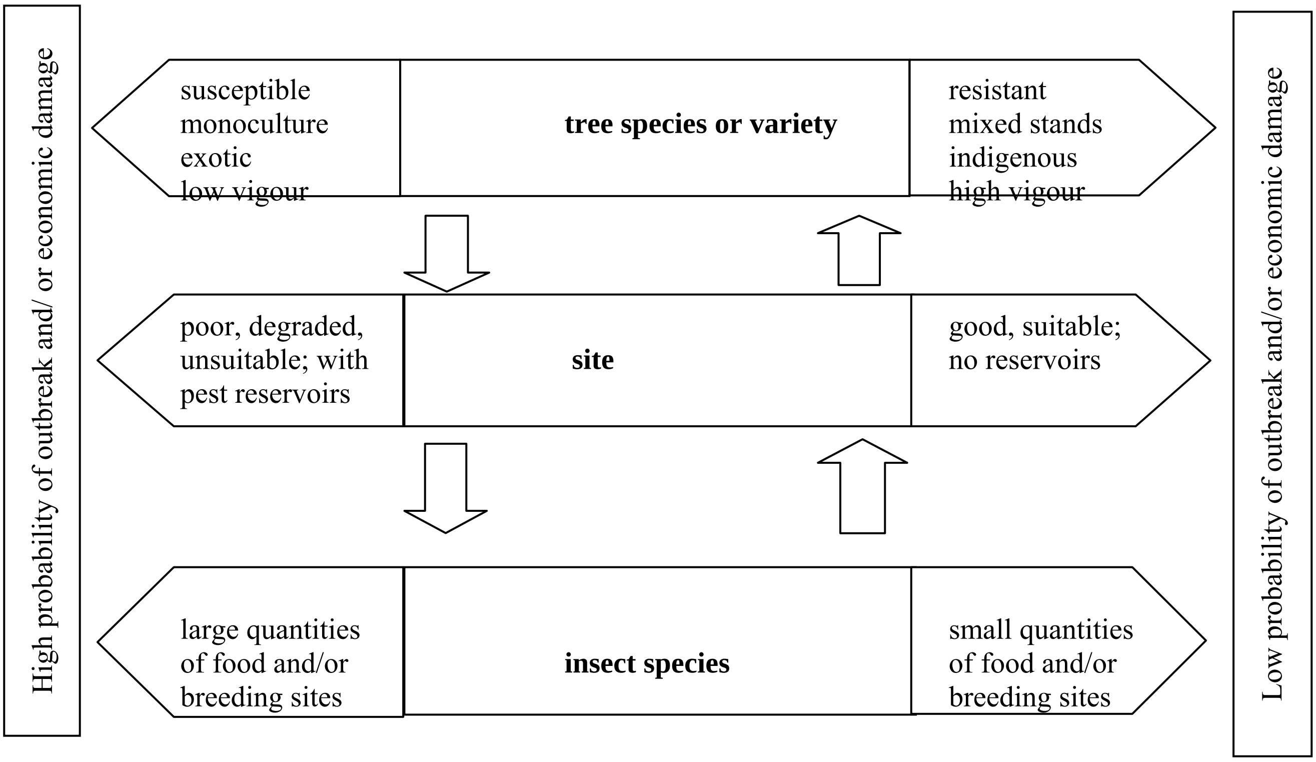
Stage	Options
A	• Site choice – avoid low tree vigour; consider history and previous cultivation • Tree species or genotype choice – consider end-use and economics • Location choice – consider proximity to older stands and natural vegetation • Silvicultural choice – consider mixed vs monoculture, shade resistance, enrichment planting (of seedlings in clearings or lines of established forest)
B	• Survey major pests and diseases in locality; consider history of problems • Research biology and ecology of major pest and disease species, especially host plant relationships • Survey pests' major natural enemies in locality
C	• Determine potential impact of major pests on crops; set economic thresholds • Monitor pest levels during vulnerable growth period; relate to economic thresholds
D	• Ecological control, e.g. sanitation thinning, nursery treatment, establishment • Biological control, e.g. parasitoids, predators, pathogens • Chemical control, e.g. insecticides, growth regulators, pheromones

Control techniques used in plant nurseries are likely to be more flexible and more intensive than techniques available for growing plantations. For example, seed treatments, fertilizer applications, irrigation treatments, drenches, hand-picking of pests, insecticide applications, etc. may all be used to good effect in nurseries while being unsuitable for maturing plantations.

An underlying tenet of pest management is that a healthy crop will minimize pest damage and its impact. This is particularly relevant to forestry systems, where interventions for pest management should be minimized or eliminated after planting out. Seedlings which have been protected from pests and which are planted with a nutrient-rich planting substrate are more likely to survive new pest attacks than material that has been stressed before it is even planted. Hence investment in protection at the nursery stage helps prevent attack by both forest pests and diseases, particularly in the case of individually planted agroforestry trees.

It is important to remember, however, that the key pests are likely to be different at different stages of tree growth, and that many pests will attack maturing trees, regardless of whether the seedlings were healthy or not. Hence plantation managers will begin implementing their pest management strategies well before they start putting seedlings in the ground (Wylie 2001). Choosing species and provenances that are resistant to potential pests and which suit the site (and which will therefore grow vigorously) is clearly important. However, resistance can be overcome if selection pressure is high enough, and planting a mixture of resistant varieties – if more than one is available – is probably the best strategy. Multi-species (or even single-species) plantations with a 'mosaic' of tree ages are also less likely to experience catastrophic pest infestations than even-aged monocultures.

FIGURE 1: SUMMARY OF FACTORS THAT MAY INTERACT TO CREATE INSECT PEST OUTBREAKS IN TROPICAL FORESTRY AND STRATEGIES FOR REDUCING RISK
(from Wylie 2001; Speight 1997)



In agricultural crops, pest management decisions are often based on the use of economic thresholds, which take into account the revenue losses resulting from pest damage and the costs of treatment. Below the economic threshold, the presence of the pest is tolerated, and only when damage rises (or is predicted to rise) above the threshold is action taken. However, this approach is difficult to apply in forestry: determining the economic threshold for long-lived perennial crops like trees is particularly difficult because economic and biological forecasts must sometimes be made over decades (Wylie 2001).

Furthermore, IPM relies heavily on monitoring to identify areas where pest populations are high and when economic thresholds are likely to be exceeded (Clarke 1995). In contrast to intensive agriculture, however, such monitoring may be impractical or at least inaccurate in large and inaccessible forest areas. Adopting an IPM approach can be complex and expensive when detailed monitoring is required. This is obviously a constraint in many tropical forestry operations where profit margins are often low.

