9

Management Systems IV: Forest Health Surveillance, Invasive Species and Quarantine

9.1 Forest Health Surveillance

9.1.1 Introduction

Once a crop has been planted, whether it be agricultural, horticultural or forest tree, there is usually a need to ensure its protection, until the time of harvest and sometimes beyond, from a variety of damaging agents both natural (wildfire, hail, rainfall extremes, insects, fungi, animals) and those related to human activities (pollution, domestic stock, mechanical injury, pesticide toxicity). As described throughout this book, it is often a combination of such factors rather than a single-agent cause which underlies many crop problems. For example, in Australia, overstocking in *Pinus* plantations accompanied by drought stress can promote attack and mortality by the wood wasp *Sirex noctilio* (Collett and Elms, 2009). Evans and Turnbull (2004) outline a general approach to follow with all organic damage (fungi, insects, other animals or microorganisms); the four stages are detection, identification, analysis and action. It is in the very first of these, detection, that some significant differences between agricultural/horticultural systems and forestry systems begin to manifest themselves.

For a start, in a comparison of the minimum areas of land required in order to provide similar economic returns on investment, industrial forest plantations (IFPs), by the nature of their product, market value and long rotation times, are generally much larger than their agricultural counterparts. Crops such as wheat and sugar are broadacre but are harvested annually, while horticultural crops such as avocado and mango may take a few years to produce fruit but are of higher value per unit area. The critical mass required to make the forest industry viable in a region may also be large. For example, in southern Sumatra in Indonesia, a plantation of 170,000 ha of *Acacia mangium* has been established to supply the fibre needs for just one pulp and paper mill. Areas of natural forest that are harvested for timber are even vaster. This by itself greatly increases the difficulty of detection of health problems. Continuing this comparison of cropping systems, the greater height of forest trees within a few years after their planting and the often more rugged terrain on which they are planted make sampling difficult. Added to this is the fact that many of the forests are remote and infrequently visited, and a serious problem can pass unnoticed for a long time.

9.1.2 Purpose of routine forest health surveys

Identifying and managing threats to forests and plantations is an essential element of sound forest management (Carnegie, 2008). What constitutes a healthy forest can vary according to differing management objectives for particular forests. For example, in a forest set aside for conservation, an outbreak of a native insect pest would be regarded as a part of the normal forest dynamics and no remedial action would be taken unless such outbreak was linked in some way with human interference. In a production forest, however, any insect outbreak which threatened significant tree mortality or serious growth loss would engender prompt remedial action. In a conservation forest, stag-headed and hollow trees could be taken as a sign of a healthy ecosystem in that they provide habitat for wildlife, whereas in a forest plantation dead or dying trees are more likely to be a cause for alarm as an indicator of a potential health problem.

As defined by Carnegie (2008), forest health surveillance involves systematic surveys of forests by trained specialists, the main purposes being to: (i) detect and map outbreaks and damage by known pests or diseases; (ii) detect change in forest health over time, including the distribution and status of pests or diseases; and (iii) detect incursions of exotic pests or diseases. The principle underlying this is that early detection of a pest problem allows more scope for its management. In forests managed for conservation purposes, the emphasis is more likely to be on the detection of any unnatural biotic or abiotic factors (e.g. introduced pests, air pollution) which threaten the long-term health or vitality of the ecosystem, and on factors which are indicative of ecosystem disturbance or decline. Such surveillance, of course, would also include naturally occurring factors.

9.1.3 Requirements for effective and efficient surveillance

Forest health surveillance or detection monitoring essentially provides a ‘snapshot’ of the health of the forests. It includes both extensive surveys and fixed-plot monitoring, and usually entails systematic observance of a predetermined set of parameters that pertain to forest health. Data obtained build up a reference baseline and assist in the early detection of changes that call for a more detailed evaluation. In the course of such surveys, the surveillance team may be able to suggest likely causes for some of the changes observed (e.g. lightning strike as a cause of observed bark beetle attack and tree mortality).

Problems or potential problems detected during broad-scale surveillance must then be investigated by protection specialists to delineate the extent of the problem, identify the cause (if possible) and make recommendations to managers as to the appropriate course of action. Such recommendations may be to do nothing (if not a problem or not economically justified), to conduct additional targeted surveys, to monitor the occurrence closely, to take control action or to initiate detailed research on the problem. These two phases (i.e. general surveillance and follow-up investigation) encompass the four stages outlined by Evans and Turnbull (2004). Barnard *et al.* (1992) include an additional phase, ‘intensive-site ecosystem monitoring’, as part of health monitoring, the goal being to obtain a more complete understanding of the mechanisms of change in forest ecosystems. Such detailed and long-term monitoring is more commonly used in naturally occurring forests and could be regarded as being in the realm of ecosystem research. It is in a somewhat different category to the routine health surveys carried out in forest plantations.

Surveillance for forest pests is practised at varying levels of sophistication in different countries throughout the tropics. In its simplest form, it involves individual workers in the forests observing a disorder or something unusual in the course of their duties and reporting it to a superior, who takes the appropriate action. These ‘eyes in the forest’ are an important component of any surveillance system, but their contribution to overall probability of detection should not be overestimated by forest managers. As an example, trials in New Zealand have demonstrated that the ‘efficacy’ of detection by such staff is extremely low (Carter, 1989). The next level of surveillance may involve the assigning of certain staff, although non-specialist, working in a particular forest area to look for, or gather information on, disorders in that forest and to liaise with specialists. At the top level, teams of highly trained professionals are employed to conduct systematized surveillance of the forests using a range of methodologies.

For forest health surveillance to achieve its goals, it is essential to have a good backup team, otherwise monitoring is pointless. Taxonomists are required to identify correctly organisms or damage brought back by the surveillance team. This allows for an assessment of the organism's known pest status and potential to cause serious damage. Experienced staff are also required to evaluate and quantify the extent and severity of the problem, gauge impact and advise on a course of action. It is in this area of technical backup that problems are experienced in many tropical countries. For a start, in comparison with temperate regions, there are few forest entomologists and forest pathologists in the tropics, and even fewer insect or fungal taxonomists. As an example, Nair (2007) mentioned that in 2000, Indonesia, with a forested area of over 100 Mha, had only about 40 researchers in forest protection (including entomologists and pathologists). As well, the number of species in the tropics is vast and the taxonomy of many groups is poorly known. Some countries are fortunate in having large and well-curated museum collections, but many do not. Under tropical conditions, good curation is essential or collections will deteriorate rapidly, but such requirements are often financially daunting in poorer countries. Countries lacking their own taxonomic facilities have usually depended on others to service their needs, but the introduction of charges for identifications by many institutions (even if the charges are subsidized) undoubtedly has reduced the numbers of specimens submitted. All these factors combine to make identification a slow process and impair the efficient functioning of health surveillance systems, although the advent of pest image libraries and online identification keys are now improving this situation.

Other backups which are essential for a well-functioning surveillance programme are facilities and equipment for rearing or culturing collected immature organisms (since mature specimens are usually required for species identification) and systems for the efficient storage and retrieval of data. For insect rearing, sophisticated facilities such as controlled-environment rooms, while very useful, are not essential. Cages or containers for rearing generally can be made quite cheaply from local materials and kept at ambient temperatures in simple insectaries, which are shielded from direct sun and screened or otherwise protected to exclude vermin or insects that might damage specimens. An essential requirement in achieving one of the main goals of forest health monitoring, the detection of change, is an established baseline to determine if, when and where changes are occurring and to quantify those changes. This requires an efficient system of data storage and retrieval. Manual systems have now been replaced largely by computer databases, which can store and sort very large data sets rapidly and can be linked to geographic information systems (GIS) if desired. An example of a very simple output from such database systems, which is of great value to forest managers, is a map which details pest occurrence and severity (Fig. 9.1) (Wallnes, 1996). Appropriate software and hardware is generally readily available worldwide, although cost remains a limiting factor for some countries.

9.1.4 Surveillance methodologies

Methodologies used for forest health surveillance or monitoring vary according to the purpose of the surveillance and the type of forest being surveyed. In industrial forest plantations, a combination of aerial and ground surveys is commonly employed, while around ports and sawmills trapping systems may be used. Examples of these methodologies and some comments on their efficacy are provided below.

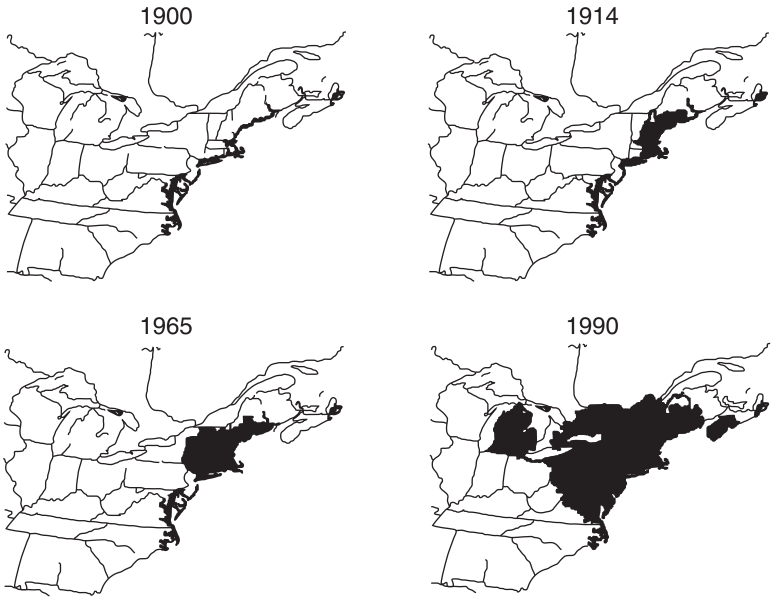

Fig. 9.1. Establishment and spread of *Lymantria dispar* in the USA (from Wallner, 1996).

Ground survey

This generally involves either drive-through or walk-through surveys, or more often a combination of both. The former are usually conducted from all-terrain (e.g. four-wheel drive) vehicles, although in northern Sumatra in Indonesia motorcycles are employed. Typically, a team of two observers will drive along roads through the plantation estate at low speed looking for symptoms of tree disorder. Routes are usually planned in advance so as to provide systematic sampling of the maximum area. Periodically, at randomly located points, observers may leave the vehicle to conduct ground inspections away from the road. When disorders are detected, the team may then sample more intensively to obtain information on the severity and extent of the problem and to collect specimens, including damage, for identification or diagnosis. Stone *et al.* (2003a,b) devised a method for assessing the effects of insect herbivory at the leaf, tree crown and stand scales for young eucalypts in the pre-canopy closure phase. Their crown damage index (CDI) is based on a visual estimate of the incidence, that is, extent of damage over the entire tree crown (as a percentage) multiplied by the average level of severity at the leaf scale (as a percentage) for the three types of leaf damage: defoliation, necrosis and discoloration. The CDI is the sum of the products of each incidence and severity and has been proposed so as to provide ground-based assessors with a generic, standardized measure of tree crown damage, which can allow comparisons to be made between plantations and districts over time.

Bulman *et al.* (1999) in New Zealand have estimated the efficiency of various pest detection survey methods. For drive-through surveys, they found that the most important factors influencing target detection were distance from the road (68% of all simulated damage was detected at road edge, 52% was detected 20 m from the road and 35% at 40 m into the stand) and driving speed – 77% of all simulated damage was detected at 15 km/h, 46% at 30 km/h and only 32% at 45 km/h. Detection was slightly better overall in the older and lower-stocked stands than the younger stands (Fig 9.2). There was also significant interaction between age/stocking and distance from the road, with better detection close to the road but worse detection further from the road in the younger, higher-stocked stands. In walk-through surveys, the most influential factor was distance; 97% of the roadside symptoms were detected, decreasing to 71% at 20 m into the stand and 47% at 40 m into the stand. Detection rates were significantly higher in the pruned stands (75%) than the unpruned stands (60%). They found that drive-through forest sampling at the slowest vehicle speed tested (15 km/h) gave detection efficiencies very similar to those obtained from walk-through sampling (Fig. 9.2). However, they caution that there is no substitute for the close-up examination of foliage and potential insect breeding sites. Insect frass on the stems or around the bases of trees, for example, is unlikely to be detected in a drive-through survey. Bulman *et al.* (1999) also examined the effect of using more than one observer and found that this increased the probability of detection considerably in all three types of survey tested (Fig. 9.3), as did repeat inspections by observers (Bulman, 2008).

In Australia, Wardlaw *et al.* (2008) measured the efficacy of aerial, roadside and ground inspection to detect nine different types of damage symptoms, ranging from very obvious (mortality and dead tops) to very cryptic (stem cankers and stem borers), each occurring at a range of incidences among five 3-year-old *Eucalyptus globulus* plantations. They found that dead tops were detected most efficiently by aerial inspection but crown symptoms produced by moderately severe insect defoliation or necrotic leaf lesions were best detected by roadside and ground inspection, both of these methods being equally efficient. Cryptic symptoms could not be detected reliably using any of the inspection platforms, even when their incidence, within small patches, was as high as 2%. They concluded that the combination of aerial and roadside inspection provided sufficient resolution to detect operationally relevant damage (i.e. damage of sufficient severity to consider remedial treatment) but was unlikely to detect damage by new incursions at a sufficiently early stage when eradication might be feasible. This finding reinforces the importance of conducting surveillance for forest invasive species at their likely points of entry, as discussed later in this chapter.

Aerial survey and remote sensing

Historically, aerial detection surveys have been of two types: visual sketch-mapping surveys and aerial photographic surveys (Pywell and Myhre, 1992). Visual sketch mapping is the technique of delineating the

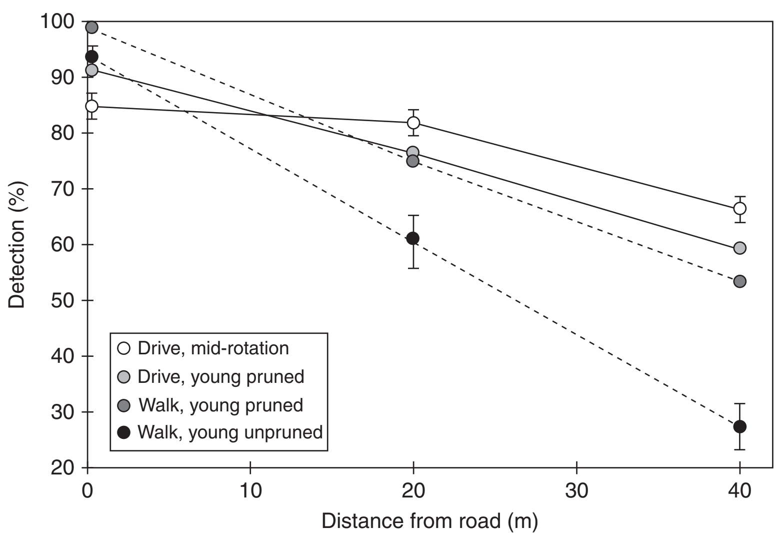

Fig. 9.2. Comparison of mean detection rates at various distances from the road for a drive-through survey at 15 km/h and a walk-through survey (from Bulman *et al.*, 1999).

