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# Integrated Pest Management Principles

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## Introduction

Integrated pest management (IPM) has a variety of definitions, but its philosophy is simple. For a particular crop–pest interaction, one or more appropriate pest management tactics are combined into a package which minimizes costs and environmental impacts, whilst maximizing yields and net profits. Its two bedrock foundations are prevention and monitoring, i.e., strive to avoid pest problems at the outset, but keep a watch on the crop in case something significant goes wrong. IPM is a concept which is now widespread through all types of crop production, and it is increasingly the goal of any grower who loses yield, both quantity and quality, to damaging organisms such as weeds and nematodes, pathogens, and insects. As a practical crop protection solution, IPM is far from universal – it is often difficult, indeed sometimes impossible, to produce a viable IPM package. Problems which arise to curtail the full implementation of IPM include pest dynamics, host-plant and climate interactions, the practicalities of crop production, and very often, the socioeconomic conditions prevalent in the region of interest.

Forestry covers a very broad range of crop production tactics, from small-scale village forestry or agroforestry to huge plantations, either artificial or, at least initially, naturally occurring. Countries practicing forest management range from small, subsistence, isolated economies with little or no infrastructure to deliver education, specialist advice or spare cash to implement modern pest management protocols, to highly developed first-world countries to whom all the benefits of science and technology are theoretically available. Trees are grown from the furthest north and south temperate regions of the world to the equator, and from below sea-level to thousands of meters above sea-level. The trees themselves may be indigenous, native species growing in natural conditions to which they have evolved, or alternatively, they may be complete exotics with not even members of the family growing as natives in the locale, planted on sites which bear little or no relation to the conditions to which these trees evolved thousands of miles away. Nevertheless, many forestry practices and their associated pests and diseases have basic similarities, principles, and interactions, wherever in the world they occur.

In this section, insect pests will be discussed, but it must be borne in mind that many of the principles and indeed examples presented have a great deal of relevance to other forest pest situations, fungal diseases in particular. In fact, the modern approach to forest pest management is frequently not to target particular pests or diseases at the outset, but instead to employ the concept of general plant health and thus consider the widest range of symptoms and their underlying causes for tree decline and debilitation.

## Insect Pests and Their Impacts

It is extremely helpful to consider trees as but one part in a complex ecology which has evolved over millions of years. Other crucial members of this association are at one end of the spectrum the environment in which the tree is growing (soil, climate, altitude), and at the other end, insects and diseases which utilize the tree for food or living space (or usually both). These herbivores themselves often have their own enemies in the form of predators, parasites, and pathogens, and the forester is simply one of these competitors for the resources which the tree provides. Unfortunately, this competition is very one-sided, especially in economic terms, since foresters cannot tolerate much, if any, resource removal by others – pests and diseases have to be defeated.

Paramount in this war to defeat the competition is the concept of impact. The actual harm done to a tree by an insect is frequently very difficult to assess. Heavy leaf loss may not be extreme when averaged over the life of the tree, especially when the trees are grown for many decades, whereas boring in the

**Table 1** Pest types – defoliators

**Insect groups**
Larvae of moths (Lepidoptera) and sawflies (Hymenoptera), nymphs or larvae, and adults of grasshoppers (Orthoptera) and beetles (Coleoptera)
**Activity**
Leaves can be eaten partially or entirely, or the epidermises between the veins removed (skeletonization or leaf mining)
**Primary impact**
Main impact involves the removal of photosynthetic area, with a very wide range of deleterious effects. These include shoot, stem, and root growth loss, reductions in height and volume increment, reduction or cessation of flowering or seed set. Growth losses may be temporary, such that the tree reflushes foliage after an isolated defoliation event and growth returns to normal, or after extended and repeated bouts of defoliation, the tree dies. Actual impact losses are often impossible to quantify economically
**Secondary impact**
Tree vigor is considerably reduced and natural defenses against herbivores diminished, resulting in attacks by secondary pests such as boring Lepidoptera or Coleoptera. Trees can be killed in a short time by ring barking or girdling
**Main examples**
Teak defoliator moth, *Hyblaea puera* (India, South Asia, Southeast Asia), nun moth, *Lymantria monacha* (Eastern Europe), pine sawfly, *Neodiprion sertifer* (Western Europe)
See **Figures 1** and **2**

**Figure 1** *Hyblaea* defoliation. From Speight and Wylie (2000) *Insect Pests in Tropical Forestry*. Reproduced with permission from CABI.

shoots or wood may not be a cause for concern if the tree can still survive and produce a marketable product. In particular, if pest management tactics have a financial implication (and they usually do), then, in order to calculate a realistic cost/benefit analysis, it is crucial to have some quantitative notion

**Figure 2** Pine sawfly.

**Table 2** Pest types – sap-feeders

**Insect groups**
Nymphs and adults of bugs (Hemiptera, especially Homoptera; aphids, psyllids, scale insects, mealybugs)
**Activity**
Removal of phloem or, less commonly, xylem sap or plant cell contents using piercing mouthparts from leaves, shoots, stems, or roots. Note that sucking is a common misnomer for many sap-feeders–relatively high internal plant pressure negates the need to suck
**Primary impact**
Removal of primary production synthates and organic nitrogenous compounds from the tree and hence a significant reduction in yield resulting in the same losses as defoliation. There may also be direct loss of foliage arising from a wound reaction to injection of saliva by the feeding insect
**Secondary impact**
Local or widespread leaf mortality and loss, with same consequences as chewing defoliation. Shoot and stem feeding also causes bark necrosis and damage, allowing invasion of inner tissues by pathogens such as fungi
**Main examples**
Cypress aphid, *Cinara* spp. (South and East Africa), Leucaena psyllid, *Heteropsylla cubana* (pan-tropical), spruce aphid, *Elatobium abietinum* (Western Europe)
See **Figures 3** and **4**

