Insects & Pathogens

Regulators of Forest Ecosystems

By Robert A. Haack and James W. Byler

John H. Hart

A red-naped sapsucker feeds its young in a cavity constructed in a living trembling aspen infected with wood-decay fungi. A new cavity was built in this tree each year from 1986 through 1990 (it fell in 1991).

Today's forest managers are challenged by issues such as soil productivity, biodiversity, threatened and endangered species, and ecosystem sustainability; and ecosystem management has been proposed as a way to deal with them. The Society of American Foresters (1993) defines this term as keeping forest ecosystems functioning well over long periods of time in order to provide resilience to short-term stress and adaptation to long-term change.

Although the vast majority of insects and microbes are beneficial, the public often views them as pests and of little significance. However, in an ecosystem perspective their contributions are critical to forest diversity, soil fertility, and long-term forest health and sustainability, so managers must consider both the beneficial and detrimental functions of forest insects and microbes (Schowalter 1991). This article will concentrate on insects and microbes that have traditionally been called pests; the term pathogen will primarily refer to disease-

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causing fungi and the mistletoes.

An ecosystem management approach to insect and disease management is not new. Largely in response to pesticide concerns of the 1960s, an integrated approach to pest management (IPM) was developed based on a strong ecosystem framework. However, IPM generally did not consider the beneficial roles of insects and pathogens. The focus has shifted in recent years from pest-related losses (primarily of timber) to a more holistic consideration of insect and pathogen effects on forest health (USDA Forest Service 1988, 1993).

One definition of forest health is the ability of a forest to recover from natural or human-caused stressors (USDA Forest Service 1992b). This definition allows epidemics in healthy forests and emphasizes forest resiliency. Ecosystem management thus must reevaluate approaches to managing forest insects and pathogens and consider more fully their effects on forest ecosystem sustainability.


Eileen Van Tassell

An ecosystem perspective requires that strategies to maintain forest health consider the beneficial as well as the detrimental effects of insects and microbes. Here, a ladybird beetle feeds on the eggs of the cottonwood leaf beetle.

Forest Health

Insects and pathogens cause tree mortality and growth loss on millions of acres of forestlands each year *(table 1)*. Several USDA Forest Service reports have consistently shown that insects and pathogens cause more losses than any other damaging agent, including fire. But allocating losses to a single agent is questionable because insects and pathogens often interact with each other (Schowalter and Filip 1993), as well as with climate and fire (Mattson and Haack 1987, Monnig and Byler 1992, Wickman 1992).

Epidemics of forest insects and pathogens have always occurred. However, past management practices and introductions of exotic organisms have probably increased the frequency, intensity, and extent of many outbreaks. Such practices include planting off-site, harvesting beyond historic rotation ages of a given species, planting susceptible varieties, establishing extensive monocultures, not moving diseased overstory trees during harvest, and suppressing fire (Wickman 1992, USDA Forest Service 1993).

Exotic insects and pathogens have dramatically altered forest ecosystem diversity, function, and productivity. More than 20 exotic fungal pathogens and 360 exotic insects now attack woody trees and shrubs in North America (pers. commun., W.I. Mattson and I. Millers, USDA Forest Service, 1993), and several have had devastating and lasting effects. For example, the chestnut blight fungus has virtually eliminated American chestnut since its introduction around 1904. Likewise, millions of susceptible five-needle pines have been eliminated in North America since the white pine blister rust fungus was introduced around 1906, and the rust continues to spread and intensify. The elm resource has been devastated by introduction of the Dutch elm disease fungus and its bark beetle vector in about 1930. A recent introduction, the Eurasian poplar leaf rust fungus, was found on the West Coast in 1992.

The gypsy moth is probably the most notorious of the many exotic forest insects in North America. Since its introduction in 1869 in Massachusetts, it has become established in 16 eastern states and defoliates millions of acres of hardwood forests annually. The beech scale, introduced around 1890, works with various *Nectria* fungi to cause beech bark disease (Manion 1981), resulting in widespread mortality in much of the Northeast and adjacent Canada. Two recent discoveries include the Asian form of the gypsy moth in 1991 in the Pacific Northwest, and the larger European

Table 1. Average annual acreage of US commercial forests affected by major insects and pathogens, 1979–83.

Insect or pathogen	Millions of acres	Native or exotic	Region affected
Dwarf mistletoes	22.6	Native	Western states
Root pathogens	16.8	Native	Primarily western states
Fusiform rust	15.3	Native	Southeastern states
Southern pine beetle	9.3	Native	Southeastern states
Western spruce budworm	6.8	Native	Western states
Gypsy moth	5.8	Exotic	Northeastern and Great Lakes states
Eastern spruce budworm	5.7	Native	Northeastern and Great Lakes states
Mountain pine beetle	4.3	Native	Western states

SOURCE: USDA Forest Service 1988.

pine-shoot beetle in 1992 in the Great Lakes region.