The Forest Stewardship Council (Case Study 17) has formulated principles for environmentally appropriate, socially beneficial and economically viable management of the world's forests. These principles recognize many of the ecological issues raised here, including the risk of introduced tree species becoming invasive. However, they also recommend minimizing the use of biological control agents and not using genetically modified organisms – statements with which not everyone would agree.

Other, similar schemes (e.g. the Montreal Process (1999), and the Sustainable Forestry Initiative (SFI 2002)) pay less attention to biosecurity, or address the management of natural forests, where some of these issues are less relevant.

3.6. Current and future trends in forest pest management

There are some discernable trends in national approaches to forest pest management, notably towards more sustainable management strategies. These changes are often related to a changed perception of the role of forests, which are now seen not only as a source of commercial products, but also as valued ecosystems in their own right, with associated ecological and social functions.

As far as pest management is concerned, the main tendencies are as follows:

- Pest outbreaks are no longer automatically viewed as a calamity, particularly in forests where logging is not the main function. As a result, the use of pesticides in forestry has greatly declined. Some countries, such as Switzerland and Sweden, have banned, or are in the process of banning, the use of pesticides on forest trees (e.g. Zahn 1999). In Canada, insecticide use in forestry has been severely restricted in recent years: registering pesticides for use in forestry has become increasingly difficult and most provinces allow only microbial insecticides (mainly Bt) in the natural forest environment (Carrow 1995).
- In the development of new, sustainable pest management methods, increasing emphasis is being placed on prevention rather than control. In Europe, forest health monitoring networks were set up at both national and EU levels during the 1980s and 1990s, partly as a result of concern over a possible large-scale decline in forestry (e.g. DSF 2000). To help coordinate surveying, monitoring and prevention methods on a European scale, a IUFRO working party was created in 1998 and has met yearly ever since (Forster *et al*. 1999).

CASE STUDY 17: PRINCIPLES OF THE FOREST STEWARDSHIP COUNCIL RELATING TO BIOSECURITY

The Forest Stewardship Council (FSC) is an international non-profit organization founded in 1993 to support environmentally appropriate, socially beneficial and economically viable management of the world's forests. Its members consist of a diverse group of representatives from environmental and social groups, the timber trade and the forestry profession, indigenous people's organizations, community forestry groups and forest product certification organizations from around the world.

FSC's Principles and Criteria (P&C) apply to all tropical, temperate and boreal forests. Many of these P&C also apply to plantations and partially replanted forests. The P&C must be incorporated into the evaluation systems and standards of all certification organizations seeking accreditation by the FSC. While the P&C are mainly designed for forests managed for the production of wood products, they are also relevant, to varying degrees, to forests managed for non-timber products and other services. The following is an extract from the P&C that highlights issues relating to biosecurity:

PRINCIPLE 6: ENVIRONMENTAL IMPACT

6.6. Management systems shall promote the development and adoption of environmentally friendly non-chemical methods of pest management and strive to avoid the use of chemical pesticides. World Health Organization Type 1A and 1B and chlorinated hydrocarbon pesticides, pesticides that are persistent, toxic or whose derivatives remain biologically active and accumulate in the food chain beyond their intended use, as well as any pesticides banned by international agreement, shall be prohibited. If chemicals are used, proper equipment and training shall be provided to minimize health and environmental risks.

6.7. Chemicals, containers, liquid and solid non-organic wastes including fuel and oil shall be disposed of in an environmentally appropriate manner at off-site locations.

6.8. Use of biological control agents shall be documented, minimized, monitored and strictly controlled in accordance with national laws and internationally accepted scientific protocols. Use of genetically modified organisms shall be prohibited.

6.9. The use of exotic species shall be carefully controlled and actively monitored to avoid adverse ecological impacts.

PRINCIPLE 10: PLANTATIONS

10.3. Diversity in the composition of plantations is preferred, so as to enhance economic, ecological and social stability. Such diversity may include the size and spatial distribution of management units within the landscape, number and genetic composition of species, age classes and structures.

10.4. The selection of species for planting shall be based on their overall suitability for the site and their appropriateness to the management objectives. In order to enhance the conservation of biological diversity, native species are preferred over exotic species in the establishment of plantations and the restoration of degraded ecosystems. Exotic species, which shall be used only when their performance is greater than that of native species, shall be carefully monitored to detect unusual mortality, disease or insect outbreaks and adverse ecological impacts.

10.7. Measures shall be taken to prevent and minimize outbreaks of pests, diseases, fire and invasive plant introductions. Integrated pest management shall form an essential part of the management plan, with primary reliance on prevention and biological control methods rather than chemical pesticides and fertilizers. Plantation management should make every effort to move away from chemical pesticides and fertilizers, including their use in nurseries. The use of chemicals is also covered in Criteria 6.6 and 6.7.

10.8. No species should be planted on a large scale until local trials and/or experience have shown that they are ecologically well-adapted to the site, are not invasive and do not have significant negative ecological impacts on other ecosystems….

Source: FSC (2000)

- Invasive alien species are now considered to be the main pest threat to forests. Since these species cannot always be controlled by sustainable management methods, preventative methods are being developed in most parts of the world. Pest Risk Analyses (PRA) are being undertaken for forest pests; quarantine laws and regulations are being developed, as are early detection methods, public education programmes, etc. These prevention programmes are by no means sufficient, since large numbers of forest pests are introduced into new regions every year. However, early detection programmes may facilitate the eradication of new invasive species.
- Large monocultures are disappearing from many European and North American landscapes and are being replaced by smaller, mixed stands of various ages (Carrow 1995), thereby reducing pest risks.
- National and international forestry and agroforestry organizations now encourage the use of several tree species together, to reduce the risk of catastrophic pest outbreaks (e.g. those of Leucaena psyllid, cypress canker and cypress aphid that decimated East African agroforestry).

At the moment, these trends are most clearly seen in developed countries, but in future are likely to be more widely adopted in developing countries as well.

4. FORESTRY TREES AS INVASIVE ALIEN SPECIES

In addition to the threats posed to forestry by the introduction of alien pest species, forestry trees may themselves become invasive and create problems of their own (Case Study 18). Curiously, relatively few countries regulate the introduction of exotic plant species and those that do (e.g. Germany and Switzerland) make a general exception for forestry species (see De Klemm 1996).

A number of definitions of ‘invasive species’ have been suggested in the literature; in the context of forestry, it is recommended that a common definition should be developed that focuses only on parameters of population expansion and avoids any preconceived negative perceptions of invasive species.

CASE STUDY 18: PAPER-BARK TREE ALTERS HABITATS IN FLORIDA

The paper-bark tree, *Melaleuca quinquenervia*, is an evergreen tree with a slender crown, which grows up to 30m tall. It has white, many-layered papery bark and white flowers in brush-like spikes. It is native to Australia and Papua New Guinea and was introduced to Florida at the beginning of the twentieth century to provide a useful crop that could grow in an area subject to drought, flooding and periodic fires. However, although hopes of using the tree for timber were not fulfilled, it did prove valuable as an ornamental.

