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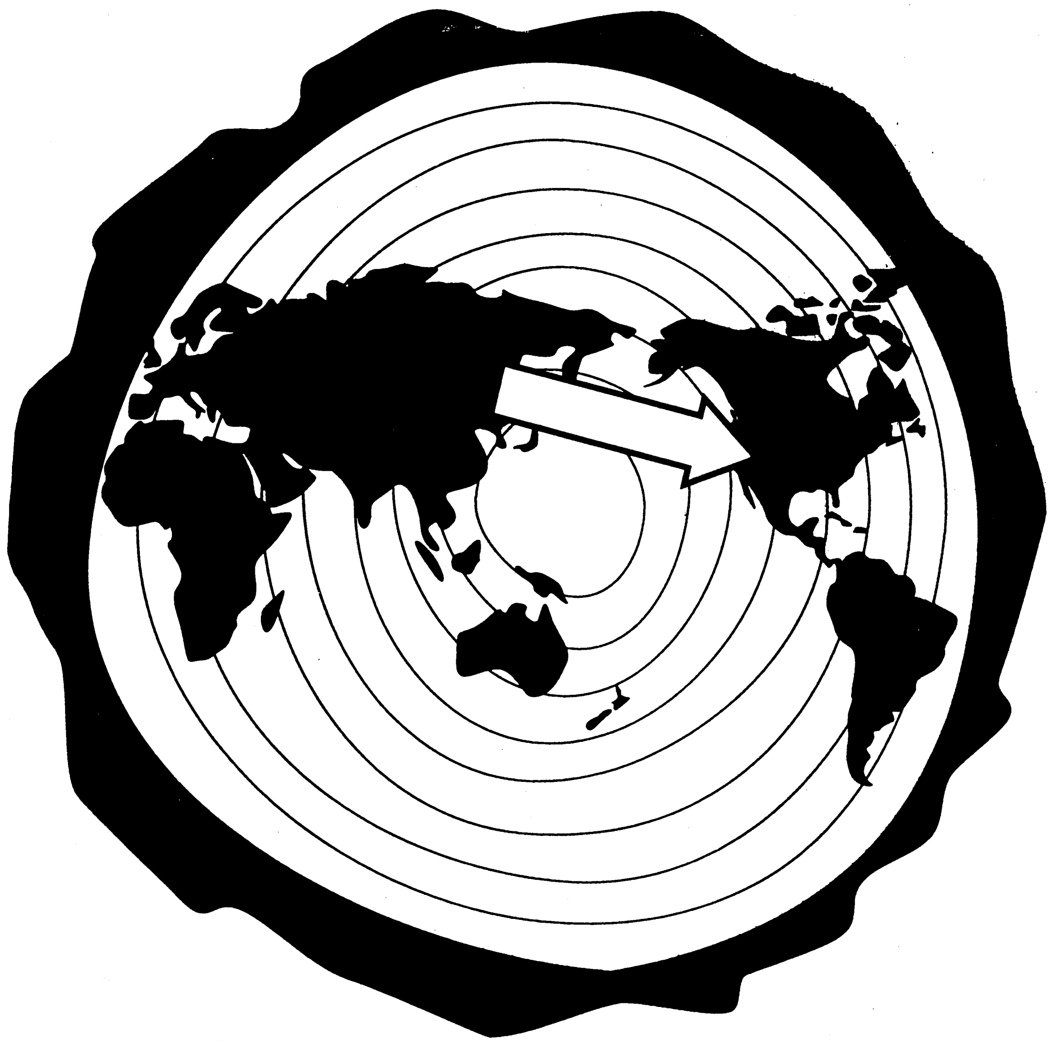
Pest Risk Assessment of the Importation of Larch from Siberia and the Soviet Far East



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Executive Summary

Several timber companies in the United States have expressed an interest in importing unprocessed larch logs from Siberia and the Soviet Far East. A variety of exotic forest pests, including insects, nematodes, and fungi, can be transported on or in logs. Many of these organisms can survive in transit and have a high potential to colonize suitable hosts near ports of entry. Experience has proven that exotic pests can become established in new habitats, sometimes producing devastating effects (see Chapter 3 for six case histories of major exotic pests and their effects). This risk assessment estimates the probability of introduction and establishment of insect and disease organisms imported on logs from Siberia and the Soviet Far East and estimates the potential effects these exotic pests may have on the forest resources and associated ecosystems of the Pacific Northwest and contiguous regions.

A team approach was used for this risk assessment, which involved prominent forest scientists from universities in the disciplines of entomology, pathology, economics, and ecology, as well as regulatory professionals from State and Federal agencies in the United States and Canada. In this way, the most current, reliable, and comprehensive information was obtained to assess the potential risks associated with introduced pests.

A conceptual framework was developed to structure the assessment of risk elements (see Appendix E). Within this framework are two components essential to assessing risk. The first is determining the probability that exotic pests will be established. This is made up of the following elements:

- Pest with host—the probability of pest organisms being on, with, or in the logs at the time of importation

- Entry potential—the probability of pests surviving in transit and the probability of pests being detected at the port of entry under present quarantine procedures

- Colonization potential—the probability of pests coming in contact with an adequate food source, the probability of pests encountering appreciable environmental resistance, and the probability of pests reproducing in the new environment

- Spread potential—the probability of pests spreading beyond the colonized area and the range of probable spread

The second component assesses the consequences of establishment. This consists of the following elements:

- Economic damage potential—the economic impact of pest establishment, including the cost of living with the pest

- Environmental damage potential—the environmental impact of pest establishment

For this risk assessment, time and data were insufficient to evaluate the risks posed by every organism (175 pests have been identified on larch in the Soviet Union) (see Appendix H); instead, representative species were selected based on their perceived risk potential and the availability of sufficient biological information. The team selected 36 organisms on which to focus this assessment. The organisms selected were grouped into three categories: those that could hitchhike on logs, those associated with the bark and innerbark, and those found in the wood. This approach facilitated the evaluation of mitigation measures being considered by a separate team.

Detailed evaluations of the potential establishment and colonization (Chapter 4, Organisms Posing Risk), economic impacts (Chapter 5, Economic Effects Evaluation), and ecological impacts (Chapter 6, Ecological Effects Evaluation) were conducted on six species—Asian gypsy moth, nun moth, spruce bark beetle, pine wood nematode, larch canker, and annosus root disease.

This assessment clearly demonstrates that the risk of significant impacts to North American forests is great. The possible economic impacts range from a low of $24.9 million (best case scenario) because of introduced larch canker to a high of $58 billion (worst case scenario) because of introduced defoliators (see table 7-1). The economic analysis of each potentially introduced pest was calculated independently. Therefore, it is impossible to estimate the cumulative effects that might result from the simultaneous introduction of other pests considered in this analysis.

The economic analyses performed in this risk assessment estimate only the potential financial impacts to commercial timber stands in the Western United States. No attempt was made to quantify nontimber-related impacts (for example, recreation, wildlife, watershed, soil erosion, and so on) or sociopolitical impacts associated with introduced pests. However, some of these impacts are described in Chapter 6 and as part of individual pest risk assessments (Appendix I).

Most of the pests emphasized in this report have the potential to infest extensive areas of one or more forest types in the West. The ecological effects resulting from extensive tree death would be profound in the short run; long-term impacts would depend on how quickly and completely the system recovered. Possible ecological effects include tree species conversion, deforestation, wildlife habitat destruction, degradation of riparian communities, increased fire hazard, and loss of biodiversity. The discussions of the ecological composition, fragility, and value of western forests are not intended to be all inclusive. Rather, they underscore that this vast resource has numerous biological components that might be affected.

This risk assessment focused on larch logs imported from Siberia and the Soviet Far East, but parallels can be drawn with other coniferous logs. Many of the organisms assessed have broad host ranges and could be imported on other genera of logs.

In July 1991, members of the Pest Risk Assessment Team and the Management Practices Team made a site visit to the U.S.S.R. The team met with Soviet scientists and foresters and viewed forest pests, forest harvesting practices, and log handling procedures in Siberia and the Soviet Far East. The team's findings (Appendix L) consistently support the risk assessments developed for pests that might be imported on logs from the Soviet Far East and Siberia.

In conclusion, importing unprocessed logs from Siberia and the Soviet Far East to North America can have serious economic and ecological consequences because of the introduction of exotic forest pests. Measures must be implemented to mitigate the risk of pest introduction and establishment.

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Chapter 1
Introduction

Statement of Purpose

This risk assessment estimates the probability of potential impacts that the introduction and establishment of insect and disease organisms from Siberia and the Soviet Far East may have on the forest resources and associated ecosystems of the Pacific Northwest and contiguous regions.

The purpose of this risk assessment is to:

- identify exotic organisms that have the potential of becoming pests that may move with unprocessed logs from Siberia and the Soviet Far East;
- assess the potential of colonization of groups or individual pests during the process of importing, processing, and utilizing logs; and
- assess the relative potential impacts of the identified organisms that may become established.

Background

The U.S. Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) is the government agency charged with regulating international commerce into the United States to prevent the introduction of exotic pests and diseases via imported nursery stock, seeds, fruits and vegetables, or forest products. APHIS also works to detect and, when feasible, eradicate exotic pests once they have been introduced.

When a request is made to import any animal or plant commodity, APHIS analyzes the potential risk. Information is collected and assessed on pests that may be hazardous. This information is then sent to APHIS policymakers, who decide whether to permit importation of a commodity that may have adverse pest impacts in the United States. Mitigation procedures may be required to allow safe passage. Risk assessments have routinely been used to apply scientific knowledge to the development and documentation of public policy formation.

At this time, the United States has no specific timber import regulations, and no permits are required. The small volume of low-risk timber that has been imported is detained at ports of entry for inspection. Importers are required to use mitigation measures to eliminate identified risks before the timber is allowed into the country. However, U.S. timber companies are now proposing to import such large quantities of potentially high-risk Soviet timber that it is necessary to identify potential pest risks to determine whether Federal regulations are required and, if so, what the provisions of such regulations should be.

Two small test shipments of Soviet logs were imported into the United States from the Soviet Far East. They arrived at Eureka, CA, in mid-1990 and were processed under a protocol developed jointly by the California Department of Food and Agriculture (CDFA) and APHIS. CDFA and APHIS investigated the shipments for plant pest species and discovered two exotic pests on sample pine log shipments. Before this, insect pests had been identified on Soviet logs imported into Sweden, China, Japan, and Korea (see Appendix A). These interceptions included various species of bark beetles, ambrosia beetles, and wood borers. The scientific community and the Forest Service (see Appendix B) have expressed concern about the pest risk. This prompted USDA to temporarily ban additional log imports from the Soviet Union until completion of a pest risk assessment. Certain segments of the U.S. timber industry have petitioned USDA and members of Congress to allow more trial shipments of Siberian logs. USDA has decided to defer consideration of new shipments until a scientific assessment can evaluate the pest risk to U.S. forest resources and determine whether the risk can be mitigated.

In the case of timber imports from the Soviet Union, APHIS determined that the nature, complexity, and scope of the potential risk required additional assistance to complete a comprehensive analysis. As a result, APHIS asked the Forest Service to identify and develop the information necessary to effect a decision (see Appendix B). In response, the Forest Service formed a Pest Risk Assessment Team to scientifically assess the risks posed by exotic pests and determine the probable significance of their introduction. An APHIS Management Practices

Team has assessed mitigation measures for the pests of concern identified by this assessment. This effort is aimed at determining whether any feasible alternatives are available or whether the import prohibition should continue.

Proposed Importation

The dramatic economic and political reforms occurring in the Soviet Union have created new opportunities for U.S. firms interested in increased East-West trade. The Soviet forest products industry is certain to play an important role in the future growth and development of the Soviet Union's international trade.

Because of the growing economic, environmental, and political pressures confronting U.S. timber companies, the forests of the Soviet Union appear to be an attractive alternative source of raw materials. However, as trade opportunities with the Soviet forest products industry increase, the United States must examine the risks involved. The threat of exotic pests being introduced into North America by way of forest products imported from the Soviet Union is an important problem that the U.S. Government, the public, and U.S. timber companies must resolve before importation becomes a viable option.

U.S. and other foreign timber companies interested in importing roundwood from the Soviet Union are looking at accessible timber resources in the southern areas of the Soviet Far East. Future development will likely concentrate in this region because logging operations and the requisite transportation infrastructure already exist for harvesting and transporting the logs. The regions most likely to provide logs for export to the United States will be Primorskiy (Maritime) Kray, Khabarovskiy Kray, Amurskaya Oblast, southern parts of Yakutskaya A.S.S.R., Chitinskaya Oblast, Buryatskaya A.S.S.R., Irkutskaya Oblast, and the southern regions of Krasnoyarskiy Kray (see figure 1-1).

The Soviet Union exports timber products from 54 different coastal ports. Special port facilities are required for loading and shipping timber and related products. The principal transshipment points in the Soviet Far East equipped for loading timber include the ports of Nakhodka, Vostochniy, Sovietskaya Gavan, Vanino, and Vladivostock.

Estimations of the amount of timber that could be imported into the United States range from 150 to 425 million board feet per year (see Appendix C). The imported logs could include up to four softwoods—larch, pine, spruce, and fir. If the species mix imported into Japan is any indication of possible U.S. imports, the United States can expect a species mix ranging from 100 percent larch to 52 percent fir and spruce, 34 percent larch, and 14 percent pine. Ultimately, the timber mix will be determined by the overall processing quality, the price of the wood, and the Soviets' prior contractual commitments.

Larch is the most common tree species found in East Siberia and the Far East regions. Current proposals to APHIS identify larch as the genus for immediate importation. For these reasons, larch is assumed to be the largest component of future importations into the United States and was selected as the primary host genus in this pest risk assessment process. An overview of Soviet forest resources and profiles of larch, pine, spruce, and fir timber species that may be imported are provided in Appendix D.

Preliminary discussions with industry officials indicate that logs from Siberia and the Far East will probably enter the United States at ports in the Puget Sound region of Washington State; Vancouver, WA; Portland, OR; and the Humboldt Bay area of California for processing. The larch logs are intended to be manufactured into veneer; all other species are to be processed into lumber. After processing, this lumber could be re-exported to markets in the Pacific Rim or used to supply domestic needs.

Resources at Risk

The forests of the Pacific Northwest are part of a broad band of vegetation that extends around the Northern Hemisphere in the mid- to upper latitudes. These forests have enormous economic, aesthetic, recreational, wildlife habitat, and watershed value, not only to the region but also far beyond its borders. The Coast Ranges and the west slopes of the Cascade Range are home to some of the highest quality stands of large sawtimber in the world. The east slopes of the Cascades and the lower slopes and benches of the interior mountains are covered by open pine forests and juniper. White fir and Douglas-fir associations and mixed conifer (pine, fir, cedar, Douglas-fir, and larch) forests are found on the interior mountains above the pine zone and on north slopes. Grasslands and

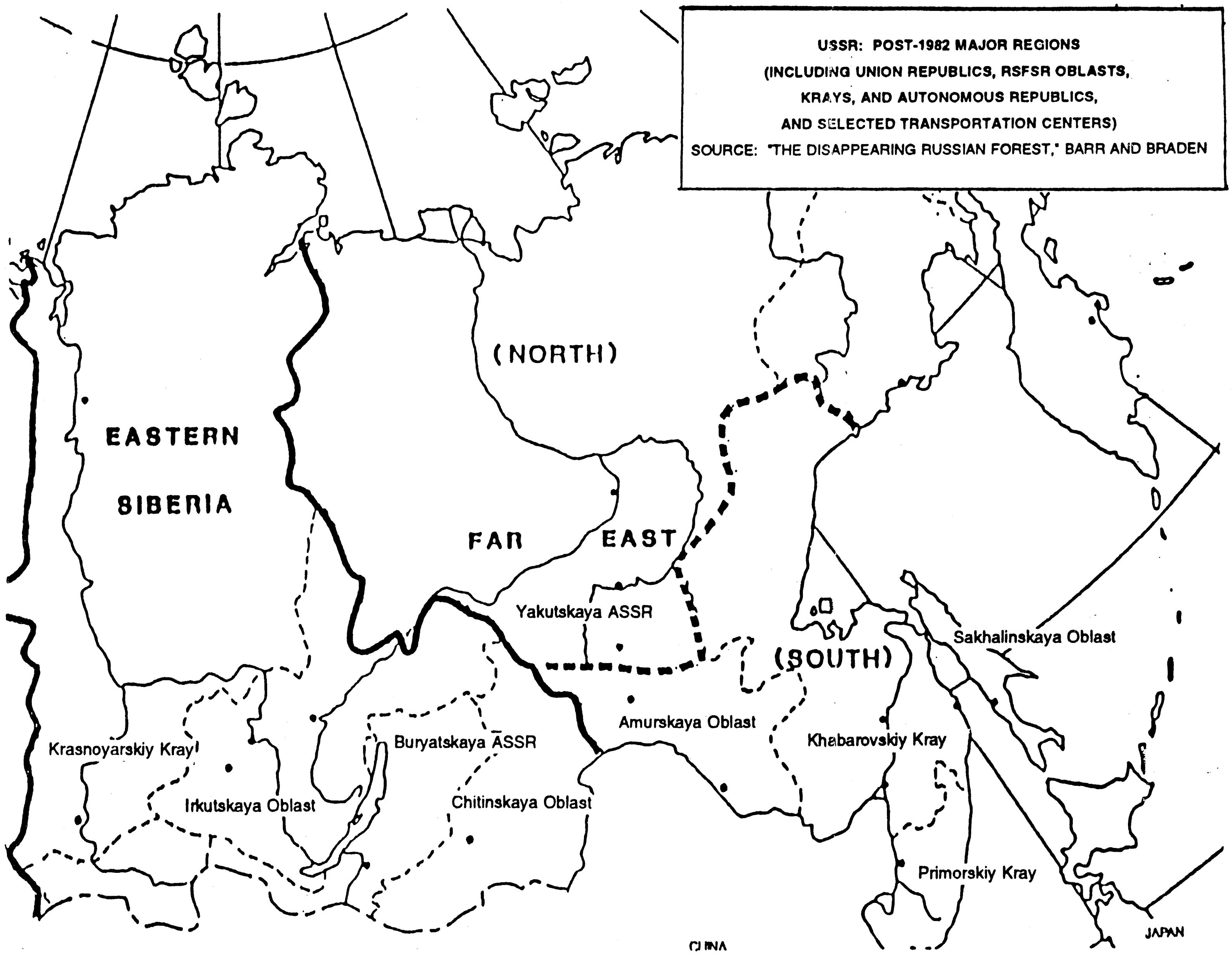

Figure 1-1. Map of Eastern Siberia and the Soviet Far East

desert shrubs extend into the forest in the basins, uplands, and plains areas. Timber resources of Alaska and the Eastern United States may be at risk from pests imported from the Soviet Union; however, these regions are not included in the risk assessment for the following reasons: (1) industry proposals are to import logs to the west coast ports in Washington, Oregon, and California; (2) natural barriers inhibit the spread of pests to the Eastern United States and Alaska, respectively; and (3) spread time to these areas is very long, and discounting reduces the present net value of economic losses virtually to zero.

Even a brief survey of some of the region's principal conifer species suggests the special value and unique diversity of the Pacific Northwest forest system. One conifer, the Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), is the world's third tallest tree, with exceptional individuals reaching 330 feet in height and 16 feet in diameter. This tree grows in the Western United States, where it is a valuable timber commodity and the dominant tree species in ecologically disparate forests from northern California to British Columbia and east to the Rocky Mountains.

Other species of the region have the following characteristics (Norse, 1990):

- In the Pacific Northwest, the shade-tolerant western redcedar is often found in mixed conifer stands and, in particularly moist areas, will occasionally form pure stands. The western redcedar (*Thuja plicata* Donn ex D. Don) grows up to 200 feet in height and 20 feet in diameter.

- Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) is probably the most abundant conifer species from coastal Oregon to southeast Alaska. Reaching a height of up to 215 feet with a diameter of 10 feet, this moisture-loving species often lives many years in the understory before becoming a canopy tree.

- The Sitka spruce (*Picea sitchensis* (Bong) Carr.) is the largest spruce species, reaching a height of up to 300 feet with a diameter of 17 feet. It is found in the coastal forest from northern California to southeast Alaska.

- The sugar pine (*Pinus lambertiana* Dougl.), which grows in the drier forests of the California Sierra Mountains and into southern Oregon, is the largest pine in several respects. It reaches a height of 250 feet and a diameter of 18 feet, which makes it the largest of the pines, and it has the longest cones, with some as long as 23 inches.

- Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) is found in a widespread area, from Oregon's Willamette Valley to northwest California, on the west side of the Cascades, throughout the Sierra Nevada, and in eastern British Columbia, Washington, Oregon, and California. This tree can attain a height of more than 230 feet and a diameter of 8 feet.

- The western white pine (*Pinus monticola* Dougl. ex D. Don) is another large member of the genus *Pinus*, with some individuals attaining almost 240 feet with a diameter of 7 feet. This tree is common to inland British Columbia, northeast Washington, throughout the Cascade Range in Oregon and Washington, northern Idaho, and western Montana.

- The noble fir (*Abies procera* Rehd.) is the world's largest fir, reaching a height of 260 feet and a diameter of 9 feet. Its habitat is the higher elevations of the Washington and Oregon Cascades Range.

- Pacific silver fir (*Abies amabilis* Dougl. ex Forbes) reaches a height of 245 feet and a diameter of 8 feet. While scattered pockets are found in northwest California, it is more common in the Cascades and Washington's Olympic Mountains and north into British Columbia and southeast Alaska. It grows in high-elevation sites and even in areas that accumulate deep snow.

- Relatively dry lowland ecosystems are the habitat of the grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl), which ranges from Vancouver Island to northwest California. This species can reach a height of 250 feet and a diameter of 5 feet.

- The white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.) extends north from the Sierras of California into southwest Oregon. It can grow as tall as 230 feet and have a 6-foot diameter.

- Incense cedars (*Libocedrus decurrens* (Torr.) Florin) can grow as tall as 225 feet with a 12-foot diameter. These trees inhabit dry sites in southern Oregon and northern California, stretching from the Cascade Range, the Siskiyou

Mountains, and Klamath Mountains south to the Sierra Nevada Range.

The Port-Orford-cedar (*Chamaecyparis lawsoniana* (A. Murr) Parl.) is confined to a small region along the southwest Oregon and northwest California coast. It reaches a maximum height of 240 feet and can be 11 feet in diameter. The Port-Orford-cedar is one of the most valuable tree species in the world, and standing timber is often worth several thousand dollars per thousand board feet.

Western larch (*Larix occidentalis* Nutt.) is the largest of the world's larches, often attaining heights of 180 feet and diameters of up to 90 inches. It is an important commercial tree and plays a significant part in the functioning of forest ecosystems in the intermountain region of the United States. Larch is a deciduous conifer and a subclimax species maintained by periodic fire. There are almost 2 million acres of commercial forest land populated with larch (more than 50 percent larch) in the West.

Coast redwood (*Sequoia sempervirens* (D. Don) Endl.) attains diameters in excess of 192 inches. It is the tallest tree in the world, reaching heights of over 300 feet. It has a limited distribution in northwest California and southwest Oregon.

Biological Considerations

Virtually all genera of trees, conifer and hardwood alike, are found in both the Old and New World (Farjon, 1984; Liu, 1971; Suslov, 1961; Tseplyayev, 1965). Many groups of insects, both pest and beneficial, occur in both regions (Linsley, 1958, 1961; Scudder, 1979; Downes and Kavanaugh, 1988; Lafontaine and Wood, 1988). The same may be said for groups of disease organisms. However, the similarities between the Eastern Soviet Union and the Pacific Northwest are largely at the family and generic level; most species are restricted to one area or the other.

Some of the most serious forest insect pests and pathogens of North American forests are believed to have originated in the Far East. Some examples include the gypsy moth, chestnut blight, Dutch elm disease, white pine blister rust, and Port-Orford-cedar root rot. Other pests that have been introduced from the Far East include the Japanese beetle and the blue alfalfa aphid (from Japan), the Asian tiger mosquito, dogwood anthracnose, and larch canker (introduced into the Northeastern United States). Pests have been directly introduced into the Pacific Northwest, some through ship ballast and others on ornamental plant material.

Many of these introduced pest organisms have had enormous environmental and economic effects. For example, the introduction and establishment of the gypsy moth and the fungi that cause white pine blister rust, chestnut blight, Dutch elm disease, beech bark disease, and larch canker (in the Northeast) have changed the structure and species composition of North American forests forever.

A review of virtually any taxonomic study, faunal or floral, dealing with Siberian biota discloses group after group with representatives found on both sides of the North Pacific (Downes and Kavanaugh, 1988; Krivolutskaya, 1983; Linsley, 1958, 1961; Ler, 1988). For example, the long-horn beetles, bark beetles, scale insects, aphids, true bugs, moths, and sawflies clearly show the close similarity between the two areas—a similarity that promises to produce many taxa from Siberia that will find suitable hosts in various parts of the forests of Western North America. Some species are likely to become serious pests.

In addition to similar pest genera found on both sides of the Bering Strait, some tree species are closely related to each other even though they are placed in different genera. Pests found on one tree species may be able to shift to another closely related species. One example would involve larch, which is closely related to Douglas-fir. Insects and disease organisms found on one might become established on the other, especially in new geographical areas where natural constraints might be missing. There is a spruce budworm found on spruce and fir in Europe and Asia that might be a potential pest to larch in North America.

The trees of the Soviet Far East and the Pacific Northwest have associated fauna and flora, including insects and disease organisms. These associations have developed over millions of years in natural environments. When trees (and other plants as well) from one region are exposed to insects or diseases from another region, the evolved defenses of the tree may not be effective against the new organisms. The results may be expressed as a severe outbreak (for example, the gypsy moth and Dutch elm disease) (Elton, 1958). Even the introduction of a slightly different genetic strain of an organism might result in a recombination more dangerous than the existing form.