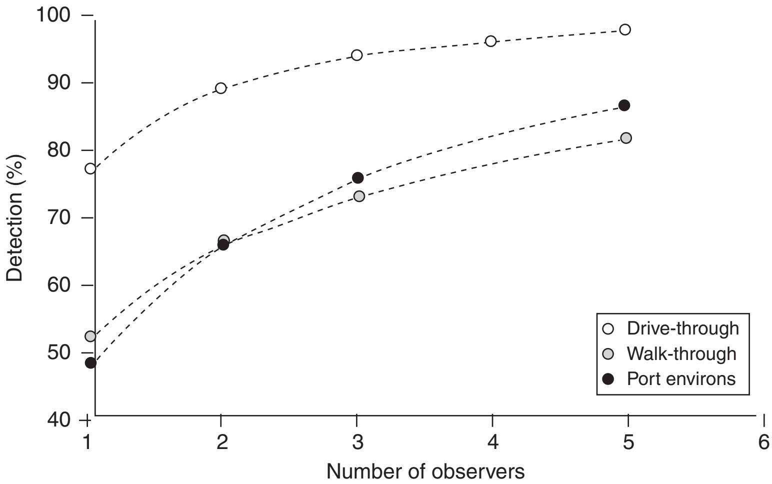

Fig. 9.3. Mean detection percentages plotted against the number of observers for drive-through, walk-through and port environs surveys (from Bulman *et al.*, 1999).

area of pest-caused damage on to maps based on observations by forest health specialists flying in a small aircraft (Johnson and Ross, 2008). The observers look for symptoms of tree disorder, usually indicated by vegetation colour change, and map such occurrences for ground evaluation, or 'truthing'. Once the causal agent and host are identified, and if the problem is sufficiently serious and the damage characteristic, further aerial surveys may be conducted to track the severity and spread of the infestation. This technique is an efficient method of detecting and appraising recognizable pest damage over large remote forest areas, although not all countries have the necessary infrastructure. Aerial sketch mapping has been used, for example, for monitoring forest conditions in southern Brazil, primarily for assessment of damage caused by the wood wasp *S. noctilio*, monkeys, armillaria root disease and other damaging agents in pine plantations (Oliveira *et al.*, 2006).

Aerial photography is another survey tool utilized for forest health monitoring. Colour and colour-infrared photographs have been used in the estimation of current and/or total levels of damage and mortality from pests. They provide a historical record of pest activity and have been used to monitor the rate of spread and trends of a pest over time. Most aerial photography applications in pest management can be divided into two broad classes, mapping photography and sampling photography (Pywell and Myhre, 1992). Mapping photography is a block of continuous photo coverage that can be assembled into a photo mosaic or photo map. It is usually used for mapping the total extent of a pest problem. Sampling photography is photo coverage of a small area that is representative of a large unit or type, and is used when it is not operationally feasible or cost-effective to evaluate 100% of the area of concern.

A limitation of sketch mapping is that it is highly subjective, although an assessment by Johnson and Ross (2008) shows that it is operationally acceptable for broad-scale detection and monitoring. Photography can provide more accurate information than sketch mapping, as well as a permanent record, but disadvantages are the high cost and the amount of time required in processing film and prints, interpreting photographs and transferring information from photographs to a map. The advent of digital camera technology has allowed images to be downloaded directly into the computer without the need for intermediate processing. There they can be manipulated and enhanced to aid in interpretation and can be incorporated into geographic information systems (GIS). They can be stored readily, although this requires considerable disk space. An advantage for observers using digital cameras from an aircraft or on the ground is that they can view the image immediately after it is taken and decide whether it is suitable or whether another 'photo' is required. Airborne videography has somewhat similar advantages over conventional aerial photography, although the quality of the imagery has generally not been as good.

A range of new technologies has enhanced the accuracy and efficiency of forest health surveys over the past decade (Carnegie, 2008). These include the use of GIS–GPS (global positioning system) interface tools and handheld computers to assist navigation and data collection in the field. In Queensland, Australia, laser rangefinders, linked to palmtop computers with integrated GPS, are used to enhance aerial surveys of pine plantations using fixed-wing aircraft (Ramsden *et al.*, 2005). This system allows highly accurate spatial data to be combined with forest health descriptive data for immediate interpretation within GIS. A digital aerial sketch-mapping (DASM) system developed by the Forest Service in the USA allows users to digitize polygons directly on to a touch-screen linked to a GPS unit and computer or on to a tablet PC with an integrated GPS (Johnson and Wittwer, 2008). Improved mobile phone technology and wireless broadband has also enabled images of symptoms and damaging agents to be transmitted quickly from the field for expert opinion and action (Carnegie, 2008). In several countries, significant progress has been made in the application of digital, remotely sensed imagery to detect and classify damaged forest canopies. In Australia, for example, the airborne instruments that have received most attention have been multispectral (with few broad bandwidths) and hyperspectral (many narrow bandwidths) optical sensors (Stone and Coops, 2004; Stone and Haywood, 2006; Stone *et al.*, 2008). Both of these instruments measure the amount of light reflected from vegetation within specific bandwidths of the electromagnetic spectrum. Any process that alters the biochemical and morphological features of leaves also influences directly the reflectance characteristics of the leaves that can be measured quantitatively (Fig. 9.4). Stone and Coops (2004) provide two examples of such use of airborne high-resolution imagery in south-eastern Australia, namely assessment of canopy decline in moist native regrowth forests associated with herbivorous insects and assessment of crown defoliation in a mature *P. radiata* plantation associated with attack by the California pine aphid, *Essigella californica*. They note that the success of the approach depends in part on a sound understanding of the progression of

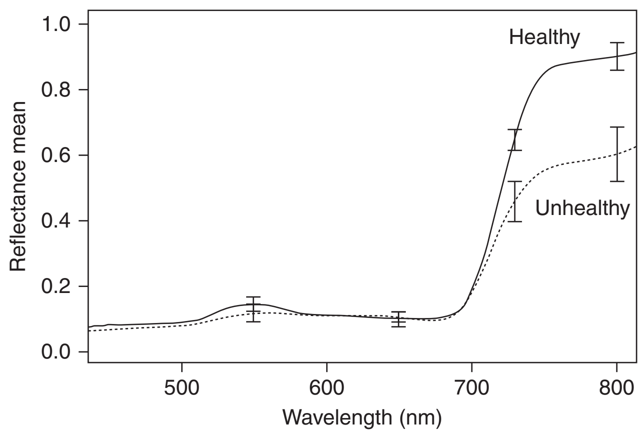

Fig. 9.4. The mean reflectance curves obtained for foliage from a *Eucalyptus paniculata* with a healthy crown compared with insect-damaged foliage from another *E. paniculata*. Vertical bars illustrate standard deviation errors of the mean of five replicates at key wavebands (from Stone *et al.*, 2001).

symptoms at the leaf, tree crown and stand scale, especially those symptoms that influence spectral reflectance behaviour. Similarly in South Africa, a study by Ismail *et al.* (2007) demonstrated the potential of high-resolution digital multispectral imagery for the improved detection and monitoring of *P. patula* trees infected by *S. noctilio*.

Satellite technology has been used in the monitoring of pest outbreaks, for example in large-scale assessments of defoliation by the gypsy moth *Lymantria dispar* (Lepidoptera: Lymantriidae) in the USA (Dottavio and Williams, 1983). In the tropics, it has been used mostly for forest inventory purposes. In Malaysia, for example, it is being used to map forest types, to measure changes in forest cover due to a range of causes such as shifting cultivation, forest exploitation and urbanization, and to monitor damage caused by harvesting and extraction (Khali Aziz *et al.*, 1992). In India, a combination of aerial photography and satellite images was used to detect a significant reduction in vegetation cover of sal (*Shorea robusta*) forests in some forest divisions (Chauhan *et al.*, 2003). The causes were identified as deforestation, encroachment, agriculture and, in one division, severe infestation of the sal borer, *Hoplocerambyx spinicornis*. A past limitation for remote sensing, particularly in tropical regions, has been in acquiring cloud-free images, but this has been overcome by the use of microwaves, which pass straight through clouds and rain and can be used during both day and night. The spatial resolution of remotely sensed data, once too coarse for any detailed analysis, is continually improving. In 1992, the maximum resolution of individual picture units (pixels) from the best commercially available satellite data was 10 m (Khali Aziz *et al.*, 1992); in 2011 it was 0.4 m.

With respect to aerial surveys conducted by observers in light aircraft, the probability of detection of tree disorder, which involved visible crown yellowing or browning, for various flight line spacings across a forest has been assessed by Carter (1989) and is shown in Fig. 9.5. For New Zealand, it was estimated that only 13% of potentially harmful exotic organisms would cause damage that would be visible from the air before the organism had spread so widely as to be considered ineradicable. Carter (1989) cautions, therefore, that the theoretical probability of detection of exotic pests as calculated above should be scaled down by a factor of 0.13. This again supports the need for targeted surveillance for invasives closer to their potential points of entry.

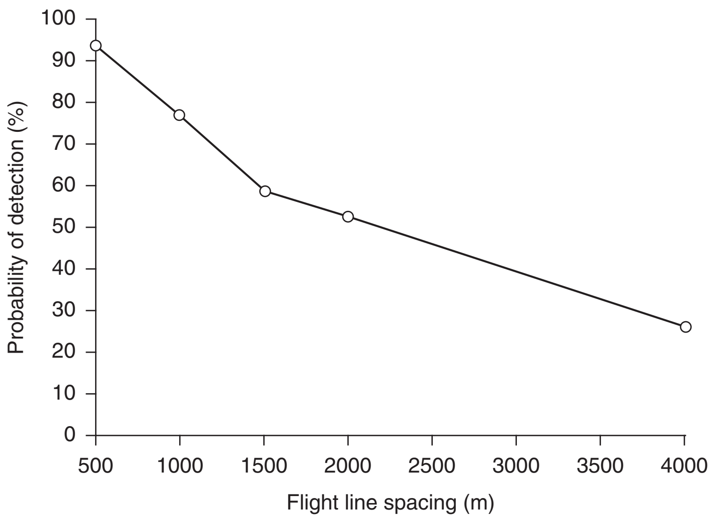

Fig. 9.5. Probability of aerial detection of visible symptoms of tree disorder at various flight line spacings (from Carter, 1989).

Trapping

Over the years, a great variety of devices or techniques have been developed for catching or trapping insects. While the intent of such devices has often been the control of insect pests, experience has shown that trapping has greatest value as a monitoring tool. Such devices may be used at ports of entry to detect the presence of imported noxious insects, to determine the spread and range of recently introduced pests in a region and to determine the seasonal appearance and abundance of insects in a locality and the need for application of control measures.

The type of trap used is governed principally by the behaviour of the insect species or group one is trying to catch. Most detection trapping is structured around the capture of flying adult insects, but some species (e.g. wood wasps) are detected through the use of trap trees or logs into which adults oviposit. The progeny which subsequently develop and/or their characteristic damage can then be identified. Traps for catching flying insects may be 'passive' (for example, suspended net traps, 'windowpane' or interception traps, water traps, sticky traps) or may lure insects from a distance (for example, light or bait traps). Some examples of detection trapping programmes that have been implemented in tropical and subtropical regions are given below and later in this chapter (see the section on hazard site surveillance).

ASIAN GYPSY MOTH – QUEENSLAND, AUSTRALIA The Asian gypsy moth, *L. dispar* (Lepidoptera: Lymantriidae), is a serious pest of forest trees and is known to feed on more than 650 plant species. It has spread from Asia to Europe, the earliest European record dating back to 1965, and in 1991 was discovered in Canada and the USA, where it was the subject of major eradication programmes. Following the finding in 1993 of viable egg masses of Asian gypsy moth on a ship that had visited Australia and New Zealand, both these countries embarked on a detection-trapping programme around designated ports, including some in tropical Queensland. Various types of pheromone trap are employed to monitor *L. dispar* in different countries. In Australia, 'Delta' traps and, more recently, 'Uni-traps' (bucket traps) baited with a sex pheromone (disparlure) are deployed around ports, usually a grid pattern of at least 40 traps at high-risk ports and a few sentinel traps in strategic areas at low-risk ports. Disparlure attracts not only *L. dispar* but also several other *Lymantria* species exotic to the region, including the Nun moth, *L. monacha*, and the Indian gypsy moth, *L. obfuscata*. Traps are inspected fortnightly during a 6-month trapping 'season' each year covering the optimum flight period of the moth and any Lepidoptera caught are sent to specialist entomologists for identification. A general contingency plan has been formulated for actions to be taken in the event of the detection of one of these exotic species.

LEPIDOPTERAN DEFOLIATORS – BRAZIL The increasing pest problems in *Eucalyptus* monocultures in Brazil led to the establishment of survey programmes in the late 1980s and early 1990s that aimed to identify and recognize the relative importance of the various eucalypt insect pests (Zanuncio *et al.*, 2001). The main pests in these plantations were found to be defoliating insects, particularly caterpillars of moths such as *Thyrinteina arnobia* (see Chapters 5 and 10), *Stenalcidia grosica* and *Glena unipennaria* (Geometridae), *Eupseudosoma aberrans* (Arctiidae) and *Psorocampa denticulata* (Notodontidae) (Zanuncio *et al.*, 2001, 2003, 2006; de Freitas *et al.*, 2005). The moths of most of the lepidopteran defoliators are night active and their populations have been monitored with light traps equipped with black-light tubes and 12-V batteries placed 2 m above ground level (Pereira *et al.*, 2001; Zanuncio *et al.*, 2006). Trapping programmes have been conducted in several Brazilian states (Fig. 9.6) and the information obtained used to predict where and when outbreaks are likely to occur and to facilitate the timing of control measures such as the release of natural enemies.