Nevertheless, it was an unfortunate choice for introduction. It is adapted to subtropical climates, with a preference for seasonally wet sites, and flourishes in standing water. Hence it grows extremely fast in Florida (18-month-old trees can be 6–7m tall) and can flower up to five times per year. Trees as young as two years old are able to produce viable seed capsules, which are retained on the tree and release their seeds in times of stress – fire, frost and herbicide can all cause the seed capsules to open. Mature trees can hold up to 20 million seeds; on the tree, these can remain viable for up to 10 years, although viability is quickly lost once the seeds are in the soil. *M. quinquenervia* forms dense, impenetrable thickets and, in addition to dispersal of its seeds by wind and water, can also spread vegetatively via adventitious roots which gradually lead to soil accretion at the water surface, and hence to an increase in the elevation of infested areas. Small increases in elevation (a few centimetres) can make a tremendous difference to the composition of Everglades plant communities and *M. quinquenervia* is threatening this unique habitat by gradually converting wetland to upland. In the last 30–40 years it has spread rapidly and in southern Florida now infests close to half a million acres (some 200 000 ha), causing extensive environmental and economic damage, particularly in the Everglades.

Source: Buckingham (1997)

On a global basis, little information is available on the status of forestry trees that have become invasive. Evaluation of the extent of such invasions is often very qualitative and subjective, making it difficult to assess the overall magnitude of the problem. Furthermore, the terminology used by authors is also very variable and there is frequent overlap in the terms ‘invasive’ and ‘naturalized’.

With these caveats in mind, a literature review by Murphy and Haysom (FAO 2003b) found 443 species of tree or woody shrub that were classed as invasive, including some listed by Binggeli (1996) as possible or potential invaders. Some 282 species used in forestry were among those listed as invasive, and a further 40 were reported as naturalized but not invasive. The majority of the species encountered were used for more than one economic purpose. Among those species named as invasive, 203 were used in agroforestry and 292 were amenity species.

There were examples of invasive species amongst both the angiosperms and gymnosperms. Fifty-eight plant families included at least one invasive species of forestry tree, and 34 families contained more than one invasive species. In decreasing order, most invasive forestry species were drawn from the families Leguminosae, Pinaceae, Myrtaceae, Rosaceae and Salicaceae. Twelve families contained no known invasive species of forestry trees.

Invasive species were reported in all seven geographic regions (Europe, Africa, Australasia, North America, South America, Pacific, Asia), with most invasive trees being reported from Africa (87), and fewest from Europe (12) and Asia (14). However, the majority of species were invasive in only one of the seven regions, and even the most 'invasive' species did not show this trait in every country in which they had been introduced. Most invasive species had a native range that included Asia, and the fewest, one that included the Pacific.

Most sources reviewed by Murphy and Haysom (FAO 2003b) gave little information on the use of the trees, details of management (forestry, agroforestry, amenity, etc.) or of the history of their introduction, scale of planting or scale of invasion (land area). Geographically, it was notable that most invasive species were reported from regions in which extensive research on the number and impact of such species has been carried out, e.g. South Africa and North America. There were distinct gaps in knowledge of invasive species in Africa (apart from South Africa, Zimbabwe, Botswana and the oceanic islands), Asia and parts of South America.

In general, there are few studies of the positive and negative impacts of invasive forest trees. Positive impacts include the provision of fuel and other resources for resource-poor communities, and soil stabilization in over-exploited natural forest areas such as in India. Research in other countries on invasive woody legumes in pasturelands has shown that, under some management regimes, such species can complement pasture grasses for livestock feed.

Amongst the potential negative impacts are the risks of hybridization between introduced species, which can potentially produce new invasive species. However, only a few such instances have been reported in forestry, notably those of *Leucaena* and *Prosopis* hybrids, which are in any case only locally important. There are relatively few cases in which forest trees have invaded agricultural systems or forest plantations, although they have been reported as major problems in grassland pastures throughout the world; most reports of invasiveness relate to natural or semi-natural habitats, e.g. riparian and wetland systems. One of the few quantitative studies conducted on the impact of invasive trees in a natural habitat was undertaken in the fynbos biome in South Africa, where trees cause substantial losses in local biodiversity and prevent natural run-off of water from catchment zones. This affects South Africa's water supply, especially in the dry seasons (Van Wilgen *et al*. 1996, 1998).

While there is a growing national and international awareness of the possible risks of invasiveness of forestry trees, it is likely that some stakeholders in forestry remain ignorant of the risks, particularly since there is a general lack of quantitative information on the ecological and economic impacts of invasive forestry trees. It is therefore recommended that a number of case studies be conducted in collaboration with countries that have a high dependence on forestry. Such case studies should cover a range of forestry situations (e.g. commercial and environmental) and include the development and promotion of tools for making ecological and economic assessments. Particular attention should be paid to those regions of the world where there is little information on the invasiveness of exotic forestry trees (e.g. tropical and temperate Asia).

Globally, the development and implementation of prevention, control and management tools for invasive forestry trees has been limited because of the basic economic and developmental benefits of the trees concerned. Some countries have made extensive investments in exotic trees and are therefore reluctant to take action against those species that have become invasive. The general lack of relevant information and methodologies also prevents many countries from implementing risk assessments, control and management schemes.

Nevertheless, some attempts have been made to develop risk assessment and risk management models, although these schemes are generally aimed at exotic plant introductions in the broadest sense rather than at forestry trees *per se*. The development of risk assessment protocols for forest trees does pose some challenges – such as factoring in the time lags that can occur before a tree becomes invasive and the problem of unpredictable hybridization with other tree species. Despite these problems, however, practical risk assessments are now in use in Australia, New Zealand and the USA, and a few other countries/territories have schemes under development. The most common methods to date are based on assigning numerical scores to various biological attributes and to factors such as whether the plant is invasive elsewhere. There is an urgent need for such risk assessments to be further evaluated for use in forestry and promoted if found appropriate.

Risk assessment and management of alien plants (i.e. introduced plants not yet invasive) have also been considered in some cases. Many researchers in this field have called for monitoring schemes to be set up once a plant has been introduced, but for forestry trees this would entail planting trials that would have to be continued for many years. Practical guidelines on monitoring aimed at forestry programmes are not readily available and this is another area where further work is required.

Where preventative methods have failed, eradication programmes have sometimes been undertaken, e.g. against woody legumes, such as *Prosopis,* that have become invasive in pastoral systems. Eradication methods have also been used effectively in Mauritius and Florida to clear alien forest trees in areas of conservation value.