Environmental stresses—drought, air pollution, late spring frosts, windthrow—often set the stage for epidemics (Manion 1981, Mattson and Haack 1987). The widespread droughts of the late 1980s and early 1990s preceded various insect and pathogen attacks and consequent regional declines in ash, birch, pine, and oak in the East and Douglas-fir, fir, and pine in the West (USDA Forest Service 1992a, 1992b).

Forest Succession

Tree death is a natural event as overmature, weakened, or susceptible trees are preferentially attacked by certain insects and pathogens. Bark beetles, inner-bark borers, and root-pathogenic fungi are the primary tree killers. Because these organisms tend to specialize in one particular species or genus of trees, they strongly control the rate and direction of succession (Edmonds and Sollins 1974, Schowalter et al. 1986, Franklin et al. 1987). For example, native root-pathogenic fungi selectively killed Douglas-fir and grand fir and thereby aided the development of pure or nearly pure stands of western white pine (Byler et al., in press).

Shade-tolerant species in the understory quickly grow into the gaps created by the selective killing of overstory trees. The gaps that form from tree death often allow increased plant and animal diversity (Schowalter 1991). However, widespread damage from exotic organisms and human actions has resulted in forests far different in stand structure and composition than what would have resulted from native processes (Manion 1981, USDA Forest Service 1993). By selectively affecting tree growth and mortality rates, insects and pathogens alter forest composition, structure, and succession.

At times, insects and pathogens can slow the process of succession. The mountain pine beetle, for example, has this effect in "persistent" and "climax" lodgepole pine stands in the West. Because of the beetle's preference for killing older trees, it produces uneven-age stands of lodgepole that, in the absence of fire, tend to perpetuate on a particular site (Amman 1977).

Selective killing of susceptible trees tends to increase overall stand fitness and resistance (Burdon 1991). Through this process of natural selection, most native insects and pathogens reach a dynamic state of equilibrium with their hosts and natural enemies. However, this situation may not be true for decline diseases, nor for newly introduced exotic insects and pathogens.

Carbon and Nutrient Cycling

Although insects and pathogens can cause tree damage and mortality, they also make positive contributions to the forest environment. Insects and other invertebrates, and pathogens and other microbes contribute significantly to biomass decomposition, carbon cycling, nutrient cycling, and energy flow in forest ecosystems and are thus pivotal to maintaining soil fertility and long-term forest health. They are the primary regulators of nutrient and energy flow in several critical ecosystem processes.

Defoliation accelerates litterfall as well as nutrient leaching from damaged foliage. Also, insect feces decompose faster than do fallen leaves and needles, which leads to faster cycling of elements such as calcium, potassium, nitrogen, and phosphorus (Schowalter et al. 1986). These nutrients often become available for tree growth. Studies by Alfaro and MacDonald (1988) and Wickman (1980) indicated that tree growth initially decreased after defoliation then increased over the next one to three decades, possibly due to changes in soil nutrient levels or a thinning effect. Such examples demonstrate the danger of prematurely judging the effects of defoliators on tree growth.

Many insects and pathogens initiate carbon and nutrient cycling of woody tissue (Seastedt and Crossley 1984, Kile et al. 1991). The decay process of logs involves a succession of invertebrates and microbes (Haack and Slansky 1987). Bark- and wood-boring insects tunnel throughout the woody tissues, often inoculating them with decay fungi and bacteria. Microbes are the principal degraders of cellulose, hemicellulose, and lignin (Edmonds and Sollins 1974, Harvey et al., in press).

A Food Source

Insects, microbes, and tree-pathogenic plants serve as food for many invertebrates and vertebrates (Martin et al. 1951, Swan 1964). Thousands of predatory and parasitic insects feed entirely on other insects; several are used in biological control programs against tree-feeding insects. Likewise, the chief prey of spiders are insects, including several defoliators. Many mites feed on plant-eating invertebrates, with some specializing on immature stages of bark beetles.

Of the vertebrates, birds probably consume the most tree-feeding insects. Some catch insects on the wing, others feed in the canopies, some work the bark, and others feed on the ground. Woodpeckers are the most important predator of bark and wood-infesting insects (Dickson et al. 1979). Most mammals, large and small, consume insects to some degree. Because of its voracious appetite for insects, the masked shrew was intentionally introduced in Newfoundland to control larch sawfly, a defoliating insect that overwinters on the ground (Swan 1964).