FIVE-SPINED BARK BEETLE – QUEENSLAND, AUSTRALIA *Ips grandicollis* (Coleoptera: Scolytinae), a bark beetle pest of *Pinus* spp., was introduced accidentally into Australia from the USA in the 1940s via imported pine logs with bark on and in dunnage. For the next four decades,

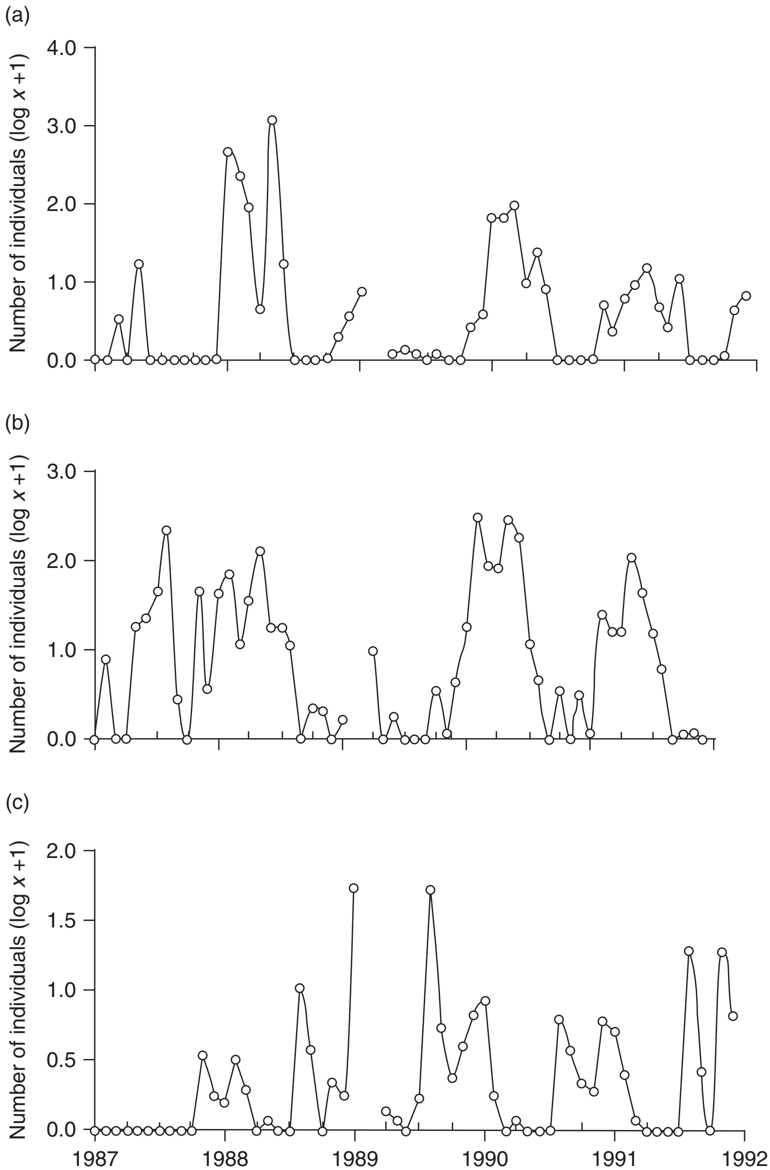

Fig. 9.6. Population fluctuation of (a) *Thyrinteina arnobia* (Geometridae) (b) *Stenalcidia* sp. (Geometridae) and (c) *Psorocampa denticulata* (Notodontidae) in the Municipality of Bom Despacho, State of Minas Gerais, Brazil, March 1987 to February 1992. Discontinued lines indicate that collections were not made on these dates (from Zanuncio *et al*., 2006).

its distribution was restricted to South Australia and Western Australia, but in the early 1980s it spread to the other mainland states and by 1994 had crossed the tropic of Capricorn in Queensland (Wylie *et al*., 1999). Its progress in Queensland has been monitored by means of 'drainpipe' traps (Plate 120) baited with a synthetic preparation combining the two bark beetle pheromones, 'ipsenol' and 'transverbenol'. Such trap systems have been shown to detect *I. grandicollis* at very low population levels. Quarantine restrictions were instituted in Queensland in 1982 to prevent the northward movement of pine logs with bark on or of pine bark which might harbour the pest. The quarantine boundaries were monitored by both ground survey of adjacent pine plantations and by pheromone trapping. The quarantine remained in place until 2009, when *I. grandicollis* was discovered in Townsville in north Queensland, believed to have 'hitchhiked' there with a shipment of logging equipment sent from the south of the state for a post-cyclone salvage operation.

BARK BEETLES – SOUTH AFRICA There are three exotic pine bark beetle species present in South Africa, all originating from Europe, namely *Orthotomicus erosus*, *Hylastes angustatus* and *Hylurgus ligniperda* (Coleoptera: Scolytinae). All three species feed on the inner bark and cambium of conifers, mainly *Pinus* species, and may be found simultaneously in the same pine tree (Tribe, 1991). All are vectors of both bluestain and pathogenic fungi. In their countries of origin, they are regarded as secondary pests but *O. erosus* can become primary if trees are stressed by adverse climatic conditions, and *H. angustatus* becomes a serious pest during its maturation feeding phase. Over 50% of pine seedlings in a newly planted stand may be killed by under-bark girdling of the roots and root collars by *H. angustatus*. Such a level of damage is a rare event and it is not economically viable to institute an annual spraying programme. The acceptable rate of seedling loss above which replacement becomes necessary is 15% and chemical protection through prophylactic insecticide sprays is regarded as the only effective control measure. The correct timing of such sprays is crucial. Similarly with *O. erosus*, their presence and numbers in a forest will determine the speed at which trees on a stressed site are colonized and the severity of this attack. *H. angustatus* populations are monitored by means of trap logs, while pheromone traps baited with a combination of ipsdienol, verbenone and 2-methyl-3-buten-2-ol have been used to monitor *O. erosus* populations (Tribe, 1991).

BROWN WATTLE MIRID – SOUTH AFRICA In South Africa, wattle is an important plantation crop, with increasing demand for bark extracts for tanning, resins and adhesives. The timber is used for the production of high-quality paper, the manufacture of furniture, the production of charcoal, building poles, fencing and floors. There are approximately 112,000 ha of black wattle *A. mearnsii* in the country. The brown wattle mirid, *Lygidolon laevigatum* (Hemiptera: Miridae), causes serious damage to trees, usually those between 0.5 and 5.0 m in height (Govender and Ingham, 1998). Attacks on shoots affect tree form, resulting in witch's broom, and reduction in growth, which in turn reduces bark and timber yield. To prevent such damage, chemical control measures need to be applied early in the season before mirid populations build up to damaging levels. Plastic bottle traps coated with sticky adhesive and placed in plantations at a height of 2 m and at a density of eight traps per compartment are used to monitor mirid numbers. If eight adults are recorded on a trap in 1 week, control measures are necessary to prevent the population exceeding the economic threshold (Govender and Ingham, 1998).

SAL BORER – INDIA The sal borer, *H. spinicornis* (Coleoptera: Cerambycidae), is a serious pest of *S. robusta* in northern India and Pakistan (Nair, 2007). It is principally a secondary pest of dying and fallen trees but during epidemics can infest and kill even healthy trees. In India, trap logs are used in the monitoring and control of the insect, taking advantage of the adult beetles' attraction to the sap (on which they feed) oozing out from the injured or wounded sal trees. The technique consists of felling a few trees and then cutting them into billets, beating up and loosening the bark. Beetles are attracted by oozing sap and take shelter underneath the loose bark, where they are collected regularly and destroyed (Roychoudhury, 1997). After every 3–4 days, the logs are cross cut again and the cut ends beaten to restore their attractiveness. A freshly cut tree remains attractive for 8–10 days. Nair (2007) rates the trap-tree operation as effective but cumbersome and research is under way to isolate the attractive components in the sal tree sap with the aim of developing synthetic lures.

9.1.5 Costs of surveillance

The costs of forest health surveillance will vary according to the purpose of the surveillance, the methodology used, the resources deployed and the technical backup required. Carnegie *et al.* (2008) compare the costs in the USA, Australia and New Zealand. In the USA in 2004, the cost of surveying over 180 Mha of forest using fixed-wing aircraft was US$0.025/ha. These surveys are designed mainly to detect landscape-scale outbreaks that can be mapped at a relatively small scale. In New Zealand, aerial surveys of pine plantations using fixed-wing aircraft cost NZ$0.02–0.08/ha, while in New South Wales in Australia, helicopter surveys of 90,000 ha of pine plantations cost AUS$0. 15 –0.30/ha. Compared to the USA, the New Zealand and New South Wales aerial surveys are designed to detect problems at a much higher resolution (compartment scale) using larger-scale mapping. As noted by Carnegie *et al.* (2008), these costs are not 'all inclusive', which can make comparisons difficult.

Speight and Wylie (2001) calculated the cost of forest health surveys of pine plantations in Queensland, Australia at AUS$1.14/ha, which included aerial and ground surveys, diagnostics and written reports. Similar costs are reported from New South Wales and New Zealand for the same services (Carnegie *et al.*, 2008). In contrast, the cost of hardwood plantation surveys in Queensland was almost tenfold that for softwood plantations (about AUS$10/ha), due to the small (unit size generally 20–50 ha) and disparate estates requiring more detailed ground surveys and the larger number of pests and diseases requiring processing (diagnosis) in this forest type. This cost is expected to reduce as hardwood plantation unit size and aggregation increase (Lawson *et al.*, 2008).

Pywell and Myhre (1992) provide cost comparisons of three remote-sensing techniques discussed earlier in this chapter (Table 9.1). As can be seen, visual sketch mapping by observers in a small aircraft is the cheapest method, although videography has several advantages over this, the main ones being that it eliminates the subjective evaluation of the observer and provides a permanent record and more accurate estimates of the real extent and severity of pest damage. Both sketch mapping and videography are far cheaper than conventional aerial photography.

Carter (1989) gives a detailed breakdown of the costs of various methods of forest health surveillance in New Zealand and compares cumulative cost against probability of detection (Fig. 9.7). He concludes that maximum net benefit is achieved at survey levels which will detect 95% of all new introductions (compared to then-current levels in that country which were achieving less than 50% detection).

Table 9.1. Cost analysis of remote-sensing techniques used to define and map gypsy moth defoliation in the USA (from Pywell and Myhre, 1992).

Technique	Time (hours)	Cost of plane/ pilot per hour (US$)	Cost of mapper/ analyst per hour (US$)	Cost of film/ processing (US$)	Total cost (US$)
Aerial sketch	2.0	105	9.68	0.00	229.36
Airborne videography	1.5	250	20.90	12.95	419.30
Office sketch	2.5		10.00		25.00
					444.30
Aerial photography	2.0	250	20.90	1100.00	1641.80
Photointerpretation	40.0		10.00		400.00
					2041.80

A further example of an operational surveillance programme in the tropics and the resources required to run it is from Aracruz Celulose SA in Brazil. This company is one of the world's largest exporters of hardwood bleached pulp and has more than 260,000 ha of plantations, mostly eucalypts (Osland and Osland, 2007) (Plate 122). Its system of preventative control against target pests involves: (i) detection of primary outbreaks; (ii) outbreak evaluations; (iii) analysis of results; and (iv) definition of control strategy (Laranjeiro, 1994), and is shown schematically below (Fig. 9.8). As reported by Laranjeiro (1994), the efficacy of this system has meant that intervention was necessary on less than 0.02% of initial outbreaks detected. In the remaining cases, the pest populations returned to a balanced state due to natural control.

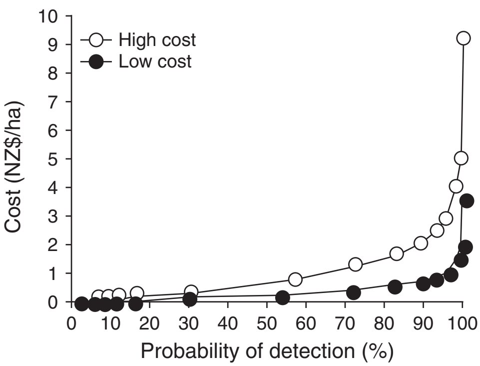

Fig. 9.7. Cumulative cost and probability of detection for high- and low-cost locations (150 and 50 km each way, to and from the forest) (from Carter, 1989).

9.1.6 Example of survey form and surveillance guidelines

A survey form that has been used in forest health surveillance in several countries in Asia and the Pacific is shown in Fig. 9.9. The form originated from ACIAR-funded capacity-building projects on forest health in the region during the period 1997–2004. Surveys were conducted in Malaysia, Thailand, Vietnam, Indonesia, Fiji, Vanuatu, Samoa, Tonga and tropical Australia to determine the key pests occurring on tree plantations and to obtain information on their distribution and impact on plantation health and growth (Wylie *et al.*, 1998). The surveys were conducted across a range of species, provenances, ages, geographical locations, site conditions and times of year using standardized data collection methods. The form shown was adapted from that used in Queensland in their forest health surveillance programme. The form is meant to act as a checklist for observers who are trained in the recognition of the symptoms listed. The information recorded assists in the

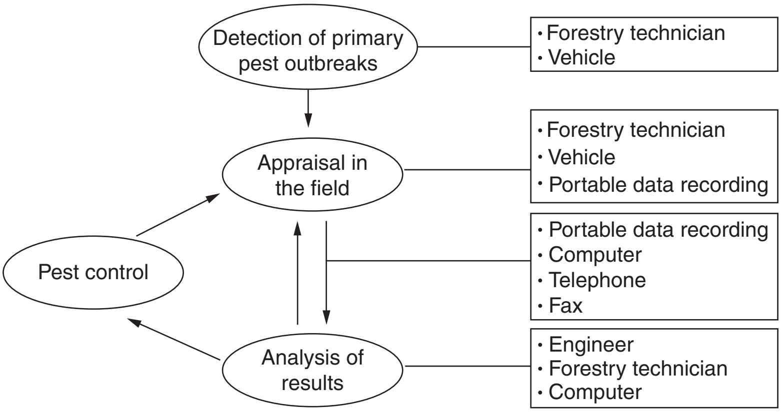

Fig. 9.8. Schematic outline of the Aracruz Celulose SA system for preventative control of insect pests of *Eucalyptus* (from Laranjeiro, 1994).