However, such programmes are costly and have not always been successful. Hence in some cases the focus is now on control rather than eradication. For example, an integrated approach using biological, mechanical and chemical methods is being used to control woody legumes in Australia, South-East Asia and South Africa. Biological control by seed feeding bruchids has been used in South Africa against several leguminous trees that have become invasive (e.g. *Acacia mearnsii*), and these programmes are now supported by new legislation restricting the planting of trees that have invasive tendencies. Other approaches being developed in South Africa include making plantation owners take responsibility for the impact of invasive tree species spreading from their plantations.

Alternative approaches to managing the risks associated with forest trees include trying to develop seedless clones of pines and near sterile hybrids of *Leucaena* species. All of these approaches could be used by other countries trying to resolve problems associated with invasive forestry trees.

5. TRENDS IN THE USE OF GENETICALLY MODIFIED FOREST TREES

The two main commercial developments which have so far arisen from the genetic modification of plants are of limited relevance to forestry, since one has involved conferring pest resistance by the insertion of a gene from *Bacillus thuringiensis*, and the other, resistance to the herbicide glyphosphate by the insertion of a resistance gene. However, neither herbicides nor insecticides are widely used in forestry: insecticides are usually restricted to occasional surface-limited treatments, and herbicides are applied only during a short initial period in a tree's life. In Canada, less that 5 percent of the pesticides sold are used in the forestry sector (Carrow 1995).

However, despite the fact that the first generation of GM products was not very relevant to forestry, there are numerous ways in which the technology could be useful to the sector, and many research groups are actively developing and implementing methods for the genetic modification of trees. Protocols are being developed for gene delivery to various tree tissues, including flower parts and pollen. This will allow researchers to bypass the long life-cycle of trees and quickly verify patterns of expression of the introduced genes in mature tissues. In this way, traits based on single genes (e.g. pest tolerance) can be rapidly transferred to superior genotypes. Future goals include the introduction of genes for flower sterility, e.g. into conifer species to eliminate potential problems of invasiveness and to minimize gene flow to related trees (Canadian Forest Service 2002). Thus, there seems to be considerable potential for developing new genotypes of forestry trees with very useful biological traits. Genetically modified biological control agents, especially pathogens such as viruses and fungi, are also being considered (e.g. Canadian Forest Service 1997).

However, as yet, there are no generally accepted protocols for assessing the risks associated with these new varieties. Assessing risks in long-term crops such as forestry trees is difficult, and the large-scale uptake of this technology is likely to be slow unless reliable protocols can be developed and the risks found to be acceptable.

Some strong opinions have been expressed against the use of genetically modified trees in forestry, e.g. by the Forest Stewardship Council (Case Study 17). In May 1999, the World Wide Fund for Nature (WWF) formulated a position statement on GMOs, which called for (i) a moratorium on the use or release of GMOs until ecological interactions are fully researched; (ii) transparent, comprehensive environmental impact assessments of planned releases; and (iii) properly regulated monitoring and control of gene technology.

Developing countries are watching developments in this area with keen interest, and are caught between the desire to gain potential benefits from this new technology and concerns over possible side-effects and fears that their farmer-generated germplasm may be used by international seed companies without adequate recompense. Many developing countries are now actively seeking objective external sources of advice on these issues.

6. FORESTRY AS A PATHWAY FOR THE INTRODUCTION OF ALIEN SPECIES

The transport of forestry materials and products is a major pathway for the introduction of alien species, particularly diseases and insects. The Asian longhorned beetle, pine shoot beetle, chestnut blight (*Cryphonectria parasitica*) and Dutch elm disease (*Ceratocystis ulmi*) are just a few examples of species that have been imported into new areas on raw wood or nursery stock. The impact of such introductions can be profound: as shown in Case Studies 2 and 8, for example, while the latter two species completely altered the composition of forest communities in the eastern USA.

Within the forestry industry, several distinct pathways for the introduction of alien species have been identified. Some of these have been alluded to earlier, but are examined here in greater depth.

6.1. Species introduced in association with silvicultural practices

The importance of alien pests in forestry and the potential for introduced forestry trees to become invasive have already been discussed. However, other species may be introduced in association with forestry practices, either deliberately or inadvertently. Specific examples include cover crops and mycorrhizae.

Fast-growing cover crops are useful for reducing weeds in the early stages of plantation establishment. Typical cover crops include various vines (e.g. nitrogen fixing species) or grasses that can subsequently be grazed or harvested. In mixed agroforestry systems, vegetable and fruit crops may be under-planted and the associated weed control will also benefit the trees.

In the early part of the twentieth century, various exotic cover crops were tried and used in some countries. However, the characteristics that make these species effective as cover crops are also likely to make them invasive. *Mikania micrantha* (Case Study 7), for example, was deliberately introduced as a trial cover crop in plantation systems and subsequently became a major weed in both agricultural and forestry systems (Parker 1972). In general, the use of exotic plants as cover crops should be approached with caution and the introduction of such crops into areas where they do not already occur should be stopped.

Similar care should be exercised over the introduction of exotic mycorrhizae to promote the growth of forestry trees. In general, these introductions may be expected to be beneficial, but it is extremely difficult to anticipate or assess the impact of such species on an ecosystem (Case Study 19). Introductions of these species should therefore be approached with caution (particularly in the case of oceanic islands) and efforts made to monitor their subsequent establishment, spread and ecological impact.

CASE STUDY 19: POSSIBLE IMPACTS OF MYCORRHIZAL INTRODUCTIONS ASSOCIATED WITH FORESTRY TREES

There is relatively little information on the impact of introduced mycorrhizal fungi, except on their direct benefit to associated trees. Their possible effect on the invasiveness of their associated trees (or other ecological effects) has not been widely investigated.

Introductions of symbiotic mycorrhizae may increase the invasiveness of exotic plants, but at present there is little evidence of this. However, there is clear evidence from Hawaii that fungal symbionts of alien tree species can significantly alter the natural ecosystem. In Hawaii, *Myrica faya*, an invasive alien tree, forms a symbiotic relationship with *Frankia* spp. (an actinomycetal genus that forms nitrogen-fixing root nodule symbioses). It is not known whether *Frankia* was naturally present in the soil in Hawaii, but the interaction between *M. faya* and *Frankia* significantly increases soil nitrogen levels. These high nitrogen levels, in turn, provide a nutrient-rich substrate for other fast-growing alien species, which can outcompete slower-growing native species. The high-nitrogen soil also attracts worms (another alien to Hawaii) that in turn attract pigs (also alien). The pigs disturb the soil looking for worms, creating germination sites for invasive alien weed species. There is thus a whole series of negative impacts associated with this particular tree–mycorrhizal relationship.