Trees from North America have been planted in other parts of the world, especially in Europe where some elements of the Siberian fauna occur (Lines, 1987). There are well-documented host shifts of native European insects and diseases onto the North American tree species planted in Europe (Bevan, 1987; Leather, Stoakley, and Evans, 1987). Larch canker has attacked Douglas-fir planted in Norway. The winter moth has moved from oak onto Sitka spruce; the great spruce bark beetle, the European spruce sawfly, and the green spruce aphid have moved to Sitka spruce as well. The pine beauty moth has moved from Scots pine to lodgepole pine as has the pine looper and the larch budmoth. The large larch bark beetle has attacked Douglas-fir during the maturation feeding phase (Bevan, 1987).

In summary, the great similarity between the climate, forests, disease organisms, and insects of Siberia and the Pacific Northwest poses an enormous risk of introducing pest organisms with great potential economic impacts.

Chapter 2
The Risk Assessment Approach

Conceptual Framework

To examine any complex problem, it is often useful to develop a conceptual framework. This pest risk assessment consists of two closely related parts and is the framework in which the problems of pest introduction and establishment are analyzed. The first part of the assessment estimates the probability of specific pests being introduced and established in the biota of the United States. In addition, this section identifies specific pests so that recommendations can be made for mitigation. The second part uses economic and ecological models to analyze the potential consequences of the establishment of a specific pest or group of pests identified in the first section. The probability of pest introduction and the subsequent economic or ecological effects are difficult to predict because subjective conclusions are used to assess the risks of a specific pest or group of pests. Nevertheless, the objective of this risk assessment is to use the best available knowledge, information, and data to identify the pests that pose the most significant risks and to assess the potential effects of these pests should they become established.

Understanding the problem of pest introduction and establishment is critical in assessing the scope and magnitude of any potential risk and its impact. The probability of pest introduction is determined by several related factors—the likelihood of a pest traveling with and surviving on a shipment from the place of origin, colonizing suitable hosts at the point of entry, and subsequently spreading to adjacent territories. Appendix E provides a complete discussion of the pest risk assessment methodology.

The Risk Assessment Process

The growth of international trade substantially increases the likelihood of a pest introduction. This likelihood places increased demands on existing plant pest exclusion procedures and their ability to detect and prevent the introduction of pests at ports of entry. The probability of introduction and establishment of exotic pests depends, in large part, on the quantity of timber imported and the efficacy of mitigation measures.

A number of difficulties must be overcome while assessing the damage that could be caused by introduced pests. One of the primary difficulties is determining which organisms to examine. It is quite possible that an insect or disease organism that is of little or no consequence in Siberia and the Soviet Far East, or an undiscovered organism, may be disastrous once it is introduced to North America. The uncertainty of predicting which organisms may be introduced and the lack of data dictate that the focus of the risk assessment be directed to representative species selected from hundreds of potential pests. While the assessment concentrates on potential forest pests, it is clear that the threat also extends to ornamental and native tree species found in urban settings, as well as to tree farms, and perhaps even to threatened and endangered animal species because of potential habitat loss.

Pest Risk Assessment Core Team

To complete this Siberian and Soviet Far Eastern Pest Risk Assessment, the Forest Service chose a team of scientists. The Core Team members (see list of contributors preceding Chapter 1) were responsible for compiling and assessing pertinent data in their specialties. The Core Team assembled an advisory group of scientists and specialists to help them on this project (see list of contributors). This advisory group was made up of scientists and specialists from universities, Federal laboratories, State and Federal regulatory agencies, and Canada. The Forest Service contracted with LABAT-ANDERSON Incorporated to assist the Core Team in assembling the advisory group, facilitating two workshops, writing and producing the risk assessment document, and creating a data base to organize the information gathered during the project.

Once the advisory group was assembled, two project workshops were conducted. The first workshop, held on March 12 and 13, 1991, determined the organisms that posed a risk and assessed the overall risk of larch importation from the Soviet Union. This first workshop was attended by entomologists and pathologists (see Appendix F). The second workshop, held on April 16 and 17, 1991, determined the economic effects of a possible introduction of pests from the Soviet Union. This workshop was attended by entomologists, pathologists, and economists (see Appendix G).

This pest risk assessment was prepared for the selected pests (Chapter 4 and Appendix I) and was delivered to the Animal and Plant Health Inspection Service (APHIS) Management Practices Team (MPT).

The MPT is preparing an associated document that investigates and evaluates the efficacy of potential mitigation measures for the pests identified in this risk assessment.

Chapter 3
Case Histories of Pest Introduction

Introduction

The following six case histories are examples of the consequences of introducing exotic pests—either insects or pathogens—into a new environment. Five of the six pests described were introduced to North America: the gypsy moth, chestnut blight, Dutch elm disease, Port-Orford-cedar root rot, and white pine blister rust. Moreover, all but the gypsy moth were unknown as pests in their native habitats. The sixth case describes the pine wilt disease, which resulted from the introduction to Japan of a North American species, the pinewood nematode. That five of the six pest introductions occurred in North America is not an anomaly, because North America has been the recipient of numerous insect and disease pests of agricultural crops, as well as forest trees. Two of the case history pests, the Dutch elm disease fungus and the pinewood nematode, are particularly relevant to this risk assessment because both were transported on logs.

Gypsy Moth

History of Introduction

Of European origin, the gypsy moth (*Lymantria dispar* (L.)) was introduced into eastern North America in the 1870's by a French entomologist seeking a silk moth that could survive in North America. Several of the moths escaped, and though local authorities were notified, nothing was done. Free from its natural enemies, the gypsy moth dispersed rapidly, and by 1910 it had spread without assistance to three New England States. The insect now occurs in more than 200,000 square miles of northeast forest, and spot infestations have arisen in California; the Carolinas; Colorado; Idaho; Kentucky; Michigan; Oregon; Utah; Washington; Wisconsin; and British Columbia and Ontario, Canada.

Range and Importance of Host

Larvae of the gypsy moth can feed on more than 500 species of trees, shrubs, and vines found in the Eastern United States. The insect prefers oak species, but additional hosts include apple, aspen, basswood, beech, grey and river birch, hawthorn, sweetgum, and willow. Other species are less preferred, but during outbreaks gypsy moths feed on almost all vegetation, including conifers.

Although the gypsy moth feeds on a number of economically important hardwood species, it is the breadth of species fed upon that is of greatest concern. During outbreaks, gypsy moth larvae will defoliate all hardwood and shrub species in their path, and at the advancing front gypsy moth populations are in an almost permanent outbreak phase.

The polyphagous nature of the gypsy moth is also of concern, especially if it is reintroduced into the Western States. Gypsy moths introduced into Oregon quickly converted from feeding on the sparse populations of hardwood to Douglas-fir before being eradicated. If the gypsy moth becomes established in the Western States, it could become a much greater problem than native pests.

Life Cycle and Biology

The gypsy moth causes its damage in the larval or caterpillar stage of its development by feeding on the foliage of susceptible vegetation. One generation of gypsy moths appears each year, and hatching occurs from April to late May, depending on the area and temperature, though it usually coincides with budbreak of most hardwood trees. The tiny larvae, or caterpillars, may remain in the egg for several days, but when conditions are favorable, they climb to the top of trees or other tall objects. They do not feed, but suspend themselves from silken threads and are dispersed by the wind. The larvae may go through several dispersals before finding a suitable host. Once they begin to feed, the larvae pass through several stages, or instars, in which they shed their skin. Males usually pass through five instars and females, through six. At the fourth stage, the larvae develop the characteristic markings of five pairs of blue spots followed by six pairs of red spots.

At low to moderate population densities, the larvae rest during the day in bark crevices, or they may descend to the ground if no suitable hiding places are available. During outbreaks or on heavily infested trees, the larvae feed day and night. On completely defoliated trees, the larvae may move short distances into adjacent woodlands in search of food.

Depending on location, the larval stage lasts about 7 weeks. Once feeding has been completed, the larvae find sheltered places to pupate. The pupal stage lasts about 2 weeks. Male moths, which are dark brown and good fliers, emerge before the white, flightless females. The females crawl to suitable sites to lay their eggs and release a sex attractant to lure male moths for mating. After mating, the females deposit their eggs in tan- or buff-colored masses that may contain a few hundred to nearly one thousand eggs.

Gypsy moth outbreaks are cyclic: Insect populations build up to epidemic levels and then collapse. The population collapse is caused by a gypsy moth virus that develops and spreads best when populations reach very high levels. Outbreaks may last 5 to 7 years and occur over hundreds of thousands of acres. (At the advancing front of the infestation, the gypsy moth population is almost continually at an outbreak level.)

Insect Spread

Natural dispersal occurs when the newly hatched larvae suspend themselves from their silken threads, allowing the wind to move them to potential hosts. In nonmountainous terrain the larvae may be deposited within one-half mile of their source; however, in mountainous terrain the larvae may be dispersed up to 3 miles. Larvae are spread artificially when egg masses are deposited on vehicles or on articles in vehicles and are transported to uninfested areas.

Economic and Ecological Impact

The gypsy moth is the most destructive insect that attacks hardwood forest and shade trees in the United States. Even vigorous trees defoliated by gypsy moths are seriously weakened, and defoliation over 2 consecutive years can kill a tree. In humans, allergic reactions to body hairs of the caterpillars are common and well documented. In urban areas, gypsy moth larvae, their droppings, and egg masses present additional nuisance factors. Urban trees have a much greater value than those grown for timber, and the loss of a tree results not only in removal and replacement costs but also in the loss of aesthetic and property values. In 1973, the value of trees lost to the gypsy moth was estimated at $375 per tree.

Defoliation by the gypsy moth can also severely affect parks and recreational areas. With heavy infestations, larvae crawl over picnic tables, cabins, roads, and trees, leaving their droppings and creating a nuisance and possible health hazard to humans. Defoliated trees are unattractive, and in the Northeast, tourism has suffered sharp declines in areas where outbreaks have occurred.

Because forests are used for many types of activities, the value loss caused by the gypsy moth is more difficult to predict than for urban areas. Value loss to Northeast forests, assessed in 1978, ranged from $0 to $468 per acre, depending on use, and averaged $14. Over the 10 years for which records have been available (1978-88), gypsy moth defoliation ranged from a low of 643,600 acres in 1978 to a high of 12,872,725 acres in 1981.

Management

Because gypsy moth outbreaks are long (often lasting from 5 to 7 years) and attack a large number of tree species, public pressure for control measures is often intense. Possible control measures for the gypsy moth include chemical insecticides; the release of sterile life stages; mass trapping using a pheromone sex attractant; and biological controls, such as the release of parasites or predators or the use of the biological insecticide *Bacillus thuringiensis* (Bt). With recent public concern over safety and the impact on nontarget insects, chemical insecticides, such as acephate and carbaryl, have lost favor as control techniques. The release of sterile life stages, such as sterile male release, has been used successfully to eliminate isolated low-level infestations, but it has had little effect on larger populations. Mass trappings using pheromones and the use of parasites and predators are likewise effective only when gypsy moth populations are very low. The use of biological insecticides, such as Bt, is favored to protect recreational areas and high-value timber species.

Chestnut Blight

History of Introduction

Chestnut blight, one of the most infamous plant diseases in North America, illustrates the devastating impact of an introduced plant pathogen. The disease was first discovered killing trees in New York City's Bronx Zoological Park in 1904. Two years later, the fungus causing the disease was identified. Five years after the blight's discovery, infected chestnuts were found 30 miles from New York, and pockets of the disease appeared in Pennsylvania, Virginia, Maryland, Connecticut, and Rhode Island. Spread was exceedingly rapid. Within 50 years the disease had spread to the extremes of the natural range of the American chestnut, with the loss of approximately 8 million trees.

Efforts to control the blight were begun soon after its discovery. In New York City, control measures included pruning affected branches and applying bordeaux mixture, but neither method was effective. In Washington, DC, all infected trees within disease centers were cut and burned, but also to little avail. In Pennsylvania, control efforts were abandoned after only 2 years. The quick proliferation of the blight and the enormous toll it took sparked prodigious research. Even by 1914, 399 articles had been published on various aspects of the epidemic.

Chestnut blight was the most destructive plant disease ever recorded. The legacy the blight fungus left was the near total decimation of the American chestnut from its natural range. Today, sprouts from the root systems of blighted trees are all that remain of this once important species.

Range and Importance of Host

The American chestnut (*Castanea dentata* (Marsh.) Borkh.) was once the most abundant hardwood in the eastern deciduous forest. Its natural range encompassed more than 200 million acres. In the southern part of its range, the tree grew to 120 feet in height and 5 feet in diameter. The chestnut had a faster growth rate than its associated hardwood species, and normal growth was 500 board feet per acre per year, with individuals on good sites adding 1 inch in diameter per year.

The American chestnut had more uses than any other tree in the eastern forest: It was important as a timber, nut, and shade tree. The wood was extremely resistant to decay because of the tannins in the bark and wood. It was used for construction, furniture, tannins for leather, fences, boxes, barrel staves, railroad ties, telegraph poles, mine timbers, and musical instruments. The delicious nuts were also an important source of food for wildlife, domestic livestock, and humans.

Disease Organism

The chestnut blight fungus (*Cryphonectria parasitica* (Murr.) Barr (= *Endothia parasitica, Diaporthe parasitica*)) is an ascomycete (subclass Pyrenomycetes) belonging to the family Diaporthaceae. The fungus is now distributed throughout the Northern Hemisphere, but it is believed to be of Asian origin. The asexual, single-celled conidia are produced within pycnidial stromata on the bark of diseased trees. The sexual ascospores are two-celled, each with one to four nuclei, and are produced in perithecia within the same stromata as the pycnidia. Both spore types are produced in abundance on diseased trees, and both are capable of causing infection on healthy trees.

Life Cycle and Biology

Cankers can occur anywhere on the branches or trunk, but the fungus requires some type of wound to gain entrance. Once established, mycelial fans produced by the fungus rapidly colonize the bark tissue, encircling and girdling the branch or trunk and killing the cambium. After the sapwood at the site of a girdling lesion ceases to conduct water, the leaves and shoots above the canker wilt and die. Typical cankers on young, smooth-barked stems appear yellowish to reddish brown in contrast to the green-brown bark. On larger stems with thick corky bark, cankers are usually inconspicuous unless the bark begins to swell or crack.

Under moist conditions, orange-brown stromata of the fungus erupt through the surface of infected bark, releasing millions of conidia embedded in a water-soluble, gelatinous matrix. These spores are adapted for spread by rain and perhaps by insects, birds, and small animals. Perithecia, producing ascospores, also form throughout the growing season in the same stromata that give rise to the conidia. These spores are released after rains and are adapted for spread by wind. New infections occur when ascospores or conidia germinate in fresh wounds that penetrate to living bark.

Disease Spread

The rate of spread of the main disease center south of New York has been estimated at 10 to 23 miles per year. The discrepancy in estimates results from spot infections occurring up to 150 miles from the leading edge of the principal center. There are two mechanisms of spread by the fungus. In one, the ascospores are forcibly ejected from the perithecia and may be carried long distances by the wind. In the other, conidia or asexual, spores of the fungus are extruded in a gelatinous matrix that is ideally suited to dissemination by insects, birds, and mammals. These spores can also be splashed by rain and dispersed. The most important insect carriers

re probably the wound makers, such as the chestnut-
ıark borer (*Strophonia nitens*) and the chestnut-bast
niner (*Ectoedema phleophaga*). Conidia of the fun-
;us have also been recovered from several species
ıf birds, including woodpeckers and the wound-
nducing sapsucker. The north to south migration of
ıirds in the fall may explain the southwest spread
ıf the blight against the prevailing winds.

conomic and Ecological Impact

[he American chestnut was once the most economi-
:ally important hardwood species of the eastern for-
ests. The time that has elapsed since the destruction
ıf the blight makes it difficult to estimate the total
mpact of the disease. In 1912, the value of the
standing chestnut timber in Pennsylvania, West
/irginia, and North Carolina alone was estimated at
$82.5 million. The value of the nut crop and shade
rees in Pennsylvania alone was estimated at another
$15 million. In Pennsylvania, $275,000 was spent
ɔetween 1912 and 1914 in a vain attempt to stop the
disease.

Chestnut blight resulted in wholesale species conver-
sions, primarily to oaks, on sites where chestnut was
predominant. On the better sites it was replaced by
red and white oaks, while on the steeper hillsides
these species gave way to pin oak and chestnut oak.
However, along many of the ridgetops in the Appala-
chian Mountains the chestnut has not been replaced,
leading to increased soil erosion.

Disappearance of the American chestnut has also led to a serious loss of biodiversity in the hardwood forests of Eastern North America. Oak species, which have predominantly replaced the chestnut, are now under severe attack from gypsy moths in the Northeast and from oak wilt and oak decline in the region between the Mississippi River and the Appalachian Mountains.

Management

Over the past 50 years, experimental attempts have been made to restore the American chestnut using fungicides, biological controls, and breeding for blight resistance. Fungicides have shown some promise for controlling the blight on individual trees of high value, but annual applications are required. Biological control of virulent strains of the fungus by avirulent strains has been shown feasible in Europe. In the United States, however, the greater spread and diversity of the virulent strains mitigates against the widespread introduction of hypovirulent strains. At this time, breeding for blight resistance is being done, but no clones of American chestnuts have sufficient blight resistance to be useful for outplanting. Attempts to produce suitable hybrids between the American chestnut and Asian species have yielded trees with the poor appletree-like form of the Asian parents.

Dutch Elm Disease

History of Introduction

Dutch elm disease, caused by the fungus *Ophiostoma ulmi* (*Ceratocystis ulmi*), was first described by Schwarz in the Netherlands in 1920. The fungus was introduced to North America, together with one of the insects responsible for its spread, the smaller European elm bark beetle, *Scolytus multistriatus* (Marsh.), on unpeeled veneer logs, with the earliest cases of the disease on this continent reported in Ohio in 1930. In 1933, a Federal quarantine inspector at the port of Baltimore intercepted elm logs from France carrying the Dutch elm fungus together with the main bark beetle vector of the fungus in Europe. Subsequent inspections revealed the fungus in elm logs intercepted in New York, Norfolk, and New Orleans. The most serious disease centers arose around New York City and Quebec in 1933. In New York City, spread of the disease was attributed to the presence of a breeding population of the introduced smaller European elm bark beetle and an abundance of the native (North American) elm bark beetle *Hylurgopinus rufipes* (Eighh.). A second major disease center occurred in the late 1930's in Ohio and Indiana. Attempts at eradicating the disease, especially in the New York City area, were abandoned at the onset of the Second World War. By 1968, the disease was present throughout the eastern half of the continent and into Colorado and Idaho, beyond the range of native elms. New, more aggressive strains of the Dutch elm disease fungus have been developed in North America and reintroduced into Europe where they cause increased mortality.

Range and Importance of Host

The American elm (*Ulmus americana* L.) is native to all States east of the Great Plains. Interspersed in this region are five other native elm species—slippery elm (*U. rubra* Muhl.), rock elm (*U. thomasii* Sarg.), winged elm (*U. alata* Michx.), red elm (*U. serotina* Sarg.), and cedar elm (*U. crassifolia* Nutt.). Elms usually grow in mixed stands with other hardwoods and in 1938 accounted for an estimated 16 billion board feet of merchantable timber.
Elm wood has been used for veneer, furniture,

shipbuilding, flooring, sporting goods, boxes, and crates.

The value of America's elms as ornamentals and shade trees surpasses that of all forest elms. Elms are especially adaptable to the urban environment. They are able to endure physical damage, such as repeated pruning for overhead utility lines, and are tolerant of soil compaction. The beauty of elms and their utility as shade trees have contributed to their popularity. As a result, they have been planted extensively on streets, roadsides, and homesites across the United States.

Disease Organism

The Dutch elm disease fungus is an ascomycete (subclass Pyrenomycetes) belonging to the family Ophiostomataceae. Its synnematal imperfect stage was named *Pesotum ulmi* (Schwarz) (Crane & Schoknecht, 1973). The perfect stage has had a number of names, the most recent being *Ophiostoma ulmi* (Buis.) Nannfeldt and the better known *Ceratocystis ulmi* (Buis.) C. Moreau. The fungus has four commonly observed spore types: (1) Sporothrix stage with conidia; (2) synnematal (*Pesotum*) stage, also with conidia; (3) "yeast-like" stage; and (4) perithecial (sexual) stage, producing ascospores. Spores produced by the two conidial stages and the perithecial stages are embedded in sticky mucilaginous drops. The yeast-like stage is thought to be involved in the spread of the fungus within a tree's vascular system.

Life Cycle and Biology

Ophiostoma ulmi is an example of a vector-borne plant disease and a highly specialized vascular-wilt organism. The fungus causes the disease, but insects are necessary to vector the fungus to healthy elms. In North America, two insects (Scolytidae) are responsible for spread of the disease: the smaller European elm bark beetle (*Scolytus multistriatus*) and the native elm beetle (*Hylurgopinus rufipes*).

The fungus is a primary colonizer of the inner bark of dying elms. The beetles lay their eggs in the inner bark of diseased or stressed trees. After the eggs hatch, the emerging larvae feed on the phloem by making tunnels through the bark. If the fungus is present in the tree, the fungus produces mycelium and sticky *Pesotum*-type spores in the beetle tunnels and pupal chambers. When the adult beetles emerge, they carry thousands of spores on and in their bodies. Dispersing beetles fly to healthy elms where they feed or to declining elms where they breed. On healthy elms, the beetles feed on or burrow into the bark of twig crotches where the spores are deposited into the wounded tissues of the tree. The fungus grows rapidly in the injured bark and wood. When it reaches the large xylem vessels of the springwood, it produces *Sporothrix*-type spores, which are carried in the sap stream. The extent of crown symptoms is directly related to the extent of vascular invasion. General invasion of the tissue begins at the dieback phase of the disease, with considerable blockage of the sapwood by gums and tyloses produced by the tree to resist the fungal invasion. Infection induces browning of the water-conducting vessels. Infected twigs and branches soon wilt and die.

Spring infections result in the invasion of the long vessels of the springwood through which spores can be rapidly spread to all parts of the tree. If the vascular invasion becomes general, the tree may die within a few weeks. In summer infections, vascular invasion is limited to the short vessels of the summerwood, resulting in localized infections; tree death occurs the following year.

Disease Spread

Once the fungus has become established, spread to nearby healthy elms can occur without the insect vector by internal movement of the fungus through root grafts. Either the insect vector or human activities can cause long-distance spread of the fungus. The spread rate of the disease across Connecticut was 4.5 miles per year, equal to the flight of two generations of the smaller European bark beetle. Elm bark beetles commonly attack green elm logs cut for lumber or fuel. Cut elm logs colonized by contaminated beetles commonly serve as reservoirs of the fungus, including logs of the elm species that are not highly susceptible to the disease itself. Subsequent commercial transport of the logs has allowed both the Dutch elm disease fungus and bark beetles to spread over long distances, even across oceans.

Dutch elm disease is particularly damaging because the insects can introduce *O. ulmi* into trees that were not killed by Dutch elm disease during their breeding colonization. Thus, the insects produced in any elm, regardless of the cause of death, will usually carry the fungus. This secondary colonization ensures that most elm material will produce contaminated beetles.

Economic and Ecological Impact
The primary impact of Dutch elm disease has been in the urban environment, rather than in forests. Because of their aesthetic appeal and their hardiness, by 1930 an estimated 77 million elms had been planted in densely populated areas across the United States. By 1977, an estimated 60 percent of urban elms in the United States had been lost to the disease.

The calculations of monetary loss and the costs of control are only rough estimates. More than $11 million was spent over a 5-year period in the 1930's by Federal and State agencies to eradicate the disease. Costs of removal and replacement vary between $100 and $425 per tree, with an average cost of $215. However, when aesthetic and other values are factored in, the cost rises to $430 per tree.

Management
Control programs enacted by urban governments in affected areas have ranged from complete neglect to an all-out assault on the disease. The primary control method has been sanitation, which eliminates the breeding material of bark beetle vectors. Experience has shown that, despite costs, the control efforts are preferable to no action: communities that did nothing eventually incurred costs two to three times greater than those that implemented control programs.

Historic and other highly valued trees may be saved if injected with a systemic fungicide. Effective treatment from 1981 to 1984 cost a minimum of $40 to $100 per tree.

Port-Orford-Cedar Root Rot

History of Introduction
Port-Orford-cedar root rot was first reported causing mortality of Port-Orford-cedar (*Chamaecyparis lawsoniana* (A. Murr.) Parl.) nursery stock around Seattle, WA, in 1923. The causal fungus was isolated and described in 1942 from declining cedar ornamentals in the Willamette Valley, and the disease appeared in the native range of Port-Orford-cedar in 1952. It subsequently spread throughout much of the area occupied by the host in southwestern Oregon and northern California. The origin of the pathogen is unknown, but based on the resistance exhibited by Asiatic *Chamaecyparis* spp., it is believed to be an Asian species. An alternative theory is that the fungus originated in North America, but outside the relatively small area where the host is native.

Range and Importance of Host
Port-Orford-cedar has a very limited natural range. It is confined to a 40-mile-wide strip along the Pacific Coast from Coos Bay, OR, south to the Mad River near Arcata, CA. It occurs in a number of plant community types, but its natural distribution appears to be limited by its need for substantial amounts of moisture. It prefers sites with year-round water seepage and generally occurs in mixed stands with other species.

The domestic market for Port-Orford-cedar lumber is limited. Though formerly considered valuable for interior paneling, venetian blind slats, and battery separators, its primary use in the United States today is for arrow shafts. However, the overseas market for Port-Orford-cedar is substantial. The wood is especially prized for construction in Japan, where it is used as a substitute for hinoki cypress and has religious significance. Between 1950 and 1980, more than 2.2 million cubic meters of Port-Orford-cedar were exported from the United States. From 1980 to 1989, an additional 307,000 cubic meters were exported. Port-Orford-cedar export logs are priced at about five times the price of prime Douglas-fir.

Disease Organism
Phytophthora lateralis Tucker & Milbrath, the fungus that causes Port-Orford-cedar root rot, is an oomycete belonging to the family Phythiaceae in the order Peronosporales. The name *Phytophthora* means plant destroyer. Members of the genus *Phytophthora* are mostly pathogenic and produce stout, colorless, freely branching hyphae that grow inter- and intracellularly in host plant tissues. They produce two kinds of infective spores: zoospores and oospores. *Phytophthora lateralis* also produces a chlamydospore resting stage. All spore types require free water for germination.