FOREST HEALTH FIELD FORM

OFFICE USE ONLY
DATE ENTERED ..../........../..........
ENTERED BY ....

DATE ..../........../.......... OBSERVER .... LOCATION NO .... OCCURRENCE NO ....

COUNTRY .... PROVINCE/STATE ....
LOCALITY/ADDRESS ....
LOGGING AREA NAME .... COMPARTMENT ....
COMPARTMENT AREA Ha .... LAT/LONG ....
OWNERSHIP/ FUNDING ☐ Private ☐ Public/Government NAME ....

AGE & AVERAGE SIZE
Plant Date yr .... mth ....
Height m ....
DBH cm ....

PRESENT STOCKING RATE
Stems/Ha ....

TREE SITUATION
- ☐ Commercial Plantation
- ☐ Native Forest
- ☐ Nursery
- ☐ Community Plots
- ☐ Agroforestry
- ☐ Amenity/Street Trees
- ☐ Other..........

ORIGINAL VEGETATION /SITE HISTORY
- ☐ Native Forest
- ☐ Tree Plantation
- ☐ Grassland
- ☐ No vegetation
- ☐ Previously agriculture
- ☐ Other..........

SITE & STAND TREATMENT
- ☐ None
- ☐ Regeneration
- ☐ Planted
- ☐ Herbicide
- ☐ Fertilised
- ☐ Pruned
- ☐ Thinned
- ☐ Clearfelled
- ☐ Stock Grazing
- ☐ Other ....

TREE SPECIES:.......... PROVENANCE .... SEEDLOT ....

TREE STATUS
- ☐ Living
- ☐ Standing dead
- ☐ Fallen
- ☐ Other..........

GROWTH STAGE
- ☐ Seedling
- ☐ Sapling
- ☐ Pole
- ☐ Mature
- ☐ Overmature
- ☐ Other ....

CANOPY POSITION
- ☐ Dominant
- ☐ Codominant
- ☐ Suppressed
- ☐ Understorey

TOPOGRAPHY
- ☐ Gully
- ☐ Ridges
- ☐ Slope
- ☐ Flats
- ☐ Undulating

ASPECT..........

DAMAGE/SYMPTOM
- ☐ None
- ☐ Mortality
- ☐ Chlorosis
- ☐ Necrosis
- ☐ Skeletonising
- ☐ Holes
- ☐ Defoliation
- ☐ Dead Crown
- ☐ Wilt
- ☐ Dieback
- ☐ Witches broom
- ☐ Other Distortion
- ☐ Stunting
- ☐ Resinosis
- ☐ Oozing
- ☐ Swelling
- ☐ Cracks
- ☐ Ringbarking, girdle
- ☐ Epicormic shoots
- ☐ Puncture
- ☐ Mining
- ☐ Chewing
- ☐ Gall
- ☐ Tunnelling
- ☐ Webbing/Tying
- ☐ Severing
- ☐ Frass
- ☐ Other..........

DISTRIBUTION OF AFFECTED TREES
- ☐ Single tree
- ☐ Scattered
- ☐ Patches
- ☐ Widespread

AVERAGE SEVERITY / TREE
- ☐ Negligible
- ☐ Minor
- ☐ Moderate
- ☐ Severe

Severity .... %

AREA AFFECTED ....Ha
% OF TREES AFFECTED
..........%
- ☐ Estimated
- ☐ Counted N=..........out of ....

PART AFFECTESD
- ☐ Entire Tree
- ☐ Stem
- ☐ Base of trunk
- ☐ Root Collar
- ☐ Root
- ☐ Sapwood
- ☐ Heartwood
- ☐ Cambium
- ☐ Bark
- ☐ New Shoot
- ☐ Twig
- ☐ Branch
- ☐ Leading Shoot
- ☐ Foliage
- ☐ Bud
- ☐ Flower
- ☐ Seed
- ☐ Other..........

- ☐ Upper
- ☐ Middle
- ☐ Lower
- ☐ Directional

POSSIBLE PREDISPOSING FACTORS
- ☐ Fungal
- ☐ Animal
- ☐ Mistletoe
- ☐ Drought
- ☐ Waterlogging
- ☐ Wind/Typhoon
- ☐ Hail
- ☐ Lightning
- ☐ Frost
- ☐ Heat/Sunshine
- ☐ Fire
- ☐ Mechanical
- ☐ Compaction
- ☐ Competition
- ☐ Nutrient
- ☐ Salt
- ☐ Herbicide
- ☐ Other ....

....
....

INSECT IDENTIFICATION ACCESSION NO ....
Scientific Name ....
Common Name..........
Family .... Order..........
Identifier .... Organisation..........

Fig. 9.9. Forest health field form.

correct diagnosis of the problem and allows, for example, a cross-check on whether the observed symptoms match those which could be produced by the putative causal agent. It also provides some initial quantitative measure of the incidence and severity of the problem, which can then be followed up by more detailed surveys if the situation warrants it. Information is stored on a database and, over time, will provide a historical record of the health of particular forest areas. Such databases can be interrogated as required to produce reports useful for forest management.

Comprehensive guidelines to assist plant health scientists design surveillance programmes for detecting pests in crops, plantation forests and natural ecosystems have been funded and published by the Australian Government (McMaugh, 2005). The guidelines cover the planning of surveillance programmes for building specimen-based lists of pests, surveillance for monitoring the status of particular pests, surveillance for determining the limits of distribution of pests, surveillance for determining the presence or absence of pests in particular areas and general surveillance. Although aimed at use by developing countries in the Asia-Pacific region, these guidelines are broadly applicable. The Food and Agriculture Organization of the United Nations also has produced guidelines for surveillance as part of its International Standards for Phytosanitary Measures series of publications (FAO, 1998).

9.2 Forest Invasive Species and Quarantine

9.2.1 The need for forestry quarantine

The best way of minimizing the damage that may be caused to plantations by exotic insects is, of course, to keep the pests out in the first place. Quarantine therefore needs to be recognized by forest managers as an essential and valuable component of the overall protection effort. Exotic insects pose great risk to the stability and productivity of the forest ecosystems into which they are introduced, as a species can become established easily if it finds a suitable climate and host material in its new environment (Ciesla, 1993). In the absence of natural enemies that may regulate the insect in its native range, its numbers may increase rapidly. In addition, as host plants in the new habitat may not have been exposed previously to the introduced insect or to microorganisms of which the insect might be a vector, they may be more sensitive to injury than those in its natural range. Frequently, insects that are not considered to be major pests in their native habitats cause widespread damage when they are introduced into new areas. Good examples of this are the wood wasp *S. noctilio* in Australia, South Africa and South America, and the cypress aphid *Cinara cupressi* in Africa, both species being of only minor importance in their native Europe but devastating pests in those countries where they have become established.

In many countries, forestry quarantine is treated as just a subset of general plant quarantine, which tends to be dominated by agricultural considerations. This situation frequently leads both forestry managers and quarantine policy makers to underestimate its importance. However, forestry has many difficulties and requirements that are quite distinct from those of agriculture and which necessitate a different approach. Unlike agricultural crops, most tree crops require decades to mature and cannot be modified quickly to control or resist new pests and diseases (Wylie, 1989). Direct control measures such as spraying or dusting, which would be employed for problems in agricultural crops, are usually not logistically, environmentally or economically practicable in forests (either plantations or natural). The potential impact of some of the more serious exotic pests and diseases of forests, if introduced, could therefore be not just the loss of a few season's crops (as is often the case with agricultural pest problems) but the loss of decades of effort and investment in plantations and irreparable damage to the native flora and timber resource.

Other special difficulties for forestry relate to the early detection of exotic organisms and the sometimes limited options available for eradicative action. Included here are the vastness and isolation of much of the forest estate and the infrequency and difficulty of inspections (compared to that for intensively managed, easily accessible agricultural crops). Past experience in many countries has been that by the time an exotic pest is detected in forests it is usually well established and beyond eradication (Wylie, 1989; Wardlaw *et al.*, 2008). Some of the economic and social consequences which can result from the establishment of exotic insect species in forests have already been chronicled in Chapters 5 and 6, for example *C. cupressi* in Africa, *I. grandicollis* in Australia and *Heteropsylla cubana* in the Asia-Pacific and Africa.

9.2.2 Modes of entry of exotic insects

Common pathways of exotic pest entry into a country and examples of such introductions are given below.

Seeds

Exchange of tree seed around the world has helped in extending and diversifying forestry and in improving yields. Unfortunately, it has also helped to spread damaging tree pests from one country to another. Among the commonest insects intercepted in seed consignments are beetles (e.g. *Bruchidius* spp. in acacia seed), wasps (e.g. *Megastigmus* spp. in eucalypt and pine seed) and moths (e.g. *Tracholena* sp. in hoop pine seed). In two examples from India, Verma (1991) records the interception of the bruchid *Merobruchus columbinus* in seeds of *Samanea saman* imported from Honduras, and Verma *et al.* (1991) list *Bruchus ervi* in seeds of *A. brachystacha* imported from Australia. As discussed in Chapter 5, seed insects have importance for tree-breeding programmes and for social forestry.

Scions and nursery stock

These are very high-risk imports, as numerous examples in the literature attest. One of the most famous, or notorious, accidental introductions on scions was that of the woolly pine aphid, *Pineus boerneri*, into Zimbabwe and Kenya in 1962 on pine scions from Australia and its subsequent spread to a further six countries in Africa, mostly by the movement of infested nursery stock (Odera, 1974; Blackman *et al.*, 1995). An early example of introduction via nursery stock is the discovery of the gum tree scale, *Eriococcus coriaceus*, on plantations of *E. globulus* in the South Island of New Zealand in 1900 (Clark, 1938), which was linked to eucalypt plants imported from Australia (Lounsbury, 1917).

The Christmas tree trade has also been a vehicle for the introduction of exotic pests into several countries. For example, in Bermuda, several organisms of quarantine importance were found accompanying Pinopsida and other Christmas foliage plants imported into the country in sealed containers from various sources. Tree pests found included the spruce gall aphid, *Adelges cooleyi*, the scale *Chionaspis pinifoliae*, the balsam gall midge, *Paradiplosis tumifex*, the mite *Trisetacus quadrisetus* and the gall midge *Monarthropalus buxi* (Anon., 1997). Bonsai trees imported from Asia have been established as a proven pathway for the introduction of *Anoplophora chinensis* (Ciesla, 2004).

Hitchhiking on non-target plants

Some forestry pests have been transported accidentally from one country to another on a plant that is not a host for the species or is not a forest tree species. The eucalyptus weevil, *Gonipterus scutellatus*, was first noticed in South Africa in 1916 (Mally, 1924). South African authorities considered it extremely improbable that the insect came with eucalypt trees because the introduction of eucalypts from overseas became absolutely prohibited in 1903. The most likely pathway was thought to be as stowaways in cases of apples from Australia.

G. scutellatus is a pest of apples in Tasmania, and beetles have often been observed clinging to the stems of apples after these have been packed in cases. Large quantities of Tasmanian apples were imported into South Africa just after the Boer War (Mally, 1924). More recently, there were four interceptions of the Tasmanian eucalypt leaf beetle, *Paropsisterna bimaculata*, in the UK in 2004 in tree ferns (*Dicksonia antartica*) imported from Australia (Central Science Laboratory, 2005), while a dead specimen of the gum tree longicorn, *Phoracantha recurva*, was found in a cluster of bananas imported into Belgium in 2005, sourced from either Central or South America or Australia (Bosmans, 2006).

Cut flower trade

The transfer of pests on live plants applies as well to the cut flower trade. Leaf miners, thrips, mites and larvae of several moth species are found regularly on cut flowers, indicating the risks associated with the intercontinental flower trade (Wittenberg and Cock, 2001). The most likely pathways for dissemination of the red gum lerp psyllid, *Glycaspis brimblecombei*, and the blue gum chalcid, *Leptocybe invasa*, around the world are plants for planting or cut foliage of *Eucalyptus* from countries where these pests occur. This pathway is linked closely to air transport and one of the earliest examples was in 1928 when the airship Graf Zeppelin made its first visit to North America; seven insect species were found in bouquets decorating the cabins (Gilsen, 1948).

Logs and sawn timber

Bark beetles, longicorn beetles and wood wasps are among the most destructive pests of forest trees and can be spread all too easily through the international timber trade unless care is taken. Unprocessed logs are particularly risky imports, especially if the bark is intact, because the cambium layer is the breeding site for many species with a highly destructive potential. A good example is provided by Ciesla (1992, 1993). In April 1992, unprocessed *Pseudotsuga menziesii* and *Tsuga heterophylla* logs exported from North America into the People's Republic of China and subsequently deposited in a forested area to be used for the construction of a Buddhist temple were found to be infested by bark beetles and wood-boring beetles indigenous to western North America. Live adults of Douglas fir beetle, *Dendroctonus pseudotsugae* (Scolytinae), and live larvae of the flatheaded fir borer, *Melanophila drummondi* (Buprestidae), were recovered from the logs. *D. pseudotsugae* is the most important bark beetle pest of *P. menziesii* throughout the range of this tree in western North America, sometimes reaching epidemic levels and killing large numbers of trees. *M. drummondi* occurs throughout the same region, attacking several species of trees and capable of killing apparently healthy trees. In this particular case, the logs were deposited in a location that did not contain suitable host material for the insects and it is doubtful they would become established in the immediate area. However, in other areas of China they could well have become established.

The hazardous nature of log imports is highlighted further by figures from China, where in 27 boatloads of timber from Malaysia quarantined in 1990–1992 in Zhoushan port, Zhejiang Province, logs from 20 boatloads were found to carry termites, including nests and winged adults (Zhang and Yang, 1994). Three species found were the rubber termite, *Coptotermes curvignathus* (see Chapter 5), *C. bornensis* and *Schedorhinotermes sarawakensis*. In India, of 2000 consignments of logs and timber (mostly from the Far East) imported into Karnataka in 1989–1991, 162 were treated to control one or more of the 40 species of coleopteran pests detected (Ghodeswar *et al.*, 1992). Ambrosia beetles are generally the most common insects transported in logs and unseasoned sawn timber, and Ohno (1990a,b) records 144 species of Scolytinae and 86 species of Platypodinae in logs shipped from the island of Borneo to the Japanese port of Nagoya over the period 1982–1987.