**Figure 3** Leucaena psyllid.

**Figure 4** Spruce aphid. Reproduced with permission from Speight MR, Hunter MD, and Watt AD (1999) *Ecology of insects: Concepts and Applications*. Blackwell Publishing.

of how much economic damage is being done to see if control, if possible at all, is cheaper. In forest situations in particular, this knowledge is frequently lacking or at least inadequate, and many countries now have active research programs involving long-

**Table 3** Pest types – shoot-borers

| | |
|---|---|
| **Insect groups** | |
| Larvae of moths (Lepidoptera – Tortricidae, Pyralidae; shoot-borers, tip moths) and larvae and adults of beetles (Coleoptera – Scolytidae – shoot beetles) | |
| **Activity** | |
| Tunneling inside growing shoots, usually leaders followed by secondaries. Tunnels become larger and more elongated as the insect grows and develops | |
| **Primary impact** | |
| Death of attacked shoot, followed by cessation of growth in very young trees, or the new dominance of one or more secondary shoots in older saplings. Trees become distorted, bushy, and dead-headed | |
| **Secondary impact** | |
| Production of straight, non-forked logs prevented. Expected dominant height not achieved | |
| **Main examples** | |
| Mahogany shoot-borer, *Hypsipyla* spp. (pan-tropical), pine shoot moth, *Rhyacionia* spp. (Southeast Asia, North and Central America, Western Europe), pine shoot beetle, *Tomicus piniperda* (Western Europe) | |
| See **Figures 5** and **6** | |

term monitoring to provide impact data related to pest density. As might be expected, such data are only likely to be available for a minority of tree/insect associations, and then mainly in developed countries.

Insects which have evolved to utilize tree resources can be split into several distinct types. The major types are sap feeders, defoliators, bark feeders, shoot borers, bark borers, wood borers, and root feeders. The methods which they employ to exploit tree resources, and the tactics available to foresters to defeat them, vary according to their behavior and ecology. **Tables 1–7** present the main characteristics of these types of pests, together with examples of some major forest pests from each category.

## Reasons for Outbreaks

The IPM of forest insects must be considered to be a preventive technique first and foremost. For ecological, economic, technological, and social reasons, it is frequently impossible to control a pest outbreak or eradicate a damaging species even locally once the damage has begun, and so it is vital to grow trees, whether at a local agroforestry level or in an industrial plantation, in ways that reduce the probability of serious pest incidence. The first stage in this preventive strategy involves developing a sound knowledge of why insect pest outbreaks occur. Armed with this knowledge, foresters and economists can, if they choose, grow trees using methods which avoid such occurrences. Of course, it may be that a tactic which is well known to increase the likelihood of pest (and disease) problems, such as intense monocultures, is essential to sound silvicultural practice, and hence


**Figure 5** (a) Shoot moth damage. (b) Shoot moth larva.

cannot be avoided. **Table 8** considers tree health and its decline, as major predisposing factors to insect and disease outbreaks, whilst **Table 9** itemizes forest management tactics known to exacerbate pest problems for even healthy trees. Note that various items in both tables are interlinked and overlap; **Figure 15** provides a flowchart which attempts to link various aspects of tropical forestry which can result in pest problems.

Some of the factors presented in the tables will be considered in more detail here.

**Figure 6** Pine shoot beetle damage.

### Tree Species Resistance and Site Matching

Of all the predisposing or avoidable problems mentioned in these tables, two related items stand out as fundamental to promoting and preserving tree health and reducing pest or disease attack. These are: (1) tree species and site-matching (essentially environmental); and (2) the use of resistant or nonsusceptible tree species or genotypes (essentially genetic). Put simply, even if a tree which is genetically resistant to an insect or a fungus is chosen, it may still be rendered prone to attacks by planting it in a place where the soils and/or climate are unsuitable. On the other hand, if a susceptible tree species or genotype has to be used for sound economic reasons, then planting it in a habitat where its health and vigor will be optimal may enable resulting pest problems to be tolerated. The type of pest also has an influence here. Sap-feeders and stem, shoot, or bark borers seem to be particularly influenced by tree stress or lack of vigor in the host, whereas defoliators are less predictable. Defoliators may be deterred, however, if a tree genotype is basically disliked or rejected by a potential pest, irrespective of where it is planted.

**Table 4** Pest types – bark feeders

| | |
|---|---|
| **Insect groups** | Larvae of moths (Lepidoptera – Cossidae and Indarbelidae), termites (Isoptera), adult weevils (Coleoptera – Curculionidae) |
| **Activity** | Larvae or adults feed on bark material, excavating shallow tunnels which may reach to the inner layers. Broad, irregular patches of bark can be excavated. Young trees may have bark stripped completely |
| **Primary impact** | Local bark necrosis; girdling and death of young transplants in the case of weevils. Most visual activity of termites such as earthen tunnels up trees from the soil is not life-threatening; only dead bark or wounds are targeted |
| **Main examples** | Subterranean termites (e.g., *Odontotermes*) (Asia-Pacific), pine weevil, *Hylobius abietis* (Western Europe) |
| See **Figures 7** and **8** | |

**Figure 7** Termite galleries.


**Figure 8** (a) *Hylobius abietis* (b) *Hylobius* damage.

A final problem may concern long-term changes to the environment, wherein host-plant or mortality factors which normally reduce outbreaks to tolerable levels break down, rendering a crop much more difficult to grow economically. One example involves the green spruce aphid, *Elatobium abietinum*, in the UK, where the incidence of cold snaps in late winter is the only significant mechanism for checking