Life Cycle and Biology
Phytophthora lateralis is highly adapted for spread in water and soil and is also capable of surviving for considerable periods of time even when conditions are unfavorable for spread and infection. Zoospores produced in sporangia are flagellate and very motile in surface or soil water. Zoospores are attracted by root exudates and will follow an increasing gradient of chemical concentration until they contact host root tissue, germinate, penetrate the root, and initiate infection. Zoospore production is favored by mild, moist conditions and is

optimal at temperatures between 10 and 20 °C. When unfavorable warm, dry conditions prevail, *Phytophthora lateralis* forms thick-walled resistant chlamydospores. These resting spores are incapable of direct movement themselves, but their structure provides protection during passive movement in mud, soil, or infected roots. When environmental conditions become favorable again, chlamydospores germinate, forming zoospore-containing sporangia. Oospores (the spore stage produced by sexual union) also act as resting spores and may be transported in infected root tissues.

After infection, mycelia of *Phytophthora lateralis* grow in the host cambium until the entire root system is colonized and the tree dies. This may require up to 4 years in large trees, while small trees may be killed in a few weeks. The fungus lives vegetatively in the host as long as the tree survives.

Disease Spread

Long-distance dispersal of *Phytophthora lateralis* occurs through transport of infected roots and foliage and through earth movement during construction, road maintenance and use, logging, and animal movement. Local spread involving zoospores occurs mainly downhill, below roads and trails in water drainage. Spread from tree to tree can also occur by mycelial growth across root grafts.

Economic and Ecological Impact

Although difficult to assess precisely, losses caused by Port-Orford-cedar root rot have been enormous. *Phytophthora lateralis* has virtually destroyed the once-thriving Port-Orford-cedar nursery industry and has killed ornamental Port-Orford-cedars throughout the Northwest, resulting in considerable property value loss and substantial replacement costs.

In their native range, mortality losses in old-growth Port-Orford-cedars are believed to have peaked at about 10 million board feet per year in the early 1970's, subsequently dropping to about 5 million board feet annually. It is estimated that 60 percent of the trees in young-growth stands have been killed by the disease. Despite some concern that the species itself is endangered, Port-Orford-cedar is an extremely prolific seeder, and many stands, by virtue of their location, have a high probability of escaping infection. Nonetheless, the disease has greatly hurt the commercial prospects for Port-Orford-cedar and has also made necessary new and costly control efforts.

Management

The only effective method to manage Port-Orford-cedar root rot involves excluding the disease from areas it has not yet reached. Such a strategy requires careful planning and strict enforcement. Exclusion necessitates road closures, timing access during dry weather, washing equipment, and establishing cedar stands on well-drained ridgetops above roads, among other measures. Screening and breeding programs to promote resistance to the disease may prove effective, but no such results have yet been produced.

White Pine Blister Rust

History of Introduction

Cronartium ribicola J.C. Fisch, the cause of white pine blister rust, is believed to be a Eurasian fungus. It was first described on eastern white pine in the Baltic region in 1854, and it was introduced into both Eastern and Western North America on diseased white pine planting stock from Europe around the turn of the century. In the East, white pine blister rust was first discovered near Geneva, New York, in 1906, although it was probably present some years earlier. In the West, introduction resulted from one shipment of infected eastern white pine seedlings shipped to Vancouver, British Columbia, from France in 1910. The disease has since spread virtually throughout the range of its host in the United States and Canada. Despite earlier hopes that unfavorable climatic conditions would prevent its spread to the Southwest, the disease has progressed steadily southward through California and has recently been discovered in New Mexico.

Range and Importance of Host

White pine blister rust is a disease of five-needle pines, including bristlecone (*Pinus aristata* Engelm.), limber (*P. flexilis* James), whitebark (*P. albicaulis* Engelm.), western white (*P. monticola* D. Dougl. ex D. Don), southwestern white (*P. strobiformis* Engelm.), eastern white (*P. strobus* L.), and sugar pine (*P. lambertiana* Dougl.). Alternate hosts are currants and gooseberries of the genus *Ribes*. Eastern white pine, western white pine, and sugar pine, in particular, are extremely valuable timber species, known for high-quality wood and excellent growth characteristics. Before the introduction of blister rust, these species often dominated forest stands over significant areas within their respective ranges.

For example, it is estimated that western white pine comprised 80 to 90 percent of the stocking in many old-growth stands in Idaho and Montana before they were ravaged by blister rust.

Disease Organism

Cronartium ribicola is a macrocyclic, heteroecious rust fungus belonging to the order Uredinales in the class Teliomycetes, subdivision Basidiomycotina. The fungus has a complex life cycle involving five spore types and requiring both pine and *Ribes* hosts for its successful completion.

Life Cycle and Biology

Basidiospores of *C. ribicola* infect pine hosts during summer and fall. Infection takes place through needles of any age. The relatively delicate, short-lived basidiospores are wind dispersed, generally over distances of no more than 100 yards. For successful spore germination and infection of pine needles to occur, temperatures must not exceed 68 °F with 100 percent relative humidity for a period of 48 hours. After germination and successful penetration, a sparse mycelium develops and grows from the needle into the bark of the stem. Twelve to eighteen months later, a slightly swollen, cankered area first becomes visible. Two to three years after initial infection, pycnia and pycniospores are produced on the cankers. They are noninfective and have a sexual function. One to two years later in the spring, aecia with aeciospores are produced in the same location on the cankers. The relatively tough aeciospores are disseminated by the wind over considerable distances and infect *Ribes* leaves. Infection of the *Ribes* host is also favored by moist conditions. Two weeks after initial infection, uredinia are produced on *Ribes* leaves. Urediniospores produced from the uredinia reinfect *Ribes* throughout the summer, causing buildup of inoculum. In late summer to early fall, hairlike telial columns emerge from the old uredinial pustules. Teliospores germinate in place on these columns and produce basidiospores, starting the process over again. The entire life cycle requires 3 to 6 years for completion.

White pine blister rust cankers develop into resinous lesions, eventually girdling the host at the point of infection. This results in branch and top mortality. The fungus continues to grow through branches and into the main stem, where it ultimately girdles the main stem and kills the tree. Infected trees are also predisposed to bark beetle infestation.

Disease Spread

The initial spread of white pine blister rust in North American forests was phenomenally rapid. In 10 to 20 years the disease had spread through most of the host ranges. The rapid spread in the United States has been the result of the combination of numerous highly susceptible hosts, the close proximity of primary and alternate hosts, favorable environmental conditions, and the fact that *C. ribicola* spores are windborne. Aeciospores, in particular, are effectively transported very long distances, sometimes up to 300 miles. Spread is episodic, and is much more dramatic during years with moist summers and falls. The disease is often not as severe in dry microsites as in moist ones.

Economic and Ecological Impact

Losses caused by white pine blister rust have been exceptionally great. It is believed that 80 to 95 percent of the western white pine, sugar pine, and eastern white pine have been killed or damaged in affected stands. In the West, 99 percent of the host type in Idaho and Montana, 96 percent of the host type in Oregon and Washington, and 80 percent of the host type in California have been affected. This represents forest stands on a combined area of about 9 million acres. Loss has occurred in the form of reduced value in salvaged mortality, unsalvaged mortality in mature stands, loss of site potential because of the killing of immature trees, and value loss through top killing. The virtual elimination of western white pine from stands in Idaho and western Montana, where it was formerly a dominant species, has also had severe ecological consequences. Douglas-fir and grand fir have largely replaced white pine in these stands, but because of the susceptibility of these two species to native root diseases and defoliating insects, the stands have since been in a chronic state of poor health and reduced productivity. Grizzly bears, a threatened and endangered species, depend on the nuts of white bark pine. White pine blister rust has recently spread to white bark pine and will greatly reduce this important food source for bears. The recent introduction of white pine blister rust into New Mexico threatens the biodiversity of southwestern mixed conifer forests.

Management

The principal control for white pine blister rust involves planting pines with various levels of resistance to *C. ribicola*. Programs to identify and screen apparently resistant pines or to breed trees for greater resistance are expensive but promising. However, there is concern that mutation of the pathogen could negate the results of these programs. Earlier control efforts aimed at eradicating *Ribes* or killing cankers on infected trees with antibiotic chemicals were unsuccessful. However, these efforts were extremely costly: as of 1959, a little more than $100 million had been spent on the largely ineffective *Ribes* eradication program. Pruning the lower branches of young white pines to prevent stem infections and alter the microclimate in plantations is occasionally useful.

Pine Wilt Disease

History of Introduction

Like Dutch elm disease, pine wilt disease is a highly specialized vector-borne plant disease, which is caused by the pine wood nematode (*Bursaphelenchus xylophilus* (Steiner and Buhrer) Nickle) and carried by cerambycid beetles.

In Japan, the first record of symptoms similar to those induced by the pine wood nematode dates from 1905 in Nagasaki, Kyushu. Although the cause of death could not be determined, the affected trees were cut and burned. Other outbreaks were recorded on Honshu in 1921, where the disease spread rapidly throughout coastal areas, and 30 miles north of Nagasaki in 1925. Efforts to control the epidemic by cutting and burning were begun in many areas but were abandoned during the Second World War.

For many years, abnormally high populations of pine bark beetles were believed to cause the wilt. But it was eventually established that the pine wood nematode in association with an insect vector, the pine sawyer (*Monochamus alternatus* (Hope)), was the real cause of the disease (Steiner and Buhrer, 1971). The pine sawyer is native to Japan, but recent research has demonstrated that the nematode originated in North America. Thus, pine wilt disease is an example of an introduced pathogen adapting to, and being transported by, a native vector.

The nematode was probably introduced to Japan in pine logs from the west coast of North America. The scattered nature of the infections throughout Kyushu and Honshu suggests that the movement of nematode-infected logs played a major role in spreading the disease.

The first report of pine wilt disease in North America was in 1979, when the disease was diagnosed on an Austrian pine (*P. nigra* L.) growing in Missouri. All subsequent reports of the disease have been on exotic pine species. Pine wilt disease has also been reported in China and Taiwan.

Range and Importance of Host

The two pine species that predominate throughout the islands of Japan are both extremely susceptible to the wilt caused by the pine wood nematode: Japanese red pine (*Pinus densiflora* Seib et Zucc.), that nation's most important timber species, and Japanese black pine (*P. thunbergii* Parl.), which is important as a shade tree and as a decorative tree. A third pine species, the Luchu pine (*P. luchuensis*), is found on Okinawa and is also susceptible.

Disease Organism

The pine wood nematode is a member of the superfamily Aphlenchoidae; is native to North America; and has been introduced to Japan, Taiwan, and China. The nematode is microscopic, 800 µm long and 22 µm in diameter. Each female lays about 80 eggs, which after hatching pass through four stages of larval development on the way to adulthood. Depending on temperature, the pine wood nematode can develop rapidly, completing its life cycle in 12 days at 60 °F or in just 4 days at 80 °F.

The nematode has two development stages, designated as propagative and dispersive. The propagative phase occurs while the host is still living and for a period after the host dies. During this time, the four larval stages are functionally similar to one another and immediately precede the adult stage. After the host dies they feed on fungi that invade the dead or dying tree. In the late stages of infection, development switches to the dispersive stage in which the third- and fourth-stage larvae are distinctive. The third-stage larvae are adapted to withstand starvation, the fourth, drying. The third-stage larvae migrate to the pupal chambers of insect vectors and molt to fourth-stage larvae. The fourth-stage larvae, called dauerlarvae, are especially adapted to survive in the respiratory systems of certain cerambycid beetles. They enter the bodies of new adult beetles just before the beetles emerge from the bark and are introduced into feeding wounds created by the beetles as the latter feed on the branches of healthy pines. Nematodes are also introduced into dying trees by the cerambycids during egg laying.

Life Cycle and Biology

The life cycle of the pine wood nematode is intimately interconnected with that of certain cerambycid beetles. In Japanese forests, *Monochamus alternatus* vectors the nematodes to healthy hosts. Female beetles searching for suitable hosts in which to lay their eggs are attracted to pines killed by the nematodes. The beetle eggs hatch in the late summer, and the first two instars of the insect feed under the bark before the third penetrates to the wood. Larvae molt into a fourth instar that overwinters. The following spring, the beetle larvae excavate small chambers in which they pupate. At the same time, third-stage nematode larvae migrate to the pupal chambers of insect vectors and molt to fourth-stage dauerlarvae.

As the adult beetle emerges, the dauerlarvae enter the beetles' respiratory system. The emerging beetles carry an average of 15,000 to 20,000 dauerlarvae. The beetles then fly to healthy trees and feed by stripping the bark to the cambium, during which the dauerlarvae emerge from the beetle and enter the plant through the wounds. Once inside the tree, the dauerlarvae undergo a final molt to adult nematodes, which can then reproduce. In the plant the nematodes migrate to the resin canals, feeding on and killing the epithelial cells.

Within 10 days of inoculation, the destruction of the resin cells leads to the cessation of resin flow. After 30 days, foliage transpiration has ceased and is followed by the sudden wilting and loss of foliage color. As the trees die, they become attractive to adult beetle females searching for stressed and dying hosts in which to lay their eggs. The next spring another brood of beetles emerges carrying thousands of nematodes, and the cycle is repeated.

In North America, pine wilt disease has been demonstrated only in exotic or stressed trees. Survival and establishment of nematodes in feeding wounds is apparently limited. However, the nematodes are almost ubiquitous in dying or recently dead trees. Nematodes are apparently transmitted very efficiently during oviposition and fully colonize trees or logs. The result is that cerambycids emerging from dying or recently dead trees usually carry pine wood nematodes.

Disease Spread

Pine wilt disease is similar to Dutch elm disease in that an insect is required to vector the pathogen to healthy hosts. In Japan, *Monochamus alternatus* is the principal vector of the nematode from infected to healthy hosts, but seven other species of cerambycid beetles can carry the nematode. Spread of the disease has been estimated at about 20 miles per year solely because of beetle movement. However, the movement of infected logs by man has greatly increased the proliferation of the epidemic.

In North America, four species of cerambycid beetles are capable of acting as vectors for the nematode, but the number of nematodes reported per beetle is lower than in Japan.

Economic and Ecological Impact

On the islands of Kyushu and Honshu, losses to pine wilt disease during the 1930's increased from 30,000 cubic meters to 200,000 cubic meters. By 1979, 2.4 million cubic meters of standing timber were destroyed, and by 1983 it was estimated that 25 percent of all Japanese pine forests had been infested.

In North America, native pine species are resistant to the pine wood nematode, and only exotic pine species have fallen prey. However, the mere presence of the parasite in a number of native pine species has prompted Scandinavian countries to embargo all wood products except squared lumber from U.S. Southern States, at an annual loss of $20 million to the U.S. forest products industry. An even greater loss is faced by British Columbia, where the discovery of the pine wood nematode in less than 1 percent of the trees sampled has caused the European Community to curtail its imports of green lumber, worth $600 million annually, after January 1, 1992.

The ecological impact of pine wilt disease can only be surmised here. The loss of one-quarter of the Japanese pine forests is comparable in scale to the loss in the United States of the American chestnut from chestnut blight. Reports that the nematode can adapt to the colder regimes found in Northern Japan and at high elevations suggest that soil erosion and flooding may become widespread, especially at higher elevations.

Management

Two methods are used for controlling pine wilt disease: spraying insecticides for eradicating the insect vectors and felling and burning diseased trees to eliminate the breeding habitat of the nematode and the beetle vector. Although destroying infested trees is preferable from an environmental viewpoint, a wider area can be treated by insecticides. However, both techniques are only moderately effective and are practical only in relatively limited areas. Costs of sanitation felling and burning are unavailable. In 1981 alone, $30 million was spent on insecticide aerial applications.

Chapter 4 Organisms Posing Risk

Introduction

A tremendous number of pest species have the potential to be introduced from the Eastern Soviet Union to Western North America (Appendix H). However, with this risk assessment, time and data were insufficient to allow an evaluation of the risks posed by every organism. Instead, representative species were selected for evaluation from each major pest group. These representative species were selected based on their perceived high potential risk and the availability of data. For example, rather than trying to investigate every bark beetle that could be introduced by way of logs imported from the Soviet Far East, several *Ips* beetles were selected as representatives. Conclusions about the likelihood of introduction, potential damage, and possible mitigation measures in these representative cases should apply to other species or even to unknown species of bark beetle.

The selected organisms of concern can be grouped into three categories: those that could hitchhike on logs, those associated with the bark and inner bark, and those found in the wood. Tables 4-1 through 4-3 summarize the Siberian forest pests of concern identified by the Core Team and its advisory groups. The tables list probabilities of transport, establishment, and colonization from each pest, along with the estimated potential loss resulting from introduction into North America.

Risk evaluations of 36 pest organisms of concern were completed by the Core Team and advisory groups. This chapter presents the risk evaluations for the possible introduction and spread of the six pest organisms that will receive detailed economic analyses in Chapter 5 and detailed ecological analyses in Chapter 6: Asian gypsy moth (*Lymantria dispar*), nun moth (*L. monacha*), pine wood nematode (*Bursaphelenchus mucronatus*), larch canker (*Lachnellula willkommii*), spruce bark beetle (*Ips typographus*), and annosus root rot (*Heterobasidion annosum*). (See Appendix I for the other pest species profiles).

Asian Gypsy Moth and Nun Moth

Scientific Name of Pest—*Lymantria dispar* L. and *L. monacha* L.
Scientific Name of Host(s)—*Larix* spp. and numerous other conifer and hardwood species
Specialty Team—Entomology
Assessor—William Wallner

Summary of Natural History and Basic Biology of the Pest

Lymantria dispar (Asian gypsy moth) and *L. monacha* (nun moth) belong to the order Lepidoptera and family Lymantriidae. *Lymantria dispar* and *L. monacha* are very similar in their habits, development, and host utilization. As major defoliators of numerous trees, shrubs and herbaceous plants, both species have consistently been considered major pests across the Soviet Union, Europe, and Asia. The gypsy moth is present in the United States; however, to date, neither the nun moth nor the Asian gypsy moth has been found in the United States. The Asian gypsy moth's behavior differs significantly from that of the gypsy moth of North America, thus warranting extensive efforts to exclude it from North America. The North American gypsy moth originated from Western Europe, and the strain lacks the capacity of directed flight by winged females. The Asian gypsy moth, on the other hand, is an active flyer, often attracted to lights, and capable of flying up to 40 kilometers.

The capacity to colonize new environments has been consistently demonstrated by the gypsy moth in North America, where it continues to spread and establish populations in the Eastern and Western United States and Canada. Cyclical outbreaks of gypsy moths in the United States have been extensive; more than 12 million acres were defoliated in 1981, and sporadic yearly defoliation continues.

Yearly monitoring, suppression, and eradication efforts cost the United States and Canada several

Table 4-1. Siberian Forest Pests of Concern on Bark (Hitchhikers)

Pest	Probability of Host Association	Transport Potential	Transport Survival	Establishment Potential	Colonization Potential	Potential Loss
Insects:						
Asian gypsy moth (*Lymantria dispar*)	M	H	H	H	H	H
Nun moth (*Lymantria monacha*)	M	H	H	H	H	H+
Root/stump insects (Scolytidae, Curculionidae: *Hylastes, Hylurgus, Hylobius, Hylurgops*)	M/H	H	H	M/H	M/H	H
Scale insects (*Physokermes, Aspidiotus, Lepidosaphes, Nuculaspis, Matsucoccus*)	H	H	H	M	M/H	?
Flatbugs (*Aradus cinnamomeus*)	H	H	H	H	H	H
Aphids (*Cinara* spp.)	H	H	H	H	H	M
Wooly adelgids (*Adelges* spp.)	H	H	H	H	H	H
Siberian silk moth (*Dendrolimus sibericus*)	M	H	H	M	M	H
Pathogens:						
Melampsora rust (*Melampsora* spp.)	L/H	L/H	L/H	L/H	H	M/H
Larch needle cast (*Meria laricis*)	L/H	L/H	L/H	L/H	L/H	L/H
Conifer shoot blight (*Sirococcus strobilinus*)	L/H	L/H	L/H	L/H	H	L/M

Note: H = HIGH, M = MODERATE, L = LOW.

Table 4-2. **Siberian Forest Pests of Concern in Bark and Inner Bark**

Pest	Probability of Host Association	Transport Potential	Transport Survival	Establishment Potential	Colonization Potential	Potential Loss
Insects:						
Engraver beetles (*Ips duplicatus*, *I. sexdentatus*, *I. subelongatus*)	H	H	M	M/H	H	M/H
Ips typographus	L	H	H	L	H	H+
Dendroctonus micans	M/H	H	H	H	H	H
Weevils (*Pissodes* spp.)	M	H	H	L	H	H

Note: H = HIGH, M = MODERATE, L = LOW.

Table 4-3. Siberian Forest Pests of Concern in Wood

Pest	Probability of Host Association	Transport Potential	Transport Survival	Establishment Potential	Colonization Potential	Potential Loss
Insects:						
Monochamus urussovi	H	H	H	H	H	H+
Xylotrechus altaicus	H	H	H	M	H	H-
Siricidae (*Paururus, Xeris, Sirex*)	H	H	H	M	M	H
Pathogens:						
Larch canker (*Lachnellula willkommii*)	H	H	H	M/H	H	H
Annosus root disease (*Heterobasidion annosum*)	H	H	H	H	H	L/H
Staining/vascular diseases (*Ophiostoma* spp., *Leptographium* spp.)	H	H	H	H	H	M/H
Wood nematodes (*Bursaphelenchus kolymensis, B. mucronatus*)	H	H	H	H	H	H
Red ring rot (*Phellinus pini*)	H	H	H	L	L	L/M

Note: H = HIGH, M = MODERATE, L = LOW.

millions of dollars every year. Defoliation by gypsy moths can severely weaken trees and, in most cases, results in reduced tree growth, aesthetic depreciation, and elimination of preferred tree species from forest composition. Both the gypsy moth and nun moth are univoltine, passing the winter as egg masses on the bark or limbs of trees or on other objects such as rocks or fallen branches, or in the litter. The egg stage lasts approximately 9 months, providing an extended period for eggs to be inadvertently transported by man's activities. Egg masses of both species may contain 600 to 1,000 eggs.

The biotic potential of numbers of progeny introduced with one egg mass and the capacity to attack numerous host plants clearly contribute to the potential for such pests to be highly contagious. Spread and establishment can occur either from first instar larvae being carried by wind currents or from female moths flying to suitable host trees.

In Siberia and the Soviet Far East, both of these species are present at varying densities every year, thereby increasing the probability of inadvertent transport. The nun moth is a principal pest of spruce, larch, and fir, and is considered to be one of the most damaging and dangerous pests in the Soviet Union. The gypsy moth currently present in the United States has more than 250 known hosts but prefers oak. The Asian gypsy moth has a similar broad host range, but prefers larch, alder, and willow.

Specific Information Relating to Risk Elements
Probability of Pest Establishment

Pest With Host at Origin—Both species prefer larch as a host and lay their egg masses on the bark of stems and branches. This ensures that there will be a high probability of presence on larch. Probability would increase when either insect is in an outbreak mode, but their common occurrence across the Soviet Union presents a risk even when populations are not high.

Entry Potential—Egg masses are preferentially deposited in bark crevices and fissures and because of their color may be very difficult to detect visually. Masses are very tolerant of extremes in temperature and moisture and are securely attached to the bark; these qualities promote high survival and transport capabilities.

Colonization Potential—As strongly polyphagous insects possessing the capacity to infest more than 250 different plant species and a proven capability to colonize new, diverse habitats, Asian gypsy moth and nun moth must be regarded as serious threats. Thus, if inadvertently introduced into coniferous, mixed conifer/hardwood, or hardwood regions, the capacity for colonization is great.

Spread Potential—Asian gypsy moths and nun moths disperse as first instar larvae carried by air currents. Though long-distance dispersal (several kilometers) is uncommon, short-distance dispersal (several hundred meters) is well documented. The capacity for prolonged and extensive flight by females of both species imparts a dangerous quality not present in existing Lymantriid moths in North America.

Consequences of Establishment

Economic Damage Potential—The establishment of the North American strain has caused significant economic losses and protection costs. Because the Asian gypsy moth and nun moth possess extremely broad host ranges and because acceptable host material is found in most regions of North America, these defoliators constitute a threat to forests, urban plantings, and agriculture. The behavioral traits of these Lymantriids would necessitate developing and adopting new management strategies and techniques if they were introduced.

Environmental Damage Potential—Defoliation by the gypsy moth in the Eastern United States has changed the composition of the forests. This change in the character of eastern forests portends comparable major shifts in the Pacific Northwest if these species become established.

Perceived Damage (Social and Political Influences)—Past experiences with the gypsy moth in North America have elicited substantial public pressure to deal with the problem. Not only does defoliation impose high costs to protect trees, but at high densities dispersing larvae cause serious allergic responses in humans because of the urticating hairs. The nun moth causes similar impacts. Millions of dollars have been spent annually on the gypsy moth problem. Moreover, control measures may have negative environmental consequences. All these problems would be expected to magnify significantly should the Asian gypsy moth or nun moth become established in the United States.

Estimated Risk
Because of the survivability, transportability, and difficulty of egg mass detection, the probability of detection would be low. The cost and effort necessary to adequately detect entries on logs is very high. Dead trees, pallets, and even the hulls and rigging of ships are known to harbor egg masses. Interception of Asian gypsy moth egg masses on Soviet ships is documented.

Additional Remarks
The introduction of either the Asian gypsy moth or the nun moth would seriously complicate and compromise ongoing gypsy moth eradication and suppression efforts. Females capable of strong directed flight would permit extensive recolonization for which current chemical and biological control procedures are extremely inadequate.