An early example of pest spread via sawn timber is that of the gum tree longicorn, *Phoracantha semipunctata*, which is believed to have been introduced into South Africa shortly before the Boer War in newly cut eucalypt railway sleepers from Australia. The insect was first observed in 1906 in a plantation near Wolseley in Cape Province, and Lounsbury (1917) noted that nearby railway sleepers of Australian origin, laid in 1898, showed tunnelling similar to that noted in the trees. *P. recurva* is thought to have entered New Zealand in a similar fashion, adults being found in Canterbury in 1873 near Australian timber imported for railway works (Miller, 1925).

Packing crates, pallets and dunnage

Timber packaging and packing materials are another common means of entry for exotic pests of forestry importance (Haack and Petrice, 2009). Such material is usually rough-sawn and often has bark remnants adhering to it, which are sufficient to harbour small numbers of adults, pupae or larvae of insects such as bark beetles (Plate 121). Haack (2006) summarized data for 8341 Coleoptera interceptions at US ports of entry from 1985 to 2000 (Table 9.2). Crating and dunnage were found to be the most common type of wood article to be infested and some of the most commonly associated products were tiles, marble and machinery. The five-spined bark beetle, *I. grandicollis*, is known to have entered Western Australia via dunnage imported from North America, and *H. ater*, *H. ligniperda* and *O. erosus* (all of European origin) have been introduced into several tropical and subtropical regions of the world via pine cargo crates (Ciesla, 1993). Larger wood-boring insects are also transported in packaging, and the wood wasps *S. juvencus* and *Urocerus* sp. are intercepted periodically in the subtropical port of Brisbane in Australia in material originating from Japan, Europe and North America (Wylie and Peters, 1987). The Asian longhorn beetle, *A. glabripennis* is believed to have entered the USA in the 1990s via wooden packaging material (Barak *et al.*, 2005).

Cargo containers

Cargo containers themselves, and not just their cargo, can serve to transport forest invasives. Gadgil *et al.* (2000) assessed contaminants on the external surfaces of 3681 shipping containers entering New Zealand. They found that 23% of containers carried quarantinable contaminants, among which were pathogenic species of *Fusarium* and a live egg mass of the gypsy moth, *L. dispar*. Most steel containers have plywood or timber floors and Stanaway *et al.* (2001) surveyed the floors of 3001 empty sea cargo containers in Brisbane, Australia, searching for live or dead insects on or in the flooring. They collected more than 7400 specimens from 1174 (39%) of the containers examined. Live insects accounted for 19% (1339) of the total specimens collected. No live infestations of timber insects were recorded, but feeding damage was detected in one floor. Insects that had the potential to infest timber were found in 104 (3.5%) of the containers inspected. Only one of these was found alive, a scolytine beetle, but 45 dead insects were found that were timber pest species exotic to Australia and of quarantine concern. They included bostrychids, curculionids, cerambycids, siricids and termites and most would have been associated with the cargo carried in the containers or with dunnage. The study shows that the wooden components of sea cargo containers are exposed constantly to timber-infesting insects from many sources. The advent of refrigerated containers for agricultural or horticultural produce may increase the risk associated with this pathway, resulting in higher survival of insects because containers are kept at constant, non-lethal temperatures throughout transport (Work *et al.*, 2005).

Air transport

Quarantine authorities have long been aware of the connection between aircraft and the dissemination of insect species from one region to another as hitchhikers in the holds or cabin areas (Dobbs and Brodel, 2004). The importance of this pathway has

Table 9.2. Summary data for 8341 Coleoptera interceptions at US ports of entry from 1985 to 2000 by insect family (from Haack, 2006, with permission of National Research Council of Canada Research Press).

	No. of interceptions identified				No. identified		No. of interceptions associated with wood articles if given				
Family*	Total	Family level only	Genus level only	Species level	Genera	Species	Crating	Dunnage	Pallets	Wood	Top five associated products in decreasing order
BOS	414	52	115	247	16	16	137	33	28	150	Tiles, woodenware, melons, machinery, marble
BUP	245	41	182	22	16	10	80	51	7	39	Tiles, marble, machinery, steel, mesquite
CER	1642	448	1048	146	79	41	390	269	57	408	Tiles, iron, ironware, machinery, marble
CUR	875	118	714	43	44	17	420	326	33	95	Tiles, steel, machinery, marble, granite
LYC	102	72	11	19	3	3	64	4	3	15	Doors, tiles, artware, bamboo, housewares
PLA	55	19	36	0	2	0	3	4	3	8	*Dracaena* plants, pineapples, bananas, woodenware, doors
SCO	5008	1547	1002	2459	40	60	2179	1841	348	601	Tiles, marble, machinery, steel, parts
Total	*8341*	*2297*	*3108*	*2936*	*200*	*147*	*3273*	*2528*	*479*	*1316*	Tiles, machinery, marble, steel, ironware

Notes: *Insect families: BOS = Bostrychidae; BUP = Buprestidae; CER = Cerambycidae; CUR = Curculionidae; LYC = Lyctidae; PLA = Platypodinae; SCO = Scolytinae.

increased steadily with increases both in the number of passenger and cargo flights around the world (Hulme, 2009) (Fig. 9.10) and in the speed of air travel. Studies by Dobbs and Brodel (2004) showed that almost one in four cargo aircraft arriving from Central American countries into south Florida harboured live, non-indigenous organisms of potential economic impact to US agriculture, forests and ornamentals (Figs 9.11 and 9.12). Insects intercepted on this pathway included chrysomelid leaf beetles, weevils, scarab beetles, leaf hoppers, plant bugs, termites, moths and crickets (Caton *et al.*, 2006). Extreme long-range dispersal by air travel is thought to be the main mechanism for spread of the winter bronzing bug, *Thaumastocoris peregrinus*. This hypothesis was supported by information from Brazil where, in the state of Sao Paulo, the bug was first found in *Eucalyptus* trees adjacent to two international airports in the metropolitan region of Sao Paulo city (Wilcken *et al.*, 2010). The insect may also hitchhike on the clothes of travellers or be dispersed by wind.

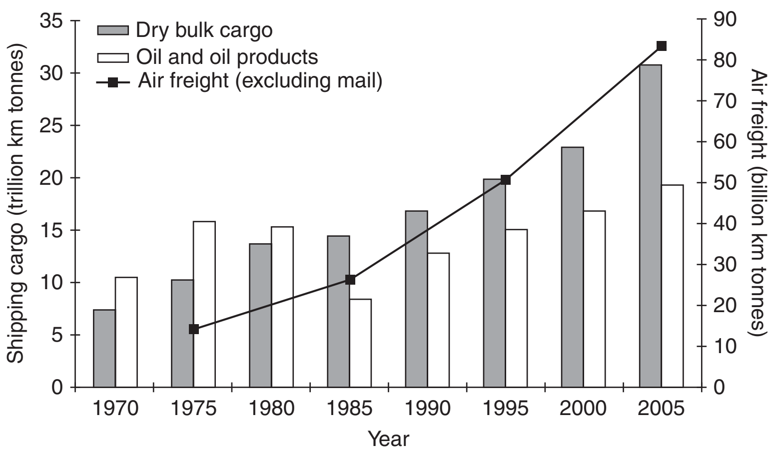

Fig. 9.10. Trends in global shipping cargo volumes and airfreight, 1970–2005. Note the three orders of magnitude difference in the scales of the left- and right-hand ordinate axes (from Hulme, 2009).

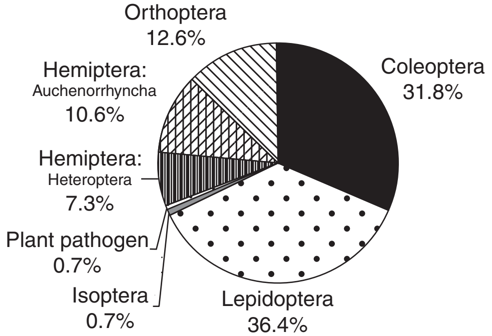

Fig. 9.11. Relative proportions of quarantine-significant taxa captured in foreign cargo aircraft arriving at Miami International Airport, 1 September 1998 to 31 August 1999 (from Dobbs and Brodel, 2004).

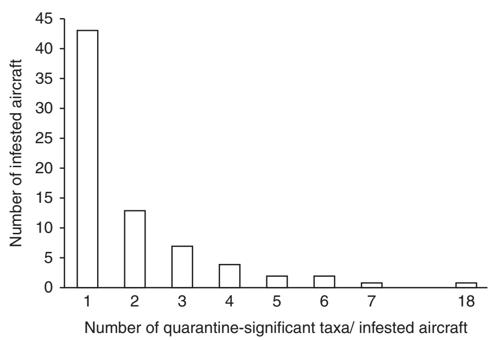

Fig. 9.12. Numbers of quarantine-significant taxa found aboard infested foreign cargo aircraft arriving at Miami International Airport, 1 September 1998 to 31 August 1999 (from Dobbs and Brodel, 2004).

Long-range dispersal by air transport may also be involved in the spread of the red gum lerp psyllid, *Glycaspis brimblecombei* (Plates 31 and 32), as evidenced in Chile where the insect was first detected in 2001 in the neighbourhood of the International Airport of Santiago on *E. camaldulensis* (Huerta *et al.*, 2010).

Wind dispersal

The dispersal of insects by aerial currents is a well-known phenomenon but it was not until the early 20th century that the first proof was obtained of long-distance transport when spruce aphids were observed in large numbers over a broad area at Spitsbergen in northern Norway. Their nearest host plants were estimated to be about 1300 km away (Elton, 1925). The first estimate of the magnitude of aerial insect population was made by Coad (1931), who found that the number of insects in a vertical column of air 2.6 km^2 and extending from 15 to 4300 m above the ground averaged 25 m throughout the year in Louisiana in the USA. In numerous studies, Hemiptera are the insect group most commonly transported long distances by wind and, among these, Aphididae is the dominant family (Holzapfel and Harrell, 1968; Hardy and Cheng, 1986). Examples of both long-distance and localized wind dispersal of forest insect pests are provided in Chapter 3.

Humans as vectors: intentional and accidental

The gypsy moth, *L. dispar*, in North America is a classic example of human-assisted introduction of an exotic pest. The European variety was brought initially into that country in 1869 for hybridization experiments with the domestic silkworm, *Bombyx mori*. A portion of the laboratory colony escaped, however, and found a suitable habitat for colonization in the surrounding oak forest, from whence they spread widely to become one of the most destructive hardwood forest insect pests in the region, defoliating an average of 1.6 Mha of forest annually in eastern USA (Ciesla, 1993). This spread was assisted by the accidental transport of life stages on recreational and commercial vehicles and on outdoor household articles (Douce *et al.*, 1994). More than a century later, North America has been involved in eradication programmes for the Asian form of the moth, which has an even more extensive host range than that of the European form. Egg masses of Asian gypsy moth were transported on ships from the Russian Far East and the newly emerged larvae blew in the wind on silk threads to shore. Since then, egg masses of the moth have been detected on machinery brought in from several countries where the insect occurs, and similar instances have been reported from other parts of the world.

The growing popularity of arthropods as pets in some places such as the USA, Europe and Japan and the increasing international trade in live insects poses quarantine risks. An example of relevance to forestry is that of the cossid moth, *Chilecomadia valdiviana*, variously known as the quince borer, carpenterworm or butterworm. It is native to Chile, where it is an emerging pest of *Eucalyptus* spp. plantations (Lanfranco and Dungey, 2001). Tens of millions of larvae of *C. valdiviana* and another species of *Chilecomadia*, *C. morrie*, are sold as fishing bait and reptile food in the USA and Europe (Thomas, 1995; Iriarte *et al.*, 1997).

In California, eucalypts are widely planted as landscape and windbreak trees, but some people in the community oppose their use, mainly because of their growth habits, facilitation of catastrophic urban wildfires and a perception that it is changing the California landscape by crowding-out or preventing the growth of native species (Paine and Miller, 2010). Between the time eucalypts were first introduced to the state in the middle of the 19th century and 1983, only two herbivorous insects, originating from Australia, had been recorded feeding on these trees. In the period between 1984 and 2008, an additional 15 species, all Australian, were recorded. The mode or route of introduction has never been established, but examination of temporal and spatial patterns suggests that the introductions are non-random processes. As outlined by Paine and Miller (2010), the hypothesis that there were intentional introductions as biocontrol agents for a perceived weed species cannot be rejected.

Tourism is also a pathway for invasive species of forestry importance. For example, in New Zealand in 2006–2007, 25% of undeclared goods seized by quarantine inspectors from arriving air passengers and crew were cut flowers or foliage (McNeill *et al.*, 2008). Items such as tents, golf bags and baggage carried by travellers between countries have also been shown to harbour live insects or foliage (Gadgil and Flint, 1983; Liebhold *et al.*, 2006; McCullough *et al.*, 2006) (Fig. 9.13), as has clothing worn by travellers. Egg masses of tussock moths (Lymantriidae) are intercepted frequently on imported used vehicles at the border in New Zealand (Armstrong *et al.*, 2003; Toy and Newfield, 2010).

9.2.3 Prevention and management options

The threat posed to plants and plant products by invasive pest species was first recognized officially in the late 1800s following a series of catastrophic pest and disease epidemics in Europe and America (Mathys and Baker, 1980). One of the earliest plant quarantine laws was passed in Germany in 1873 prohibiting the importation of plants and plant products from the USA to prevent the introduction of the Colorado potato beetle. Asia was also involved early in plant quarantine, with Indonesia legislating in 1877 to prevent the entry of coffee rust from Sri Lanka. The first international plant protection convention was established in 1881 after the introduction of grape phylloxera into Europe from America in 1865 caused major losses in the vineyards of France (Mathys and Baker, 1980). Since that time, invasive species have continued to cause significant damage, but it is not until recently that such losses have been better quantified. Pimentel *et al.* (2001) estimate that damages worldwide from invasive species are more than US$1.4 trillion/year, which represents nearly 5% of the world economy. For the forestry sector, in the USA alone annual losses due to invasive species total US$4.2bn (Pimentel *et al.*, 2001). As noted by Holmes *et al.* (2009), biological invasions by non-native species are a by-product of economic activities and the potential costs generally are not factored into decisions about exports, imports and domestic transport of goods and people, all of which are pathways for the introduction and spread of invasive species. They suggest that the greatest economic impacts of invasive species in forests are likely to be due to the loss of non-market values (Fig. 9.14). This has prompted a range of global initiatives to address the problem. These initiatives, together with some of the key elements of pre-border, border and post-border quarantine, from a forestry perspective, are discussed below.