**Table 5** Pest types – bark-borers

**Insect groups**
Larvae and adults of beetles (Coleoptera – Scolytidae, Platypodidae, Cerambycidae, Buprestidae; bark beetles, ambrosia beetles, longhorn beetles, flathead borers)

**Activity**
Adults lay eggs on bark surface or in maternal galleries excavated in the bark at the parenchyma/sapwood surface. Larvae ramify through inner bark in usually solitary tunnels which expand as the larvae grow. Pupation occurs at the end of the tunnel or within the wood and new adults emerge through characteristically shaped holes in bark. Nonvigorous trees are more likely to be attacked

**Primary impact**
Species-specific patterns of engraving of galleries on sapwood which, if extensive, causes ringbarking (girdling of tree and hence death). Dead trees then become breeding sites for more beetles of the same or different species

**Secondary impact**
Production of large numbers of new-generation adults that may overcome defenses in even healthy trees (mass outbreak). Note that attack by secondary pests can be indicative of general tree decline and ill-health, linked to climate or site mismatches, pathogens, soil conditions, overcrowding, and so on

**Main examples**
Acacia longhorn beetle, *Xystrocera festiva* (Southeast Asia), eucalyptus longhorn, *Phoracantha semipunctata* (pan-tropical, Mediterranean), European spruce bark beetle, *Ips typographus* (continental Europe), southern pine beetle, *Dendroctonus frontalis* (USA)

See **Figures 9–11**

population upsurges. Warmer winters, for whatever climatic reason, are now allowing the pest to cause much more damage to the widely planted but genetically susceptible Sitka spruce.

One example which encompasses both environmental and genetic factors involves the eucalyptus longhorn beetle, *Phoracantha semipunctata* (Coleoptera : Cerambycidae). This species is a native of Australia, but has now spread to most parts of the tropical, semitropical, and warm temperate parts of the world where eucalyptus is grown, including Asia, Africa, southern Europe, and the USA. Adult female beetles seek out trees whose bark moisture contents are reduced – larvae cannot survive in hosts with high bark moisture. Some commercial species of eucalypt such as *Eucalyptus grandis* are known to be drought-intolerant, in that they grow poorly on dry soils and should therefore be inappropriate for planting on arid sites in low-rainfall conditions or at or near the tops of slopes, and so on. Such tree species seem to exhibit low bark moistures in general, and although they may be able to withstand attacks by *Phoracantha* in relatively high rainfall areas, in drier conditions the beetle larvae thrive under the bark, killing large numbers of trees. The logical approach to the prevention of this pest is (1) to plant *Eucalyptus* species which are naturally drought-tolerant; and (2) if drought-intolerant ones are required for silvicultural reasons, only put them on sites with moist soils in climates without a prolonged dry season.


**Figure 9** (a) *Xystrocera* larva. (b) *Xystrocera* damage.

**Figure 10** Bark beetle larvae. From Speight and Wylie (2000) *Insect Pests in Tropical Forestry*. Reproduced with permission from CABI.

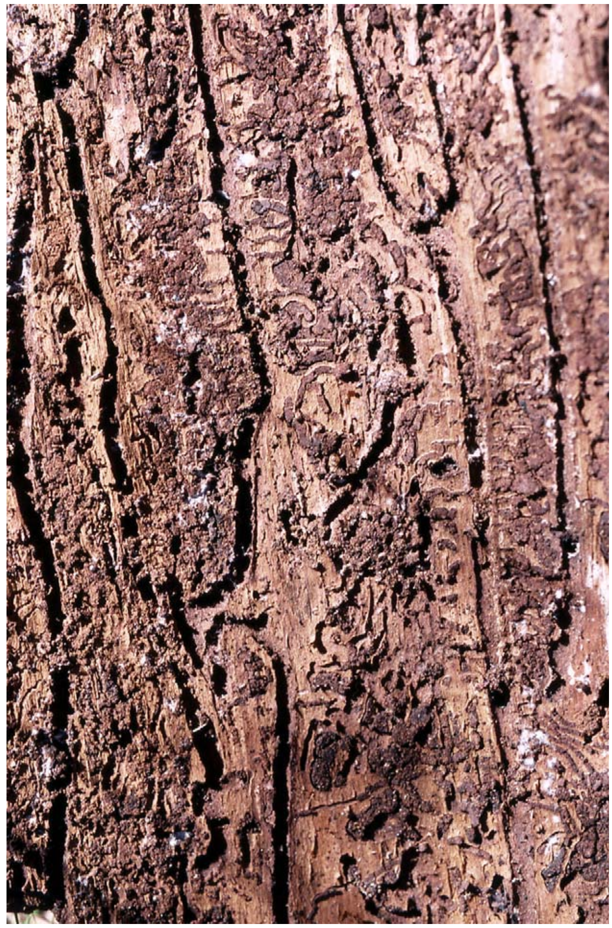

**Figure 11** *Ips* galleries.

## Pest Reservoirs

Even when relatively resistant tree genotypes are to be utilized, and the sites in which they are to be planted are essentially suitable for them, it is possible to increase pest risks. In the case of pine shoot moth outbreaks in Southeast Asia, it was clear that the most serious damage to tropical pines caused by the tunneling larvae of *Dioryctria* and *Rhyacionia* species occurred when the young plantations were established in close proximity (literally mere tens of meters) to naturally occurring stands of indigenous *Pinus* species. The latter trees were relatively lightly attacked by the pest, but the insects quickly discovered the exotic trees, which were not only more suitable but also planted in large, even-aged stands on very poor soils. The resulting damage to leading shoots caused a reduction in expected dominant height at 10 years old of 25+ m down to a non-economic 5–6 m at the same age.