In New Zealand, the introduced ectomycorrhizal fungus *Amanita muscaria* has become naturalized in some *Nothofagus* forests. This fungus was introduced to New Zealand relatively recently, but before 1997 it had only been reported in three or four native forests within the Nelson Lakes National Park. Recent records, however, suggest that it is now widespread in indigenous forests in the northern half of the South Island. In most localities where it is found, *Amanita muscaria* is present at numerous separate sites. This distribution may be due to some local characteristic of the environment, the fungus, or the host, or it may be the result of local spread following a single invasion. So far, it has been recorded only in association with *Nothofagus* spp., with no reports of it occurring with the only other indigenous ectomycorrhizal trees in New Zealand, *Leptospermum scoparium* or *Kunzea ericoides*.

This system provides an ideal opportunity to research various questions relating to the effect of mycorrhizal species on the forest ecosystem, including:

- The effect of these exotic mycorrhizal associates on the indigenous *Nothofagus* particularly with respect to nutrient uptake, resistance to root diseases, etc.
- The impact of these invasive fungi on the diversity of native ectomycorrhizal fungi normally expected at the invaded sites.
- The possible effect of these exotic mycorrhizal fungi on the invasion of *Nothofagus* forests by exotic mycorrhizal trees. For example, in New Zealand, there is no evidence that exotic conifers can utilize indigenous mycorrhizal fungi, and it could be that this restricts the spread of these conifers into New Zealand's native forests. However, since *Amanita muscaria* is often found as a mycorrhizal associate of introduced conifers (e.g. *Pinus* spp. and *Pseudotsuga menziesii*), establishment of the fungus in native forests may make it easier for *Pinus* spp. to invade them.

Sources: *http://www.landcareresearch.co.nz/research/biosecurity/fungal/*; Candace J. Felling, personal communication, 2002; Tim Low, personal communication, 2002; Peter Johnston, personal communication, 2002. See also Lutzow-Felling *et al.* (1995); Vitousek (1986, 1992).

The accidental or deliberate introduction of pollinating species can also have unpredictable effects. Most trees are pollinated by wind or by generalist pollinators – usually insects (particularly bees), but also sometimes by vertebrates. However, some trees have highly specialized pollinators, which may be restricted to the tree's indigenous range. For example, many fig species are dependent on highly specific fig wasps (Agaonidae) for pollination, and without them the fig tree will bear no seeds. Three exotic fig tree species grown in Florida gardens for over a century only started spreading approximately 20 years ago, when their fig wasp pollinators arrived. Thus *Ficus microcarpa*, widely planted in Florida as an ornamental, only became a pest about 45 years after its introduction, when its associated fig wasp (*Parapristina verticillata*) was introduced. There are similar examples from California and Bermuda.

In the case of the oil palm (*Elaeis guineensis*), pollinators were deliberately introduced into South-East Asia from the tree's centre of origin in West Africa. For many years, oil palm was thought to be wind pollinated, and in South-East Asia hand-pollination was necessary to obtain satisfactory fruit set. However, research in West Africa revealed several weevil species whose adults pollinate oil palm flowers. After detailed studies on host specificity, one of these species (*Elaidobius kamerunicus*) was introduced into Malaysia. It soon became established and spread rapidly, providing excellent pollination and obviating the need for hand-pollination. The introduction was considered to be an outstanding success and the weevil was subsequently introduced into other oil palm growing areas with the same results. The host specificity testing, which was based on the practices for weed biological control, was considered to have accurately predicted the risks. This approach might be applicable to some forestry trees which show low levels of seed production in areas outside their native range, but it should be approached with caution, since the host range testing is a long, detailed and expensive process, and, perhaps more importantly, improved fertilization could help an exotic tree to become invasive (Section 4).

A rather more speculative example in a similar vein is worth mentioning. *Eucalyptus* trees are very widely planted in the tropics, but conservationists often do not like them because they show allelopathic effects and the leaf litter beneath them breaks down only slowly, tying up nutrients and maintaining the allelopathic action. The biodiversity associated with exotic eucalypts is also low. In Australia, the breakdown of *Eucalyptus* leaves is facilitated by a group of specialized and probably highly specific detritus feeders. It may be that the introduction of one or more of these detritus feeders into the exotic range of *Eucalyptus* could improve nutrient cycling under these trees, to the benefit of both forestry and conservation. However, the ecological implications of this idea would obviously need careful evaluation before it could be taken further.

6.2. Movement of germplasm

The importation of plants is a major pathway for the accidental introduction of alien species. For example, of 23 alien insect species that have become established in California since 1980, 20 arrived on imported plants (two others were on fruit and one was on infested wood) (OTA 1993). The Sternorrhynchan bugs, particularly the most sedentary groups such as scale insects and mealy bugs, are particularly prone to dispersal in this way. Less obvious threats include the seeds of other plant species, which may be carried either on the above-ground parts of the plant, or in the soil. The latter may also harbour arthropod pests, soil-borne diseases and other soil organisms. Knowledge of the taxonomy and natural distribution of some of the latter is rather limited and the distribution of some so-called cosmopolitan species is probably human-mediated. The increasing availability and use of tissue culture should reduce such problems in the future.

Extensive literature is now available on the safe movement of germplasm, some directly concerned with forestry trees, e.g. *Eucalyptus* (Ciesla *et al.* 1996). National and regional trade protocols and legislation may also encompass the movement of forest reproductive material (e.g. Ackzell 2002), but this area is beyond the scope of this report.

6.3. Solid wood packaging materials

Packaging material is frequently composed of raw wood from any available species and represents one of the most important pathways for the introduction of alien organisms inhabiting woody substrates (Case Study 20).

The Asian longhorned beetle entered the USA in wooden packing material from China and is now established in New York and Illinois (Case Study 21). This is just one potentially devastating species that has arrived on wood packing material – to date, insects from 54 families have been intercepted in solid wood packaging materials (SWPM) by the USDA.

<u>Case Study 20</u>: Solid wood packaging materials: an important potential pathway for the introduction of alien species into the USA

Globally, solid wood packaging materials (SWPM) pose a considerable risk for the introduction of exotic forest pests. Shippers may use virtually any species of woody plant, in any state from fresh-cut to re-used, seasoned lumber, and often use low-grade and scrap wood to minimize costs. Cargo shipments may therefore contain SWPM of various types and ages and from unexpected and multiple origins. Solid wood can contain many different potential pest organisms – most pests that feed or occur in or on live or dead stems and branches of woody plants may be found in or on untreated SWPM. The risk is even greater if intact bark is present, since many potential pests feed under bark, particularly bark beetles (Scolytidae) and their associated fungi. Recently, US inspectors found that 9 percent of maritime and 4 percent of air shipments containing SWPM had bark present, despite import requirements that SWPM be bark-free.