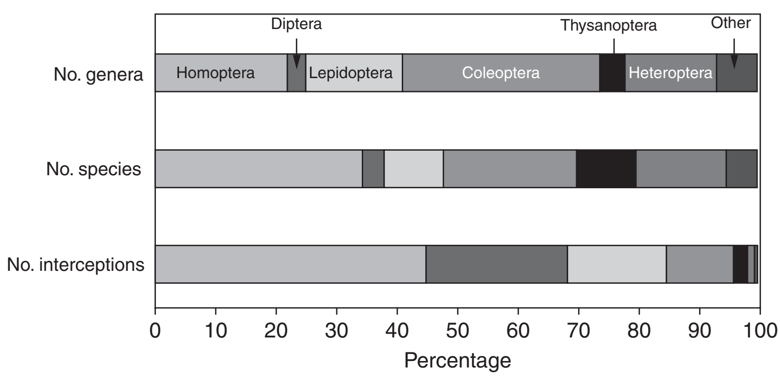

Fig. 9.13. Frequencies of different insect orders intercepted in airline baggage coming into the USA expressed as numbers of genera, numbers of species and total numbers of interceptions. The 'other' category includes Hymenoptera, Orthoptera, Isoptera and Collembola (from Liebhold *et al.*, 2006).

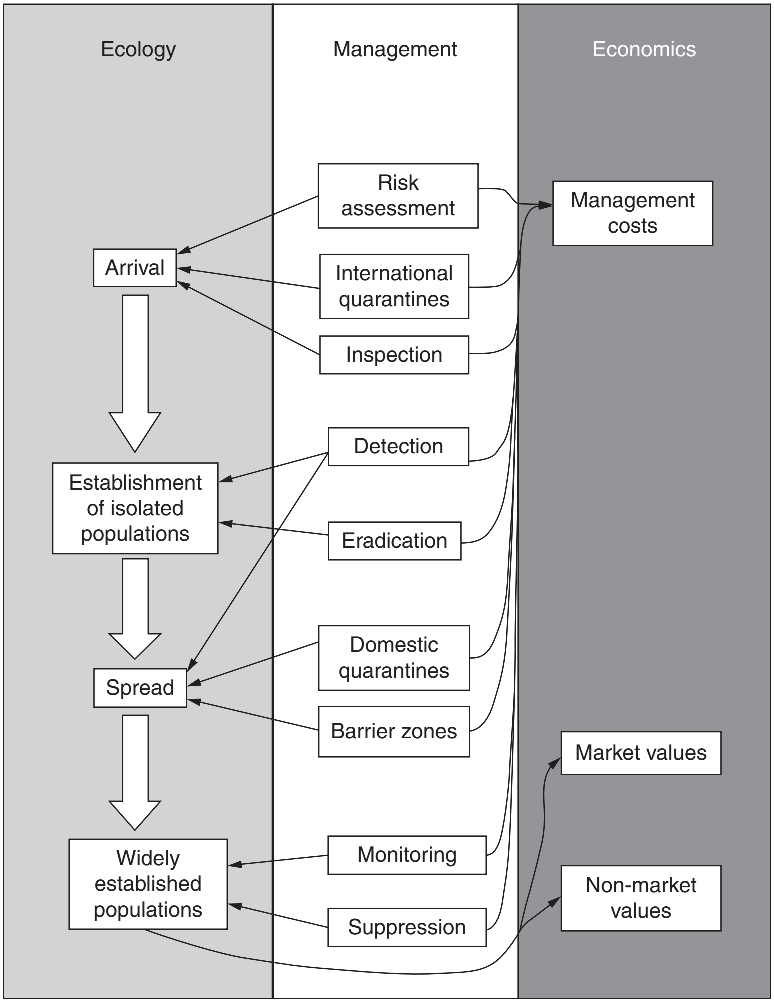

Fig. 9.14. The stages of a biological invasion are linked to management actions that can be applied at each stage; each of these management actions has economic implications (from Holmes *et al*., 2009).

Pest awareness

For any country endeavouring to implement forestry quarantine, knowledge of the pest species occurring elsewhere, which may pose a risk to its own forest resources should they be introduced accidentally, is important. This allows for targeting of preventative and inspection measures to exclude these pests. Such information is variously available in the literature (print or electronic), or through international and regional quarantine bodies such as the International Plant Protection Organization (IPPO) and the Pacific Plant Protection Organization (PPPO). It may also be obtainable through networks of forest protection specialists.

A recent global initiative to raise awareness of the immense costs and dangers posed by invasive species to the sustainable management of forests is the formation in 2004 of Forest Invasive Species Networks. The Asia-Pacific Forest Invasive Species Network (APFISN) is a cooperative alliance of the 33 member countries in the Asia-Pacific

Forestry Commission (APFC) – a statutory body of the Food and Agriculture Organization of the United Nations (FAO). The network focuses on inter-country cooperation that helps to detect, prevent, monitor, eradicate and/or control forest invasive species in the Asia-Pacific region. Specific objectives of the network are to: (i) raise awareness of invasive species throughout the Asia-Pacific region; (ii) define and develop organizational structures; (iii) build capacity within member countries; and (iv) develop and share databases and information. The Forest Invasive Species Network for Africa (FISNA) comprises seven African countries (Ghana, Kenya, Malawi, South Africa, United Republic of Tanzania, Uganda and Zambia). Its mandate is to coordinate the collation and dissemination of information relating to forest invasive species in sub-Saharan Africa with objectives similar to that of the APFISN.

Knowledge of indigenous fauna

Ideally, in setting up quarantine protocols to exclude exotic organisms, an ability to be able to distinguish between what is exotic and what is indigenous would seem to be of key importance. In practice, few, if any, countries would have a complete inventory of their forest insect fauna. This applies particularly in the tropics, where the number of species is large, many unidentified, and the number of entomologists few. Nevertheless, to comply with the requirements of world trade, countries need to be able to demonstrate an acceptable capacity in this regard (through their own resources or with external assistance) and an ongoing commitment to such work. This is especially the case where area freedom arrangements are sought (i.e. the ability to trade based on a certification that a particular pest does not occur in the area where the exports originated). Information about endemic and established forest organisms comes from many sources, including arthropod and pathogen collections with validated, well-curated specimens, databases, scientific literature, surveillance conducted by forest services, faunal surveys and specialist networks.

Assessing risk and selecting target pests

It should be cautioned that, when attempting to set up pest lists based on perceived risk, knowledge of the pests of much of the forest flora of the world is meagre in comparison with that for agricultural crop pests (Wylie, 1989). Coupled with this is the difficulty referred to earlier of predicting just how an organism will behave outside its native environment. Many countries have target pest lists, but again the experience has been that most of the insects that have entered and become problems are not on such lists. Despite this, knowledge of exotic pests, their behaviour and likely mode of entry is very useful in formulating generic measures to combat pest ‘types’ rather than individual species.

Pest risk assessment (PRA) and associated risk mitigation is the purview of biosecurity and quarantine agencies and, by its nature, focuses mainly on pre-border and border activities. It is a disciplined process that is used to predict whether or not a species is likely to become established and be invasive and to generate a relative ranking of risk (Wittenberg and Cock, 2001). Usually, scores are assigned to each of the risk components and then the scores are added or averaged to give the final result, or odds may be assigned instead of scores (Holt *et al.*, 2006). Entire pathways may also be analysed for risk. Application of the risk assessment process, while reducing the amount of subjective judgement involved, can be labour-intensive, time-consuming and costly. For example, a risk assessment of importing unprocessed logs from Russia to the USA was estimated to cost US$500,000 (Wittenberg and Cock, 2001). However, the process also has relevance for post-border activities such as targeted surveillance and response planning. One of the issues raised by several countries attending the 2008 APFISN workshop in Vietnam on ‘Risk-based targeted surveillance for forest invasive species’ was the need for assistance in selecting which pests to target for post-border surveillance (FAO, 2009). Wylie (2010) proposed a nine-step guide to the selection of target pests, incorporating most elements of published international standards on pest risk assessment (EPPO, 1998; FAO, 2004), but with a slightly different emphasis and a forestry perspective. The guide and two worked examples from the Asia-Pacific region are reproduced here. Note that this is not meant as a substitute for the standard PRA, rather it is intended as a screening tool which will allow agencies involved in forest health to select a few key pests for post-border monitoring.

A nine-step guide to selection of target forestry pests for surveillance

1. WHAT DO WE WANT TO PROTECT? Most PRAs are initiated in response to requests for import of new commodities, or awareness that a new pathway has opened up or a new pest comes into prominence. Sometimes, it is because of the review or revision of a policy (FAO, 2004). Here, we commence not with the commodity but with the resource we want to protect – this may be the country's commercial forest plantations (pine or hardwood), or conservation native forests, or timber-in-service (e.g. the built environment). Ideally, surveillance would be conducted for the full range of potential pests across all resource types, but financial and other constraints may require that surveillance be prioritized.

2. WHAT EXOTIC PESTS COULD BE A THREAT TO THIS RESOURCE? Information about potential forest pest and disease threats already may reside with biosecurity or quarantine agencies in-country, and these should be consulted first. However, in several Asia-Pacific countries, the quarantine focus historically has been on agricultural pests, and forestry needs are largely unexplored. In such case, information can be sourced from international forest health or quarantine networks, the published literature, scientific meetings and the Internet.

3. DOES THE PEST HAVE THE POTENTIAL TO BE TRANSPORTED BY TRADE OR HUMAN MOVEMENT? Aspects to be considered here relate to the biology and behaviour of the organism and its potential to be transported with human assistance. In the case of an insect pest, pertinent questions are:

- What is its life cycle and behaviour?
- What are its hosts and where does it lay eggs, feed and pupate?
- Is there a resting stage?
- Is it associated with a commodity?

A longicorn beetle, for example, which is long-lived, lays its eggs in wood and whose immature stages feed and pupate inside wood, has a greater potential to be transported than a leaf beetle defoliator, which lays its eggs and spends its larval period in the soil and only feeds on tree foliage as an adult. Potential pests are not necessarily associated with a commodity. In the Russian Far East, where forests are close to the main seaports, Asian gypsy moths (*L. dispar*) are attracted to port and ship lights and lay their eggs on the superstructure of ships or on cargo. Spores of Eucalyptus rust (*Puccinia psidii*) have been found on the surfaces of cargo containers and can be transported on the clothes of travellers. The New Zealand burnt pine longicorn, *Arhopalus ferus*, is a regular hitchhiker on timber cargo being shipped to Australia (Pawson *et al.*, 2009).

4. IS THERE A PATHWAY INTO THE COUNTRY FOR THE PEST? Pathway analysis is a key component of pest risk analysis. Its purpose is to determine the likelihood of a pest arriving in a country as a result of trade in a particular commodity or human-assisted movement and the likelihood that, if it arrives, it will transfer to an appropriate local host. The four main elements of pathway analysis are listed below:

- Likelihood of trans-shipment with a commodity
    - Prevalence of pest in source area
    - Occurrence of relevant life stage associated with the commodity
    - Frequency of movement with the commodity
    - Season
    - Pest management, cultural and commercial procedures applied at the place of origin

- Likelihood of a pest surviving during transport and storage
  - Speed and conditions of transport
  - Duration of life cycle of pest in relation to transport conditions
  - Vulnerability of pest life stages to transport conditions
  - Prevalence of pest in the consignment
  - Commercial procedures

- Likelihood of a pest surviving existing pest management procedures
  - Likelihood pest will survive existing pest management procedures applied for other pests from origin to end use
  - Likelihood that pest will go undetected during inspections

- Likelihood of transfer to suitable host
  - Dispersal mechanisms including vectors
  - Number of destination points
  - Proximity of entry, transit and destination points to suitable hosts
  - Time of year of importation
  - End use of commodity
  - Risks from by-products or waste

As is evident from the list above, pathway analysis requires the gathering of a considerable amount of information from a variety of sources. Detailed knowledge of the pest in relation to the pathway is required, such as how the rate of development matches with the speed of transport (although with air transport a pest may be moved anywhere in the world within 24 h), the frequency of association with a commodity and history of past interceptions. If the pest is seasonal, then there will be periods when the risk of trans-shipment is reduced. The capability of a pest to survive adverse conditions such as low temperatures or desiccation, which it may experience on the pathway, is an important consideration, as is knowledge of how it disperses (naturally or via a vector). Information is required on the worldwide distribution of the pest and its prevalence in the source area, as well as on commercial procedures (e.g. drying, chemical application, fumigation, visual inspection) applied to the commodity at the point of origin, during transport and on arrival. This information gathering will require input from forest health specialists, biosecurity/quarantine agencies and industry in both the importing and exporting country.

5. What is the likelihood of establishment?

- Environmental suitability of country – climate, suitable hosts
- Geographical location of ports – proximity to suitable hosts
- Numbers and life stages of the pest present and reproductive potential

Comparison of the ecoclimatic zones of the pest's distribution with that of the country conducting the PRA is the first step. What climatic conditions, such as temperature, rainfall, relative humidity, day length, have been shown to be conducive or suppressive to the survival, development, reproduction and dispersal of the pest? It is important to keep in mind the adaptability of many invasive organisms. The wood wasp *S. noctilio*, a native of temperate Europe, is now a major pest of *Pinus* species in several subtropical regions around the world (in Australia, for example, it has taken 50 years since introduction into temperate Tasmania to spread to the subtropics of Queensland). The presence of suitable hosts in the potential recipient country is also of great importance, especially if the pest has a restricted host range. The geographical location of ports and proximity of suitable hosts will also influence the likelihood of establishment. It should be noted, however, that most major ports in a country are likely to be in close proximity to cities where, usually, a wide range of exotic tree species are used as amenity plantings, and this could facilitate establishment. Such plantings are useful in post-border surveillance. Establishment also depends greatly on the numbers and life stages of the arriving pests, whether they are likely to find a mate and their reproductive potential.