Trees of the same species within the same stands can also act as pest reservoirs, especially when

**Table 6** Pest types – wood-borers

| |
|---|
| **Insect groups** |
| Larvae of moths (Lepidoptera – Hepialidae, Cossidae (goat and swift moths)), larvae of woodwasps (Hymenoptera – Siricidae); larvae of beetles (Coleoptera – Cerambycidae (longhorn beetles), Buprestidae (flathead borers)), termites (Isoptera) |
| **Activity** |
| Larvae tunnel from the outside, frequently leaving a telltale wound or exudation point on the bark surface. Tunnels extend either within the surface timber, or in the center of the heartwood |
| **Primary impact** |
| Serious degrade of timber. Note that, in most cases, the tree itself remains healthy, only the economic value is degraded. With termite attack, ingress is normally only through previous physical damage such as pruning wounds, or after primary fungal infection. Almost all woodwasp and beetle attack is secondary, following tree stress |
| **Main examples** |
| Beehole borer, *Xyleutes ceramica* (South Asia, Southeast Asia), woodwasp, *Sirex noctilio* (Europe, New Zealand, Australia), pine sawyers, *Monochamus* spp. (worldwide in temperate forests) |
| See **Figures 12** and **13** |

**Figure 12** Woodwasp.

**Figure 13** Xyleutes larvae.

outbreaks are, initially at least, localized to small pockets of damage or death. These small pockets provide new colonists which spread into the surrounding forests, causing much more widespread and serious damage. One example of this involves the mountain pine beetle, *Dendroctonus ponderosae,* in the USA and Canada. Larvae feed and grow under the bark of lodgepole pine trees; when they are sufficiently abundant, their tunneling ring barks (girdles) the host tree which dies, providing, incidentally, ideal breeding sites for a large number of secondary pests. Low-level (endemic) populations of mountain pine beetle persist in one or two stressed trees per stand until numbers build up sufficiently to

**Table 7** Pest types – root-feeders

**Insect groups**
Termites (Isoptera), larvae of beetles (Coleoptera – Scarabaeidae (white grubs or chafers), Curculionidae (vine weevils)), larvae of moths (Lepidoptera – Noctuidae (cutworms))
**Activity**
Roots of very young transplants most frequently eaten whole or have bark removed. Some tree genera such as *Eucalyptus* are more susceptible than others
**Primary impact**
Small trees wilt, die back, and die soon after planting, particular problems in forest nurseries
**Secondary impact**
Older trees may be attacked following root deformation or damage earlier in life (as in nursery handling)
**Main examples**
Subterranean termite*, Coptotermes curvignathus* (Asia-Pacific), white or curl grub, *Lepidiota* spp. (Australia), vine weevil, *Otiorhynchus sulcatus* (Europe)
See **Figure 14**

**Figure 14** Root termite damage. From Speight and Wylie (2000) *Insect Pests in Tropical Forestry*. Reproduced with the permission from CABI.

**Table 8** Reasons for insect pest outbreaks – tree health decline

| |
|---|
| Attack by a primary pest |
| Damage at nursery stage |
| Dry soil |
| Infection by a primary pathogen |
| Natural disasters (fire, drought, wind) |
| Old age |
| Overcrowding |
| Poor soil |
| Waterlogged soil |
| Wrong site/species matching |

**Table 9** Reasons for insect outbreaks – detrimental management tactics

| |
|---|
| Damage during growth (e.g., pruning or brashing) |
| Introduction of exotic pests by travel and trade |
| Mishandling in nursery |
| Monocultures |
| Planting near to pest reservoirs in older and/or natural stands |
| Poor match between tree and site/climate leading to tree stress |
| Provision of pest reservoirs in thinnings or logs |
| Underthinning |
| Use of susceptible species or genotype |

overcome the resistance of healthier, large-diameter trees in the vicinity. Outbreaks then ensue as groups of infested trees form bigger patches until most of the stand is infested and all the trees are killed.

### Handling Damage

There are various stages in the growth of a forest crop when hands-on intervention is called for. This can start in the nursery, continue into young plantations, and still be prevalent as far as harvest and beyond. For example, it is very easy to damage the roots of nursery stock by rapid and rough transplanting. Root curling is a common problem which, whilst not serious enough at the outset to prevent vigorous young trees establishing in a plantation, can lead to early root decline, secondary pest attack, and tree death, as in the case of *Acacia mangium* in Sabah. Pruning and brashing are frequently called for as the young forest grows, and untrained or careless actions can provide ideal sites for the ingress of insects such as termites, and other problems such as fungal pathogens. Later, stands need thinning to reduce competition between trees. Certainly, the maintenance of tree vigor by thinning is a significant factor in reducing susceptibility to pests, but it is important not to leave thinned timber lying within stands or even in adjacent log piles, for fear of new pests breeding and proliferating in the debris. Examples include the massive increase in bark beetles, especially the highly damaging spruce bark beetle, *Ips typographus,* in Europe after wind storms. In such cases the wind-felled trees act as breeding resources for pioneer beetles that build up to sufficient numbers to attack and kill the remaining healthy standing trees. Forest hygiene is, therefore, another form of preventive pest control. Finally, when the trees are eventually harvested, damage to remaining trees by logging or skidding damage must be avoided, and log piles must not remain for any length of time close to younger plantations. Felling only when a market is ready to receive the produce can avoid the risk of mass outbreaks of pests such as bark beetles and longhorns.

