Nature of the Problem

In recent years, increased international trade has resulted in a corresponding increase in the amount of untreated solid wood packing materials (SWPM) such as pallets, crating, and dunnage entering the United States in association with a wide variety of commodities. Many potential exotic plant pests may inadvertently be transported on SWPM. Recent introductions of the Asian longhorned beetle, *Anoplophora glabripennis* (Motschulsky), and pine shoot beetle, *Tomicus piniperda* (L.), have been associated with importation of SWPM (USDA APHIS 1999). Between August 1995 and March 1998, 97 percent of pests intercepted by Animal and Plant Health Inspection Service (APHIS) inspectors at U.S. ports and recognized as potential threats to forest resources of the United States were associated with SWPM. Approximately 500 infested shipments were detected with origins from around the world, including countries in Europe, Africa, South America, and Asia (see appendix A).

This pest risk assessment was initiated to support the recognized need to replace the interim rule for China (7 CFR Part 319.40–5, effective 17 December 1998) pertaining to shipment of SWPM with a permanent rule that addresses the problem of pest transport in SWPM on a global basis. In accordance with the World Trade Organization (WTO) Agreement on the Application of Sanitary and Phytosanitary Measures, this pest risk assessment serves as a basis for developing appropriate protection measures, as stated in Article 5 (WTO, n.d.).

The United States Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS) is the Government agency responsible for preventing the introduction of exotic pests on materials brought into the United States via international commerce. The USDA Forest Service (FS) has provided assistance to APHIS through a Memorandum of Understanding signed in February 1992 for conducting pest risk assessments for wood commodities. Pest risk assessments have been completed for importation of logs from Russia (USDA Forest Service 1991), New Zealand (USDA Forest Service 1992), Chile (USDA Forest Service 1993b), and Mexico (Tkacz et al. 1998). A pest risk assessment for plantation-grown *Eucalyptus* species from South America is also currently being developed. On November 6, 1998, APHIS requested assistance from the FS to conduct a pest risk assessment for SWPM that would evaluate the potential risk of pest entry and establishment resulting from transport with such materials entering the United States from any foreign country. This document is a collaborative effort between APHIS and FS personnel.

Statement of Purpose

A pest risk assessment is one stage of the pest risk analysis process and is generally defined as the “determination of whether a pest is a quarantine pest and evaluation of its introduction potential” (FAO 1999, NAPPO 1993). A quarantine pest is further defined as “a pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled.” This document presents a pathway analysis of pest risk potential for import cargo containing SWPM rather than a specific pest-initiated pest risk assessment.

The specific objectives of this pest risk assessment are to

- describe the characteristics of the SWPM pathway (i.e., means of transport of potential pests),
- assess the potential for entry and establishment (i.e., introduction) into the United States of insect and pathogenic pests of trees that may be transported with SWPM, and
- estimate the potential economic and environmental consequences these pests may have on forest and tree resources if established in the United States.

Although this assessment attempts to describe potential risks associated with transport of pests in SWPM, there is no way to predict which specific organisms may actually become established and cause damage, when such events may occur, or the magnitude of actual damage (Orr et al. 1993).

Scope of Assessment

The intent of this document is to evaluate the risk of transporting potential exotic pests with SWPM imported into the United States and is the first of several analyses needed to support changing U.S. import requirements for SWPM. A baseline assessment is presented in this pest risk assessment that describes pest risk in relation to current import regulations and practices. As such, it contains only a portion of the information and analyses that need to be considered in making a decision about what changes to make in import requirements. It does not evaluate how pest risk might change with different mitigation measures and import regulations, nor does it propose mitigation alternatives (i.e., options for new import requirements or restrictions that may be imposed to reduce risk of pest introduction). Additional analyses that will be assembled in separate documents to support the decision-making process for developing new regulations include a pest risk reduction analysis, environmental impact statement, and economic analysis. The pest risk reduction analysis will evaluate the effectiveness of various available treatments and potential mitigation alternatives in reducing the risk of entry and establishment of potential pest organisms that may be transported with SWPM. A range of mitigation alternatives will be proposed based upon information gathered during development of the pest risk reduction analysis, and a preferred alternative will be endorsed by APHIS administrators. The environmental impact statement will evaluate the potential environmental consequences of imposing proposed mitigation measures. The economic analysis will address the benefits of avoiding pest impacts relative to the costs of proposed mitigation measures and will identify potential impacts to industry and trade. Selection of the mitigation alternative to implement and promulgation of a final rule will follow public input and completion of all required analyses.

The organisms considered in this pest risk assessment are chiefly phytophagous (i.e., plant-eating) insects and plant pathogens that may cause damage to tree resources. Major emphasis is placed on representative pests having potential to be transported in, on, or with untreated SWPM. Although it is recognized that other organisms that do not use wood as host material (such as weed seeds, mollusks, and many agricultural pests) may “hitchhike” on SWPM, this pathway is not a unique avenue for entry of these organisms, and changes in U.S. regulations pertaining to such organisms are not being reviewed at this time.