Various birds and mammals consume the fruit of tree-parasitic true mistletoes and dwarf mistletoes (Kuijt 1969). Fungal fruiting bodies—including mushrooms of many mycorrhizal fungi—nourish shrews, squirrels, pocket gophers, mice, and voles (Maser et al. 1978). The fungal spores pass through these mammals and are thereby spread throughout the forest. Humans also consume many species of mushrooms, both mycorrhizal and tree-pathogenic.

Creating Wildlife Habitat

Insects and microbes create wildlife habitat primarily by killing trees that either remain standing (snags) or fall to the ground or in water; and by decomposing wood, which allows easier access by vertebrates. Many vertebrates use deadwood to roost, nest, or forage—including at least 270 species of North American reptiles and amphibians, 120 species of birds, and 140 species of mammals (Ackerman 1993).

Wildlife needs for plant communities, successional stages, and forest edges are all affected by the activities of insects and pathogens (Thomas 1979). Pathogens can even be important in living trees. For example, the endangered red-cockaded woodpecker constructs its nesting cavity in living southern pines, preferring trees with heartrot (Walters 1991). Likewise, according to Irwin et al. (1989), about half of the nesting sites of the endangered northern spotted owl are in dwarf mistletoe broom.

Integrated Pest Management: A Window of Opportunity

Forest ecosystems are exposed to myriad biotic and abiotic stresses that sometimes alter normal ecosystem processes and cause major change. Diseases, both biotic and abiotic, and insects, individually and in concert, influence forest ecosystem dynamics—not only as pests and agents of stress, but also as beneficial agents in the natural processes of forest succession and sustainability. Yet we still don't know the answer to the question, "Are disease organisms and insect pests the cause or the effect of changing forest health?"

Although insects and microbes at times regulate forests because they selectively attack overmature and weakened trees, many forest defoliators (gypsy moth, Douglas-fir tussock moth, spruce budworms), are not at all selective and cause a range of diverse effects on a specific environment.

This was most obvious during the gypsy moth outbreak in the early 1980s, when 12.8 million forested acres were defoliated in a single year (1981). The impact extended beyond tree mortality of hardwoods and conifers to include human health (allergic reaction to gypsy moth larvae), the water quality of watersheds, wildlife food sources, and public use of denuded parks and forests. At least in the case of the gypsy moth, the problem was exacerbated more by lack of management of extensive oak forests than by poor management practices.

I believe most natural resource specialists support the USDA Forest Service's commitment to an ecological approach to managing the national forests and grasslands. Entomologists and pathologists active within the forestry profession should perceive this "ecosystem management" approach as both a welcome return to the basics and an opportunity for the rebirth of their respective specialties. During the past three decades, the professions of forest entomology and pathology have been deemphasized in both federal land management agencies and academia. In many cases, this was preceded by a deemphasis in forest protection in forestry and natural resource curricula. For example, forest entomologists who attended a special session on "Integrated Pest Management (IPM) of Forest Insects" at the 1978 joint convention of the Society of American Foresters and the Canadian Institute of Forestry found themselves talking to each other. Forest managers, the targeted audience, did not attend.

Since that meeting, IPM has made substantially greater strides in agriculture than in forestry. The agricultural community has renewed its commitment to biological control as an important part of IPM. Biocontrol espouses the use of parasites, predators, and disease organisms to mitigate the damaging effects of insects and weeds. Its techniques promote sustainability because they are either self-perpetuating or, because of their specificity, much less disruptive to nontarget organisms than chemical pesticides. This specificity promotes the maintenance of diversity in the environment and contributes to overall community stability.

However, biological control agents alone will not be sufficient to maintain episodic forest pests below population densities that cause defoliation. We aspire to an IPM strategy that either reduces the amplitude of outbreaks or lengthens the time period between outbreaks. When forest resources in highly sensitive habitats must be protected, forest managers can turn to microbial pesticides. The development and improvement of microbial pesticides (which contain bacteria, viruses, fungi, or protozoa) have accelerated recently because the US Environmental Protection Agency has streamlined the guidelines for registering these products.

IPM needs to be an integral component of forest resource management—biological control and microbial biological control tactics have been underused in forest protection and should be encouraged to promote forest health and facilitate ecosystem management of our forests. This provides a window of opportunity for entomologists, pathologists, and ecologists to join with resource specialists in initiating research studies to better understand the complex interactions among disease organisms, insects, and their hosts in the forest environment. Perhaps together we can answer the question, "Are disease organisms and insect pests the cause or the effect of changing forest health?"

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Pollination and Mycorrhizae

Insects are responsible for pollinating several hardwood trees—such as species of *Acacia*, most *Acer, Aesculus, Amelanchier, Arbutus, Catalpa, Cercis, Citrus, Cornus, Crataegus, Diospyros, Eucalyptus, Ficus, Gleditsia, Ilex, Liriodendron, Magnolia, Malus, Nyssa, Prunus, Rhamnus, Rhizophora, Robinia*, most *Salix, Sassafras, Sorbus, Tilia*, and *Zanthoxylum*. In addition, insects pollinate many herbaceous flowering plants, vines, and shrubs. The principal insects involved in pollination are bees and wasps, beetles, flies, and butterflies and moths.