Pine Wood Nematodes

Scientific Name of Pest—*Bursaphelenchus mucronatus, B. kolymensis,* and other xylem-inhabiting nematodes
Scientific Name of Host(s)—*Abies* spp., *Larix* spp., *Pinus* spp., and other conifers
Specialty Team—Pathologists
Assessor—Dale R. Bergdahl

Summary of Natural History and Basic Biology of the Pest
Species of nematodes from the genus *Bursaphelenchus* are known to inhabit both the wood and bark tissues, including the roots of many species of conifers. These nematodes are not known to naturally inhabit the soil. The life cycles of *Bursaphelenchus* species are very similar to the cycle of *Bursaphelenchus xylophilus* (pine wood nematode) (see Chapter 3). These nematodes are associated with a large number of species of coleopterous insects and are believed to be primarily vectored by Cerambycidae.

A large number of wood-staining fungi (*Ceratocystis, Leptographium, Verticicladiella,* and so forth) are also associated with and vectored by many species of Coleoptera. Some of these fungi are pathogenic to trees, and some also serve as a food source for *Bursaphelenchus* in the wood and bark tissues of their respective coniferous hosts.

In general, these nematodes are introduced into either healthy, stressed, or dying trees, as well as into freshly cut trees or logs maintained in storage areas while awaiting shipment or processing. These nematodes can affect a large number of relatively vigorous trees (under some circumstances), but they usually prefer a predisposed or dead host substrate. These nematodes have a tremendous capacity to reproduce, especially in dead or dying trees or in wood products, such as roundwood logs or wood chips. Their rate of reproduction is increased greatly by warm temperatures, but they can also be found in areas with a wide temperature range.

Under laboratory conditions *B. xylophilus* and *B. mucronatus* can interbreed and therefore have the potential to form interspecific hybrids. However, the ecological or pathogenic potential of these interspecific hybrids remains unknown. In addition, different pathotypes have been described for *B. xylophilus* and variation of this kind also should be expected for *B. mucronatus*.

Bursaphelenchus xylophilus is the only species of *Bursaphelenchus* that has been associated with considerable tree mortality, especially as an introduced pest. Seedling inoculation tests suggest that *B. mucronatus* may also be capable of killing some tree species, though it appears to be much less virulent.

Specific Information Relating to Risk Elements
Probability of Pest Establishment

Pest With Host at Origin—Highly probable. Species of *Bursaphelenchus* are commonly found in all types of dead timber and harvested logs, especially those infested with Cerambycidae. Some of these Cerambycidae (*Monochamus* sp.) complete their maturation feeding on living trees and then oviposit in dying or dead trees or in recently cut logs. If cut logs remain in a forest environment for any length of time during the summer months prior to processing, they will likely be attacked by these Cerambycidae and also will become contaminated with *Bursaphelenchus* spp. *B. mucronatus* and *B. kolymensis* have been reported in Siberia. *B. mucronatus* and associated cerambycids were found in test shipments of imported logs described in Chapter 1.

Entry Potential—Very high. Species of Cerambycidae (*Monochamus* spp.) will easily survive transit to

North America, assuming bark is left on the logs. If the bark has been removed prior to shipment the insects' survival rate may be reduced, especially if the logs were debarked soon after harvesting. *Burasphelenchus* spp. will survive transit to North America in wood or bark tissues. Nematodes will even survive mill processing of wood into lumber or other mill products. However, the nematode will be eliminated by kiln heating/drying when kiln temperatures exceed about 60 °C.

Species of Cerambycidae can be detected at ports of entry by looking for oviposition sites or larval feeding galleries. *Bursaphelenchus* spp. can be detected at ports of entry only by using nematode extraction procedures designed for sampling wood products. These standard extraction methods are time consuming, cumbersome, and not very efficient.

Colonization Potential—Very high. The conifers near U.S. ports of entry are very susceptible to attack by the Cerambycidae. If these exotic insects emerge from nematode-infested logs, the probability of nematode transmission to our native conifers will be extremely high. Once the nematode has been successfully transmitted, native Cerambycidae will continue the vector relationship without any additional involvement by the exotic vector. Any recently dead or dying trees or any logs scattered in the yard or left in piles around the general area of the port of entry could potentially serve as a breeding site for both the nematode and its exotic or native vectors.

There does not appear to be any appreciable environmental resistance to either *Bursaphelenchus* spp. or their insect vectors. The only exception would be that during the winter months the vectors and nematodes are dormant.

Certain environmental stress factors have been reported to enhance the success of *B. xylophilus*. These factors include predisposition of trees as a result of infection by other pathogens, high temperatures, prolonged drought, and insect attack. Also, trees growing outside of their native ranges are believed to be more susceptible to *B. xylophilus*. Other species of *Bursaphelenchus* may also be favored by similar factors of environmental stress.

If the exotic *Bursaphelenchus* spp. enter this new North American environment, they could propagate without any known obstacles. The host species are quite similar and some extend across the entire northern boreal region of North America. Also, significant coniferous forests extend along the Pacific Coast and throughout the Rocky Mountain regions of North America. In addition, the meteorological and climatological parameters should not offer any resistance to colonization by the exotic species of *Bursaphelenchus* because native species of this nematode (and their vectors) commonly occur throughout the geographic regions and host ranges just described.

Spread Potential—Very high. Species of *Bursaphelenchus* are commonly found on a wide range of coniferous hosts, though *B. xylophilus* appears to be more pathogenic on some hosts than others. Host specificity for other species of *Bursaphelenchus* is unknown but is likely to exist. However, when these nematodes are feeding on fungi in wood they appear to feed on a large number of different fungal species. Whatever level of host/pathogen specificity that exists should not hinder spread because the species of *Bursaphelenchus* are capable of propagating on a large variety of substrates. These nematodes also have a relatively large number of vector species that may have particular host preference, and this factor should serve to enhance probable spread. See the earlier section on colonization potential for additional discussion of the potential for spread as related to host and geographic range and to environmental factors.

Consequences of Establishment

Economic Damage Potential—In North America, *B. xylophilus* is not considered a serious pest of U.S. native conifers. However, some exotic pines (*P. sylvestris*, *P. nigra*, and *P. thunbergii*) have experienced considerable mortality in certain areas. This mortality has occurred when these tree species have experienced environmental stress such as prolonged drought and associated high temperatures. To date, our native conifers have not experienced this kind of mortality, but they do become infested with the nematode once attacked by some Cerambycidae.

In Japan, the pine wood nematode is considered the most serious pest of native conifers in both forests and landscape settings, especially in the warmer coastal areas. The economic and aesthetic impacts associated with this exotic pest have been very substantial, especially in landscape settings. Forested areas also have been decimated.

In Japan, the overall cost of pest management has been very high, and management options are consequently limited to management of the insect vector. The vector management program requires strict sanitation procedures for diseased trees and the application of chemical insecticides to prevent vector feeding on healthy trees. This pest management program has reduced the nematode problem in some areas, but in general it has not been an overall success.

If exotic species or strains of *Bursaphelenchus* spp. were introduced into North America, the outcome of such an introduction would constitute a serious threat to western conifer resources. The nematode experience in Japan, along with experiences in the United States with other pathogens and insect pests, demonstrates the need for concern about the introduction of exotic pests, such as *Bursaphelenchus* spp.

The overall economic impact of exotic pathogenic strains of *Bursaphelenchus* spp. on the forests of North America would be devastating. Also, new strains of the pathogen would most likely emerge due to both the interspecific and intraspecific breeding behavior of this group of nematodes. The potential development of new nematode strains in association with native, established insect vectors is another reason for concern.

Environmental Damage Potential—The experience with *B. xylophilus* in both the Japanese forest and landscape ecosystem clearly demonstrates potential for significant environmental impacts. Many old-growth trees have been destroyed, thus significantly changing ecological succession. Also, environmental damage could result from the application of pesticides for vector control or during the implementation of sanitation procedures. These sanitation procedures require tree removal, and substantial mechanical damage to the site could result.

Perceived Damaged/Social and Political Influences—If new species or strains of *Bursaphelenchus* are introduced to or are developed in North America, our forest industries would face new restrictions (embargoes) on coniferous wood products by importing countries. A number of European countries have placed embargoes on the importation of coniferous wood from countries known to have *B. xylophilus*. These restrictions have reduced U.S. and Canadian timber exports, negatively affecting our forest industries and the working communities they serve. In the long run, these restrictions also will have an impact on our forest management practices. Effects on landscape plantings could make this a local political issue. In addition, effects on Christmas tree growers and nurseries could also be significant and carry additional political implications.

Estimated Risk
The estimated risk for the pine wood nematode is high in all categories.

Larch Canker

Scientific Name of Pest—*Lachnellula willkommii* (Hart.) Dennis (cause of larch canker)
Scientific Name of Host(s)—Affects members of the genus *Larix*: *L. eurolepsis*, *L. laricina*, *L. decidua*, *L. sibirica*, and *L. occidentalis* Nutt. are rated as highly susceptible, whereas *L. gmelinii* and *L. kaempferi* are less so; closely related species of *Lachnellula* affect *Abies* spp., *Pinus* spp., and probably other species of conifers. *L. willkommii* has been reported on *Pseudotsuga menziesii* planted in Norway.
Specialty Team—Pathology
Assessors—Catharine Parks and Donald J. Goheen

Summary of Natural History and Basic Biology of the Pest
Lachnellula willkommii is a Discomycete in the order Helotiales, family Hyaloscyphaceae. It forms apothecia in the centers of young cankers and around the edges of old cankers. Throughout the year these discharge ascospores into the air when moistened by rain. Spores are wind dispersed. Precise sites of new infections are not known but are suspected to be dead branchlets and dwarf shoots. Frost injury may aggravate damage by *L. willkommii*. It is believed that most new infections occur in autumn. The fungus is a good saprophyte and survives for a considerable time in dead wood and bark. The pathogen is alien to North America. *Lachnellula willkommii* is favored by oceanic climates. Its most extensive damage is associated with cool conditions, high humidity, frequent fog formation, and moist soils.

Effect of Pest on Host—*Lachnellula willkommii* causes perennial cankers, usually centered on dead dwarf shoots, twigs on branches, or small-diameter (up to 10 cm) main stems. Cankers are misshapen, swollen, and resin impregnated. Stems are often girdled, resulting in the death of the branch or tree.

Specific Information Relating to Risk Elements
Probability of Pest Establishment

Pest With Host at Origin—Lachnellula willkommii is widely distributed on larch in Siberia and the Soviet Far East.

Entry Potential—There is a high probability of entry. The fungus survives well as a saprophyte on dead branchlets and in the bark and wood of cankers. It can survive in wood protected from surface disinfection and bark removal. *Lachnellula willkommii* has been introduced at least twice into the Eastern United States and Canada.

Colonization Potential—Presumed to be moderate to high. Climatic conditions should be particularly favorable for the fungus in Washington, Oregon, and northern California. Western larch is a highly susceptible host. Fortunately, however, the natural range of western larch is east of the Cascade Mountains, so wild trees should not be directly exposed to inoculum from imported logs unless such logs are transported from the coast to east-side mills. Ornamental larch are grown on the west side and could be infected and serve as bridges to natural stands of western larch. Colonization of eastern larch has been very widespread following introduction into the Eastern United States and Canada. If the fungus could infect *Pseudotsuga menziesii*, colonization potential would be extremely high.

Spread Potential—Once established, potential to spread should be high. Favorable climate, a highly susceptible host, and fairly extensive, contiguous stands, often containing substantial components of young trees, should be ideal for this fungus. Wind-borne spores allow rapid and extensive spread of *L. willkommii*. An introduction of the pathogen in 1980 has resulted in the establishment of the disease throughout much of Maine and New Brunswick and into Nova Scotia.

Consequences of Establishment

Economic Damage Potential—Economic losses would be considerable if the pathogen is established in western larch stands. Based on experiences in the Eastern United States and Canada, 50 to 100 percent of larch in plantations and young managed stands are infected and damaged by *L. willkommii* when the fungus is present.

Environmental Damage Potential—Western larch is an extremely important seral tree species in many plant communities in Oregon, Washington, Idaho, and Montana. If populations were seriously affected by larch canker or if foresters discriminated against larch because of real or perceived management problems associated with the disease, successional tree species, including true fir and Douglas-fir, would probably be favored in management on east-side sites (especially high-elevation sites where pines would not do well). These tree species are much more susceptible to damage by native insect and disease pests than western larch.

Perceived Damage (Social and Political Influences)—There is the possibility of severe damage to ornamental larch plantings. Aesthetic effects in natural stands could be substantial but are difficult to assess.

Estimated Risk
The estimated risk for the larch canker is high.

Additional Remarks
To mitigate this pest, a procedure would have to be developed that could kill the fungus at some depth in the wood of cankered stems. Treating the bark only is not sufficient.

Spruce Bark Beetle

Scientific Name of Pest—*Ips typographus* L. (spruce bark beetle)
Scientific Name of Host(s)—*Picea* spp., *Pinus* spp., and *Larix* spp.
Specialty Team—Entomology
Assessor—Alan A. Berryman

Summary of Natural History and Basic Biology of the Pest
Ips typographus belongs to the order Coleoptera, family Scolytidae. It breeds in cut logs, windfallen trees, and, during epidemics, standing spruce trees and occasionally other species of conifer (for example, pines and larches). The beetle is found in all areas where spruce grows on the Eurasian continent. Adult beetles bore through the bark of the tree and construct "tuning-fork" shaped galleries in the phloem-cambium layers of the host. During attacks, they inoculate the tissues of the tree with several species of fungi, some of which are extremely pathogenic. In Norway, the most pathogenic

species is *Ophiostoma polonica*; living spruce can be killed by mass inoculation of this fungus alone.

During initial attack on a susceptible host, beetles release powerful chemical pheromones that draw other beetles to the attacked tree. This aggregated attack enables the beetles to mass inoculate the tree with pathogenic fungi, which then kill the tree by invading its conducting tissues.

Female beetles lay their eggs in tunnels constructed in the inner bark of dead or dying trees. Larvae hatching from these eggs feed on the phloem and eventually pupate at the end of their mines. All the life stages are located in the inner bark layer (phloem-cambium region) of the tree. Finally, the brood adults bore out of the dead tree and either overwinter or fly to new host material.

Spruce beetles normally complete a single generation each year in the cooler parts of their range but may complete two or even three generations in warmer areas. Adults usually overwinter in the forest litter and duff, but about 10 percent of the brood can be found overwintering within trees.

Spruce beetles most often infest downed trees (for example, logs and windfalls), and in this endemic state do little damage to the forest. On occasion, however, their populations can grow following large windstorms or droughts, and they can then attack and do considerable damage to forested ecosystems. For example, spruce beetle epidemics in Norway in the 1850's and 1970's were preceded by windstorms and accompanied by severe droughts, while the outbreaks in Germany after World War II started in neglected forests damaged by warfare.

Specific Information Relating to Risk Elements
Probability of Pest Establishment

Pest With Host at Origin—The probability of association with raw logs depends on the species of tree. Spruce is the preferred host, followed by pine and then larch. The probability of host association is high for spruce, moderate for pine, and low for larch.

Entry Potential—Given host association, the probability of entry on raw logs is very high because brood larvae and adults can be found under the bark of the host almost all year round; i.e., eggs or larvae can be found in logs all year, but most abundantly in spring and summer. Adults will usually be found in logs in fall and winter but in rather low numbers, because most emerge from logs and overwinter in the litter and duff on the forest floor.

Colonization Potential—If beetles are introduced into an area containing spruce logs or windfalls, the probability of colonization and establishment would be high. Highest risk would be around ports of entry in Washington, Oregon, northern California, and Alaska where Sitka spruce forests grow along the coasts.

Spread Potential—Spruce beetles are strong fliers and, once established, would be expected to spread rapidly into adjacent spruce forests. For example, native American bark beetles have been found frozen on the glaciers of Mt. Rainier, which demonstrates that they can disperse over the Cascade Range. The rate of spread of bark beetle outbreaks is quite variable. In general, beetles will fly as far as necessary to find suitable hosts. Mass attacks on many trees 30 miles away from a source of beetles have been observed. The rate of spread of spruce beetles is estimated to be from 1 to 30 miles per year, with a mean of approximately 10 miles per year. If established in the spruce forests of Western North America, the beetle would probably spread throughout the Pacific Northwest, eventually, north into Alaska and east to the Atlantic in the contiguous boreal spruce forests.

Consequences of Establishment

Economic Damage Potential—The introduction of *Ips typographus* into the spruce forests of North America could have disastrous consequences. The outbreak in Norway during the 1970's killed 5 million cubic meters of spruce. In addition, the spruce beetle carries one of the most pathogenic conifer fungi known, *Ophiostoma polonica*. If this fungus becomes established in North America, it could also be picked up and transmitted by native *Dendroctonus* spruce beetles. This could be as disastrous to North American spruce as the Dutch elm disease was to elms.

Environmental Damage Potential—Infestation by *I. typographus* could cause replacement of Sitka spruce by western hemlock and hardwoods in coastal areas and replacement of Engelmann spruce by true firs, mountain hemlock, and lodgepole pine at high elevations.

Perceived Damage (Social and Political Influences)—British Columbia has extensive and very valuable Sitka spruce forests. Destruction of these forests by insects or diseases introduced by U.S. interests could have severe political consequences. The possibility of lawsuits by injured parties, including U.S. forest landowners and foreign governments, should be considered. Several spruce species are extensively planted as ornamentals. Damage to homeowners' trees could have considerable political ramifications.

Estimated Risk
Because of economic, social, and political damage potential of the introduction of *Ips typographus* and its associated fungi, particularly *Ophiostoma polonica,* into North America, the estimated risk must be considered extremely high in raw (unpeeled) spruce logs, high in unpeeled pine logs, and moderate in unpeeled larch logs.

Annosus Root Disease

Scientific Name of Pest—*Heterobasidion annosum* (Fr.) Bref. (=*Fomes annosus)* cause of annosus root disease.
Scientific Name of Host(s)—This fungus has been reported on virtually all conifers and many hardwoods in the Northern Hemisphere. Different strains of the fungus exist that are specific to certain hosts or host groups.
Specialty Team—Pathology
Assessors—Donald J. Goheen and William J. Otrosina

Summary of Natural History and Basic Biology of the Pest
Heterobasidion annosum belongs to the division Eumycota, subdivision Basidiomycotina, class Hymenomycetes, order Aphyllophorales, and family Polyporaceae. Basidiocarps (conks) of *H. annosum* develop in hollow stumps, root crotches, hollows in logs, on the outsides of trees or stumps near ground level, or on the undersides of windthrown trees. Basidiospores are released throughout the year (fewer during particularly cold or warm periods) and are dispersed over long distances (100 miles or more) by the wind. Spores that land on freshly cut stump surfaces or fresh wounds germinate, and the fungus colonizes the tree or stump (Rishbeth, 1951; Yde-Andersen, 1962; Cobb and Barber, 1968). Subsequently, the pathogen can grow via root contacts into surrounding hosts, creating gradually expanding disease foci (Hadfield et al., 1986; Sinclair et al., 1987; Otrosina and Cobb, 1989). In addition to basidiospores, *H. annosum* has an asexual conidial spore state, designated as *Spiniger meineckellus*. Asexual spores can also initiate infections (Kuhlman and Hendrix, 1964; Kuhlman, 1969; James et al., 1980). Asexual spores are readily produced on damp, decayed wood and may be dispersed by water and perhaps insects (Hunt and Cobb, 1982). Wind dispersal by this spore stage is not believed to be nearly as effective as that of basidiospores, but there is evidence that it does occur (Shaw and Florance, 1979; Florance and Shaw, 1988).

Heterobasidion annosum is a heterothallic fungus. Individual basidiospores of the fungus, upon germination, give rise to homokaryotic mycelia (multinucleate cells with haploid nuclei). Homokaryotic mycelia are self-sterile and do not differentiate to form a basidiocarp. Mating must take place between two sexually compatible homokaryotic mycelia to form a dikaryon (which has cells with n+n nuclear condition) prior to mitotic division and formation of a sexual fruiting body. There are several subpopulations of morphologically identical but genetically different strains within the species *H. annosum* (Chase, 1989). These strains cannot be distinguished on the basis of appearance, but they are intersterile and will not form dikaryons with each other. They also differ markedly in pathogenicity and host range. In Europe, "P," "S," and "F" strains have been identified that are quite specific to pines, spruce, and true firs, respectively (Korhonen, 1978; Korhonen et al., 1988). In North America, a "P" strain that affects pines and an "S" strain that affects mainly true firs and hemlocks have been identified (Chase, 1989; Chase et al., 1989). European and North American strains differ. Identities of *H. annosum* strains from Siberia and the Soviet Far East are not known. They may differ from all strains that have been studied to date.

Effect of Pest on Host—*Heterobasidion annosum* affects host trees in two ways, either by causing outright mortality or by causing progressive butt and stem decay. Generally, among North American hosts infected by native strains of *H. annosum*, pines are killed fairly rapidly, while hemlocks develop butt rot and true firs exhibit both kinds of damage (Sinclair et al., 1987; Hadfield et al., 1986; Schmitt, 1989). The literature suggests that the strain or strains of *H. annosum* that occur in Siberia and the Soviet Far East cause mortality of *Abies, Picea, Pinus* and *Larix* spp., with the latter being somewhat less severely damaged than the other three (Davidenko and Nevzorov, 1978; Korotkov, 1978). *Heterobasidion annosum* also causes butt rot in *Picea* spp. (Fjodorov and Poleschuk, 1978) and old-growth *Larix* spp. (Rozhkov, 1966).

Specific Information Relating to Risk Elements
Probability of Pest Establishment

Pest With Host at Origin—*Heterobasidion annosum* is reported to be widely distributed on *Larix, Picea, Abies,* and *Pinus* spp. in Siberia and the Soviet Far East (Rozhkov, 1966; Negrutsky, 1975). It is also reported to be one of the most damaging tree diseases of the Soviet Union. According to Negrutsky, "On the territory of the U.S.S.R., *H. annosum* is one of the most dangerous and widespread pathogens which, at the same time, is encountered in the forests of the Baltic Republics—in Estonia, Latvia, Lithuania, and in the forests of Byelorussia, the Ukraine, in the central region of the R.S.F.S.R., the Urals, Siberia, Kazakhstan, and it may be characterized by the concept of epiphytation."

Entry Potential—Entry potential for *H. annosum* is very high. Infected logs would be difficult to detect and discriminate against at logging or shipping sites. Incipient decay of *H. annosum,* in particular, is difficult to distinguish, but even conks on infected trees could be missed because of their cryptic appearance and inconspicuous nature. *Heterobasidion annosum* is an excellent saprophyte that can survive for 10 to 60 years in old stumps (Sinclair et al., 1987). Survival periods in logs would be shorter but still substantial, especially if logs were shipped and stored in moist, cool environments. Survival times of the fungus in large logs would be greatest. To effectively deal with *H. annosum,* a mitigation treatment would have to kill fungal mycelia in the center of logs. If untreated *H. annosum*-colonized logs are delivered to ports in northern California, Oregon, and Washington, the likelihood of spore production would be high. It is possible that conks already present on or in logs before shipment or that develop on logs subsequently during storage would produce basidiospores. A much more likely scenario, however, is that the *Spiniger* form of the fungus would develop on logs or wood and bark scraps and release asexual spores.

Colonization Potential—Colonization potential would be high. Suitable hosts and sites for initial infections (stumps, wounded trees) are common in the vicinities of the proposed ports of entry. Though the various strains of *H. annosum* exhibit host specificity, it is usually at the level of genera rather than species, and some strains affect several genera. Given the similarity of conifer genera in the Eastern Soviet Union and Western United States, it is almost certain that *H. annosum* strains that are capable of infecting *Larix, Pinus, Abies,* and *Picea* spp. in Siberia and the Soviet Far East could infect members of the same genera in the Western United States. It is also possible that an introduced strain could affect other hosts here. For example, seedling inoculation tests suggest that *Pseudotsuga menziesii* is very susceptible to a strain of *H. annosum* from pine in Scandinavia, according to a personal communication with E. M. Hansen.

Spread Potential—If established, the potential for *H. annosum* to spread is high. Basidiospores from sexual fruiting bodies are wind dispersed, giving the fungus an extremely dangerous ability to spread far and rapidly. Asexual spore spread would probably cover much shorter distances, but there is the possibility of insect-vectored spread and some wind dispersal with this spore stage as well. Spread from tree to tree via mycelial growth across roots occurs at a rate of 1 to 2 feet per year.

Consequences of Establishment

Economic Damage Potential—The amount and type of economic damage associated with *H. annosum* from the Eastern Soviet Union would largely depend on whether the strain or strains of the fungus introduced were the same as native North American strains. If the same, there would probably be little or no increase in amount of *H. annosum*-caused tree mortality or decay. If a different strain were introduced, however, increased damage would be very likely and would take one of two forms: (1) increased killing or decay in a host genus or species that is already affected by *H. annosum* in the Western United States; or (2) mortality or decay in a host not previously damaged by *H. annosum.* Relative to this second scenario, the possibility of introducing a strain of the fungus that would be damaging to *Pseudotsuga menziesii* or *Larix occidentalis* in the Pacific Northwest would be of special concern.

Obviously, a comparison of the strains of *H. annosum* from the Eastern Soviet Union and the Western United States is key to a definitive assessment of risk associated with importing infected logs. To date, there has been no effort to do this. In the absence of this research information, there is reason for caution because forest pathologists who have studied the genetics of *H. annosum* in other parts of the world believe that there is a high probability that strain differences exist, and the little existing literature indicates that the pathogen acts more aggressively in the Soviet Union than in the United States. The research necessary to answer this critical question should be done before unprocessed logs are allowed entry into the United States.

The magnitude of wood losses caused by native strains of *H. annosum* in the Western United States varies. Loss due to decay in young *Tsuga heterophylla* stands has been measured at approximately 1 to 3 percent of the volume (Goheen et al., 1980; Littke and Browning, 1989); however, in stands over 180 years old it may be as high as 25 to 50 percent (Buckland et al., 1949; Foster et al., 1954). Loss due to mortality in *Pinus ponderosa* stands ranges from 3 to 20 percent of the basal area on especially dry sites (Goheen and Goheen, 1989). Losses reported in managed *Abies concolor* stands ranges from 0.5 to 21 percent of the trees (Goheen and Goheen, 1989). Associated basal area losses were from 0 to 50 percent. In the Pacific Coast States, *H. annosum* is rarely found on *Pseudotsuga menziesii* and *Larix occidentalis* and causes virtually no damage to these species. This could change with the introduction of new strains of the fungus. When considering economic implications of annosus root disease, it should be noted that chemical control (stump infection prevention) is possible. Cost of stump treatment is about $0.75/stump. Effectiveness of control is believed to be about 95 percent.