About 52 percent of maritime shipments and 9 percent of air shipments imported into the USA are accompanied by SWPM, the presence of which is generally not identified on a shipping manifest, making it difficult for port inspectors to select shipments for inspection. SWPM can be associated with importations of over 250 different commodities, entering the USA through approximately 100 ports of entry and often accompanying the cargo to its final destination. SWPM may be reused or reconditioned for additional use, contributing to the further redistribution of potentially infested wood. Furthermore, many primary cargo destinations coincide with the most heavily forested regions of the USA, which thus provide a ready source of host material for the establishment of potential pests.

The species most likely to be imported on infested wood materials are those forest insects and pathogens with life stages closely associated with the trunks of trees, especially those that remain in the host for long periods (e.g. wood borers, bark beetles, deep wood pathogens). Other potential pests pose less of a threat since they are present only in certain life stages and seasons (e.g. eggs of some Lepidopteran species such as the gypsy moth).

Between 1996 and 1998, US inspectors made 1205 interceptions of live exotic pests associated with SWPM from 64 different countries of origin. The species involved represented 156 taxa, with Coleoptera (beetles) accounting for 94 percent of the total; Scolytidae (bark beetles) and Cerambycidae (long-horned wood borers) were the most common families.

Many pests probably escape detection at ports of entry. Visual inspections are labour intensive and inefficient at locating live pests: plant pathogens in particular can be very hard to detect and identify. Furthermore, only a small percentage of all cargo entering the USA can be inspected, and the increasing use of containerized cargo has made inspection more difficult, since only 1 to 5 percent of SWPM may be accessible.

Given the importance of this pathway, and the difficulties involved in detecting pests arriving with SWPM, more stringent importation requirements appear to be warranted. Measures to minimize the likelihood of live pests being transported with SWPM could greatly reduce the risk of introducing destructive exotic pests into US forests.

Source: USDA (2000).

CASE STUDY 21: ASIAN LONGHORNED BEETLE, A THREAT TO NORTH AMERICAN FORESTS[3]

Anoplophora glabripennis, the Asian longhorned beetle (ALB), probably entered the USA inside solid wood packing material from China, and has been intercepted at ports and in warehouses throughout the USA. The insect is a serious pest in China where it has few natural enemies; in North America no natural enemies have been recorded as yet and if this insect becomes established it could destroy millions of acres of America's hardwoods.

The female beetles lay their eggs in the bark of trees, and on hatching, the larvae bore into the trunk, feeding on the heartwood and girdling stems and branches. When mature, the beetles burrow out of the tree leaving a ⅜ inch exit hole. The adults then feed on the bark and leaves. Repeated attacks lead to dieback of the tree crown and, eventually, to the death of the tree. In the USA the beetle prefers maple species (*Acer* spp.), including Norway, red, silver, sugar and sycamore maples. Maples are not only a dominant tree species in the northeastern part of the USA, but are the basis of the US$40 million maple syrup industry. The beetle also attacks many other hardwood trees, including horse chestnut, mulberry, black locust, elm, birch, willow, poplar and green ash.

Currently, the only effective means of containing ALB is to remove and destroy infested trees. The area is then quarantined to prevent the movement of infested trees and branches. Early detection of infestations and a rapid response are critical if the spread of the beetle is to be controlled. However, the chances of eradicating the beetle are low: in 1996, State and Federal Governments spent more than US$4 million on a suppression programme in New York City and Amityville, NY, but these efforts are not believed to have resulted in eradication.

Sources: Wittenberg and Cock (2001); USDA (2002); USDA-APHIS (2003); Illinois Department of Agriculture (2001)

Given the uncertainties concerning the origin of SWPM, only globally accepted measures that can be applied to wood packaging material by all countries can reduce the risk of inadvertent introductions of organisms associated with this material. The International Plant Protection Convention has recently published some guidelines for regulating wood packaging material (IPPC 2002), which specify approved measures for preventing pest infestation, including 1) heat treatment to a core temperature of about 56ºC for a minimum of 30 minutes and 2) fumigation with methyl bromide at a minimum of 10ºC and for an exposure time of more than 16 hours. However, wood packaging material is very often reused or recycled and, if it is stored in places where it can be attacked by pests it needs to be treated again before being used. An alternative approach would be to use different materials, e.g. plastic or chip wood (which would exclude larger organisms, but not necessarily pathogens).

6.4. Timber

Timber is the most important forestry commodity of international significance and is a major source of forest pests and pathogens. Timber shipped in containers is a particular threat, since the container provides additional protection. Moreover, as mentioned above, modern containers limit access for inspection and the sheer number of containers arriving at ports makes it impossible to check all shipments.

[3] Editorial note: Since this document was prepared, ALB has been found in eastern Canada (September 2003).

Strict importation regulations are necessary, and risk analysis with regard to specific import routes may be appropriate (e.g. Case Study 22).

CASE STUDY 22: SIBERIAN TIMBER IMPORTS: ANALYSIS OF A POTENTIALLY HIGH-RISK PATHWAY

Siberia has almost half the world's softwood timber forests. In the late 1980s, a few US timber brokers and lumber companies, short on domestic supplies, sought to import raw logs from the Russian Far East to West Coast USA sawmills. This could have created a pathway for alien forest pests that would be pre-adapted to many North American climate zones and tree communities.

In 1990, in response to concerns raised by the scientific community concerning the potential risks, the US Animal and Plant Health Inspection Service (APHIS) imposed a temporary ban on Russian log imports until a detailed risk assessment could be completed. A joint USDA Forest Service/APHIS Task Force was convened and worked for almost a year on a detailed risk assessment focusing on larch (*Larix* spp.) from Siberia and the Russian Far East. The project involved 80 forest pathologists, entomologists, economists and ecologists and cost approximately US$500 000. The task force identified many insects, nematodes and fungi that could be potential pests if introduced into North America. The probable consequences of introduction were examined by considering the possible economic and ecological impacts if selected pests successfully invaded forests in the northwest USA. For example, the estimated cumulative potential economic losses from the Asian gypsy moth (*Lymantria dispar*) and the nun moth (*L. monacha*) between 1990 and 2004 is in the range of US$35 billion to US$58 billion (net present value in 1991 dollars). The report concluded that "measures must be implemented to mitigate the risk of pest introduction and establishment".

A companion report prepared by APHIS evaluated possible ways of mitigating the risk of importing exotic pests. This review identified many gaps in the scientific data on the subject and suggested that heat treatment appeared to be the best control option. The assessment concluded that "if technical efficacy issues can be resolved, APHIS will work with the timber industry to develop operationally feasible import procedures".