This pest risk assessment does not attempt to provide a comprehensive listing and evaluation of all potential pest species that may be transported with SWPM. Rather, selected species are used to demonstrate the potential risks that may be associated with the SWPM pathway.

Assessment Approach

Discussion sections in this document address the following topics:
- Past and current APHIS regulations pertaining to SWPM,
- Characteristics of the pathway for importation of SWPM that contribute to pest risk,
- Interceptions of pests in cargo shipments containing SWPM,
- The history of previous introductions of exotic forest pests,
- The potential for entry and establishment of organisms transported with SWPM,
- What is and is not included in the definition of SWPM,
- Types of tree resources in the United States that could be at risk for infestation by pests introduced with SWPM,
- The potential environmental consequences of introduction,
- The potential economic consequences of introduction,
- A summary of pest risk potentials for selected organisms, and
- Conclusions.

Supporting information contained in appendixes includes the following:

- Summaries of interception records,
- Case histories of previous introductions,
- Pest risk assessment methodology,
- Individual pest risk assessments for 19 selected representative organisms (or groups of organisms) that may be transported with SWPM,
- Methodologies for economic impact projections, and
- References consulted.

In describing characteristics of the SWPM pathway, pest risk assessment collaborators considered the association of pests with wood used in SWPM, the amount of import cargo containing SWPM, the movement and distribution of imported SWPM within the United States, and the difficulties involved in inspecting shipments containing SWPM and detecting wood pests. Appendix A summarizes interception records of live quarantine-significant pests arriving with SWPM and provides an indication of the kinds of insects that may gain entry, their origins, and their destinations. No attempt was made, however, to develop a comprehensive listing or assessments of the potentially thousands of species of organisms that might be transported with SWPM originating from other countries worldwide. Organisms that are difficult to detect and identify, particularly microscopic plant pathogens, generally do not appear on interception lists, and APHIS does not keep records for exotic organisms that are considered to be innocuous. Pest interception records were not the only source of information used in the selection of organisms for detailed pest risk assessment, and examples of plant pathogens as well as insects were included in individual assessments of pest risk potential.

In addition to the ability of an exotic organism to be transported with SWPM, it must be possible for the pest to become established in a new environment and cause harm in order for it to be considered a threat. Case histories of past introductions (appendix B) are the best evidence of the types of organisms that can become established and the degree of harm they can inflict. Biological characteristics of organisms contribute to their ability to gain entry, become established, and cause harm in new environments; knowledge of these characteristics can be used to categorize an organism's pest risk potential. However, gaps in knowledge about how organisms will behave or respond to particular situations contribute to uncertainty in predicting what effects a new introduction will have. Potential impacts on the environment are particularly difficult to describe because of the complexity of biotic and abiotic influences and interactions and the difficulty of quantifying and recording such effects. A general discussion of a range of potential environmental impacts that can result from the introduction of exotic forest insects and pathogens is presented on the basis of ecological principles and various reports of interactions between exotic forest pests and environmental factors. Potential economic consequences of the introduction of exotic insects and pathogens can also span an array of impacts, some of which are more readily quantifiable than others. The pest risk assessment collaborators developed hypothetical introduction scenarios for seven selected exotic pest organisms transportable with SWPM to illustrate the potential magnitude of economic damage over a 30-year period. The 7 pest organisms are a subset of 19 organisms selected for qualitative assessment of pest risk potential. They were selected based upon the availability of sufficient quantifiable biological information to develop reasonable assumptions for modeling and include an array of organism types. Potential economic impacts for which quantitative data are generally lacking, such as cultural and amenity values, are described briefly qualitatively.

To lend support to general discussions of introduction potential, environmental impact potential, and economic impact potential of exotic organisms transported with SWPM, 19 organisms or groups of organisms with potential for quarantine significance were selected for detailed individual pest risk assessments, including the 7 for which hypothetical economic impact projections were developed. These representative organisms are insects and plant pathogens known to infest trees and cause harm and were chosen to illustrate a variety of potential pest types. Because the intent of the assessment was to demonstrate that pest risks exist that are not adequately addressed by existing import requirements for SWPM, organisms that would be expected to pose low pest risk and those for which little biological information exists were not chosen. The organisms selected for assessment were not limited to those reported in APHIS interception records, given their incompleteness, particularly for plant pathogens. Organisms were selected to represent various combinations of geographic origin (temperate, tropical and subtropical), host type (conifer, hardwood), and pest habitat (on bark, under bark, in deep wood). Although the risk assessment collaborators chose at least one organism to represent each possible combination (e.g., an organism that occurs in temperate countries of origin, on conifers, and on bark), an attempt was made to identify both a suitable insect and plant pathogenic organism to serve as examples, where appropriate. Organisms for which prior pest risk assessments had been conducted for the United States were chosen first to facilitate information gathering. Where no prior pest risk assessments existed to fit a particular combination (e.g., an organism of tropical or subtropical origin, on hardwoods, and under bark), specialists knowledgeable about organisms fitting the criteria were consulted to identify suitable organisms to include in the pest risk assessment. Some additional organisms were chosen beyond the minimum needed to cover each combination of geographic origin, host type, and pest habitat to better represent a variety of organisms with differing biological characteristics. Groups of organisms were chosen rather than individual species whenever taxonomic differentiation of species, strains, varieties, or biotypes is difficult (such as frequently occurs among microorganisms) or closely related organisms behave similarly (e.g., termites). A matrix illustrating how the selected pest organisms fall into the combinations of geographic origin, host type, and pest habitat is presented in table 1. Organisms selected for assessment are also listed by taxonomic species or group in table D–1 in appendix D.