6. What is the likelihood of spread?

- Pest's ability for natural dispersal
- Potential for human-assisted dispersal

- Distribution and abundance of hosts
- Natural barriers

Organisms such as rust fungi, psyllids and aphids, which have short life cycles and are wind assisted, will spread rapidly on arrival and are difficult to contain. Many timber-boring insects with a long life cycle and a propensity to exploit a food resource fully before migrating are much easier to contain or eradicate. Most pests, it seems, whether short-lived or long-lived, cryptic or exposed, have potential for human-assisted dispersal. The Asian gypsy moth, *L. dispar*, is a dispersal specialist – the female moth is capable of flight distances of up to 40 km but also lays eggs on containers, cargo and motor vehicles, which assist its spread. Natural barriers such as an inhospitable region for the pest or lack of host plants may limit risk of spread.

7. WHAT ARE THE POTENTIAL CONSEQUENCES OF ESTABLISHMENT?

- Economic impact – direct damage/crop loss, costs of control or containment measures, effect on trade with other countries
- Environmental impact – damage to ecosystems or biodiversity, loss of key species, non-target effects of control measures
- Social impact – effect on workers, families, communities of loss of income/wages from affected products and imposition of area quarantine

All of the above factors will be taken into consideration in a well-constructed benefit/cost analysis. Experience with the pest in other countries may serve as a guide.

8. WHAT IS THE ABILITY TO DETECT THE PEST? As outlined by Wylie *et al.* (2008), the choice of targets for surveillance will be influenced by the ability to detect them by inspection and/or trapping. For many pests and diseases of trees, visual inspection for symptoms of disorder is the most common, and sometimes the only, practical method of detection. Tree health assessments in the vicinity of ports or high-risk sites may be undertaken periodically by trained inspectors. This method may be supplemented by the planting of 'sentinel' trees of locally important species at selected sites and then monitoring these trees at regular intervals.

For some other pest organisms affecting trees and timber, but in particular for insects, trapping is the preferred method of detection. A wide variety of devices or techniques have been developed for this purpose, the type of trap being governed mainly by the behaviour of the target insect species or group. As mentioned earlier in this chapter, most detection trapping is structured around the capture of flying adult insects using either 'passive' traps (e.g. suspended net traps, water traps, 'windowpane' traps), or luring insects from a distance (e.g. light or bait traps). For wood-boring insect species, static traps in combination with lures have been used effectively in many countries (e.g. Brockerhoff *et al.*, 2006). Lures utilizing plant-host volatiles, sex or aggregation pheromones are now commercially available for some key pest species. Spore traps have been used for the detection of some fungal pathogens.

9. WHAT IS THE CAPACITY TO ERADICATE THE PEST? The final consideration in determining which pests to target for surveillance is the ability to eradicate or contain the pest once detected. For some fungal pathogens and small insects which are dispersed rapidly by wind currents, eradication or containment is difficult, but not impossible, if detected early enough. Even if eradication or containment is considered impossible once a pest arrives, surveillance may nevertheless be conducted for such organisms to allow time to mitigate for expected impacts (for example, the deployment of resistant/tolerant tree species or clones against a pest such as the eucalypt gall insect, *Leptocybe invasa* (Nyeko *et al.*, 2009). If there is no capacity to deal with certain pests, then surveillance may be directed to other potential pests more amenable to control.

Examples of how these nine guidelines may be applied in a preliminary screening of potential target pests for the Pacific and Asia are presented in Tables 9.3 and 9.4, respectively.

Table 9.3. An example of the selection of an invasive forest pest for targeted surveillance in Fiji using the nine-step guide.

Selection criteria	Comment
1. What do we want to protect?	Fiji's mahogany plantations (*Swietenia macrophylla*), the major hardwood plantation resource totalling 50,000 ha and worth about US$200 m.
2. What exotic pests could be a threat to this resource?	The most important pests of mahogany worldwide are shoot borers *Hypsipyla* spp. which, within the pests' range, prevent the commercial growing of any of the high-value Meliaceae, including American mahoganies *Swietenia* spp., African mahoganies *Khaya* spp., cedars *Cedrela* and *Toona*, and Asian mahogany *Chukrasia*. *H. robusta* is the main pest species in Africa and the Asia-Pacific region.
3. Does the pest have the potential to be transported by trade or human movement?	The life cycle of *H. robusta* is 1–2 months, depending on climate. The moth lays its eggs on shoots, stems and leaves. Larvae burrow into new shoots and tunnel in the primary stem or branches, feeding on the pith. Pupation occurs in cocoons spun in the stem tunnels or among leaf litter and soil around the tree base. Larvae also feed on the bark, fruit and flowers of their hosts. Young plants can be infested. The pest has the potential to be transported on living host plants (family Meliaceae, mainly sub-family Swietenioidea) or via seedpods of host species.
4. Is there a pathway for the pest into the country?	The import of living plant material and seed into Fiji via international ports is regulated. Inspection of the material on arrival is likely to result in detection of the pest. Another possible pathway is via unregulated inter-island trade at a community level. The insect would be transported as eggs, larvae or pupae on living plant material or in seedpods of the host-plant species. A less likely, but possible, pathway is as a larva or pupa inside the large seed of the cannonball mangrove, *Xylocarpus granatum*, which is a host of the pest. The seeds are carried by ocean currents, can float for a month and are dispersed long distances (Smith, 1990). *H. robusta* is present in neighbouring Vanuatu, the Solomon Islands and Papua New Guinea, as well as Australia.
5. What is the likelihood of establishment?	High. Fiji has a climate suitable for the pest and host plants are distributed widely throughout its islands (Fiji has native *Xylocarpus* spp. mangroves, which are a host). The main mahogany resource is on the island of Viti Levu and there are considerable mahogany plantings within several kilometres of the principal port of Suva. The moth has high reproductive potential (a female can lay about 450 eggs over several days). The simultaneous arrival at a site of a few infested plants with late instar larvae or pupae (for example, in a consignment of nursery stock) may be sufficient to produce a mating pair of moths which could initiate establishment.
6. What is the likelihood of spread?	High. The moth is a strong flier and has impressive host-finding ability. Movement of nursery stock is also a risk.
7. What are the potential consequences of establishment?	The economic cost could be high. Forestry ranks fourth in the Fijian economy and third in foreign exchange earnings. Mahogany is a high-value timber and alternative species would not be as profitable. Line plantings as currently practised may offer some protection against the pest, but nursery stock is at risk. *Xylocarpus* mangroves are indigenous to Fiji and some ecological effects could be expected. The inability to establish new mahogany plantations would affect employment, unless an alternative species was chosen. Village plantings would also be affected, resulting in a reduction in income.
8. What is the ability to detect the pest?	A lure has been developed that will attract *H. robusta* moths and can be used in combination with static traps. The usual method of detection is by visual inspection of plants for the characteristic signs of shoot boring. Sentinel plantings can be used close to ports.
9. What is the capacity to eradicate the pest?	There is a possibility of eradication only if the pest is detected early. Once the pest is established, there are very few management options available. Enrichment or line planting in native forest such as in Fiji (and Sri Lanka) offers better prospects of a harvestable crop than open plantings.

Table 9.4. An example of the selection of an invasive forest pest for targeted surveillance in Asia using the nine-step guide.

Selection criteria	Comment
1. What do we want to protect?	*Pinus* species throughout Asia – a major plantation tree and also naturally occurring in some countries. Common species are *P. merkusii*, *P. caribaea*, *P. elliottii*, *P. massoniana*, *P. kesiya*, *P. koraiensis*, *P. roxburghii*, *P. thunbergii*, *P. yunnanensis*.
2. What exotic pests could be a threat to this resource?	There are many pest species that could be considered for surveillance by individual countries; some are exotic to the region and others (e.g. pine shoot moths and pine wilt nematode) occur in Asia but have limited distribution at present. Among pests exotic to the region, the wood wasp *S. noctilio* is a serious threat to the *Pinus* resource. It is native to Eurasia and North Africa. The female wasp lays eggs into stressed or suppressed trees, along with a phytotoxic mucus and wood decay fungus, and this combination kills the trees. It is a major pest of *Pinus*, where it has been introduced in the southern hemisphere – Australia, New Zealand, South America and South Africa – and is capable of devastating large areas of pines, causing up to 80% tree mortality.
3. Does the pest have the potential to be transported by trade or human movement?	The life cycle of the pest is approximately 1 year. Eggs are laid into the outer sapwood of standing or recently felled trees and the immature stages feed and pupate in the wood. The pest has the potential to be transported in its immature stages with *Pinus* timber, whether as a commodity or as packaging or dunnage.
4. Is there a pathway for the pest into the country?	The pest is likely to survive harvesting and milling procedures and is transported readily in pine logs and timber, as well as in solid wood packaging and dunnage. Inspection of pinewood on arrival is likely to result in detection of sirex if emergence holes and exposed tunnels of the insect are present, but otherwise would not detect immature stages in the wood. *S. noctilio* is a very common intercept in many countries, often emerging from containers in which there had been infested cargo or packaging.
5. What is the likelihood of establishment?	Analysis of the suitability of climate and hosts shows that there is a strong probability of the pest being able to establish in many parts of Asia. Container cargo and items with timber packaging are moved widely throughout most countries.
6. What is the likelihood of spread?	Adults are strong fliers capable of travelling several kilometres in search of host trees. In Australia, the annual spread of the pest is about 50 km. Human-assisted transport of infested wood is also a major factor.
7. What are the potential consequences of establishment?	Considerable timber losses can result from outbreaks of the pest. In Australia, for example, an outbreak between 1987 and 1989 killed more than 5 m *P. radiata* trees with a value of AUS$10–12 m (Haugen *et al.*, 1990). Costs of instituting control measures can be significant and there may be severe environmental impact where native pine forests are attacked.
8. What is the ability to detect the pest?	The pest may be detected by inspection of logs, timber, dunnage or wood packaging for emergence holes or exposed tunnels. Adults may be trapped using □-pinene + □-pinene as a lure. The use of 'trap trees' is another detection method whereby selected trees are injected with an herbicide to stress the trees and make them attractive to *S. noctilio*.
9. What is the capacity to eradicate the pest?	Eradication would be attempted in the early stages of an incursion, for example, destruction of infested material and inspection/destruction of infested pine trees. Should the pest become established, biocontrol measures using the nematode *Beddingia siricidicola* and parasitoids will keep damage at a level of about 1% per annum.

The process of selecting target pests for surveillance provides a focus on pathways and helps to direct efforts towards preventing the entry of invasive species. A generic rather than species-specific approach to surveillance is preferable, but having target species is nevertheless useful. For example, in focusing on *Dendroctonus* spp. bark beetles we essentially are targeting all bark beetles, since they are likely to have a similar mode of entry.

Contingency planning

Another important aspect of preparedness is contingency planning – what to do in the event of an incursion of an exotic pest and disease. As with pest lists, preparation of very detailed plans for a specific pest may well be a fruitless exercise if, as experience shows, 'unknowns' are more likely to turn up. Generic plans for 'types' of pests are favoured. Contingency planning must be backed up by adequate resources, clear lines of responsibility and appropriate legislation to allow rapid eradicative action when required.

International treaties and standards for phytosanitary measures

The International Plant Protection Convention (IPPC) is an international treaty that was adopted in 1951, revised in 1997 and is administered within the Food and Agriculture Organization of the United Nations (Haack and Petrice, 2009). As of March 2009, there were 170 countries or multi-country contracting parties to the IPPC. The Commission on Phytosanitary Measures, the governing body of the IPPC, develops and adopts International Standards for Phytosanitary Measures through a process that includes consultation with member countries. Among recent global initiatives to contain the spread of pests of forestry importance, the International Standard for Phytosanitary Measures (ISPM) 15 for regulating wood packaging material in international trade is a major advance (FAO, 2002). It requires that all such wood packaging material be either heat treated (minimum of 56°C core temperature for 30 min) or fumigated with methyl bromide. One of the shortcomings of this standard is that the treatments are aimed at killing pest organisms that reside in the wood at the time of treatment and neither treatment has any residual effect, so reinfestation is possible, especially when bark is present (ISPM 15 does not require the elimination of bark). Haack and Petrice (2009) found that Cerambycidae and Scolytinae readily infested and developed in logs with bark after heat treatment and laid eggs in all sizes of bark patches tested down to about 25 cm^2, but did not infest control or heat-treated lumber without bark. In surveys at six US ports in 2006, 9.4% of 5945 ISPM 15-marked wood packaging material items contained bark, and 1.2% of the items with bark contained live insects of quarantine significance under the bark. While the risk of introducing quarantine pests is not entirely eliminated, there is no doubt that ISPM 15 has reduced drastically the incidence of live insects in wood packaging material.

As discussed in 9.2.2 above, many forest pests have been introduced into new locations on plants for planting. The complexity of the international horticultural plant distribution chain is shown in Fig. 9.15. There are three problems with the current phytosanitary regulatory approach: (i) it relies on inspection, but the volume of world trade has expanded far beyond inspection capacity; (ii) it focuses on addressing the risks associated with known quarantine organisms, but most pests introduced on plants for planting are previously unknown or unpredictably aggressive pests; and (iii) the IPPC prohibits requiring phytosanitary measures against unregulated pests (Britton, 2007; Campbell, 2007; IUFRO, 2007). A pathway approach to plants for planting, using IPSM 15 as an example, is in development and in April 2010 a draft ISPM was circulated for member consultation.