Ultimately, APHIS placed the burden on the importers to propose new pest treatment methods and protocols that "evidenced complete effectiveness" in mitigating risk. To date, the industry has identified no feasible, cost-effective procedures that APHIS has deemed completely effective; thus, unprocessed logs from Siberia have been denied entry to the USA. While costly, the risk analysis was successful in preventing the potential introduction of several serious pests.

Source: OTA (1993); USDA (1991a,b)

6.5. Aid programmes

This issue deserves separate consideration, despite its relation to earlier sections, because of its importance in the movement of alien species. Those promoting forestry aid programmes should consider the full implications of their activities, and prior to implementation should consult conservation authorities to prevent introductions of alien organisms. Otherwise, the benefits of the aid programme could be outweighed by larger losses due to new invasive species.

In regard to forestry, the Central American tree *Cordia alliodora* is a classic example of a problem arising from an introduction via an aid programme. This species was introduced to Vanuatu with the best of intentions as a potential timber plantation tree, but, for various reasons, failed to live up to expectations (probably due to climatic differences between Central America and Vanuatu). *Cordia* subsequently started to penetrate the native bush and became a nuisance (Tolfts 1997). Other well-known examples include the promotion of pines and eucalypts as timber trees in various places around the world.

6.6. Contaminants of forest fruits and seeds

Conifer cones, nuts, fruits of forest trees, etc. can harbour a wide variety of immature stages of insects, and although detection and treatment techniques are available they are not often used, since these products are not major commodities. For example, X-ray techniques can detect infested conifer seeds amongst healthy ones, but are rarely used even in the seed trade. Furthermore, this type of material is often moved by tourists (e.g. as souvenirs of their holidays), so that public education and support from the tourist industry should help reduce this traffic.

An example of a pest probably imported via this pathway is the Douglas-fir seed chalcid, *Megastigmus spermotrophus* (Forster) (Torymidae), which was introduced to Europe from North America, subsequently becoming Europe's most important pest in conifer seed orchards.

7. COMMUNICATION AND STAKEHOLDER INVOLVEMENT

In establishing the objectives of any biosecurity activity, it is critically important to consider the various interests and mandates of the full range of stakeholders. It is also essential to establish the necessary capacity to fulfil all required functions at each stage of the biosecurity cycle.

The development of an effective biosecurity programme is an iterative process, so that the initial stages (including the objectives) may have to be reconsidered at a later date. However, given this proviso, a simple three-step approach suffices in many areas of biosecurity. Various groups may be involved in each of the three stages:

- **Pre-risk:** identification of objectives; identification and assessment of risks; agreement on methods to be employed; identification of critical decision points and establishment of the financial, human and infrastructural capacity needed to implement checking procedures at these decision points.
- **Surveillance:** monitoring the targeted risk to ensure that checking procedures at the critical decision points are functioning correctly. This may be the exclusive responsibility of a particular body, but more usually will be a secondary responsibility of a number of sectoral bodies.
- **Management, including containment and eradication:** in the event of failure, actions to redress or mitigate the situation are usually required.

Good communication is crucial at each stage. This has a number of aspects: communication between those responsible for managing risk at any particular moment, or in relation to particular events; informing the public and consumers of ongoing biosecurity measures in a transparent way, and, in the event of an outbreak, rapid and effective mass communication with the aim of securing public understanding and support. Various recent crises have demonstrated the critical role of communication in effective biosecurity.

There is no 'one-size-fits-all' system for biosecurity – it requires the use of various tools on a case-by-case basis. Such tools should include a set of proven practices for handling various aspects of risk management in local, national and supra-national contexts. Understanding the 'toolbox' nature of biosecurity is particularly important when considering the interface between national biosecurity systems and the relevant international policy and regulatory framework. Typically, because of the specificity of the problems addressed, different solutions to biosecurity problems have been adopted not only in different countries, but also in various sectors within a single country.

In relation to trade, a well-developed national biosecurity system can be of real benefit in allowing a country to enter otherwise restricted markets. This can be of particular value to developing countries, where biosecurity capacity-building should concentrate on need-driven, progressive and sustainable implementation and harmonization of their legal frameworks and institutional structures. Technical assistance and experience gained in other countries can be invaluable in informing this process (adapted from FAO (2002)).

8. DISCUSSION AND CONCLUSIONS

Biosecurity is clearly an important issue in forestry, although specific aspects of the issue (and their importance) differ from other sectors. The dominant concern in forestry is the risk posed by invasive alien species, either to the forestry sector itself, or to other ecosystems. Since the problems caused by invasive species are often complex and frequently impinge on other sectors, the forestry industry should work in close collaboration with other sectors and stakeholders in order to reduce the risks associated with the movement of alien species. Apart from protecting their own forestry industries from invasive alien species, countries also need to be able to objectively and realistically assess the risks of introducing alien species to other countries via their trading activities. This is a large task, even within the forestry sector, and there is considerable scope for experience-sharing between countries and international support from organizations such as FAO.

The Convention on Biological Diversity and World Trade Organization's SPS agreement have placed countries under new obligations with regard to alien species and biodiversity. To address their obligations under the CBD, signatory countries have agreed to "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species". However, predicting which alien species are likely to cause serious damage if introduced is not easy. Many species are innocuous or minor pests in their area of origin, but can be devastating when introduced elsewhere. At present, the best guide to potential invasiveness and pest status seems to be a prior history of causing problems elsewhere, particularly in regions with similar habitats and climatic conditions to those of the country under consideration. Thus, access to reliable information is critically important for assessing the potential risk of invasiveness.

In many cases, developed countries have already established procedures to address some of the key risks associated with alien species, although developing countries have tended to lag behind. Historically, small island stateshave suffered some of the worst damage by invasive alien species, and small island developing states are now the most vulnerable. Such states often have only a very small public sector budget and hence may need considerable external assistance to develop appropriate biosecurity programmes.

Of the various threats posed by alien species, pests (in the broadest sense) are an important consideration in forestry. While indigenous pests may be chronic or occur in outbreaks, introduced pests usually occur in an initial outbreak followed by continuous chronic damage. Both can be extremely damaging, to the extent that some species of trees cannot be economically grown in some areas. However, the option of substituting tree crop species is an important difference between forestry and agriculture, and may offer a solution in some cases.

There is an urgent need for more research on tropical forestry pests, both to develop management methods and for developing pest risk assessments. Plantation forestry, particularly agroforestry, is relatively new to the tropics, but in recent years has grown rapidly (e.g. in terms of new trees, new technologies, etc.). However, knowledge of pests and pest management methods in such systems has not developed at the same rate. In this respect, it would be useful to compile information on the actual composition of forestry tree species in different areas, since pests are often specific to their hosts at the species level and such information would highlight species at risk. International cooperation and information exchange on pest distribution, impact, pathways, interceptions, etc. should therefore be encouraged, especially between neighbouring countries and trading partners.