There is some question about the future environmental suitability of chemical stump treatment.

Environmental Damage Potential—Because the tree killing strains of *H. annosum* tend to cause mortality of one or several closely related genera or species and because killing tends to occur in radially expanding infection centers, the pathogen could be responsible for tree species shifts. The type or magnitude of any such shift cannot be predicted without additional information on specific fungus strains and hosts that might be involved.

Perceived Damage (Social and Political Influences)—Depending on the strain of the fungus introduced, *H. annosum* could have significant impacts on ornamental plantings, nurseries, and Christmas tree plantations.

Estimated Risk
The estimated risk for annosus root disease is high.

Chapter 5
Economic Effects Evaluation

Introduction

Oregon, Washington, and northern California are major exporters of timber, agricultural, and fish products. The regional economy is diversifying to some extent; however, these natural resources will continue to be a significant part of the area's employment and commerce.

Forest products remain the core of the Pacific Northwest regional economy, and directly account for 44 percent of Oregon's income and 28 percent of Washington's. Forest products of the inland West play a lesser, yet significant role in their regional economies. Conifers constitute California's major timber resource. From 1977 to 1981, the State's commercial forests yielded an average of 3.5 billion board feet of timber with a value of almost $621 million. Softwood log exports from Washington, Oregon, northern California, and Alaska totaled 3,370,444 thousand board feet in 1989. The average value for those logs varied from $443.71 per thousand board feet in Washington to $632.71 per thousand board feet in Oregon. If the introduction of exotic pests causes an international embargo on logs from the Western United States, the economy of these States will be severely affected.

These forest lands, both public and private, are among the most productive in the world. About 76 percent of the forested land in the Pacific Northwest has a timber productivity of at least 20 cubic feet per acre per year. Approximately 85 percent of this acreage is currently available for regulated timber management and represents approximately 65 percent of the total national forest land in the Pacific Northwest region.

Lands west of the Cascades constitute the Douglas-fir subregion, while the lands to the east are part of the ponderosa pine subregion. The two subregions differ markedly in their timber production. The Douglas-fir subregion is the more productive, with 43 percent of the Douglas-fir subregion yielding more than 120 cubic feet per acre per year, while only 7 percent of the ponderosa pine subregion is in this class. Yet even with its lower productivity, the ponderosa pine subregion is still valuable timber producing land, vital to the local economy.

This chapter presents the economic evaluations of infestations of defoliator insects, pine wood nematodes, larch canker, spruce bark beetles and annosus root rot developed by separate teams during the second workshop. The following analyses estimate the potential economic costs to the commercial timber resources of the Western United States from each pest and disease group evaluated in Chapter 4. The following factors should be considered:

(1) Each pest group was analyzed independently, and the economic costs were developed in isolation from other potential economic costs caused by other introduced pests. The sum total of economic costs of individual pest groups may not produce a valid estimate of the total costs from introduction of all the pest groups considered because:

(a) Many of the host trees may be simultaneously attacked by several other introduced pests and it would be impossible to estimate what proportion of host type mortality is attributed to a particular pest. Similarly, it would be impossible to allocate growth loss estimates to each group of pests. In this context, summing up the economic costs of each group may overestimate the total economic costs from a simultaneous introduction of pests since a tree only dies once.

(b) Simultaneous attack on host types may also increase mortality rates and growth losses through the synergistic effect of multiple attacks. In this context, summing up the economic costs of each pest group may underestimate the total economic costs from a simultaneous introduction of all or some of the pests considered in this analysis.

(2) There are various assumptions made for each group of pests analyzed. To determine the assumptions, one should refer to each separate pest group analysis. Each economic analysis may use different, yet acceptable, economic methodologies to segregate problems through the use of the team approach. The use of different methodologies makes summation of

economic impacts from individual pest groups a problem.

(3) The separate analysis of pest groups is considered a useful approach for the Animal and Plant Health Inspection Service (APHIS) management practices assessment, particularly when a given mitigation measure is effective for only one or a few groups of pests. The residual effect of the unmitigated pest(s) may be more clearly illustrated when viewed according to independent behavior. This approach may also allow the placement of values on benefits gained for each mitigation measure under consideration.

(4) Analysis of each pest group considered unreserved forests (all ownerships, both public and private) in the Western United States at risk. Potential additions to forest reserves that are being considered for withdrawal or modified management to provide habitat for threatened species were considered in this analysis. If significant reserves are eventually withdrawn, this may significantly decrease the cost figures given below.

(5) It is recognized that control costs for eradication of infestations would be an expected occurrence for epidemics of introduced pests. However, these costs were not considered in the analyses because of: (a) uncertainty about efficacious treatments for introduced pests, (b) uncertainty of optimal funding levels thus affecting efficacy of control efforts, and (c) uncertainty of public acceptance of pesticide use.

Defoliator Insects

Summary

The following ranges display a best case and worst case scenario for damage caused by the introduction of defoliators. Worst case damages are $58.41 billion, assuming a net growth loss of 25 percent per decade. Best case damages are $35.05 billion, assuming a 15-percent net loss in growth per decade.

Economic Analysis

The market effects of defoliators were estimated in a supply and demand context for three regions—the Pacific Northwest, Pacific Southwest, and the Rockies—using derived demand and stumpage supply functions from the 1989 Resources Planning Act (RPA) Timber Assessment (Haynes, 1990). The Alaskan region was investigated early in the study, but was omitted from the published results because of the extreme time frame required for defoliators to spread to Alaska (more than 90 years).

The method decreases the stumpage supply functions (from the 1989 RPA Timber Assessment, (Haynes, 1990)) by the amount of the change in softwood growing stock inventories from reduced forest growth. This approach was adopted because inventory levels are one of the main determinants of stumpage supply. Mortality is reflected in the stumpage supply functions. Changes in inventories act to shift stumpage supply functions in the longer term, while price changes help establish supply levels in the near term. These changes in inventories were computed using a growth drain identity, and the supply functions were shifted by the ratio of base inventory (that is, without defoliators) to the modified inventory.

Assumptions for the Analysis
Among the assumptions employed in this analysis of the economic impacts of defoliators were the following factors:

(1) Basic loss data as given in Appendix J (Data Table for Calculations of Potential Impacts). It is assumed to result in a 15-percent net loss in growth per decade.

(2) Spread rate is assumed to be 20 kilometers/year. Spread rates for each region are assumed (moving from west to east) as follows:

Year	Percent of Spread		
	PNW	PSW	Rockies
1990	0	0	0
2000	45	53	0
2010	91	100	0
2020	100	100	44
2030	100	100	100
2040	100	100	100

(3) Harvest fractions by timber type (information derived from tables 15 and 29 in Waddell et al., 1989).

Area	Percent of Harvest				
	Douglas-Fir	Fir/Spruce	Hemlock	Larch	Other Softwood
PNW	48.1	13.0	19.3	1.8	17.8
PSW	27.4	27.4	0.2	0.0	45.0
Rockies	22.9	28.8	1.0	4.9	42.3

(4) Average reduction in net growth (computed from assumptions 1 and 3):

Year	Percent of Reduction		
	PNW	PSW	Rockies
1990	0.0	0.0	0.0
2000	6.0	6.8	0.0
2010	12.2	12.8	0.0
2020	13.4	12.8	5.9
2030	13.4	12.8	13.5
2040	13.4	12.8	13.5

(5) Effect of growth reductions on softwood growing stock inventories (that is, the ratio of RPA figures to those modified for changes in growth shown above) areas as follows (inventory figures computed using the growth drain identity $I_t = I_{t-1} + G_t - H_t$):

Year	Growth Reductions		
	PNW	PSW	Rockies
1990	1.0	1.0	1.0
2000	0.986	0.988	1.0
2010	0.958	0.967	1.0
2020	0.927	0.949	0.992
2030	0.896	0.932	0.975
2040	0.865	0.918	0.961

Where I_t = current year inventory, I_{t-1} = previous year inventory, G_t = current year growth, H_t = current year harvest.

Economic Impacts

Economic impacts were compiled by: (1) computing the equilibrium price and quantity by decade and by region, and then (2) recomputing the modified equilibrium price and quantity following a shift in the stumpage supply functions, assumed to be induced by changes in growing stock inventories. Basic economic impacts are slow to develop and depend on the extent to which lower growth reduces inventories and hence timber supplies.

The impacts are the largest in the Pacific Northwest with effects eventually reaching the Rockies (see, for example, the differences in stumpage prices shown in table 5-1). The different rates of impact among the three regions reflect both the differences in growth impacts and the rate of spread.

The largest effect is on producers of forest products, who, for example, lose roughly one-half their potential gains in the year 2020. Consumers are much less affected, losing less than 4 percent of their potential gains. The reason for this disparity is the possibility that production in unaffected regions will offset lost production in the West.

This analysis makes no explicit assumption about salvage except to the extent that the demand for some product demands (fuelwood) is often filled by using dead material. In much of the West, fuelwood becomes the only market after tree mortality. Much of the dead material remains in the woods, where it may contribute to non-commodity products. When dead or dying material is salvaged, it is often sold on a per-unit basis at base rates.

This assumption causes stumpage prices to rise, increasing returns to stumpage owners, although this increase is slight in the next decade in the Pacific Coast States. Stumpage price increases in the Rockies are slower to develop because a lower rate of spread is assumed.

All of these analyses assume independence of events among the regions. Taking such direct effects into account would alter the results, as stumpage price increases in one region would shift production to unaffected regions. One further caveat: much of the timber harvest in the West comes from public timberlands where harvest levels are set using harvest scheduling algorithms that would attempt to reduce harvest levels as net growth fell.

The following table summarizes price, quantity, and welfare impacts from reduced growth with the introduction of defoliators and without the introduction of defoliators.

Table 5-1. Price, Quantity, and Welfare Impacts of Reduced Growth Caused by Defoliators, Best Case Scenario

Prices
(1967$/MBF)

	With Defoliators			Without Defoliators		
Year	PNW	PSW	RM	PNW	PSW	RM
2000	49.40	46.48	19.21	48.17	45.81	18.84
2010	75.02	63.64	45.76	71.41	61.78	45.42
2020	89.35	82.07	61.92	84.42	79.52	60.07
2030	91.58	85.81	68.62	85.19	82.75	62.63
2040	91.13	85.98	71.58	83.07	82.51	62.48

Quantities
(million cubic feet)

	With Defoliators			Without Defoliators		
Year	PNW	PSW	RM	PNW	PSW	RM
2000	2,548.65	628.53	835.13	2,557	633	834
2010	2,667.43	625.73	919.82	2,684	636	919
2020	2,707.85	583.50	947.16	2,737	598	950
2030	2,761.26	551.27	941.09	2,799	568	951
2040	2,761.86	511.71	940.51	2,804	530	958

Welfare Impacts—Without Defoliators
(millions 1967 $)

	Consumer Surplus			Producer Surplus		
Year	PNW	PSW	RM	PNW	PSW	RM
2000	2,352.65	163.76	740.37	534.42	129.85	76.44
2010	2,645.13	171.54	924.09	773.60	172.17	197.26
2020	2,823.84	156.51	1,019.54	880.57	199.49	267.08
2030	3,045.08	149.33	1,055.66	890.93	191.88	279.43
2040	3,149.28	132.66	1,111.57	921.61	176.20	281.98

With Defoliators
(millions 1967 $)

Year	PNW	PSW	RM	PNW	PSW	RM
2000	2,336.55	161.64	740.38	543.78	130.57	78.01
2010	2,604.39	165.65	924.07	524.57	126.43	83.46
2020	2,760.70	148.99	1,012.07	498.85	112.52	84.95
2030	2,959.85	138.47	1,030.80	494.21	103.00	84.25
2040	3,046.27	123.72	1,070.38	485.83	94.08	84.29

PNW=Pacific Northwest, PSW=Pacific Southwest, RM=Rocky Mountain Regions of the USDA Forest Service.

Table 5-2. Net Welfare Impacts Resulting From Defoliators in Millions of 1967 Dollars, Best Case

Year	Consumer Surplus			Producer Surplus			Net Welfare Effects	NWE PNV
	PNW	PSW	RM	PNW	PSW	RM		
2000	16.10	2.12	-0.01	-9.36	- 0.72	-1.57	6.56	6.56
2001	18.56	2.50	-0.01	16.48	3.93	9.97	51.43	49.45
2002	21.03	2.87	-0.00	42.32	8.57	21.50	96.29	89.03
2003	23.49	3.25	-0.00	68.16	13.22	33.04	141.16	125.49
2004	25.96	3.63	0.00	94.00	17.86	44.58	186.02	159.01
2005	28.42	4.01	0.01	119.83	22.51	56.12	230.89	189.77
2006	30.88	4.38	0.01	145.67	27.16	67.65	275.76	217.93
2007	33.35	4.76	0.01	177.13	32.23	80.13	327.61	248.96
2008	35.81	5.14	0.01	197.35	36.45	90.73	365.49	267.06
2009	38.28	5.51	0.02	223.19	41.09	102.26	410.35	288.31
2010	40.74	5.89	0.02	249.03	45.74	113.80	455.22	307.53
2011	42.98	6.05	0.77	262.30	49.86	120.63	482.59	313.48
2012	45.22	6.22	1.51	275.57	53.99	127.47	509.97	318.52
2013	47.46	6.38	2.26	288.84	58.11	134.30	537.34	322.71
2014	49.70	6.54	3.00	302.11	62.23	141.13	564.71	326.11
2015	51.94	6.71	3.75	315.38	66.36	147.96	592.08	328.76
2016	54.18	6.87	4.49	328.64	70.48	154.80	619.46	330.73
2017	56.42	7.03	5.24	341.91	74.60	161.63	646.83	332.07
2018	58.66	7.19	5.98	355.18	78.72	168.46	674.20	332.81
2019	60.90	7.36	6.73	368.45	82.85	175.30	701.58	333.00
2020	63.14	7.52	7.47	381.72	86.97	182.13	728.95	332.68
2021	65.35	7.85	9.21	383.22	87.16	183.44	736.23	323.08
2022	67.56	8.19	10.95	384.72	87.35	184.74	743.51	313.73
2023	69.77	8.52	12.69	386.22	87.54	186.05	750.78	304.61
2024	71.98	8.86	14.43	387.72	87.73	187.35	758.06	295.74
2025	74.19	9.19	16.16	389.22	87.92	188.66	765.34	287.09
2026	76.39	9.52	17.90	390.72	88.12	189.96	772.62	278.67
2027	78.60	9.86	19.64	392.22	88.31	191.27	779.90	270.48
2028	80.81	10.19	21.38	393.72	88.50	192.57	787.17	262.50
2029	83.02	10.53	23.12	395.22	88.69	193.88	794.45	254.74
2030	85.23	10.86	24.86	396.72	88.88	195.18	801.73	247.19
2031	87.01	10.67	26.49	400.63	88.20	195.43	808.43	239.67
2032	88.79	10.48	28.13	404.53	87.53	195.68	815.13	232.36
2033	90.56	10.28	29.76	408.44	86.85	195.93	821.83	225.26
2034	92.34	10.09	31.39	412.34	86.18	196.18	828.53	218.36
2035	94.12	9.90	33.02	416.25	85.50	196.44	835.23	211.66
2036	95.90	9.71	34.66	420.16	84.82	196.69	841.93	205.15

Table 5-2. Net Welfare Impacts Resulting From Defoliators in Millions of 1967 Dollars, Best Case (continued)

Year	Consumer Surplus			Producer Surplus			Net Welfare Effects	NWE PNV
	PNW	PSW	RM	PNW	PSW	RM		
2037	97.68	9.52	36.29	424.06	84.15	196.94	848.63	198.83
2038	99.45	9.32	37.92	427.97	83.47	197.19	855.33	192.69
2039	101.23	9.13	39.56	431.87	82.80	197.44	862.03	186.73
2040	103.01	8.94	41.19	435.78	82.12	197.69	868.73	180.95
Total PNV 1967 $								10,144.17
Total PNV 1990 $								35,048.70

Notes:
PNW=Pacific Northwest, PSW=Pacific Southwest, RM=Rocky Mountain Regions of the USDA Forest Service.

The scenario for table 5-2 is the best case scenario analysis of 15 percent growth reduction per decade. The worst case scenario is 25 percent reduction in growth per decade.

Consumer/Producer Surplus (net welfare impacts)—Net consumer and producer surplus impacts were derived from table 5-1 by determining the difference between consumer and producer surplus with and without defoliators. Impacts between decades were derived by simple linear interpolation.

NWE = Net welfare effects—Consumer surplus plus producer surplus.

Net welfare effects (PNV)—a discount rate of 4 percent was used. Net welfare effects are then expressed in 1990 dollars by using Producer Price Index multiplier from "Economic Report of the President, 1991."

Pine Wood Nematodes

Summary
The following ranges display a best case/worst case scenario of potential damage caused by the introduction of the pine wood nematode. Worst case damages are $1.67 billion, for an assumed mortality rate of 100 percent. The best case damages are $33.35 million, for an assumed mortality rate of 2 percent.

Economic Analysis
In the following sections, we analyze the cash flow from timber harvest by assuming pathogenic infestation and concomitant salvage operations net of stand conversion costs and cash flows from timber harvest and the residual stand value without infestation. For the sake of simplicity, we analyzed only the 100 percent mortality case. The other scenarios can be scaled down under an assumption of linear and proportional relationships.

Assumptions
(1) Vectors native to the United States will effectively transmit introduced nematodes. Vectors introduced to the United States (*Monochamus*) may be even better vectors but are not necessary for disease development.

(2) The introduced nematode, whether it is *Bursaphelenchus xylophilus*, *B. mucronatus*, or *B. kolymensis*, will be pathogenic. Although the nematode occurs in many conifer genera, only the pines are damaged. We assume that only one species, ponderosa pine and its close relative Jeffrey pine, are as susceptible as the Japanese pines. However, the possibility that an introduced nematode could affect other genera of conifers or other pines cannot be excluded.

(3) Within 25 years of introduction, the nematode would be established throughout the western conifer region and as far east as the Great Plains.

(4) Based on the Japanese experience, susceptible species could be eliminated in as little as 10 years. Thus, within 35 years of introduction (10 years after it is established throughout the region), all

ponderosa and Jeffrey pine, pole sized and larger, would be killed. Several other scenarios are possible:

a. all ponderosa and Jeffrey pines killed;
b. 50 percent of ponderosa and Jeffrey pines killed;
c. 10 percent of ponderosa and Jeffrey pines killed;
d. 2 percent of ponderosa and Jeffrey pines killed.

Mortality and premature harvest are the primary components of examined loss; growth loss and defects are not important or can be minimized with prompt salvage.

Justification for Assumptions

(1) *Monochamus* spp. present in the United States are demonstrated vectors of *Bursaphelenchus xylophilus* and *B. mucronatus*, which are also endemic. There is no reason to expect that they would not be as effective in transferring nematodes of the same or closely related species.

(2) Because these are closely related nematodes—*B. xylophilus* and *B. mucronatus* are capable of mating, and there is a "mucronate" form of *B. xylophilus*—the standard taxonomic classification of the organisms tends to minimize the potential for reproduction and spread.

Although *B. xylophilus* is at most a weak pathogen in the United States, causing minimal losses if any, the nematode presents a more substantial threat in other nations, including some where it is already present. Considering that it already causes serious damage in Japan, and that nematodes imported from Japan will mate with those in the United States, it is reasonable to assume that a similar nematode (or even a different subspecies) introduced from the Soviet Union could become a formidable pathogen in this country.

Although the wilt disease can be initiated in seedlings of many species, in the United States the disease has been reproduced only in larger trees—Scotch pine and slash pine. Tests on seedlings are thus poor indicators of mature plant susceptibility.

(3) In Japan, the nematode spreads about 20 miles per year. Potential spread is more rapid when transport of logs and firewood is a contributing factor. By the time the nematode damage is discovered, movement of logs and firewood will have established infestations well beyond the damaged area.

(4) The nematode is a beetle-vectored wilt disease, similar to Dutch elm disease. We believe that movement of logs will be a major factor in the spread of the nematode and any introduced vectors. *Monochamus* introduced in imported logs will quickly infest domestic log decks. Thus, it is not just the movement of imported logs that poses a risk for the spread of an introduced nematode.

Economic Impacts

The economic analysis is summarized in tables 5-3 through 5-6. Table 5-3 shows the rate of spread and the rate of mortality over 10 years, both in terms of acres and volume. Note the implicit assumption of constant volume per acre, made in the interest of simplicity. Table 5-4 translates the data in table 5-3 into current-year market values and their present-value counterparts. Table 5-5 presents the current value of stand conversion costs after nematode infestation and table 5-6 contains present value analyses without nematode infestation. Table values were computed using the following assumptions:

(1) An exponential rate of spread of the infestation of approximately 2.8 percent per year was assumed, such that the entire ponderosa-Jeffrey pine region is infested in 25 years.

(2) The same spread rate of mortality after a 10-year period of incubation was assumed. Thus, at 100 percent mortality, the entire inventory of this timber type will be gone in 35 years.

(3) The inventory was assumed to be salvaged within 1 year of mortality as it occurs, and that stand conversion to species resistant to the nematodes takes place concurrent with salvage operations.

(4) Total area of this timber type throughout the western conifer region of 26,645,000 acres with a total volume of 192,065,000 MBF was assumed (USDA, 1982).

(5) The normal annual harvest without infestation was assumed to be 4.267 billion board feet, equal to the annual rate of growth of the residual stand. This represents a growth rate of approximately 2.22 percent per year, which is a reasonable

Table 5-3. Volume of Pine Mortality (MBF) Based on Acres of Ponderosa Pine Timberlands Infected by Pathogenic Nematodes After Hypothetical Introduction in Imported Siberian Logs

Year	1+% of Area	% of Area Infected	Total Acres Infected	Annual Acres Infected	Average MBF/Acre = 7,208,294,239	
					Current Year Acres of Pine Mortal. Based on 100% Kill Rate	Current Year Volume of Pine Mortal. Based on 100% Kill Rate
1	1.028113827	0.028113827	749,093	749,093		
2	1.057018041	0.057018041	1,519,246	770,153		
3	1.086734863	0.086734863	2,311,050	791,805	N.A.	N.A.
4	1.117287138	0.117287138	3,125,116	814,065	N.A.	N.A.
5	1.148698355	0.148698355	3,962,068	836,952	N.A.	N.A.
6	1.180992661	0.180992661	4,822,549	860,482	N.A.	N.A.
7	1.214194884	0.214194884	5,707,223	884,673	N.A.	N.A.
8	1.248330549	0.248330549	6,616,767	909,545	N.A.	N.A.
9	1.283425889	0.283425898	7,551,883	935,116	N.A.	N.A.
10	1.319507911	0.319507911	8,513,288	961,405	N.A.	N.A.
11	1.356604327	0.356604327	9,501,722	988,434	749,093	5,399,682
12	1.394743666	0.394743666	10,517,945	1,016,223	770,153	5,551,488
13	1.433955248	0.433955248	11,562,738	1,044,793	791,805	5,707,561
14	1.474269217	0.474269217	12,636,903	1,074,166	814,065	5,868,023
15	1.515716567	0.515716567	13,7412,68	1,104,365	836,952	6,032,995
16	1.558329159	0.558329159	14,876,680	1,135,413	860,482	6,202,606
17	1.602139755	0.602139755	16,0440,14	1,167,333	884,673	6,376,985
18	1.647182035	0.647182035	17,244,165	1,200,152	909,545	6,556,266
19	1.693490625	0.693490625	18,478,058	1,233,892	935,116	6,740,588
20	1.741101127	0.741101127	19,746,640	1,268,582	961,405	6,930,092
21	1.790050142	0.790050142	21,050,886	1,304,247	988,434	7,124,923
22	1.840375301	0.840375301	22,391,800	1,340,914	1,016,223	7,325,232
23	1.892115293	0.892115293	23,770,412	1,378,612	1,044,793	7,531,172
24	1.945309895	0.945309895	25,187,782	1,417,370	1,074,166	7,742,963

Table 5-3. Acres of Ponderosa Pine Timberlands Infected by Pathogenic Nematodes After Hypothetical Introduction in Imported Siberian Logs (continued)

					AVE. MBF ACRE = 7,208,294,239	
Year	1+% of Area	% of Area Infected	Total Acres Infected	Annual Acres Infected	Current Year Acres of Pine Mortal. Based on 100% Kill Rate	Current Year Volume of Pine Mortal. Based on 100% Kill Rate
25	2	1	26,645,000	1,457,218	1,104,365	7,960,585
26	N.A.	N.A.	N.A.	N.A.	1,135,413	8,184,388
27	N.A.	N.A.	N.A.	N.A.	1,167,333	8,414,482
28	N.A.	N.A.	N.A.	N.A.	1,200,152	8,651,045
29	N.A.	N.A.	N.A.	N.A.	1,233,892	8,894,299
30	N.A.	N.A.	N.A.	N.A.	1,268,582	9,144,311
31	N.A.	N.A.	N.A.	N.A.	1,304,247	9,401,333
32	N.A.	N.A.	N.A.	N.A.	1,340,914	9,665,702
33	N.A.	N.A.	N.A.	N.A.	1,378,612	9,937,442
34	N.A.	N.A.	N.A.	N.A.	1,417,370	10,216,821
35	N.A.	N.A.	N.A.	N.A.	1,457,218	10,504,055
Totals					26,645,103	192,065,139

N.A. = Not available.