Practices which increase the risk of pest outbreaks can be avoided under the general heading of ecological (or silvicultural) control, which is summarized in **Figure 16**.

## Interventionist Management Tactics

Prevention is thus much better than cure, but is unfortunately not entirely dependable. As mentioned above, defoliators in particular are less influenced by attempts to grow the healthiest trees, and various ‘risky’ strategies such as growing monocultures of exotic tree species on poor soils may be unavoidable logistically and economically. Appropriate management tactics differ for different types of insect pest, and actual ‘hands-on’ control of insects and indeed diseases is often not a viable option. However, recourse may be made to more interventionist tactics if available. These may either be in the form of longer-term, semipermanent control using natural enemies of pests in biological control, or the short sharp tactic of employing various types of pesticides, biological or chemical, in response to an acute outbreak.

### Inspection and Quarantine

Almost all countries in the world take part in some form of trade in trees, timber, and/or wood products. The movement of such material from one region of the world to another, especially across international borders, is an ideal way of spreading forest pests. There are classic examples of forest pests being introduced deliberately into new countries, such as the gypsy moth, *Lymantria dispar*, into the USA from Europe in the 1880s to form a new silk industry, but **Table 10** shows some examples of pests introduced by accident. Hence, a vital part of IPM for forest insect pests these days is a routine but efficient system of inspection at docks and harbors to prevent such imports, to quarantine infested material, and to seek out and destroy imports already arrived and potentially dangerous.