Many higher plants—including most tree species—form mycorrhizal associations with fungi. In this symbiotic relationship, the fungus forms a close, nonpathogenic association with the roots, which improves the tree's ability to absorb soil minerals (especially nitrogen and phosphorus) and provides some protection from root-pathogenic fungi.

Conclusions

The activities of forest insects and pathogens are complex and varied, and can have positive or negative effects depending on management objectives. In an ecosystem context, they can contribute to forest diversity, soil fertility, and long-term forest health and sustainability. Strategies to restore or maintain forest health must consider both their beneficial and detrimental functions.

Monnig and Byler (1992) concluded that the health of a forest will be judged by how it functions and how it can meet current and future objectives. Managing a forest for some "desired future condition" requires that we make predictions

Pest Risks of Unprocessed Russian Larch Logs

For the past three years, a number of American timber companies have shown considerable interest in the possibility of importing raw logs from Siberia and the Russian Far East to the United States. This is viewed as an opportunity to obtain relatively inexpensive but high-quality softwood logs for processing here at a time when many American mills, especially in the Pacific Northwest, are facing serious domestic log shortages. Several species have been considered, but most interest has been shown in larch.

Though we do not oppose free trade and support efforts to locate new sources of raw material, the USDA Forest Service and the scientific community were concerned in 1990 when exotic nematodes and Cerambycid borers were detected in two small test shipments of Siberian logs. We believe strongly that great caution is needed when considering the possibility of importing unprocessed logs. Destructive forest insects and pathogens have considerable potential to be transported on or in logs that are shipped intercontinentally, and there is ample historical evidence that exotic insects and pathogens can have devastating effects. Once established, introduced insects and diseases tend to be especially difficult if not impossible to eradicate or control.

A joint USDA Animal and Plant Health Inspection Service (APHIS) and Forest Service team was organized to do the risk assessment of Russian larch logs. We were members of the team. Our objectives were to identify insects and pathogens that might be introduced on unprocessed larch logs from Siberia and the Russian Far East; assess the potential for these organisms to colonize logs, survive transit, and subsequently become established on North American tree species; and consider relative potential impacts of these organisms should they become established in the United States.

Identifying 175 different organisms that use larch as hosts, the team determined six that constitute documentable risk to US trees, particularly in the West. Many other organisms, including a substantial number of presently unknown insects and pathogens, probably have similar potentials. The six detailed in the team's final report were:

- Asian gypsy moths and nun moths—both of which are very adaptable and reproduce frequently. These two moths differ from moth species currently in the United States, including the gypsy moth.
- Spruce Ips beetle—which could be introduced into this country on larch and then spread to spruce, its preferred host.
- Xylem-inhabiting nematodes—many species of which are not currently present in the United States. These tissue-inhabiting worms are capable of occupying wood to considerable depth.
- Larch canker fungus—which prefers moist, cool conditions and is difficult to detect. There are indications that it may also affect Douglas-fir.
- Annosus root disease fungus—considered the most damaging tree pathogen in Siberia and the Russian Far East. Strains currently exist in the United States, but it is unknown what the consequences would be if the Russian strains were introduced.

In our estimation it is very likely that introduction of some of these pests could have significant economic, ecological, and social effects. Because the pathogens are difficult to detect and often occupy logs to considerable depth, they represent particularly great risks. We recommend that logs imported from eastern Russia to the United States receive mitigating treatments that would eliminate insects and pathogens on the surface, in the bark, and to the center of the wood.

Contributed by Donald J. Goheen, plant pathologist, USDA Forest Service, Portland, Oregon, and Borys M. Tkacz, Arizona zone leader, USDA Forest Service, Flagstaff. Adapted from "Pest Risks Associated with Importing Unprocessed Russian Larch Logs to the United States," published in the Western Journal of Applied Forestry, *July 1993. For information or reprints of this article, contact* WJAF *editor Ronald Lanner, Utah State University (801) 750-2537.*

about the future. To be successful, managers need to understand the functions of forest insects and pathogens because they can so strongly influence that future.

Effective ecosystem management must integrate the functional roles of insect and microbial communities. This ecosystem view also increases our need for information on insect and pathogen functions and effects. The National Research Council (1990) listed five research areas needed to address major issues facing society. Two of these were studies on the biology of forest organisms (including insects and pathogens) and ecosystem function and management. We fully endorse research that examines and integrates these critical components of forest ecosystems. JOF

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