Table 5-4. Economic Analysis of Pine Wood Nematode Infestation

Year	% Inventory Affected	Total MBF Affected	Annual MBF Affected	Market Val. 1986 Prices (@ $141 MBF)	(Includes Normal Cash Flow Before Mortality Starts)	
					PV Factor	Present Value
				---$MILLIONS---		
1	0.028113827	5,399,682	5,399,682	601.6	1.04	578.5
2	0.057018041	10,951,170	551,488	601.6	1.0816	556.3
3	0.086734863	16,658,731	5,707,561	601.6	1.124864	534.9
4	0.117287318	22,526,754	5,868,023	601.6	1.169859	514.3
5	0.148698355	28,559,750	6,032,995	601.6	1.216653	494.5
6	0.180992661	34,762,356	6,202,606	601.6	1.265319	475.5
7	0.214194884	41,139,340	6,376,985	601.6	1.315932	457.2
8	0.248330549	47,695,607	6,556,266	601.6	1.368569	439.6
9	0.283425898	54,436,195	6,740,588	601.6	1.423312	422.7
10	0.319507911	61,366,287	6,930,092	601.6	1.480244	406.5
11	0.356604327	68,491,210	7,124,923	761.4	1.539454	494.6
12	0.394743666	75,816,442	7,325,232	782.8	1.601032	488.9
13	0.433955248	83,347,615	7,531,172	804.8	1.665074	483.3
14	0.474269217	91,090,517	7,742,903	827.4	1.731676	477.8
15	0.515716567	99,051,102	7,960,585	850.7	1.800944	472.3
16	0.558329159	107,235,490	8,184,388	874.6	1.872981	466.9
17	0.602139755	115,649,972	8,414,482	899.2	1.947900	461.6
18	0.647182035	124,301,017	8,651,045	924.4	2.025817	456.3
19	0.693490625	133,195,277	8,894,259	950.4	2.106849	451.1
20	0.741101127	142,339,588	9,144,311	977.1	2.191123	446.0
21	0.790050142	151,740,980	9,401,393	1,004.6	2.278768	440.9
22	0.840375301	16,1,406,682	9,665,702	1,032.9	2.369919	435.8

Table 5-4. Economic Analysis of Pine Wood Nematode Infestation (continued)

Year	% Inventory Affected	Total MBF Affected	Annual MBF Affected	Market Val. 1986 Prices (@ $141 MBF)	(Includes Normal Cash Flow Before Mortality Starts) PV Factor	Present Value
				---$MILLIONS---		
23	0.802115293	171,344,124	9,937,442	1061.9	2.464716	430.8
24	0.945309895	181,560,945	10,216,821	1091.7	2.563304	425.9
25	1	192,065,000	10,504,055	1122.4	2.665836	421.0
26	N.A.	SUM=	192,065,000	1154.0	2.772470	416.2
27	N.A.	N.A.	N.A.	1186.4	2.883369	411.5
28	N.A.	N.A.	N.A.	1219.8	2.998703	406.8
39	N.A.	N.A.	N.A.	1254.1	3.118651	402.1
30	N.A.	N.A.	N.A.	1289.3	3.243398	397.5
31	N.A.	N.A.	N.A.	1325.6	3.373133	393.0
32	N.A.	N.A.	N.A.	1362.9	3.508059	388.5
33	N.A.	N.A.	N.A.	1401.2	3.648381	384.1
34	N.A.	N.A.	N.A.	1440.6	3.794316	379.7
35	N.A.	N.A.	N.A.	1481.1	3.946089	375.3
Totals						14,687.9

Table 5-5. Current Value of Stand Conversion Costs After Nematode Infection

Year	Annual Acres Treated	Stand Reestablish Cost @ $200/Acre	PV Factor	Present Value (Million $)	Summary-NPV of Cash Flow Minus Costs With Infection
1	N.A.	N.A.	1.04	N.A.	
2	N.A.	N.A.	1.0816	N.A.	Equals
3	N.A.	N.A.	1.124864	N.A.	15687.9 [Table]
4	N.A.	N.A.	1.169859	N.A.	Minus
5	N.A.	N.A.	1.216653	N.A.	
6	N.A.	N.A.	1.265319	N.A.	2,126.8
7	N.A.	N.A.	1.315932	N.A.	
8	N.A.	N.A.	1.368569	N.A.	Equals
9	N.A.	N.A.	1.423312	N.A.	$13561.1 Million
10	N.A.	N.A.	1.480244	N.A.	
11	749,093	149.8	1.539454	97.3	
12	770,153	154.0	1.601032	96.2	
13	791,805	158.4	1.665074	95.1	
14	814,065	162.8	1.731676	94.0	
15	836,952	167.4	1.800944	92.9	
16	860,482	172.1	1.872981	91.9	
17	884,673	176.9	1.947900	90.8	
18	909,545	181.9	2.025817	89.8	
19	935,116	187.0	2.106849	88.8	
20	961,405	192.3	2.191123	87.8	
21	988,434	197.7	2.278768	86.8	
22	1,016,223	203.2	2.369919	85.8	
23	1,044,793	209.0	2.464716	84.8	
24	1,074,166	214.8	2.563304	83.8	
25	1,104,365	220.9	2.665836	82.9	
26	1,135,413	227.1	2.772470	81.9	

Table 5-5. Current Value of Stand Conversion Costs After Nematode Infection (continued)

Year	Annual Acres Treated	Stand Reestablish Cost @ $200/Acre	PV Factor	Present Value (Million $)	Summary-NPV of Cash Flow Minus Costs With Infection
27	1,167,333	233.5	2.883369	81.0	
28	1,200,152	240.0	2.998703	80.0	
29	1,233,892	246.8	3.118651	79.1	
30	1,268,582	253.7	3.243398	78.2	
31	1,304,247	260.8	3.373133	77.3	
32	1,340,914	268.2	3.508059	76.4	
33	1,378,612	275.7	3.648381	75.6	
34	1,417,370	283.5	3.794316	74.7	
35	1,457,218	291.4	3.96089	73.9	
Total	26,645,000			2,126.8	

Table 5-6. Present Value of Cash Flow and Residual Stand Value After 35 Years Without Nematode Infection

Year	Annual Timb Harvest MBF Pond. Pine	Market Val. [@ $141/MBF] (millions of $)	PV Factor	Present Value (millions of $)	Notes
1	4,267,000	601.6	1.04	578.5	market val
2	4,267,000	601.6	1.0816	556.3	[@ 1986 prices]
3	4,267,000	601.6	1.124864	534.9	equals $141/MBF
4	4,267,000	601.6	1.169859	514.3	
5	4,267,000	601.6	1.216653	494.5	
6	4,267,000	601.6	1.265319	475.5	
7	4,267,000	601.6	1.315932	457.2	Residual val
8	4,267,000	601.6	1.368569	439.6	of stand after 35 yrs
9	4,267,000	601.6	1.423312	422.7	[Pres Val]
10	4,267,000	601.6	1.480244	406.5	3811.7 (millions of $)
11	4,267,000	601.6	1.539454	390.8	
12	4,267,000	601.6	1.601032	375.8	Pres Value
13	4,267,000	601.6	1.665074	361.3	of Cash Flow
14	4,267,000	601.6	1.731676	347.4	11,229.5
15	4,267,000	601.6	1.800944	334.1	
16	4,267,000	601.6	1.872981	321.2	NPV of
17	4,267,000	601.6	1.947900	308.9	Unaffected
18	4,267,000	601.6	2.025817	297.0	Situation
19	4,267,000	601.6	2.106849	285.6	15,041.2 (millions of $)
20	4,267,000	601.6	2.191123	274.6	
21	4,267,000	601.6	2.278768	264.0	
22	4,267,000	601.6	2.369919	253.9	
23	4,267,000	601.6	2.464716	244.1	
24	4,267,000	601.6	2.563304	234.7	

Table 5-6. Present Value of Cash Flow and Residual Stand Value After 35 Years Without Nematode Infection (continued)

Year	Annual Timb Harvest MBF Pond. Pine	Market Val. [@ $141/MBF] (millions of $)	PV Factor	Present Value (millions of $)	Notes
25	4,267,000	601.6	2.665836	225.7	
26	4,267,000	601.6	2.772470	217.0	
27	4,267,000	601.6	2.883369	208.7	
28	4,267,000	601.6	2.998703	200.6	
29	4,267,000	601.6	3.118651	192.9	
30	4,267,000	601.6	3.243398	185.5	
31	4,267,000	601.6	3.373133	170.4	
32	4,267,000	601.6	3.508059	171.5	
33	4,267,000	601.6	3.648381	164.9	
34	4,267,000	601.6	3.794316	158.6	
35	4,267,000	601.6	3.946089	152.5	
Total				11,221.70	

estimate for a normal forest of the ponderosa-Jeffery pine type (USDA, 1982).

(6) An average value of $141 per MBF in 1986 constant dollar prices was assumed to extend into the indefinite future.

A continued harvest at normal rates until mortality begins was also assumed. Thereafter, we assume that dead trees are salvaged within 1 year of mortality without significant defect. We also assume that the increase in the volume of pine-types salvaged is offset by an equal reduction below normal levels of other coniferous types in the mixed forest. This latter assumption is important in simplifying the analysis for two reasons: first, we assume no effect on the average price of stumpage; second, we assume no fall-down below normal levels of coniferous timber harvest after the completion of pine-stand conversion, because levels of inventory of other species will have been built up. The age-class distribution of the total coniferous inventory will have been altered along with the species composition after the passage of 35 years, but the increased inventory of other species should be nearly enough to prevent significant reductions in annual harvest levels.

Table 5-4 shows that under all of the above assumptions, salvage of ponderosa pine mortality would generate present value of cash flow of about $15.7 billion 1986 dollars. Table 5-5 shows that, assuming that the average cost of stand conversion is $200 per acre more than the cost of stand regeneration under normal conditions, the present value of the salvaged timber would be about $13.6 billion.

Table 5-6 shows that the present net value of the cash flow under the normal condition, subject to the above assumptions, is approximately $11.2 billion. Note that this figure is actually smaller than the figure for the infestation scenario. This is due to the accelerated rate of harvest to salvage dead timber. However, under our assumptions, the value of the residual stand of pine must be added to the present value of the cash flow, which is $3.8 billion, bringing the total to $15.04 billion. Thus, the net economic cost of the assumed infestation is 1.67 billion 1990 dollars for the worst case scenario of 100 percent mortality. The best case scenario, which assumes 2 percent mortality, would be $33.35 million 1990 dollars. Note that these latter figures do not include a downward adjustment for the value of the new stand established concurrently with the salvage operation. While the new stand will not have reached financial maturity, it would have market value as growing stock.

Larch Canker

Summary

The following ranges display a best case/worst case scenario for damage caused by the introduction of larch canker disease from the Soviet Union. The worst case damages are $240.6 million, assuming high rates of infection and high rehabilitation costs. The best case damages are $24.9 million, assuming low rates of infection and no rehabilitation costs. For background material on larch canker and its effects, see Appendix K.

Economic Analysis

We limited our analysis to three financial impacts:

(1) Reduced yields in present larch stands;
(2) Premature conversion of larch to other tree species;
(3) Direct rehabilitation costs, consisting of:
  (a) Stumpage value lost in unsalvageable mortality in salvage and sanitation operations;
  (b) Direct costs of further disposal, including piling, burning, or activities in excess of normal silvicultural treatment.

Biological Assumptions

(1) Larch canker disease will spread completely through the larch forest resources in 25 years.
(2) Larch forest types in the seedling/sapling and poletimber size (up to 9-inches mean diameter) are susceptible. Our final estimate was 793,000 acres at risk.

(3) The average age of the susceptible larch stand is 30 years. For calculation simplicity, we assumed that all stands are exactly 30 years old.
(4) The larch component of other forest types (less than 50 percent larch stock) will be killed by the disease, but the stands will not undergo yield reduction.

Silvicultural Assumptions

(1) Larch stands will be replaced with Douglas-fir that will be grown under a management regime with costs, rotation length, yields, and values identical to the larch regime.

(2) The basic management regime is as follows:

Activity	Age	(Cost)/Revenue
(a) Site Preparation	1	($150)
(b) Planting	1	($100)
(c) Precommercial thinning	20	($100)
(d) Commercial thinning	50	$150 (3 MBF/acre @ $50/MBF)
(e) Final harvest	100	$2,100 (30 MBF/acre @ $70/MBF)

Note: The higher final harvest stumpage value is based on higher quality and lower cost logging. See financial assumptions.

(3) In two-thirds of the infected host acreage, there will be enough residual growing stock in conversion species to finish out the rotation. In the other third, immediate conversion will be necessary.

(4) In infected host acreage, all of the merchantable sawtimber will be sold at current (projected) stumpage prices identical to those of green larch. Furthermore, the volume salvaged is identical to what would have been harvested in planned commercial thinnings. Therefore, the kill of any merchantable volume does not contribute to any value loss.

(5) In stands that are allowed to finish the rotation, yields will be reduced by 1/3 from 30 MBF per acre to 0 MBF per acre at 100 years.

Rehabilitation Program Assumptions

(1) The larger larch (above 11 inches diameter at breast height (d.b.h.)) in all forest types will be removed.
(2) The only value loss from the rehabilitation program is the unsalvageable mortality, which is 25 percent of the current sawtimber volume of the greater than 11 inch d.b.h. trees.
(3) Rehabilitation costs, net of the logging costs included in the unsalvaged mortality, is $10 per MBF of unsalvageable volume cut in the rehabilitation program.
(4) Stumpage values for larch removed in the rehabilitation program are identical to prices for green uninfected larch.

Financial Analysis Assumptions

(1) Current stumpage prices for green larch are assumed to be $70/MBF. This represents the average stumpage price paid for larch on national forest sales in the Northern and Pacific Northwest Regions for the years 1985 to 1989 (Warren, 1990).
(2) Real discount rate is 4 percent.
(3) Rate of inflation for all costs is 3 percent per year.
(4) Real timber price increase is 1 percent per year.
(5) Present rotations are financially optimal. None of the stands of susceptible size is financially overmature.
(6) The total financial impact from premature conversion and yield reduction is the sum of the stand-level estimates for the assumed acreage infected. We estimated no allowable cut adjustments.
(7) The premature conversion effect is calculated with the formula:

$$\text{Value Change} = PNW^{wo} - PNW^{w}$$

where PNW^{wo} is the discounted present value of the present rotation and all future rotations without larch canker and PNW^{w} is the discounted present value of the present and future rotations with the larch canker.
(8) The form of PNW used in this analysis combines the present value of the remaining rotation with the soil expectation value (SEV) of an infinite series of rotations after the stand is converted. The SEV component is discounted to the present from its starting point, which is 70 years in the future for stands in which the current rotation is allowed to finish.
(9) The annual rehabilitation cost-plus-loss is the total rehabilitation impact divided by 25 years. Since the disease spreads uniformly over the acreage during the period, the impact is the discounted present value of a stream of 25 equal annuity payments, using the 4 percent rate.

(We assumed no real net of inflation increase in stumpage prices in the rehabilitation impacts.)

Economic Methods

(1) Develop three alternative scenarios composed of different levels of infection and extent of rehabilitation.

(2) Estimate the acres of susceptible larch (host) type for each scenario. Larch in this area are completely killed in each scenario. Seedlings, saplings, and poletimber size classes of larch are at risk. Acres that are reserved or deferred are not included.

(3) Estimate the sawtimber volume of nonsusceptible larch that is affected in a direct rehabilitation program for the scenario. Part of this volume is salvageable at current market prices for stumpage; the rest is unsalvageable mortality. The volume that occurs as reserved or deferred timberland is not included.

(4) Estimate a combined yield reduction and conversion impact for the host acreage.

  (a) Estimate a per-acre yield reduction impact for infected stands that are assumed to finish the rotation.
  (b) Estimate a per-acre stand conversion impact for infected stands that are converted immediately after infection.
  (c) From (a) and (b) above, calculate a weighted average per-acre impact based on estimated relative frequencies of the two situations.
  (d) Multiply the average loss in (c) above by the number of host acres infected in the scenario, adjusting for unreserved acres.

(5) Estimate the direct rehabilitation cost-plus-loss.

  (a) Estimate the value of the merchantable-size larch that are cut during rehabilitation measures, but are not sold, multiplying the stumpage prices by the portion of the standing sawtimber volume. That portion is specified by each scenario.
  (b) Estimate the disposal costs not included in (a) above by multiplying some assumed net cost per MBF by the unsalvaged volume.
  (c) Add (5 a) and (4 b), and adjust to the unreserved volume.

(6) Add (4 d) and (5 c) for an estimate of the total impact for the estimated duration of the disease epidemic.

(7) Calculate the discounted present value of the impact in (6).
  (a) Divide the total impact by the number of years of the epidemic (see the assumptions listed below).
  (b) Apply the formula for the present value of an annuity to the annual impacts calculated in (6).

Scenarios

(1) High infection level with no rehabilitation program.
  — 100 percent of the susceptible host acreage is affected.
(2) Medium infection level with a medium intensity rehabilitation effort.
  — 50 percent of the host acreage is affected.
  — 25 percent of the sawtimber volume in nonsusceptible larch is cut.
(3) Light infection level with a high intensity rehabilitation effort.
  — 25 percent of the host acreage is affected.
  — 50 percent of the volume in nonsusceptible larch is salvaged and sanitation cut.

Economic Impacts

The impact of larch canker disease will be a timber and forestland value loss of $129 million. This figure represents the net present value of a stream of impact over the 25-year spread period. This figure is the average of the three infection and rehabilitation scenario impacts, which range from $99 million to $166 million (table 5-7).

Half of this impact would come from yield reduction and conversion in present stands, and half from rehabilitation costs and unsalvageable rehabilitation mortality.

Under the high infection scenario, 100 percent of the impact would come from yield reduction and stand conversion. By contrast, under the low infection and high rehabilitation scenario, 81 percent of the impact would come from control cost-plus-loss. A worst case scenario would include a high infection level in spite of an intensive control program, producing a value reduction of $99 + $141 = $240 million.

Table 5-7. Financial Loss From Larch Canker on Western Larch Under Three Scenarios, Four Western States

Scenario	Impact component		
	Yield reduction/ Stand conversion	Control cost/ loss	Total impact
	present value in millions of dollars for 25-year period		
1. High infection and control	99.2	0	99.2
2. Medium infection and medium control	49.7	70.6	120.3
3. Low infection and high control	24.9	141.4	166.3
Average Impact	57.9	70.7	128.6

Spruce Bark Beetles

Summary

The following ranges display best case and worse case scenarios for damage caused by the introduction of spruce bark beetles from the Soviet Union. These figures are expressed in 1990 dollars. Worst case damages are $1.5 billion, assuming that the spruce resource in Washington and Oregon is entirely killed in 7 years. Best case damages are $201 million, assuming that 25 percent of the spruce resource in Washington and Oregon is killed in the next 30 years.

Economic Analysis

Economic effects are analyzed by considering the timber supply effects of catastrophic mortality to the spruce resources in Washington and Oregon. Damages are computed in a comparative static framework; that is, as the difference between a precatastrophe market equilibrium (the base case) and a sequence of "catastrophic" market equilibriums. Change in measures of economic surplus are used to indicate the magnitude of potential economic effects.

Biological Assumptions

(1) The most important pest of concern for evaluating potential bark beetle impacts associated with log imports from Siberia is *Ips typographus* (European spruce bark beetle).

(2) The spruce bark beetle will vector pathogenic fungi such as the highly pathogenic species *Ophiostoma polonica*. Once established, vectors native to the United States, such as *Dendroctonus* spruce beetles, could effectively transmit pathogenic fungi.

(3) The primary hosts of concern in the Western United States are Sitka spruce (*Picea sitchensis*) and Engelmann spruce (*Picea engelmannii*). The analysis is focused on forests in Washington and Oregon.

(4) Increased mortality is the biological endpoint of significance, rather than decreased growth. Mortality occurs at the rate of 100 percent in the infested area.

(5) The rate of spread (r) of spruce beetles is from 1 to 30 miles per year, with a mean of about 10 miles per year. If *Ips typographus* became established in the forests of the Western States, it would likely spread into Canada and Alaska. For our analysis, we parametrically vary the r value.

(6) The host type is homogeneously distributed in all directions from the epicenter (port of entry). Considering that the area of a semi-circle with ϕ radians = $\phi\, r^2/2$, where r is the radius (that is, the rate of spread) and the relevant number of radians (accounting for the Pacific Ocean) equals π. By "redistributing" the entire spruce resource in Washington and Oregon around the epicenter, we have, in effect, increased the rate of spread above r = 10.

(7) Beyond the current rotation, the soil expectation value of damaged forests remains unchanged. This implies no change in future yield or management costs.

Mortality Computation

The expected volume of timber killed in year t is the area of the year t annulus times the volume per unit area. This can be computed as:

$$K_t = \frac{c_t \pi r^2 s}{2}$$

$$\textit{given } c_t = c_{t-1} + 2 \textit{ if } t > 1$$
$$c_t = 1 \textit{ if } t = 1$$

Where: K_t = the volume of timber killed in year t, r = the rate of beetle spread in miles/year, t = year, c_t = annulus area coefficient in year t, s = timber volume per square mile.

Notice that $\partial K_t/\partial r = 2c_t\pi rd > 0$ and $\partial^2 K_t/\partial r^2 = 2c_t\pi D > 0$. Therefore, the volume of timber killed increases at an increasing rate in response to a parametric increase in r.

Timber volume per square mile(s) is computed using:

(1) The net volume of Sitka spruce growing stock in Oregon and Washington = 1,735 million cubic feet (USFS, 1989).

(2) The number of hemlock-Sitka spruce forest acres in Washington and Oregon = 3,984 thousand acres (USFS, 1989).

(3) One square mile = 640 acres.

(4) Therefore, the volume of Sitka spruce per acre or mi^2 can be computed: (1,735,000,000/3,984,000) = 435.5 ft^3/acre or 278,715 ft^3/mi^2.

(5) Net volume of Engelmann and other spruce types in Oregon and Washington = 1,193 million cubic feet (USFS, 1989).

(6) Number of fir-spruce forest type acres in Washington and Oregon = 4,088 thousand acres (USFS, 1989).

(7) Therefore, the volume of Engelmann and other spruce per acre or mi^2 can be computed: (1,193,000,000/4,088,000) = 291.8 ft^3/acre or 186,771 ft^3/mi^2.

(8) The total spruce volume per acre or mi^2 is the sum of all spruce types: 727.3 ft^3/acre or 465,472 ft^3/mi^2.

(9) Board foot volumes are computed assuming 1 cubic foot = 5 board feet.

Based on the annual mortality formula and the above timber volume computations, the spruce inventory in Washington and Oregon is completely destroyed in slightly more than 6 years if r is not equal to 10. If the rate of spread is not equal to 1, approximately 25 percent of the standing inventory of spruce is killed over a 30-year period.

Economic Method

Similar to a method used by Binkley and Dykstra (1987) and Holmes (1991), constant elasticity inverse supply and demand curves are used in our analysis: $S_t(Q) = b_0Q^{b1}$, $D_t(Q) = a_0Q^{a1}$, where b_1 and a_1 are inverse supply and demand elasticities, respectively. Timber supply and demand elasticities were chosen to be broadly representative of estimates reported in the literature. We used a supply elasticity of 0.25 and a demand elasticity of -0.50. The base case parameters b_0 and a_0 are calibrated using data reflecting 1989 market conditions in Washington and Oregon (Warren, 1990).

Two supply impacts are modeled. First, a reduction of spruce inventory shifts lagged supply back, because damaged timber stocks are no longer available for harvest in the future. We use an inventory elasticity of 1 (Adams and Haynes, 1980). Second, we considered the possibility that spruce mortality is salvaged during the year it is killed. Since the opportunity cost of dead timber approaches zero, the salvage supply curve is perfectly inelastic. Market supply is the sum of salvage supply and supply from undamaged forests. Therefore, the consequence of salvage is to increase market equilibrium quantity and reduce equilibrium price. To understand the potential impact of salvage on timber markets, we compute market equilibrium assuming: (1) 100 percent salvage, and (2) 0 percent salvage.

Market impacts are computed over a 30-year period. Since future impacts are discounted to the present, after 30 years market impacts are relatively small.

To add salvage supply to the supply from undamaged forests, invert $S_t(Q)$ and add the volume of timber salvaged Q^d to the volume of undamaged timber Q^u:

$$Q_t^m = Q_t^d + Q_t^u = Q_t^d + \left(\frac{P_t}{b_{0_t}}\right)^{\frac{1}{b_1}}$$

Equilibrium price for various levels of Q^d are found by numerical methods. Of course, equilibrium quantity is found by substituting equilibrium price into either the supply or demand equation.

The impact of a change in inventory on timber supply is computed assuming that price elasticity does not change. Following Binkley and Dykstra (1987), a change in inventory alters the location parameter b_0 in the following fashion

$$b_{0_{t+1}} = \frac{b_{0_t}}{\left(\frac{I_{t+1}}{I}\right)^{b_1}}$$

where $b_{0,t+1}$ is the revised location parameter, I_{t+1} is revised inventory, and I is initial (base case) inventory. The next period's timber inventory is computed from current inventory I_t, current mortality K_t, current harvest of undamaged timber Q^u_t, and current growth G_t using the growth-drain relationship:

$$I_{t+1} = I_t - K_t - Q_t^u - G_t$$

Economic Impacts
Several results are worthy of note. First, economic losses to owners of damaged forests are not very sensitive to the salvage assumption. Under the 100 percent salvage scenario, losses to owners of the damaged resource are somewhat smaller (about $1.0 billion). This is due to: (1) under the 100 percent salvage scenario, owners of damaged timber receive a return—thereby reducing their losses, and (2) under the no salvage option, timber damages are valued as a proportion of inventory from the year of mortality to the year in which they would have been marketed, if the stocks had not been killed. This latter effect imparts a downward (conservative) bias to damage estimates, due to the proportionality impact and the effect of discounting.

Second, timber salvage has the greatest impact on owners of undamaged forests and timber consumers. Under the 100 percent salvage scenario, owners of undamaged forests suffer the greatest economic damages resulting from the decrease in equilibrium price. Producers of undamaged forests move back along their timber supply curves (reduce their harvest level) in response to a decrease in price. Of course, timber consumers benefit from the decrease in timber price and move out along their timber demand curve. Conversely, under the no salvage option, timber consumers suffer the greatest economic loss, due to the overall rise in equilibrium market price. Timber producers with undamaged forests benefit from the price rise and move out along their supply curve (increase their harvest level).