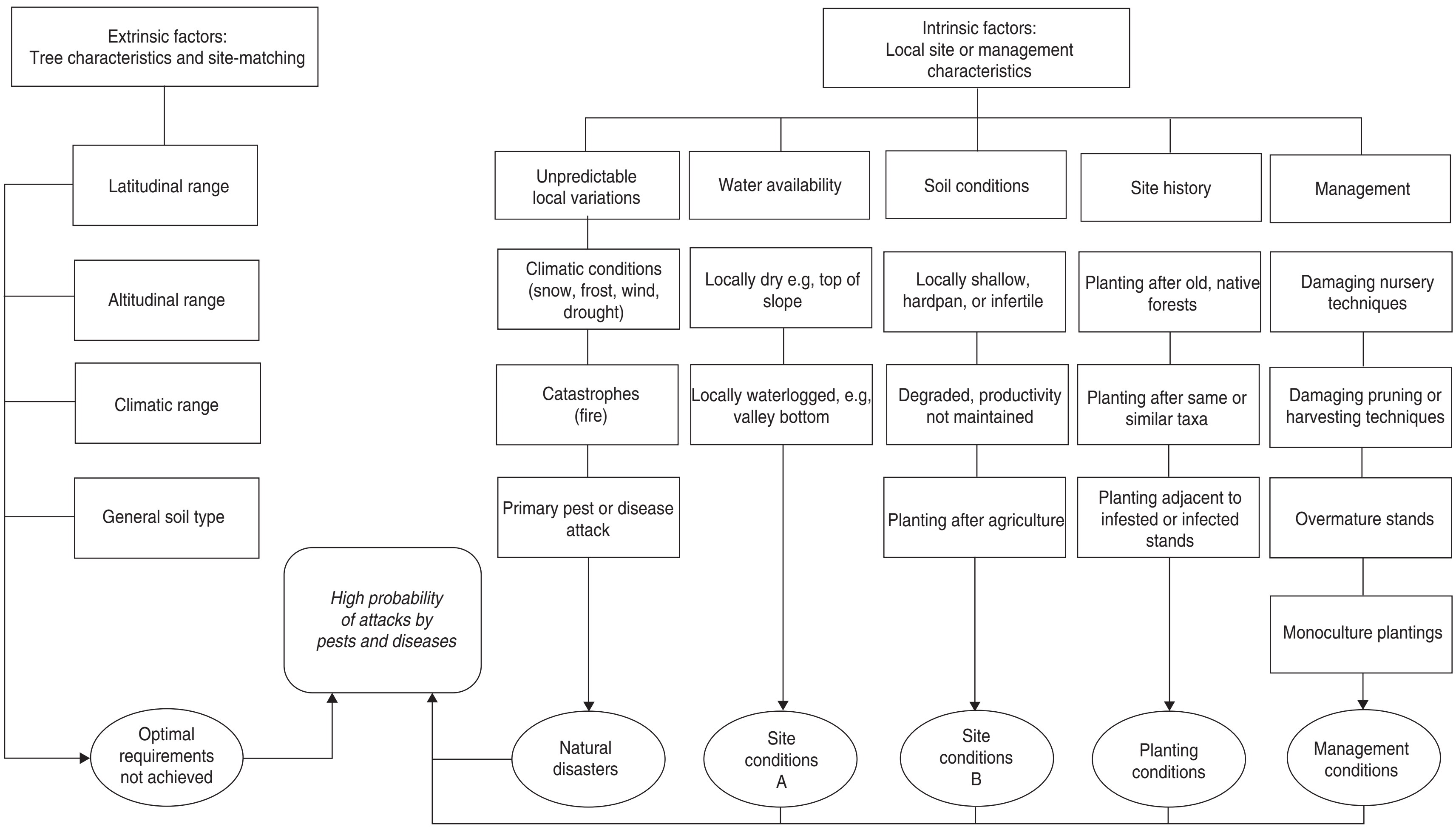


**Figure 15** Factors which increase the risk of trees being attacked by pests and diseases.

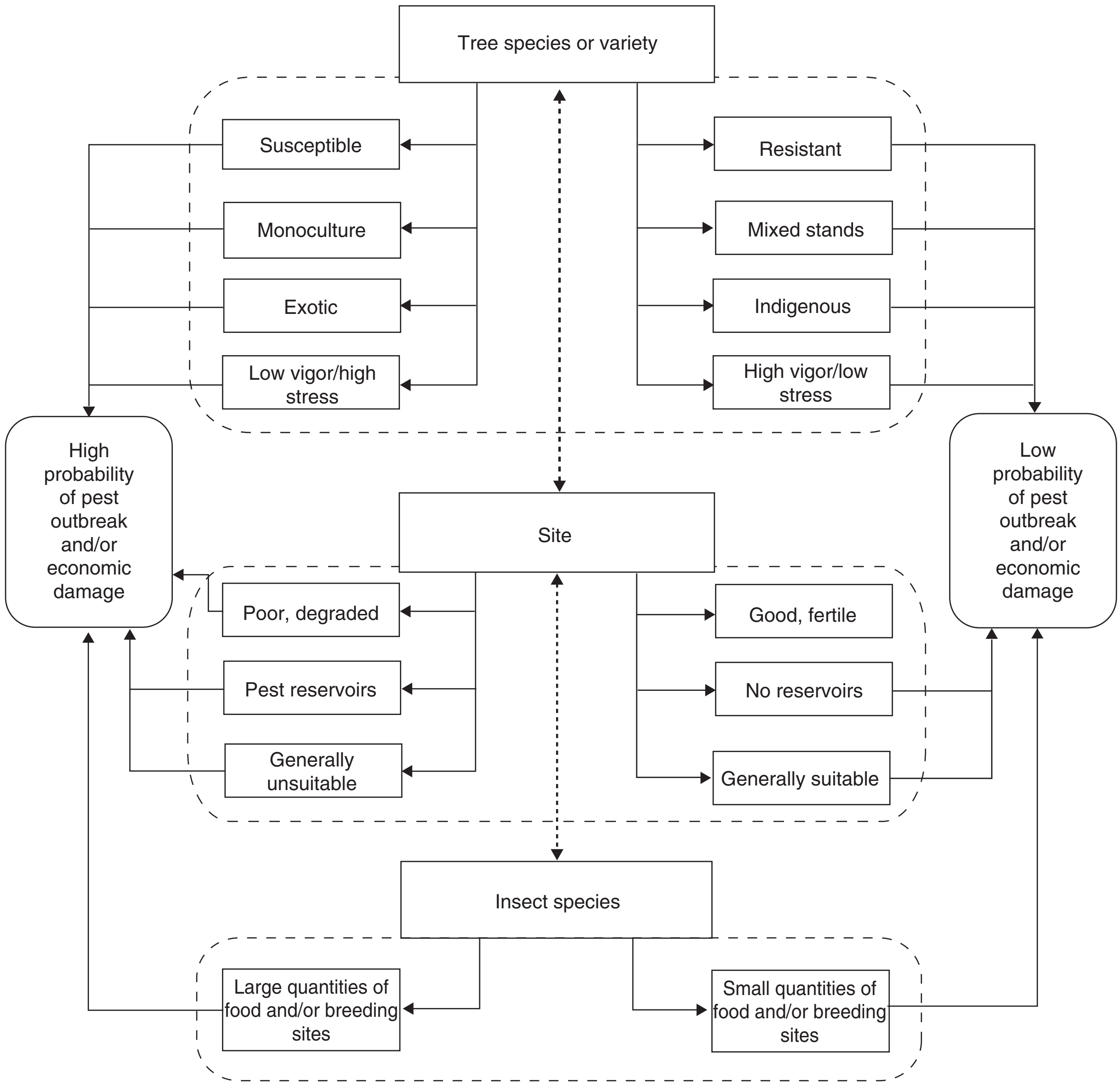


**Figure 16** General flowchart depicting the 'rights and wrongs' of ecological control.

**Table 10** Examples of forest pests introduced from one country to another

| *Pest* | *From* | *To* | *Method* |
|---|---|---|---|
| Gypsy moth (*Lymantria dispar*) | Europe | USA | Egg masses on wheels and chassis of returning army trucks |
| Bark beetles (Scolytidae) | South Africa | St Helena | Bark beetles in the timber of food packing cases |
| Asian longhorn beetle (*Anoplophora glabripennis*) | Asia | USA | Larvae carried in solid wood palettes and crates |
| Spruce bark beetle (*Ips typographus*) | Continental Europe | UK | Adults in packing, bark, debris, 'wainy edge' on saw timber |
| Termites (Isoptera) | Asia | New Zealand | In processed timber products such as chopsticks |
| Pine woolly aphid (*Pineus pini*) | Australia | South Africa | On imported pine seedlings |
| Eucalyptus snout weevil (*Gonipterus scutellatus*) | Australia | USA | Aircraft stowaways |
| European pine woodwasp (*Sirex noctilio*) | Europe | Australia | Larvae inside miscellaneous wood and timber material |

## Biological Control

In theory, the use of natural enemies of forest insect pests to regulate their numbers below a level where damage is economically important is a very useful strategy. Predators such as birds, small mammals, and especially other insects seem to consume large numbers of lepidopteran larvae or aphids, whilst more host species-specific parasites (parasitoids) in the insect orders Hymenoptera and Diptera can reduce the densities of pests considerably. The problem, however is that in many cases this reduction in percentage mortality is insufficient either to prevent significant damage or to reduce existing outbreaks sufficiently. Put very simply, the reasons behind the outbreak where clearly the pest is being very successful for one reason or another tend to outweigh the ability of the enemies to make serious inroads into the pest population until most of the pest's food, such as foliage, has disappeared. By then, of course, it is too late for pest management to prevent significant losses. In the case of forestry, unlike many situations in agriculture and horticulture, there are relatively few pest management success stories for biological control using predators or parasitoids of insect pests. Major limitations include the sheer size of forest stands, the fact that many pests are concealed in bark wood or soil, and that many forest pest outbreaks occur because the odds are stacked in favor of the pests, as indicated earlier. However, **Table 11** shows some examples where at least partial success has been achieved.