Barrier quarantine

The terms 'barrier quarantine' or 'border operations' are used to describe a wide range

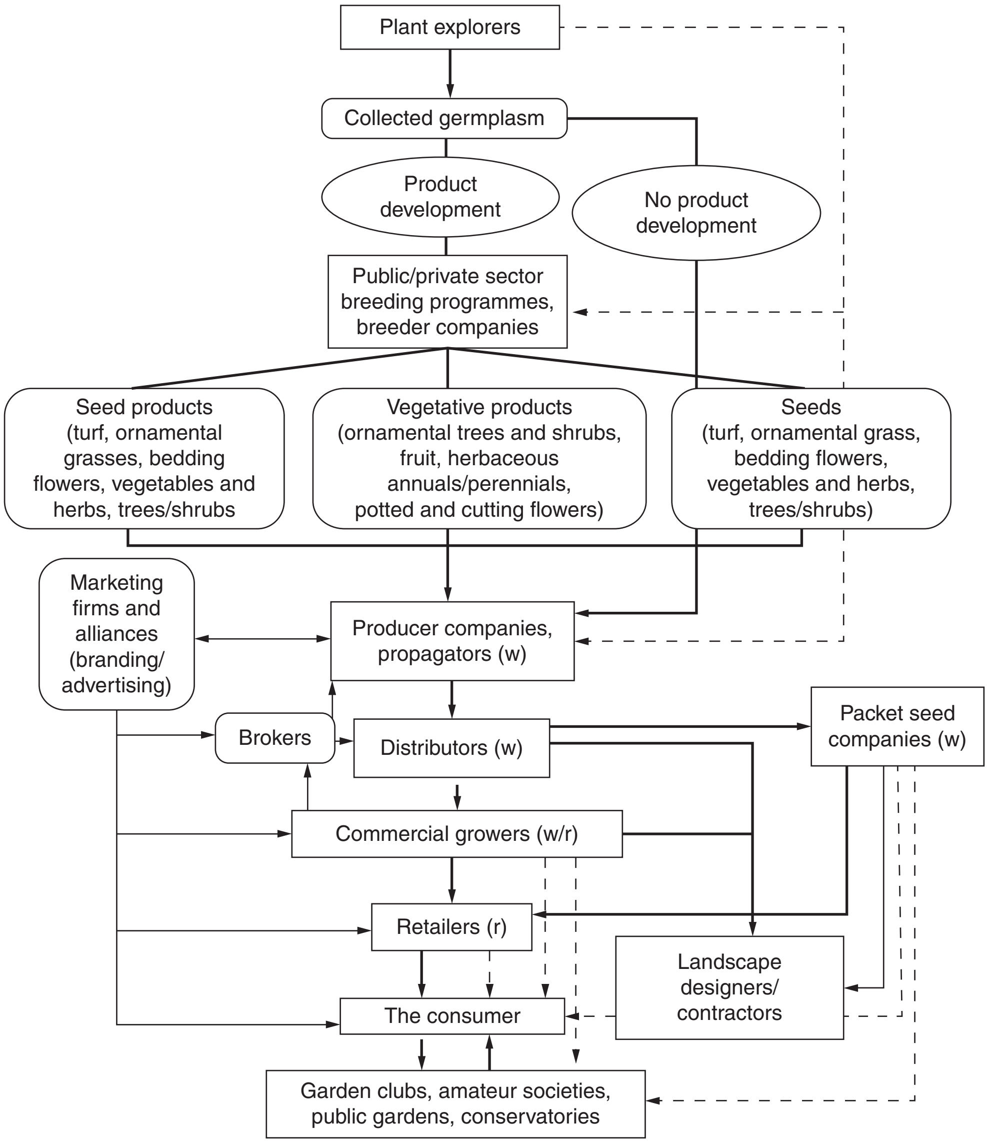

Fig. 9.15. International horticultural plant distribution chain. Key: *r* = retail; *w* = wholesale; *thick solid line* = traditional marketing conduits; *thin solid line* = information conduits; *broken line* = web-based marketing conduits (from Drew *et al.*, 2010).

of activities undertaken at airports, seaports and mail exchanges to intercept material of quarantine interest, whether introduced in accordance with quarantine procedures or as a result of illicit activity, or unintentionally. This is probably the most crucial stage of forestry quarantine, given the number of pests that can enter in lumber, wooden packaging, manufactured wooden articles and artefacts. A skilled eye is required to detect borer activity, and quarantine inspectors can benefit from specific training on forest, not just agricultural, pests. New technology is assisting in the detection of cryptic timber pests, for example, the use of odour-detection dogs and X-rays.

Interception data from national quarantine agencies are important in the development or improvement of invasion risk assessment methods, providing insight into pathways and vectors of introduction (Kenis *et al.*, 2007). For example, McCullough *et al.* (2006) summarized more than 725,000 pest interceptions recorded in the Port Information Network database maintained by the US Department of Agriculture, Animal and Plant Health Inspection Service from 1984 to 2000 to examine origins, interception sites and modes of transport of non-indigenous pests. They found that about 62% of intercepted pests were associated with baggage, 30% were associated with cargo and 7% were associated with plant propagative material. Pest interceptions occurred most commonly at airports (73%), land border crossings (13%) and marine ports (9%). Insects dominated the database, comprising 73–84% of the records annually, with Homoptera, Lepidoptera and Diptera collectively accounting for over 75% of the interception records. Haack (2001), using the same database, focused on intercepted scolytine bark beetles and showed that 73% were found in solid wood packing materials, 22% in food or plants and 5% in other or unspecified materials. The products most commonly associated with scolytine-infested wood packing materials were tiles, marble, machinery, steel parts, ironware, granite, aluminium, slate and iron. Kenis *et al.* (2007) found that the majority of introductions of alien insects in Europe were associated with the international trade in ornamental plants.

Hazard site surveillance

As outlined by Wylie *et al.* (2008), hazard site surveillance is a system for post-border detection of new pest incursions targeting sites which are considered to be potentially at high risk of such introductions. The ever increasing volumes of containerized freight and competition for space at domestic ports means that many goods are being first opened at premises some distance from the port of entry, thus dispersing risk away from the main inspection point. Hazard site surveillance acts as a backstop to border control to ensure that new incursions are detected sufficiently early to allow the full range of management options, including eradication and containment, to be considered. This is particularly important for some of the more cryptic forest pests whose presence in a forest often is not discovered until populations are already high and the pest is well established (Wardlaw *et al.*, 2008).

In setting up a hazard site surveillance programme you need to: (i) know what pests you already have; (ii) know what pests you do not want; (iii) assess the likely pathways for exotic pest entry; (iv) identify and categorize risk sites; (v) have a methodology for detection of target pests; and (vi) be able to identify what you find. All of these requirements except (iv) have already been discussed in this chapter. What constitutes a risk site for exotic forest pest incursions will vary greatly within and between different countries and cities according to such factors as trade patterns, geography, infrastructure and quarantine policy, but some generalities can be made. Self and Kay (2005), in a consultancy for the Australian Government on targeted post-border surveillance using Brisbane as an example, developed a methodology for the selection of high-hazard sites that could be used as a model. As a first step, they divided likely risk sites into four broad groupings from primary to quaternary, the primary sites being considered of highest risk. Port and international airport environs were classed as primary risk sites, and secondary risk sites included areas where containers were opened, quarantine-approved premises (QAP) and importers of raw material (timber importers). Botanic gardens, military camps and transport corridors were listed as tertiary risk sites, and forests or forest parks within city boundaries as quaternary risk sites. Primary risk sites were recommended as the first choice for trapping and inspections, and other categories could be included according to the resources available.

In determining secondary risk sites, Self and Kay (2005), with the assistance of the Australian Quarantine and Inspection Service, compiled a list of business premises involved in the importation or handling of significant volumes of high-risk items such as timber, timber packaging, wooden furniture and artefacts. Many of these sites were QAPs. Sites were assessed for risk using an arbitrary scale of 1 (low risk) to 5 (high risk) for each of five criteria, namely type of goods (likelihood of harbouring pests), volume of risk goods, cargo source (potential pest threat from country of origin and similarities of its climate and flora to that of Australia), vegetation at site (extent and type) and habitat (intensity of land development). For each site, scores for the five risk criteria were multiplied and then sites ranked according to their total score. This process aided decision making in the final selection of sites for surveillance.

Fledgling hazard site surveillance programmes have commenced in several tropical countries, e.g. Fiji, Vanuatu, Malaysia and Vietnam.

Post-entry quarantine

This is a measure to reduce further the likelihood of import of an undesirable exotic organism and is applied to high-risk products. Living plant material may be inspected on arrival and then kept in special quarantine glasshouses for several months to allow time for pest and disease symptoms to manifest themselves. Unprocessed timber may be allowed entry following barrier inspection, but there may be a requirement for subsequent inspections at the mill where the timber is being processed.

Treatment

A variety of treatments are applied worldwide for disinfestation of imported materials. Seeds are usually dusted with insecticidal powder, and living plant material is sprayed or dipped in an insecticidal solution. Fumigation is the treatment most commonly used for timber and wood products. However, care is needed in the choice of fumigant and the concentrations employed. Some fumigants are effective against the adult and larval stages of insects but do not kill the eggs; others may be effective ovicides but less successful against other stages, depending on the concentrations used. One approach to overcome this problem is to use a mixture of gas fumigants at lower dosages; for example, a low dose of methyl bromide, providing high efficacy against egg stages of forest insect pests, and sulfuryl fluoride, providing high efficacy against the other stages (Oogita *et al.*, 1998). Methyl bromide is the fumigant that has been most commonly used against timber borers and is generally very effective at the right concentrations. However, it should be noted that methyl bromide is not completely effective against borers in logs and large dimension timber when the moisture content is high. Cross (1991) has shown that it is not practical to achieve useful insecticidal doses much beyond a depth of 100 mm in 'green' (unseasoned) material using conventional tent fumigation techniques (Fig. 9.16). The use of methyl bromide is being phased out to comply with the Montreal Protocol (Barak *et al.*, 2006), although it is still the approved fumigant under ISPM 15 for wood packaging material. Other fumigants being considered under this standard are sulfuryl fluoride, phosphine and carbonyl sulfide.

Heat treatment is another measure commonly employed for disinfestation of timber. For example, coniferous sawnwood is sometimes kiln dried to eliminate possible infestations of the pinewood nematode, *Bursaphelenchus xylophilus*. This nematode is transmitted when its vector, the pine sawyer *Monochamus* spp. (Coleoptera: Cerambycidae), lays its eggs in freshly cut, felled, dying or recently dead conifers. Therefore, the nematode occasionally may be present in 'green' timber. Heat treating the timber in a kiln to a wood temperature of 56°C for 30 min is sufficient to kill all nematodes and their vector (Dwinell, 1997). This is an approved treatment for wood packaging material under ISPM 15 (FAO, 2002). A variety of other treatments are being used or tested to control wood-infesting insects, e.g. gamma radiation, X-rays, microwaves,

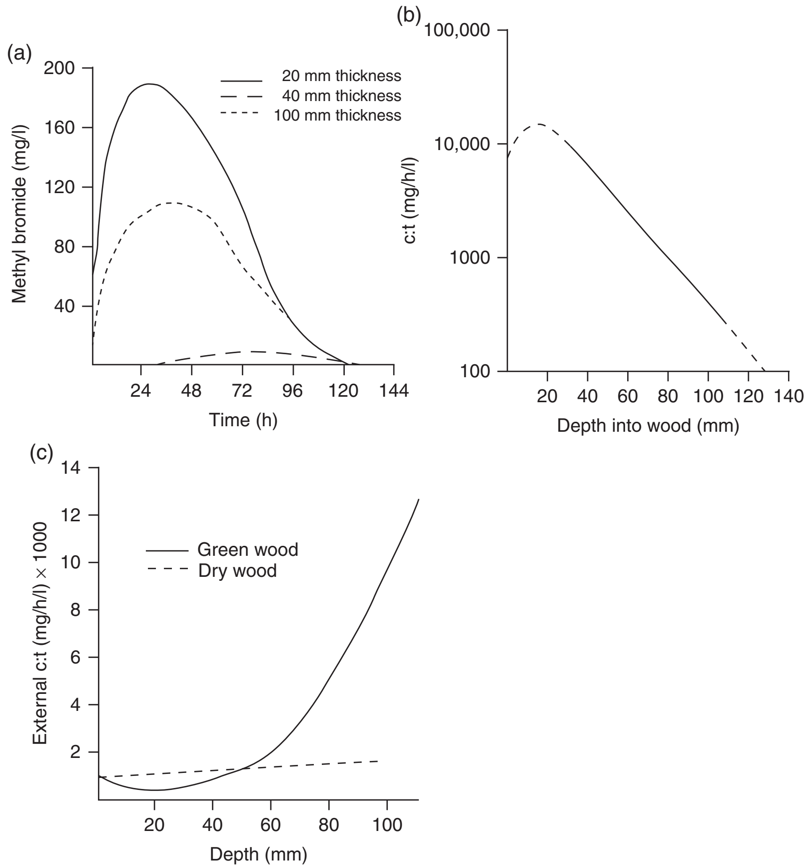

Fig. 9.16. Penetration of methyl bromide fumigant into test blocks of wood. (a) Equivalent concentration curves for the three thicknesses of test block. (b) Relationship of internal c:t (dosage = concentration × time) to external c:t held at 6224 mg/h/l. (c) c:t product to get 1000 mg/h/l at increasing depth in wood (from Cross, 1991).

infrared, electron beam treatment and chemical pressure impregnation (FAO, 2002; Fleming *et al.*, 2003). Finally, in some cases where the usual treatments are impractical or not economically justified, infested items may be destroyed (burned).

Within-country quarantine

Once an exotic pest is detected post-barrier, quarantine restrictions are usually applied immediately within country to contain its spread while eradicative options are being assessed. Even when it becomes apparent that the pest is well established and eradication is unlikely to be successful, restrictions on the movement of high-risk material may still be imposed so as not to assist the spread of the pest to other parts of the country. In Queensland, Australia, where the exotic bark beetle *I. grandicollis* became established in the south of the state in the early 1980s, quarantine zones were declared in an effort to slow the northward spread of the pest. Movement of logs with bark on, or of bark chip, out of the zone was prohibited unless the material had been fumigated. These quarantine boundaries remained in place for 27 years until 2009, when *I. grandicollis* was discovered in Townsville in north Queensland, believed to have 'hitchhiked' there with a shipment of logging equipment sent from the south of the state for a post-cyclone salvage operation.

In the West Indies, entry of all plant products into Bermuda from the islands of Grenada and Trinidad and Tobago was prohibited in 1995 following the first observation of the mealybug, *Maconellicoccus hirsutus*, in Grenada in 1994 and subsequent widespread damage to many crops including tree crops (Jones, 1995). Another example is from North America, where the exotic bark beetle, *Tomicus piniperda*, was first detected in 1992. The insect breeds in phloem of recently cut or dying pine logs, stumps and slash. Adults feed in shoots of live pines to complete maturation. Federal and state quarantines were imposed to regulate movements of pine Christmas trees, logs and nursery stock out of infested counties (McCullough and Sadof, 1998; Haack and Poland, 2001). The final example is from Central America. The Nantucket pine tip moth, *Rhyacionia frustrana*, was first recorded in Costa Rica in 1980, where it was believed to have spread from its natural range in neighbouring Nicaragua via ornamental pines. The pest established in the north and central regions of the country and a quarantine was imposed on the movement of living pine material to the southern region with the aim of preventing the introduction of the insect to Panama and South America (Ford, 1986).