Third, the net loss in economic welfare from catastrophic damage to the spruce resource in Washington and Oregon ranges from a low estimate of $201 million to a high estimate of $1.5 billion.

Annosus Root Disease

Summary
The following ranges display best case and worse case scenarios for damage caused by the introduction of a new strain of annosus root disease from the Soviet Union. The figures are expressed in 1989 dollars. Worst case damages are $331.4 million, assuming a mortality of 2.3 billion board feet (bbf) per year. Best case damages are $81.1 million, assuming a mortality of 0.5 bbf per year.

Economic Analysis
Effects of a new strain of annosus root disease (*Heterobasidion annosum*) are assessed using a comparative statics framework. Supply and demand equations are used to estimate equilibrium price and quantity, and changes in these values that result from effects on the timber resource are computed. This provides a means to calculate the changes in net economic welfare. Two different impacts are analyzed: (1) the effect of changes in inventory resulting from increased mortality, and (2) the effect of increased log defect due to damage. Both of these impacts result in an inward shift in supply. The high and low damage scenarios are presented in table 5-8.

Assumptions

(1) Damage begins at year 20, and continues until the end of the planning horizon used in this analysis (30 years). New growth on damaged sites and discounted values will lessen future impacts.

(2) Losses consist of (a) increased mortality in Douglas-fir and larch ranging from 0.5444 to 2.2864 bbf per year, and, (b) increased defect causing volume reductions of 0.01502 to 0.0601 bbf per year.

(3) Beyond the current rotation, the soil expectation of damaged forests remains unchanged. This implies no change in yield or management costs.

(4) Control efforts are considered too costly over a large area, and we therefore assume no control measures are taken.

(5) None of the annosus mortality is salvaged, which is consistent with the actual practice in much of the Western United States.

Economic Method
Effects of mortality and the defects from annosus on timber markets are examined using the methodology outlined in Binkley and Dykstra (1987) and Holmes (1991) and used in the bark beetle impact

analysis found in this report. We use constant elasticity inverse demand and supply curves (equations 1 and 2), and inventory accounting and adjustment equations using an inventory elasticity of 1 (Adams and Haynes, 1980) (equations 3 and 4).

Table 5-8. Market Equilibrium Price and Quantity Harvested Resulting From Annosus Damage

	Low	Alternative	High	Alternative
Year	Price ($/mbf)	Quantity (bbf)	Price ($/mbf)	Quantity (bbf)
0 (base year)	277.17	14.974	277.17	14.974
"				
"				
20	277.19	14.983	277.22	14.982
21	277.55	14.973	278.72	14.942
22	277.90	14.963	280.23	14.901
23	278.26	14.954	281.77	14.861
24	278.62	14.944	283.31	14.820
25	278.98	14.935	284.88	14.779
26	279.34	14.925	286.45	14.739
27	279.70	14.915	288.04	14.698
28	280.06	14.905	289.64	14.616
29	280.42	14.896	291.27	14.616
30	280.80	14.886	292.61	14.575

$$S_t(Q) = b_{0_t} Q_t^{b_1} \tag{1}$$

$$D_t(Q) = a_0 Q_t^{a_1} \tag{2}$$

$$b_{0_{t+1}} = \frac{b_{0_t}}{\left(\frac{I_{t+1}}{I}\right)^{b_1}} \tag{3}$$

$$I_{t+1} = I_t - K_t - Q_t^u - Q_{t+1}^d \tag{4}$$

where Q is quantity, Q^d is quantity of harvest with defect, Q^u is undamaged harvest, K is mortality, a_0 and b_0 are location parameters, a_1 and b_1 are inverse elasticities, I is inventory, and G_t is growth. These equations are further explained in the bark beetle analysis section of this chapter. Both mortality (K) and defect (Q^d) are accounted for by a decrease in inventory, reflected by a pivotal shift in the supply curve (a change is bα). Economic welfare changes are computed for (1) timber consumers (ΔCS), representing a loss to timber buyers (equation 5), (2) timber producers with undamaged forests (ΔPS^u) representing a gain (equation 6), and, 3) timber producers with damaged forests (ΔPS^d), representing a loss (equation 7).

$$\Delta CS = \int_{P^*}^{P_t} D(x)dx = \int_{P^*}^{P_t} (P_t/u_0)^{-.5}\, dP \tag{5}$$

$$\Delta PS^u = \int_{P_t}^{P^*} S_t(x)dx = \int_{P_t}^{P^*} (P_t/b_{0_t})^{.25}\, dP \tag{6}$$

$$\Delta PS^d = \int_{0}^{P^*} [S^*(x) - S_t(x)]\, dx = \int_{0}^{P^*} [(P^*/b_0)^{.25} - (P_t/b_{0_t})^{.25}]\, dP \tag{7}$$

where P^* is the initial equilibrium price, P_t is the equilibrium price resulting from annosus impacts, and S^* is the initial supply function.

Economic Impacts

Table 5-8 shows equilibrium price and quantity that result from the high and low alternatives. No impacts were assessed before year 20, and all values are present values, using a discount rate of 4 percent. Table 5-9 and table 5-10 show the discounted welfare impacts of the low and high alternatives, respectively.

Consistent with the theory and with this model's development, losses in consumer surplus are slightly higher than gains to producers of undamaged forests. Producers with damaged forests lose on the value of mortality as well as through reduced harvest volumes resulting from defect. Total welfare impacts for the 30-year horizon are from -\$81.1 million to -\$331.4 million. The primary influence on welfare is the change in inventory resulting from mortality.

Table 5-9. Welfare Impacts of Annosus Root Disease (Mortality and Defect): Low Alternative. (Mortality = 0.544 bbf/year, Defect = 0.01502 bbf/year)

Year	ΔPS-damaged ($million)	ΔPS-undamaged ($million)	ΔCS ($million)	ΔNet welfare ($million)
20	-.054	.111	-.111	-.054
21	-1.831	2.562	-2.564	-1.833
22	-3.569	4.767	-4.777	-3.579
23	-5.124	6.845	-6.865	-5.144
24	-6.553	8.752	-8.786	-6.587
25	-7.864	10.543	-10.594	-7.916
26	-9.065	12.136	-12.235	-9.164
27	-10.161	13.586	-13.679	-10.254
28	-11.159	14.904	-15.021	-11.275
29	-12.064	16.097	-16.239	-12.206
30	-12.883	17.247	-17.416	-13.051
Total	**-80.326**	**107.551**	**-108.286**	**-81.063**

Note: All dollar figures are present values. Δ denotes change and PS, CS, and NW refer to producer surplus, consumer surplus, and net welfare, respectively.

Table 5-10. Welfare Impacts of Annosus Root Disease (Mortality and Defect): High Alternative. (Mortality = 2.2864 bbf/year, Defect = 0.0601 bbf/year)

Year	ΔPS-damaged ($million)	ΔPS-undamaged ($million)	ΔCS ($million)	ΔNet welfare ($million)
20	-.198	.321	-.321	-.198
21	-7.559	10.129	-10.171	-7.601
22	-14.357	19.203	-19.360	-14.514
23	-20.614	27.583	-27.925	-20.956
24	-24.237	35.308	-35.893	-24.822
25	-31.666	42.414	-43.294	-32.547
26	-34.094	48.974	-50.115	-35.235
27	-40.931	54.845	-56.449	-42.536
28	-44.961	60.277	-62.300	-46.984
29	-48.615	65.238	-67.711	-51.087
30	-51.928	69.737	-72.686	-54.876
Total	**-319.161**	**434.030**	**-446.225**	**-331.356**

Note: All dollar figures are present values. Δ denotes change and PS, CS, and NW refer to producer surplus, consumer surplus, and net welfare, respectively.

Chapter 6
Ecological Effects Evaluation

The Resource

The forests of the Western United States have their own unique and delicate ecosystems. These systems, in turn, are home to thousands of animals that depend on the forests for their existence. The forests of the Western United States have about 1,000 vertebrate species, including resident and migrant bird species, freshwater and estuarine fish species, mammals, reptiles, and amphibians. However, little basic inventory information is available for many of these species.

Several of these animal species have specific management needs. These include species dependent on specific habitat conditions, such as riparian areas; cavity-nesters; species requiring early, mature, or old-growth forest conditions for optimum habitat; and popular game species.

A mission of the Forest Service is to secure for the Nation the benefits of an enduring wilderness resource by administering and protecting designated wilderness in the National Forest System. National forests and national parks in the West contain millions of acres of designated wilderness. The rate of use differs widely among individual wilderness areas throughout the region. Some areas are used little, while some of the more popular wilderness areas near population centers are beginning to exhibit signs of resource degradation. Approximately 25 percent of all National Forest System recreation use occurs in California, despite the fact that only about 10 percent of the total U.S. population lives in California. Many of California's national forests are concentrated in northern California and in the Sierra Nevada Mountains. Most of the distinctive and natural-appearing forest and mountain scenery that remains in California is located within the 20 million acres of national Forest system lands, the national and State parks, and Bureau of Land Management lands.

Private industrial forest lands are managed principally for timber production rather than wildlife, while private, nonindustrial lands are more likely to have multiple uses. Nevertheless, privately owned forest and rangelands are important wildlife habitats. About 60 to 80 percent of small game hunting and 20 to 35 percent of big game hunting occur on private land. Lands managed by other Federal agencies (principally the Bureau of Land Management, Department of the Interior) along with State-managed lands, contribute about 20 percent of small game hunting and 20 to 30 percent of big game hunting.

Recreation

The Western United States has a national and international reputation for outstanding mountain, valley, and coastline scenery. The most valuable scenery in the West is on those lands that are not only distinctive in character, but highly visible from scenic travelways, resorts, and recreation areas. Both the demand for scenic quality and the concern over the degradation of scenic resources are increasing and are expected to continue to increase. The policy of the U.S. Department of Agriculture is to advocate the conservation of natural and artificial scenic resources and protect and enhance the visual quality of the landscape. The Forest Service likewise strives to protect and improve the quality of natural beauty. Along with its other goals, the Forest Service is charged with applying these policies to all activities that result in visual alteration of the national forest landscapes. The forest recreation industry is structured around this scenic beauty with billions of dollars of capital investments tied to this resource.

The recreational resources on forest lands in the Western United States provide an enormous range of opportunities because of the mix of climates and landforms and their relative accessibility. Nearly any type of recreational experience, from resort living to rugged backcountry treks, is available. Regardless of the recreational activity, the northwest tourist industry depends heavily on the scenic beauty people associate with the forested landscapes of this area. Recreation use includes camping, hotels, lodges, resorts, motoring, hiking, hunting, fishing, and skiing. The Western United States maintains campgrounds with a capacity to accommodate hundreds of thousands of people at a time. These campgrounds are distributed throughout the area, and most are located close to population centers.

Wildlife

The forests of the Western United States provide habitats for a variety of wildlife, including important game species and many threatened or endangered species. Game species in the Western United States include deer, elk, bear, bighorn sheep, cougar, pronghorn, mountain goat, caribou, moose, grouse, rabbit and hare, quail, dove, squirrel, pigeon, turkey, chukar, and a variety of waterfowl. Economically important furbearers include beaver, raccoon, bobcat, and coyote. Threatened and endangered species that are sensitive to habitat changes include Columbian white-tailed deer, peregrine falcon, grizzly bear, northern and Mexican spotted owls, wolverine, tassel-eared squirrel, and accipiter hawks.

Perhaps no old-growth forest animal has received as much media attention as the northern spotted owl. It has been the focus of intense study, debate, and legal battles, and has become the symbol for the effort to save the old-growth forests of the Pacific Northwest. It is believed that the northern spotted owl has fairly selective habitat requirements that are closely tied to stands of old-growth Douglas-fir. The owl may require dense cover for protection from predators and the weather, a specific type of tree for nesting, sufficient food, and a large range for foraging. The owl is found only in southwestern British Columbia, western Washington and Oregon, and northwestern California, and destruction of stands in these areas may result in the loss of this species.

Important resident game fish, which have high recreational fishery values, include rainbow, eastern brook, brown, Dolly Varden, and cutthroat trout, as well as Kokanee and mountain white fish. Anadromous fish have both sport and commercial value, and are found in virtually all watersheds in the western part of the Pacific Northwest. Most of the spawning and rearing habitat for anadromous fish in the Pacific Northwest is found on the national forests. These salmon are born in the streams that run throughout these forests, migrate to the Pacific Ocean where they feed and grow, then return to the freshwater streams to reproduce. Reaching the mating grounds is often difficult, and once there, the chinook require the proper substrates—plentiful, cool, well-oxygenated fresh water and food. In addition, the forests provide the streams with blowdown logs, which create vital microhabitats for the salmon. The Olympic salamander is a species native to the springs and streams in the forests of the Pacific Northwest. Like most salamanders, it needs cool, moist conditions for survival, and it is extremely sensitive to sedimentation. Thus, disturbances in the forest riparian zone can harm populations of this species for decades.

These discussions on the ecological composition, fragility, and value of western forests are not intended to be all inclusive. Rather, they underscore that this vast forest resource has numerous biological components that might be affected. The following are perceived impacts (both positive and negative) that could occur as a result of the activity of one or more exotic pests acting alone or in combination.

Potential Pest Impacts

Plant-eating insects and pathogens are a normal part of forest ecosystems—at low population levels they play a positive role in cycling nutrients and diversifying habitats. Even the periodic insect outbreaks that have characterized many northern forests in the past were normal cyclic or episodic phenomena that had little long-term impact on forest health, and may have even improved it (Mattson and Addy, 1975). However, when outbreak cycles intensify or population numbers remain chronically high, insects and diseases become destructive forces within ecosystems. This generally happens when some ecological constraint on pest population growth is removed; it is much more common in exotic than in native pests. While it is impossible to say how many exotic pests are imported across national boundaries without becoming established in their new habitat, there are sufficient examples of exotics becoming major pests to conclude that introduction of organisms carries considerable risk. Chestnut blight, Dutch elm disease, white pine blister rust, gypsy moth, balsam wooly adelgid, larch casebearer, larch sawfly, and the European pine shoot moth are a few of the introduced pests that have caused economic and ecological disruption in forests of the United States. As of 1977, 70 foreign insects were established in forests of the Western United States, 4 of which had become major pests (Furniss and Carolin, 1977).

The risk associated with introduced pests is even greater now than in the past. To understand why this is so, it is necessary to briefly discuss the ecology of pest population dynamics. In natural ecosystems, four factors constrain the ability of insects and pathogens to attain high population levels: (a) the availability of suitable food plants; (b) chemical defenses produced by food plants; (c) climate; and (d) biotic controls, such as parasites, predators, and diseases (DeBach, 1974; Baker and Cook, 1974; Furniss and Carolin, 1977; Perry, 1988; Perry and Maghembe, 1989). These factors do not operate independently but rather work together to limit pests. For example, by dampening the growth of pest populations, natural enemies may reduce the rate at which the pests can adapt to plant chemical defenses. On the other hand, by slowing the growth of individual pest organisms, climatic factors and plant chemical defenses combine to make the pest more vulnerable to natural enemies. Imbalance in ecosystems occurs periodically. For example, the reduction in the array of plant chemical defenses is curtailed when trees become stressed by any factor (Waring and Schlesinger, 1985; Perry and Maghembe, 1989). Drought, for example, is a common trigger of insect outbreaks throughout the world (Mattson and Haack, 1987).

Exotic pests are particularly destructive because they are operating in a new ecological context, one in which one or more of their natural controls is absent: they may have few or no natural enemies, and trees that have effective defenses against the pests with which they have coevolved may have none against an invading pest. To give just one example, two factors contributed to the European pine shoot moth (*Rhyacionia buoliana*) becoming a greater pest in the United States than in its native Europe: trees were more palatable to it in the United States, and in contrast to its native habitat, the moth had no internal parasites in the United States (Miller, 1967). Attempts to control *R. buoliana* by introducing its parasites from Europe failed, perhaps because the parasites did not have suitable alternate hosts in the United States (Miller, 1967). Similarly, of 40 natural enemies of gypsy moth introduced into the United States, only 10 became established, and only 1 of these provided a measure of control (Pimentel, 1986). The point here is that controls over pest populations in their native habitats involve many direct and indirect interactions within the ecosystem, which implies that there are no quick technological fixes. This is not to say that attempts to control exotic pests by introducing their natural enemies are doomed to fail—there have been a number of clear successes (Ryan, 1987; Ryan et al., 1987); however, success is far from guaranteed, and even when achieved may take many years (Elton, 1958; Pimentel, 1986). For example, *Entomophaga maimaiga*, a fungal parasite of the gypsy moth that was released in the United States in 1910 did not begin to kill the moth in large numbers until 1989.

North American forests are likely to be particularly vulnerable to the introduction of exotic pests during the coming decades. Factors, such as environmental stress associated with anthropogenic agents, may reduce the ability of trees to defend themselves, and extensive habitat modification and fragmentation have altered various ecosystem and landscape factors that affect pest dynamics.

Environmental Stress

The history of biological invasions clearly shows that exotic pests establish themselves most successfully in ecosystems that have been stressed by mismanagement, overutilization, or some other factor (Elton, 1958; Orians, 1986). Air pollution is a unique stress that affects even pristine ecosystems: outbreaks of bark beetles and the balsam woolly adelgid in the Eastern United States are believed to have been triggered by pollution (Hain, 1987); in the San Bernardino National Forest of California, ponderosa pines stressed by pollution become more susceptible to bark beetles (Taylor, 1973).

Possible effects of climate change on forest health are complex and incompletely understood, but in all likelihood pest problems will be exacerbated in a warmer, drier climate (Oregon Department of Energy, 1990; Perry and Borchers, 1990). Drought stress will reduce the ability of trees to produce defensive chemicals, weakening an important line of defense against pests (Mattson and Haack, 1987). It has been suggested that higher levels of atmospheric CO_2 will allow plants to produce more defensive chemicals, but the experimental evidence is unclear on that point: studies conducted to date show that insects consume from 20 to 80 percent more when fed on plants grown in an elevated CO_2 atmosphere than when fed on plants grown in ambient CO_2; however, they perform relatively poorly on the former (Bazzaz, 1990). Another factor that strongly influences the probability of pest outbreaks is the intrinsic rate of pest population growth, which is likely to increase with warmer average temperatures (Andrewartha and Birch, 1954). At least one of the Siberian pests that might be imported, the pine wood nematode (*Bursaphelenchus xylophilus*), is known to be limited by low temperatures (Rutherford et al., 1990); other factors being equal, the nematode will favor a warmer climate.

In summary, while the issue is complex, the weight of evidence indicates that forests will be more vulnerable to both native and introduced pests in a changing climate. It should be noted that trees stressed by one pest often become more vulnerable to others. For example, balsam fir attacked by the introduced insect, balsam wooly adelgid, became more susceptible to the root pathogen, *Armillaria mellea* (Hudak and Singh, 1970). It is entirely within the realm of possibility that changing climate, increased incidence of established pests, and the introduction of new pests could act in combination and amplify one another.

Habitat Modification

Modified habitats have increased the risk associated with introduced pests because the relative uniformity of managed forest landscapes facilitates the spread of pests and the severity and spread of some tree pathogens has been exacerbated by forest management (Perry, 1988). The habitat for some natural enemies of pests has been reduced by forest fragmentation and the removal in managed forests of certain key structural elements, such as snags, logs, and multi-structured canopies (Wilcove, 1985; Torgersen et al., 1990). Declining numbers of migratory songbirds, important consumers of forest insects, have been well documented in the United States and Canada over the past several years (Wilcove, 1985). Holling (1988) concludes that, while the presence of fewer insect-eating birds alone is unlikely to trigger insect outbreaks, one important line of defense has been clearly weakened, and forests have consequently become more vulnerable to pests.

Moreover, Schowalter's (1989) studies in the Northwest and Southeast show that, in both areas, plantations support quite a different insect fauna than old-growth forests. Canopies of the former are dominated by tree-eating insects (aphids and related sucking insects), while older forest canopies have a much more diverse insect fauna, including many more species of spiders that prey on tree-eating insects. The same results from two different forest types suggests a general phenomenon.

It is unclear what Schowalter's findings imply for the ability of forests to resist newly introduced pests, but other factors being equal, the combination of fewer natural enemies and more preexisting pests suggests that plantations would be more vulnerable to introductions than older forests. If so, that has considerable implications for the rate at which new introductions will spread, since a high proportion of the forested landscape is now occupied by younger forests as a result of logging and subsequent replanting.

Criteria for Assessing Ecological Impacts

While the ecological impacts of potential pest introduction are difficult to assess because of the complexity of forest ecosystems, general concepts can be applied.

Proportion of the Total Susceptible Plant Cover in the System

Ecological impacts from a particular pest are most severe when its host preferences are general, or, if its preference is specific and the host upon which it feeds accounts for most of the primary timber production. Even a highly virulent pest, such as chestnut blight, may have a relatively minor long-term ecological impact if it attacks only one or a few tree species within a species-rich forest, if the tree species that are attacked do not perform some unique function within the ecosystem. However, many western forests differ significantly from the eastern deciduous forests that were attacked by chestnut blight and gypsy moth, in that western forests are often dominated by relatively few (or even one) tree species, hence they are particularly vulnerable to specialized pests.

The Role of the Susceptible Plant Species in the Ecosystem

Hardwoods provide a good example of keystone species in the conifer-dominated West. Riparian hardwoods shade streams, stabilize channels, and provide organic matter to aquatic foodwebs (Cummins, 1980). Nitrogen-fixing plants, such as the various species of alders and ceanothus, are critical to long-term soil fertility. Hardwoods and other flowering plants serve as a vital link in the food chain for some animals, including species of wasps and flies that parasitize defoliating insects.

Adaptability and Aggressiveness of Potential Introduced Pests

The following sections discuss the adaptability and aggressiveness in North American forests of the potential introduced pests profiled in Chapter 4.

Asian Gypsy Moth

The gypsy moth has been relatively specialized in the Eastern United States, attacking hardwoods most readily, and particularly oaks. Spread to conifers has occurred only when they are mixed with hardwood hosts. The California Department of Food and Agriculture (CDFA) (1982) lists 71 plant species native to that State that would be susceptible to gypsy moth defoliation, including Douglas-fir, sequoia, redwood, five species of oaks, nine species of pine, and four species of manzanita. Feeding trials with western plant species indicate that oaks, alders, maples, poplars, and manzanita are highly suitable hosts (Miller and Hanson, 1989; CDFA, 1982). Suitability of Douglas-fir varies widely with temperature, with larval survival peaking at 84 percent at 22 °C, then dropping sharply at both cooler and warmer temperatures (Miller et al., 1991). With regard to virulence, trees in the Eastern United States were able to recover from gypsy moth defoliation so long as they were initially healthy, and providing they were not chronically defoliated. The potential threat to keystone hardwood species is high; the potential for extensive infestation of conifer forests is largely unknown but probably ranges from moderate to high. Based on experience in the Eastern United States, tree kill resulting from attack is likely to range from moderate in healthy forests to high in stressed forests.

Nun Moth

Based on its host preferences in Siberia and the Soviet Far East, the nun moth will attack all western conifers except the pines. Hence the potential for extensive infestation is high if this insect is introduced and becomes established. This insect consumes most or all foliage on a tree, which is particularly devastating to conifers; mortality resulting from nun moth attack is likely to be high.

Pine Wood Nematode

Host records suggest that this nematode would readily attack ponderosa and Jeffrey pines. Ponderosa pine is the dominant tree on 27 million acres of forest, second only to Douglas-fir in the Western United States in terms of area on which it is the principal tree (Van Hooser and Keegan, 1988); however, stands at lower elevations in the more southerly portions of the range are most likely to be attacked under current climatic regimes. The pine wood nematode is extremely virulent in areas where the average summer temperature exceeds 20 °C, and relatively innocuous where it does not (Rutherford et al., 1990).

Larch Canker

Specific to members of the genus *Larix,* this disease could have a major impact on the 2 million acres of Western U.S. forest with 50 percent or more larch cover.

Annosus Root Disease

If introduced and established, this pathogen has a high potential to infest extensive areas of true fir and dry pine forests. Mortality in infested areas would probably be high.

Spruce Bark Beetle

Though it will occasionally attack pines and larch, this insect's main hosts are *Picea* spp. It can infest and kill substantial numbers of standing trees during epidemics. If introduced, spruce bark beetle has a high potential to cause extensive mortality in Sitka and Engelmann spruce stands in the Western United States and Canada.

Ecological Impacts of Large-Scale Infestations

Most of the pests emphasized in this report have the potential to infest extensive areas of one or more forest types in the West. It is impossible to state the probability of extensive infestation should one or more exotic pests be introduced, or the feasibility of their control. However, since the risk of spread of these pests is high, large-scale infestations and tree mortality are likely to occur. Ecological effects of extensive tree death would be profound in the short run. Long-term impacts would depend on how quickly and completely the system recovered. Trees provide the energy that fuels ecosystems, and much of the habitat structure required by animals and microbes. Roots and associated microorganisms stabilize soils, thereby protecting watersheds, and canopies affect regional climates by cycling water and absorbing heat. Hence, the more total tree cover is reduced, and the longer it stays reduced, the greater will be the impact on local ecosystems, associated streams and rivers, and entire regions.

Loss of a significant proportion of living trees within stands would trigger complex changes in food supply and habitat. One of the first effects would be a shift in the pathways of energy flow through ecosystems, accompanied by changes in community composition. Detrital food chains—fueled by dead organic matter—would be favored, while food chains that depend on living trees would collapse unless the system recovered very quickly. The latter include a complex community of microbes, invertebrates, and from several score to perhaps several hundred vertebrate species (Harris, 1984). It is uncertain how many species could switch successfully from the living food chain to the detrital one; among those unlikely to make that transition are a number of mycorrhizal fungi, several species of voles, flying squirrels, and spotted owls.

Greater forage production beneath open canopies would provide more summer food for elk and deer; however, older closed-canopy forests are believed to be the most limiting habitats for elk in west-side forests (Raedeke and Lehmkuhl, 1986), and for deer in southeast Alaska (Wallmo and Schoen, 1980). Hence, the net effect on those animals would probably be negative. Other species that would be negatively impacted by loss of the habitat structure provided by old-growth or closed-canopy mature forests include western yew, spotted owl, and accipiter hawks. Species that depend on snags and logs for habitat would benefit in the short run from the pulse of dead wood, but would lose a future source of snags and logs.