Biological control in forest pest management has a better track record when considering the potential of insect pathogens. Bacteria, nematodes, viruses, and fungi have all been shown to have real success in pest management in other types of crop production, and for certain groups of forest pests, the defoliators in particular and possibly some of the shoot-borers and stem-feeders, pathogens show promise. **Table 12** summarizes the various types of pathogen, and shows how they are or may be employed. The most widespread pathogen at the moment is *Bacillus thuringiensis*, which is used in much the same way as a conventional insecticide. Major forest areas in North America, for example, are routinely sprayed from aircraft with *B. thuringiensis*, targeting pests such as gypsy moth, *Lymantria dispar,* and, in particular, spruce budworm, *Choristoneura fumiferana*. For the future, nematodes are showing a great deal of promise for the control of pests such as root

**Table 11** Insect enemies as biological control agents in forestry

| *Enemy type* | *Pest insect* | *Country* | *Biological control* |
|---|---|---|---|
| Predator | Great spruce bark beetle (*Dendroctonus micans*) | UK | Specific predatory beetle, *Rhizophagus grandis*, introduced from continental Europe; success in 5–10 years |
| Predators and parasitoids | Golden mealybug (*Nipaecoccus aurilanatus*) | Australia | Severe damage to hoop, bunya, and kauri pines reduced by a combination of 10 or so indigenous natural enemies |
| Parasitoid | Web-spinning larch sawfly (*Cephalcia lariciphila*) | UK | Fortuitous appearance of *Olesicampe monticola* in UK; success in 3–5 years |
| Parasitoid | Cypress aphid (*Cinara* spp.) | East Africa | *Pauesia juniperorum* released and dispersed over large areas of Kenya and Malawi; significant reductions in pest damage predicted |

**Table 12** Insect pathogens as pest control agents

| *Pathogen* | *Pests* | *Limitations* |
|---|---|---|
| Fungi, e.g., *Metarhizium*, *Beauveria Entomophthora* | Pine shoot-borers, termites, white grubs (scarab larvae), defoliating Lepidoptera | Moist conditions required; concealed pests may not encounter spores |
| Bacteria, e.g., *Bacillus thuringiensis* | Defoliating Lepidoptera, some Coleoptera | Bacterial toxins must be ingested (eaten); some commercial formulations are relatively expensive; nonpersistent; no proliferation in environment; application problems |
| Nematodes, e.g., *Steinernema*, *Heterorhabditis*, *Deladenus* | Root- and stem-feeding weevils; woodwasps | Relatively slow to contact pest larvae under bark; bulk production and application problems |
| Viruses, e.g., nucleopolyhedroviruses (NPVs) | Defoliating Lepidoptera and sawflies (Hymenoptera) | Viruses must be ingested (eaten); host-specificity means cross-infectivity unlikely; application problems; time lag before killing pests |

and collar weevils, and great potential has been shown in the use of viruses. The nucleopolyhedrovirus (NPV) of the teak defoliator moth, *Hyblaea puera,* in southern India is the best example so far of pathogens in the control of tropical forest pests. NPVs are usually extremely species-specific, have enormous multiplication rates, and can persist in a stable forest environment for long periods of time. The remaining problems to their commercial adoption center around their production prior to application, the efficient timing and application of the pathogens, and the ability to respond rapidly to new and geographically isolated pest outbreaks.

### Chemical Control

There are basically two types of chemicals with potential in the management of insect pests in forestry; insecticides and pheromones.

It is simplest to state that the use of insecticides in all but a very small minority of cases of forest pest problems is impossible, for economic, technological, and environmental reasons. The only occasions when they may be useful are in the nursery, or just at planting out when they may be used as dips or soil granules on occasion to protect young transplants from root- or stem-feeding insects such as termites, grasshoppers, or weevils. In a nursery, the major dilemma of a manager is when not to spray. It is very tempting to take action at the first sign of an insect or fungus in a forest nursery, especially if the person involved is responsible to a higher authority for the production of large numbers of healthy transplants. Caution has to be advised. Most observations of defoliation in a nursery are ephemeral and localized. In the vast majority of cases, a strategy of doing nothing will undoubtedly save money and reduce pollution of everything from silk farms to fish farms. However, more confidence can be gained by effective monitoring against known economic injury levels defined by a threshold population size for a given sampling effort.

The chemical treatment of growing plantations is extremely problematic, and only in the most severe cases should spraying be contemplated, even when the most advanced technological standards are available. These days, the whole concept of interventionist IPM is based on monitoring and prediction, so that if aerial applications of pesticides are called for, they are over a very small area with specific targets and timing. The technology for application is vital, ideally using atomizers producing optimal droplet sizes in a spray cloud (controlled droplet application: CDA) and hence minimizing the volume of chemical used (ultralow-volume: ULV). Most important is the type of insecticidal compound employed. Many developed countries have ever more stringent legislation preventing the use of older insecticides which have been employed effectively for generations, and those which remain tend, for political more than ecological reasons, to be the most specific and environmentally 'friendly.' Hence in Europe, for example, one of the most widely used insecticides for the control of defoliating Lepidoptera is diflubenzuron (Dimilin), not a poison at all, but instead a chemical which kills insects by interfering with chitin formation and thus effectively prevents larval pests molting to the next lifestage. This increases the relative specificity because it is only those organisms with chitin (invertebrates, mainly insects) that could possibly be susceptible.