Tropical and subtropical plantation forestry has typically focused on a small number of fast growing, colonizing species, normally planted as monocultures. However, it is generally accepted that monocultures, especially of genetically similar trees, increase the probability of pest outbreaks. Monoculture also tends to transform sporadic pests into more permanent problems. Mixed planting of native (and exotic) trees is therefore preferred as a strategy for avoiding pest problems.

There has been some debate over the relative risk of pest outbreaks on exotic versus indigenous trees, especially in plantation settings. There appear to be no firm conclusions, except that monoculture of either indigenous or exotic trees increases the chances of pest outbreaks. The pest risks associated with a particular tree/location combination should therefore be evaluated on a case-by-case basis and pilot plots established before widespread planting is undertaken.

Alien weeds can be particularly damaging during plantation establishment, but can also have important effects on biodiversity, particularly in the tropics. In contrast to most insect pests and plant pathogens, alien weeds tend to affect not just forestry but also various other sectors, and hence may need to be addressed with a multisectoral approach.

As far as addressing these various issues is concerned, the best approach is obviously prevention, but managing potential pathways for the introduction of alien species is often more efficient than trying to prevent the introduction of individual species. Most of our current knowledge on this issue comes from developed countries, and although much of it can be transferred to developing countries, there are likely to be large differences between the two situations – not just in the actual risks, but also in the perception of those risks and in the resources available to address them. Hence, further research is necessary on the possible introduction pathways for all types of pest in tropical/developing countries.

At present, the principal known pathways through which forestry can contribute to the introduction of alien species include the movement of germplasm, solid wood packaging materials, trade in unprocessed timber, aid programmes and contaminants of forest seeds and other products. Once identified, potential pathways must be prioritized according to each country's most serious and immediate invasion threats and managed accordingly. Pathways known to have led to introductions (e.g. timber and solid wood packaging materials) merit immediate attention. Imported material, such as germplasm, should be subject to assessment and quarantine procedures, reinforced where necessary with legal powers to treat, destroy or ban suspect material. Deliberate introductions of other species associated with forestry, including biological control organisms, pollinators, mycorrhizae, etc., constitute an additional risk and should be considered with caution and on a case-by-case basis.

However, despite various approaches to managing these risks and preventing accidental introductions, the increase in world trade and the difficulties involved in providing adequate inspection and quarantine services make it virtually inevitable that alien species will continue to be inadvertently introduced to suitable new habitats in different parts of the world. When preventative measures fail, an eradication programme is then generally the preferred method of action, provided that its feasibility has been adequately assessed by suitable cost-benefit analyses. The success of such an approach is critically dependent on early detection, surveys for which should be carefully designed to provide maximum information at minimum cost.

If establishment occurs and eradication is no longer an option, containment and control is necessary. Various options are available for the control of alien species, amongst the most useful of which is biological control by the introduction of exotic natural enemies from the pest's area of origin. Again, however, such an approach should only be adopted after appropriate risk assessment.

Further research is needed on the best ways of managing forestry plantations so as to minimize the impact of indigenous (or alien) pests. In particular, tactics such as multispecies planting need further evaluation in developing countries. In some cases (notably for rubber), the development of pest or disease-resistant clones may be the only effective solution, although this is obviously a long-term and expensive approach. Other options for containment (e.g. buffer zones) should be evaluated further and examples of good practice made more widely available.

Many species of tree used in forestry and agroforestry have the potential to become invasive when grown as exotics, particularly in the tropics. Further work is needed to identify the biological characteristics that make a species invasive, and those that tend to make tropical trees more invasive than temperate species; for example, many trees used in tropical agroforestry produce seeds after only two to three years growth, which radically changes the population dynamics of the plant and may well contribute to invasive tendencies. Protocols need to be developed and validated to assess these risks. Pilot schemes should include monitoring for any indications of invasiveness, and safer options for introductions (e.g. sterile trees) should be identified and evaluated.

The advent of GM technology poses new challenges to the forestry industry, since assessing risks in long-term crops such as forestry trees is particularly difficult. As yet, there are no generally accepted protocols for these types of assessment, and priority should be given to their development and testing. The large-scale uptake of this technology is likely to be slow until such protocols are available.

Finally, in establishing the objectives of a biosecurity activity, it is critically important to consider the full range of stakeholders, as well as their various interests and mandates, in order to identify areas where cooperation is necessary and where synergies and efficiencies can be achieved. In formulating and developing an appropriate approach to biosecurity, the whole regulatory cycle and the views of all interested parties must be considered.

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Appendix. Selected invasive alien species affecting forestry eco-systems

Species	Origin	Where introduced	Trees affected	Indicative Sources
Cypress aphis, *Cinara cupressivora*	SE Europe	Southern and Eastern Africa	*Cupressus*, *Juniperus*, *Widdringtonia*	Case Study 1
Pine woolly aphid, *Pineus boerneri*		Southern and Eastern Africa	*Pinus*	Case Study 1
Pine needle aphid, *Eulachnus rileyi*		Southern and Eastern Africa	*Pinus*	Case Study 1
Chestnut blight, *Endothia parasitica*	China	North America, Europe	American and European chestnuts, *Castanea dentate, C. sativa*	Case Study 2
Dutch elm disease, *Ophiostoma ulmi*	Asia	Europe, North America	Elms, *Ulmus* spp.	Case Study 8
Eucalyptus weevil, *Gonipterus gibberus*	Australia	Southern Africa and other areas	*Eucalyptus* spp.	Case Study 14
Gypsy Moth, *Lymantria dispar*	Europe	North America	Many deciduous trees	http://www.fs.fed.us/ne/morgantown/4557/gmoth/
Hemlock woolly adelgid, *Adelges tsugae*	Asia	North America	Hemlock (*Tsuga* spp.)	http://www.fs.fed.us/na/morgantown/fhp/hwa/hwasite.html
Orthezia scale, *Orthezia insignis*	South America	St Helena and through tropics	Gumwood, *Commidendrum robustum*	Case Study 13
Asian longhorned beetle, *Anoplophora glabripennis*	China	North America (Chicago, New York, New Jersey)	Hardwoods, especially maples (*Acer* spp.)	http://www.aphis.usda.gov/oa/alb/alb.html; Case Study 21
Emerald ash borer, *Agrilus planipennis*	Eastern Asia	North America (Michigan, Ontario)	Ash (*Fraxinus* spp.)	http://www.na.fs.fed.us/spfo/pubs/pest_al/eab/eab.htm
Pine shoot beetle, *Tomicus piniperda*	Europe	North America (eastern USA and Canada)	*Pinus* spp.	http://www.aphis.usda.gov/oa/pubs/fspsb.html