With regard to aquatic habitat, the combination of more water moving through the soil and reduced root strength would increase the probability of surface erosion and mass soil movements, which would in turn pulse more sediment to streams (Swanson et al., 1989). Salmonids are particularly sensitive to sediments, which reduce aeration within spawning gravels. One study found that emergence of alevins from eggs declined from greater than 90 percent to less than 5 percent as the percentage of fine sands mixed with spawning gravels increased from 0 to 50 percent (Cedarholm and Salo, 1979).

Regional hydrology would be altered if trees were killed over a wide area. Reduced evapotranspiration and sublimation of snow from tree canopies would cause more of the yearly precipitation in heavy tree kill areas to run into streams (Bosch and Hewlett, 1982), while rainfall in downwind areas could decrease because less water was cycled back to the atmosphere (Andre et al., 1989; Newson and Calder, 1989). Without the modulating effect of upslope forests, stream flows would probably become more variable, with greater peak flows in the spring and lower summer water levels.

The long-term implications of the impacts discussed in this section depend critically on how fast the pest (or pests) spreads, and how quickly the system recovers from attack. A rapidly spreading, virulent pest would almost certainly destroy forests faster than they could recover, and species whose habitat is already limited (such as spotted owls) may be pushed toward extinction. Longer term effects of a more slowly spreading, or less virulent, pest could be relatively minor if new forests were established quickly; even suitable old-growth structure might be recouped in several decades if enough large trees survived to provide the basic structural framework. The establishment of new forests would depend on various factors, principally availability of seed, the degree to which pests attacked establishing seedlings, and other environmental stresses that might limit successful seedling establishment. In some areas of the Eastern United States, regeneration has completely failed due to the combined effects of defoliation by gypsy moth and deer feeding on the seedlings (Gottschalk, 1990).

System recovery from pest attack will depend upon abiotic factors such as climate. While the reality of global climate change is unpredictable, it is instructive to consider its implications relative to potential pest introductions. Successful seedling establishment is likely to become more difficult if the trees occupying a given site become increasingly maladapted to their local climate. Drought already hampers reforestation throughout much of the interior West and from southern Oregon south into California; increasing dryness can only exacerbate that problem. Heavy fuel loads will make young stands particularly vulnerable to wildfire (Franklin et al., 1989; Gottschalk, 1990), and a warmer, drier climate would greatly exacerbate fire danger. It is entirely possible that a combination of unusual stresses could tip forested sites into relatively stable grasslands or chaparral—such threshold changes have occurred, and may even be widespread (Perry et al., 1989). In some situations at least, including high-elevation forests of the Western United States, deforestation triggers physical and biological changes in soils that make reforestation more difficult; soils can actually lose their ability to support trees (Perry et al., 1989).

Potential ecological impacts of introduced pests upon ecosystems vary with the pest, the severity of damage, and the structure and health of the forest resource. An analysis of select pest species effects serves to illustrate the complexity of these interactions.

Asian Gypsy Moth

While the gypsy moth will potentially feed on a wide variety of western trees and shrubs, experience in the Eastern United States suggests that hardwoods will be most heavily affected. Gottschalk (1990) listed the following effects of the gypsy moth infestation in the Eastern United States:

- Higher water temperatures.
- Lower water quality.
- Less hard mast production (acorns); defoliation can result in several consecutive years of complete mast failure.
- More woody debris in streams.
- More snags, dens, and cavity trees.
- More understory vegetation and vertical stratification.
- Altered microclimate due to loss of canopy cover.
- More patchiness within forests resulting from site-related tree mortality.
- Greater insect availability to consumers.
- Loss of nesting sites.

While most of these effects could be expected in the West as well, several factors argue that there would also be significant differences between Asian gypsy moth in western forests and European gypsy moth in the East. Unlike the European variety, female Asian gypsy moths fly (up to 40 km) and will disperse much more effectively. Furthermore, gypsy moth larvae survive better in dry summers than in moist ones (Leonard, 1974). Hence, other factors being equal, gypsy moth populations may have a higher growth potential in the West, where summers are drier than in the East. Species composition and structure of eastern and western forests differ in ways that are likely to influence gypsy moth behavior and patterns of defoliation. Many eastern forests are dominated by hardwoods with admixed conifers, while the situation is quite the opposite in most western forests—hardwoods are admixed with dominant conifers. That difference has two implications. Lower hardwood density might slow gypsy moth spread in western forests; on the other hand, older larvae will eat some conifer species, hence spread may be little affected by admixed conifers.

Unlike the East, where some hardwood species are relatively resistant, feeding trials indicate that western hardwoods are uniformly palatable to the insect (Miller and Hanson, 1989). In the relatively species-rich hardwood forests of the Eastern United States, gypsy moth infestations caused species composition to shift toward trees that were less susceptible to the insect, but had little or no long-term impact on total stocking (Herrick and Ganser, 1988). In the West, gypsy moths could shift mixed conifer-hardwood forests toward pure conifers, with the loss of certain roles played by hardwoods. Western forests that are dominated by hardwoods, including some keystone communities such as riparian zones, are relatively monotypic, and likely to be much more heavily affected than diverse eastern forests. In the West, defoliation will translate to losses in total tree cover, or to losses in keystone species such as nitrogen-fixing alders. Risk is greatest in riparian forests, and in upland forests with a significant hardwood component.

Riparian forests are frequently dominated by alders, maples, or, in the interior West, poplars; all of which are highly palatable to the gypsy moth (Miller and Hanson, 1989). These communities provide critical habitat for a variety of terrestrial animals, and link with streams in multiple ways. Riparian zones are considered the most critical wildlife habitats in the Blue Mountains of Oregon and Washington: "Of the 378 terrestrial species known to occur in the Blue Mountains, 285 are either directly dependent on riparian zones or utilize them more than other habitats" (Thomas et al., 1979). Riparian zones play the same keystone role in western Oregon and Washington (Oakley et al., 1985), and in the arid interior (McKern, 1976). Removing riparian trees increases productivity of headwater streams since more light stimulates primary production within the stream, but it also raises water temperatures and could destabilize stream banks by increasing the silt load. Both effects would be detrimental to salmonids.

Hardwoods commonly occur intermixed with conifers in upland forests west of the Cascade crest. Alders are common pioneers on disturbed sites, where they play a keystone role as nitrogen-fixers. Maples frequently form a secondary canopy layer in mature Douglas-fir forests. Hardwoods are a particularly important component of the so-called mixed conifer forests that cover extensive upland areas from southern Oregon through California and Arizona, while relatively monotypic oak woodlands frequently occur at lower elevations in the same areas. In California alone, hardwoods occur on 21.3 million acres of forest or savannah (more than 20 percent of the total land area in the State), including 9 million acres classified as hardwood forest types and 1.8 million acres of savannah (Bolsinger, 1988).

The effect of gypsy moth defoliation and subsequent tree mortality in mixed-species forests could shift communities toward greater dominance by conifers, with varying long-term ecological effects, depending on the degree to which hardwoods are reduced. In some cases, past management practices have inadvertently shifted forests toward a greater hardwood dominance than probably occurred in the past; some hardwood defoliation would increase biological diversity in these situations by permitting conifers to be reestablished. However, extensive hardwood defoliation throughout the region would diminish tree diversity and affect animals as well. Biologists generally agree that conifer monocultures support fewer animal species than mixed forests (Salwasser and Tappeiner, 1981). As flowering plants within conifer forests, hardwood nectar provides a unique source of food for some animals. Loss of hard mast (acorns) as a result of oak defoliation was a primary concern in the Eastern United States (Gottschalk, 1990) and would also be a factor in the West.

In addition to their role in supplying habitat and food, hardwoods are keystone players in certain processes within mixed conifer forests. Nitrogen fixation is clearly one of these, but even non-nitrogen-fixing species strongly influence soil fertility by accumulating cations and stimulating nutrient cycling (Klemmedson, 1987; Amaranthus et al., 1990; Borchers and Perry, 1990; Freid et al., 1990). Hardwoods are better adapted than many conifers to quickly recover from catastrophic disturbance, and stabilize soils during the critical early stages of system recovery following wildfire or clearcutting (Amaranthus and Perry, 1989; Borchers and Perry, 1990). Considerable anecdotal evidence indicates that some hardwoods are relatively inflammable and protect admixed conifers from fire. The strong regenerative capacity of hardwood species within the mixed conifer type could allow them to recover quite well from one or perhaps several defoliations. However, chronic defoliation would eventually exhaust that capacity.

Oak woodlands are quite monotypic, hence defoliation would translate to lost tree cover rather than shifts in species composition. Valley oak forests in California are already threatened because of various factors that have greatly reduced regeneration success (Bolsinger, 1988), and extensive defoliation would probably convert these forests to annual grasslands. Despite their relatively low tree species diversity, oak forests provide important animal habitat. They are important winter range for deer, and support a surprising diversity of breeding birds (Landres and MacMahon, 1983); extensive loss of oak woodlands would seriously threaten at least one of these, the acorn woodpecker.

Nun Moth

The nun moth has tremendous potential for extensive defoliation of western forests; probable hosts cover 172 million acres in the Western United States (including Alaska), and extensive areas of Canada. Virtually all forests west of the Cascade Crest would be vulnerable, as would high elevation spruce-fir forests throughout the Cascades, Rockies, and Sierras. All boreal conifers, except lodgepole and jack pines, would be vulnerable.

The nun moth is reported to defoliate trees more rapidly and completely than spruce budworm and tussock moth, the two most common native defoliators in spruce-fir forests. Hence, tree mortality would almost certainly be greater in a nun moth infestation than is the case with the native defoliators. Experience with gypsy moth suggests that 60 percent defoliation is a critical level beyond which hardwoods must use vital reserves to refoliate (Herrick and Ganser, 1987); however, conifers are more likely to die following complete defoliation than hardwoods (CDFA, 1982). As discussed earlier, the ecological factors that reduce outbreaks of native pests (tree resistance, natural enemies) seldom operate as effectively on exotic pests; hence, barring some unforseen control agent, nun moths would have a significantly greater long-term impact on ecosystems and regions than the native defoliators.

The most probable outcome of nun moth establishment in the United States is complete conversion of vegetation type in susceptible forests. Ecological impacts would depend on the nature of the conversion. If converted to pine, habitats would be altered somewhat, but basic ecological processes such as nutrient and water cycling would probably remain intact. If converted to nonforest vegetation, effects on both habitats and ecosystem processes would be considerable.

Under favorable conditions, high elevation spruce-fir forests in the Rockies would probably be replaced by lodgepole pine, while boreal spruce-fir would be replaced by lodgepole pine, jack pine, aspen, and alder (assuming that the hardwoods are not attacked by gypsy moth). Rocky Mountain forests without a nearby source of colonizing pine would probably convert to shrubs, forbs, and grasses. High elevation true fir forests on the west slopes of the Cascades support no hardwoods, and only rarely pines, so these forests would probably convert to grasses, sedges, and shrubs. This has already happened in many high elevation clearcuts. Pines do not occur in Douglas-fir/western hemlock and Sitka spruce/western hemlock forests, and the hardwood trees within these types are generally restricted to moist sites. Assuming no gypsy moth infestation, alders and maples would tend to replace conifers in the moist Sitka spruce/hemlock types of the west slopes of the coast range. In the Douglas-fir/hemlock type, those species are likely to successfully replace conifers only on north slopes and other moist microsites. Many of the west-side forests now dominated by Douglas-fir could be converted to nonforest.

Potential ecological impacts of this insect correspond to those discussed earlier for a widespread, lethal pest, especially in forest types with few or no resistant tree species. The combined effects of altered habitats and food supply would produce complex responses in animals that are beyond the scope of this report to analyze in any detail. One food chain that would almost certainly collapse in western Oregon and Washington is that based on truffles, which includes several species of mycophagous small mammals that are virtually the sole prey of the spotted owl. It is difficult to see how remaining owls could survive a combined loss of remaining habitat and food supply. On the other hand, insect-eating birds would benefit, at least in the short run. Elk and deer would gain summer food in herbaceous and shrubby undergrowth, but that could outweigh the loss of winter food and thermal cover. Because they remain relatively snow-free, old-growth coniferous forests are critically important winter foraging areas for elk and deer (Wallmo and Schoen, 1980; Witmer et al., 1985). Extensive loss of forest cover in the Western United States and Canada would lead to the destruction of an important source of carbon sequestering.

Pine Wood Nematode

Of the two western pines believed susceptible to this pest, the Jeffrey pine has a relatively narrow distribution and usually occurs in mixed stands, while the ponderosa pine is widely distributed and often occurs in monotypic stands. Therefore, the greatest ecological impacts would be associated with infestation of the latter species.

The pine wood nematode is highly lethal to pines, but only in areas where the mean July temperature exceeds 20 °C (Rutherford et al., 1990). Siberian nematode strains that operate at lower temperatures are possible. According to climatic data compiled by Neilson et al. (1989), July temperatures in the southern interior West, circa 42 degrees north latitude, average greater than 20 °C. The areas of maximum ponderosa pine development includes southern Oregon, California, Arizona, and New Mexico. The low elevation stands most likely to be attacked are relatively pure ponderosa pine forests that occur in an elevation band immediately above oak woodlands, chaparral, rangelands, or pinyon juniper, depending on locale (Shelford, 1963). In theory, death of the pines would convert the pine stands to whatever type formed their lower boundary. In fact, one or more of the many exotic weeds that have a strong foothold in the West (for example, cheatgrass) are likely to be the first to invade areas with heavy tree kill. Once established, the weeds would make it more difficult for other plants to invade. Nematodes would affect higher elevation forests in two ways if the climate warms as predicted. First, pines growing at higher elevations would become vulnerable. Second, the loss of ponderosa pine would eliminate the tree that is most likely to colonize areas vacated by spruce-fir forests as the latter migrate upward in elevation. The end result would be further spread of exotic weeds up the mountain slopes (these weeds are highly aggressive and will spread to high elevations once tree cover is lost) (Amaranthus and Perry, 1987).

As with losses of forest cover discussed earlier, extensive death of ponderosa pine forests would alter habitats, regional hydrology, water quality, and carbon stores. Ponderosa pine forests are heavily used by animals. Thomas et al. (1979) list 135 species that use ponderosa stands for feeding, and 95 species that use them for breeding; few rely solely on ponderosa forests. One animal that does depend on ponderosa pine for most of its food is the tassel-eared squirrel (*Sciurus aberti*), which is native to the southern Rockies (Keith, 1965). Extensive loss of ponderosa pine in the Southwest would very likely drive that species toward extinction. Effects on most other animals, indeed on all ecological factors, would depend on whether ponderosa forests were converted to nonforest vegetation or to other forest types (such as, pinyon-juniper or, barring gypsy moth, oaks). Conversion to nonforest would have the greatest impact. For example, of 35 bird species recorded by Szaro and Balda (1979) in Arizona ponderosa pine, 25 would not breed in clearcuts. The pulse of snags and secondary insects (bark beetles) would favor some bird species in the short run; however; longer term effects would be detrimental to those guilds as well. Ponderosa pine snags are important nest sites for pileated woodpeckers, but other trees might serve as adequate substitutes. Deer and elk would find more summer forage beneath the openings created by tree kill, but less thermal cover and winter forage; the net effect on those animals would depend on what was most limiting in any given area.

Extensive death of ponderosa pine in any one region would significantly affect the hydrologic cycle. According to one model, streamflows in the Southwest would increase by one-third with an 80-percent loss of ponderosa pine cover (Covington and Wood, 1988). Greater flow of water to streams would result in decreased rainfall to downwind areas.

Larch Canker

A primary ecological role of western larch is colonization of disturbed sites at mid- to upper elevations in the intermountain region and northern Rockies. Other species also play that role, especially lodgepole pine and Douglas-fir, and to a lesser extent white pines and Engelmann spruce. While the immediate effect of extensive larch mortality would probably accelerate conversion to late successional forest types, the more serious long-term impact would be loss of redundancy in the early seral tree guild. In essence, the burden of maintaining early successional tree cover in the spruce-fir zone would shift to lodgepole pine, spruce, and on drier sites, Douglas-fir.

Late successional trees in western conifer forests are prone to fire, insects, and diseases, and will become more so if the climate changes as predicted. The early successional tree species play a vital, important ecological role in these ecosystems by maintaining continuity in forest cover, thereby preserving habitat, and protecting soils and watersheds. Though other early seral trees would fill some of the niche vacated by larch, they are unlikely to fill it. Consequently, with the reduced presence of larch, the probability that disturbed spruce-fir stands will convert to relatively persistent nonforest vegetation would increase. Ecological effects would be similar to those discussed earlier for conversion of forest to nonforest, with the severity of the effect critically depending on how effectively other early seral trees replaced larch.

Annosus Root Disease

Annosus root disease already causes widespread growth loss and mortality in true fir, old-growth hemlocks (150 years old and older) and ponderosa pine on dry sites. The fungus is capable of infecting a number of other western tree species; however, it appears to cause little mortality or growth loss in these species.

Ecological impacts of an imported strain (or strains) would depend on its aggressiveness compared to strains currently present in the Western United States. For example, a more virulent strain would probably be less restricted to drought-affected habitats and spread more widely throughout ponderosa pine stands than current strains. An introduced strain that successfully infected Douglas-fir, western larch, or lodgepole pine would greatly increase the area affected by the disease. Ecological impacts would include reduced vigor and increased mortality of important early successional tree species, with the same consequences that were discussed in the previous western larch section. A strain that was generally virulent, something that is at least theoretically possible in this fungus, has the potential to seriously disrupt western forests. Even if mortality resulting from the infection were low, trees would be less able to resist other biological and climatic stresses to which they either currently are or will be subjected to.

Spruce Bark Beetle

If introduced into Western North America, *Ips typographus* and its virulent fungal associate *Ophiostoma polonica* have the potential to kill spruce over large areas at unprecedented rates. Beetle epidemics triggered by wind storms, droughts, or other disturbances could greatly reduce or even eliminate Sitka and Engelmann spruce from stands where they are now major components.

Sitka spruce occurs mainly in moist, coastal forests. If killed by the spruce bark beetle, it would likely be replaced by western hemlock, western red cedar, and hardwood species, especially red alder.

Engelmann spruce generally occurs in harsher high-elevation ecosystems. If killed by beetles, it would probably be replaced by true firs, mountain hemlock, and lodgepole pine. In some cases, areas of extensive Engelmann spruce stands would not be reforested following a beetle epidemic unless they were planted.

Summary

Exotic pests pose a particular threat because they are generally free of the ecological constraints with which they have coevolved in their native habitat.

Risks associated with all pests are higher now than in the past because of stresses associated with disturbed habitats, reduced populations of natural enemies, and increased anthropogenic agents. The ecological effects of a pest depend on: host generality, the degree to which hosts play some keystone role, and the rate of spread compared to the rate at which attacked ecosystems recover. Extensive tree kill from one or more exotic pests would benefit some animals and threaten others, lower water quality, alter regional hydrology, increase the probability of wildfire, and reduce the carbon storage capacity of western forests. The primary impact of gypsy moths would be on hardwoods, which play a number of keystone roles in western forests; with warmer springs, gypsy moths might also successfully attack Douglas-fir. The nun moth could convert many conifer forests to either hardwoods or nonforest, particularly west of the Cascade Crest, with serious consequences for a number of animals, including spotted owls, salmon, and elk. Under current climatic conditions, the pine wood nematode would affect primarily lower elevation ponderosa pine stands in California and the Southwest, converting them to hardwood scrub or nonforest; at least one animal, the tassel-eared squirrel, would be endangered, and regional hydrology would be significantly altered. Extensive larch mortality caused by larch canker would reduce the presence of an important early-seral tree species, increasing the probability that at least some disturbed sites in the interior West would be captured by weeds. The effect of introduced strains of annosus root disease would depend on whether their host range and environmental tolerances differed significantly from strains currently present in the West. More than one lethal pest would increase the probability of large-scale conversion of western forests to nonforest. It is possible that the combined effects of environmental stress, greater activity of pests already present in western forests, and the introduction of new pests could create a scenario whereby the ecology of western forests would be rapidly degraded.

Chapter 7
Conclusions

Pests introduced into North America through the importation of unprocessed logs from Siberia and the Soviet Far East pose a significant risk to North American forests. A variety of exotic forest pests, including insects, nematodes, and fungi, can be transported on or in logs. Many of these organisms can survive in transit and have a high potential to colonize suitable hosts near ports of entry. The subsequent spread of these exotic pests beyond the colonized area could have severe adverse impacts on the economic and ecological value of North American forest resources.

Because of the numerous factors involved in any pest introduction, it is impossible to predict exactly which organisms might be introduced during log importation. Therefore, the histories of previous pest introductions were examined to provide insight into identifying and assessing the risks associated with the movement of plant material. The six case histories presented in Chapter 3—on the gypsy moth, chestnut blight fungus, Dutch elm disease fungus, Port-Orford-cedar root rot fungus, pine wood nematode, and white pine blister rust—indicate that although introduced organisms are often innocuous or even unknown in their place of origin, they can have catastrophic effects when introduced into new environments. All but the gypsy moth were unknown as pests in their native habitats. These case histories also provided information on the scope and magnitude of the consequences associated with the importation of forest pests. This provided a basis for understanding and predicting impacts from the establishment and subsequent spread of pests that could be transported with logs from Siberia and the Soviet Far East.

A large number of pest species have the potential to be introduced. For this risk assessment, however, not enough time and data were available to evaluate the risks posed by every organism. The specific organisms evaluated during this assessment represent the types of pests that could be introduced on logs as hitchhikers, those that occur in the bark, and those that are within the wood (see tables 4-1, 4-2, and 4-3). This was done to facilitate the APHIS Management Practices Team's evaluation of effective mitigation measures.

Risk assessment profiles were developed for those pests considered to pose the greatest potential risk to North American forests and for which information is available on their life cycle, ecology, invasion ability, and their potential ecological and economic impacts. Mitigation practices developed for these known pests are presumed to be as effective in combating similar unknown pests. Nematodes, larch canker fungus, annosus root disease fungus, Asian gypsy moth, nun moth, and spruce bark beetle were the six pests considered to represent the greatest known risk to North American forests in the event of an introduction. Detailed assessments of the potential consequences of introduction and establishment were prepared for these pests (see Chapters 4, 5, and 6).

The potential economic costs associated with the introduction of these pests are high. These costs would result from reduced yields caused by growth loss, increased mortality, and defects in the host species—problems that lead to reduced stumpage prices. Table 7-1 summarizes the range of potential economic impacts to the commercial timber resources of the Western United States from the introduction and establishment of each pest group considered in the analysis. Note that expenditures for pest control and management should also be expected from such introductions.

Exotic pests pose a particular threat because they are generally free of the ecological constraints with which they have coevolved in their native habitat. The introduction and establishment of any organism could result in extensive mortality rates for host species. The resulting ecological effects on North American forests could include tree species conversions, deforestation, wildlife habitat destruction, degradation of riparian communities, increased fuel loading, and loss of biodiversity.

The following are some of the principal ecological impacts:

- Gypsy moths would affect hardwoods that play key roles in western forests.

Table 7-1. Summary of Economic Costs to the Timber Resources of the Western United States From Introducing Selected Soviet Forest Pests (All Ownerships Consist of Unreserved Timber)

Pest	Host	Economic Cost (millions 1990 $) Best Case	Worst Case	Affected Acres (millions)
Nematodes	*Pinus* spp.	33.35	1,670.00	26.7
Larch canker	*Larix* spp.	24.90	240.60	0.8
Annosus root disease	*Pseudotsuga menziesii* *Larix* spp. *Pinus* spp.	84.20	343.90	9.6
Defoliators	*Pseudotsuga menziesii* *Picea* spp. *Abies* spp. *Tsuga* spp. Other	35,049.00	58,410.00	77.1
Spruce bark beetle	*Picea* spp.	201.00	1,500.00	8.1

- The nun moth would convert many conifer forests to hardwoods or nonforest, with serious consequences for a number of animals, including spotted owls, salmon, and elk.

- The pine wood nematode would affect ponderosa pine stands in California and the Southwest, converting them to scrub or nonforest. At least one animal, the tassel-eared squirrel, would be endangered, and the regional hydrology would be significantly altered.

- Larch canker would reduce the presence of larch, an important early seral species in western forests, increasing the probability that disturbed sites would be invaded by weeds.

- A new strain of annosus root disease would affect Douglas-fir stands, with consequences similar to those created by the nun moth.

- Spruce bark beetle and its associated pathogenic fungus would increase the probability that spruce forests would convert to nonforests.

This risk assessment focused on risks associated with importing larch logs from Siberia and the Soviet Far East. However, parallels can be drawn with other coniferous logs. Many of the organisms assessed have broad host ranges and could be imported on other types of logs. The grouping of organisms for assessing their transport potential can be applied to logs from any tree genera. The process of evaluating the risks associated with the importation of other logs would be the same. Although the magnitude of consequences may be different for any particular type of log, the methods for estimating risk would apply to other genera of logs.

A team of specialists from the U.S. Department of Agriculture (USDA), including members of the Pest Risk Assessment Team and the Management Practices Team, traveled to the U.S.S.R. to meet with Soviet scientists and foresters in early July 1991 to discuss the pest risk assessment and to view forest pests, forest harvesting practices, and log handling procedures in the Soviet Far East and Siberia. The USDA team met with forest entomologists and pathologists at V.N. Sukachev Institute of Forestry and Wood in Krasnoyarsk, the Siberian Technological Institute in Krasnoyarsk, and the Far Eastern Forestry Research Institute in Khabarovsk. These discussions and field observations (Appendix L) confirmed that the selection of pests of concern identified during the pest risk assessment process was accurate and that concern about their possible introduction into North American forests was justified (Appendix L).

In summary, importing unprocessed larch logs from Siberia and the Soviet Far East into North America can have serious consequences because of the potential for introducing exotic forest pests. Measures must be implemented to mitigate the risks of pest introduction and establishment.

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