Pheromones are used extensively for monitoring insect pest populations, but they have also had limited success in a technique known as mating disruption or confusion. In this technique, synthetic analogs of species-specific sex-attractant pheromones are uniformly released over large areas of forest from various types of dispenser. Male moths attempting to locate the point-source attractiveness of females lose the ability to find mates, resulting in far fewer eggs laid and hence significantly reduced pest populations. Field trials show that even shoot-dwellers, such as the pine shoot-borer *Eucosma sononama*, can be effectively controlled, and the potential for the technique for other more serious borers such as pine shoot moths (*Rhyacionia* spp.) and mahogany shoot-borers (*Hypsipyla* spp.) needs to be investigated.

**Table 13** Monitoring systems for forest insect pests

| *Pest* | *Country* | *Monitoring technique* |
|---|---|---|
| Pine looper moth (*Bupalus piniaria*) | UK | Count pupae in soil under canopies in winter to determine high-risk sites; eggs counted only in these sites in early summer |
| Five-spined bark beetle (*Ips grandicollis*) | Australia | Pheromone traps baited with synthetic pheromones to determine spread and arrival in new areas |
| Southern pine beetle (*Dendroctonus frontalis*) | USA | Aerial surveys to detect browning leaves in canopies, mid to late summer |
| Douglas fir tussock moth (*Orgyia pseudotsugae*) | USA | Pheromone delta traps catch male adults, known relationship between number of males in traps and later larval densities |
| Nun moth (*Lymantria monacha*) | Eastern Europe | Pheromone traps to determine the period of peak flight, monitor incidence of swarming moths during the period (walk-and-watch method) |

### Monitoring and Prediction

Using the appropriate chemical or biological tactic in the right place at the right time without wasting labor and money, whilst still achieving successful control, is an IPM juggling act. Perhaps the most fundamental feature of IPM compared with conventional pest management tactics is the reliance on some form of monitoring procedure to tell the forester whether or not he or she can expect to have a pest problem in the future. Hence the luxury of IPM is the decision to take no action, safe in the knowledge that nothing economically serious is going to happen. It is crucial to note that no monitoring system can be regarded as reliable without impact assessments, risk or hazard ratings, and a knowledge of threshold densities (numbers of the lifestage counted above which significant pest damage can be expected). Various techniques, some more laborious than others, are used in forestry as monitoring systems, and **Table 13** shows some examples.

## Conclusions

An IPM 'toolbox' may be imagined which contains all the elements of pest management discussed above. These include preventive systems such as site choice and species matching, as well as interventionist tactics such as chemical and biological control. Underpinning these tactics is a sound and reliable monitoring system with which management decisions can be made. Clearly, not all specific forest pest situations will require each of these tactics, and so the 'toolbox' concept can be applied whereby the various components appropriate to a particular problem (and its solution) can be used, leaving the rest for a different scenario.

*See also*: **Entomology**: Bark Beetles; Defoliators; Foliage Feeders in Temperate and Boreal Forests; Population Dynamics of Forest Insects; Sapsuckers. **Health and Protection**: Integrated Pest Management Practices. **Pathology**: Insect Associated Tree Diseases.

## Further Reading

Speight MR, Hunter MD, and Watt AD (1999) *Ecology of Insects: Concepts and Applications*. Oxford, UK: Blackwell.

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# Integrated Pest Management Practices

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## Introduction

The principles of integrated pest management (IPM) (*see* **Health and Protection**: Integrated Pest Management Principles) require a comprehensive knowledge of the reasons for pest outbreaks and, further, an understanding of which processes can be manipulated to reduce the severity of any outbreaks. While the concepts of IPM are intuitively sound, the practical implementation of those concepts to reach a successful conclusion is not always so easily achieved. In fact, case studies to illustrate IPM successes in forestry are relatively few if a strict definition of 'integrated' is adopted, such that there is a requirement for a multifaceted approach across a range of disciplines. In reality, although there are multiple variables to contend with, management will tend to rely on one or two key elements to achieve pest reduction.

This article deals with case studies that have been selected to illustrate the principles of IPM in practice and also to illustrate how those principles are applicable in both temperate and tropical forest systems. In providing these case studies, it is clear that not all groups of insect pests can be included and, therefore, some emphasis is based initially on discussion of management tactics in a wider sense, followed by the specific case studies.

## Options in Integrated Pest Management

Traditional pest management tends to rely on one or, occasionally, a low number of options for reducing the damage caused by a particular organism. Choices are driven by the economic threshold that can be tolerated and by how quickly the pest population must be reduced below the economic threshold. In some cases, there is little choice but to use direct intervention methods based on chemical pesticides and this is an option within an IPM strategy. However, the key advantage of IPM is assessment of a range of options and the choice of a combination of these to achieve pest reduction. IPM therefore requires a disciplined approach to decision making, taking account of the individual and combined effects of a range of options. Ideally, the choices will also be dynamic in that the strategies employed will change and evolve with the changing densities of the target pest. **Figure 1** illustrates a range of the steps required to develop IPM in forestry and distinguishes two complementary approaches to management, namely prevention and cure.

Although the actions involved in achieving these ends may be similar, the ultimate aim will be to develop prevention so that long-term, sustainable population management can be achieved. In reality, there is usually a balance between prevention and