Pest risk potential was rated for each selected species or group of organisms based upon biological characteristics (appendix D). Pest risk potential combines evaluations of the likelihood of introduction with the expected consequences, (environmental and economic). Risk elements contributing to the likelihood of introduction include the presence with host or commodity at origin potential, and the entry, establishment, and spread potentials. The assessment of the consequences of introduction includes evaluations of economic damage potential, environmental damage potential, and social and political considerations. Criteria were developed to facilitate the assignment of ratings of low, moderate, or high risk to each of the seven elements that constitute a rating for pest risk potential, when combined. The pest selection and pest risk assessment processes are further detailed in appendix C.

Definition of SWPM

Regulations on the importation of unmanufactured wood articles define SWPM as “wood packing materials other than loose wood packing materials, used or for use with cargo to prevent damage, including, but not limited to, dunnage, crating, pallets, packing blocks, drums, cases, and skids” (7 CFR 319.40–1). Loose wood-packing materials, such as excelsior (wood wool), sawdust, and wood shavings, are excluded. Synthetic or highly processed wood materials such as plywood, oriented strand board, corrugated paperboard, plastic, and resin composites also are excluded.

Each type of SWPM is designed for a specific use. Dunnage is “wood used to wedge or support cargo” (FAO 1999) and often consists of odd, loose boards but may also include whole logs. It is usually layered between units of cargo in a ship’s hold to prevent motion and chafing of the goods being shipped. A wooden pallet is a portable platform for storage and movement of materials and packages that is designed for handling by a forklift truck or crane. A crate is a wooden box, case, or protective framework for shipping. Skids may include pairs or sets of timbers, planks, poles, or logs used to form a slideway or elevate cargo, or may consist of low, wheeled wooden platforms designed to slide cargo. A wooden spool is a cylindrical device with a rim on each end and usually an axial hole for a pin or spindle and is designed to hold wound wire or cable. A shipping drum is a cylindrical container or barrel made of wood. Braces are wooden reinforcements intended to prevent loads from shifting. Blocking is a rectangular piece of wood used to support cargo.

Table 1. Matrix of representative pest species selected for individual assessments of pest risk potential. Primary combinations of geographical origin, host type, and pest habitat for which pest species were chosen are in bold.

Pest habitat	**Temperate region; Hardwoods**	**Temperate region; Conifers**	**Tropical/subtropical region; Hardwoods**	**Tropical/subtropical region; Conifers**
In deep wood	**Kalotermitidae spp. (termites)**	**Kalotermitidae spp. (termites)**	**Kalotermitidae spp. (termites)**	**Kalotermitidae spp. (termites)**
	Rhinotermitidae spp. (termites)	**Rhinotermitidae spp. (termites)**	**Rhinotermitidae spp. (termites)**	**Rhinotermitidae spp. (termites)**
	***Armillaria/ Phellinus/ Ganoderma* spp. (fungi)**	*Armillaria/ Phellinus/ Ganoderma* spp. (fungi)	***Armillaria/ Phellinus/ Ganoderma* spp. (fungi)**	*Armillaria/ Phellinus/ Ganoderma* spp. (fungi)
	Ophiostoma/ Ceratocystis spp. (fungi)	***Ophiostoma/ Ceratocystis* spp. (fungi)**	*Ophiostoma/ Ceratocystis* spp. (fungi)	*Ophiostoma/ Ceratocystis* spp. (fungi)
	Heterobasidion spp. (fungi)	***Heterobasidion* spp. (fungi)**	***Phellinus noxious* (fungus)**	*Phellinus noxious* (fungus)
	***Anoplophora glabripennis* (insect wood borer)**	***Sirex noctilio*/ *Amylostereum areolatum* (woodwasp/fungus)**	*Ceratocystis fimbriata* (fungus)	
			Erythricium (*Corticium*) *salmonicolor* (fungus)	
Under bark	*Ophiostoma/ Ceratocystis* spp. (fungi)	*Ophiostoma/ Ceratocystis* spp. (fungi)	*Ophiostoma/ Ceratocystis* spp. (fungi)	*Ophiostoma/ Ceratocystis* spp. (fungi)
	***Scolytus intricatus* (bark beetle)**	***Hylurgus ligniperda/ Leptographium* spp. (bark beetle/fungi)**	***Ceratocystis fimbriata* (fungus)**	
		***Ips typographus*/ *Ceratocystis polonica* (bark beetle/fungi)**	*Erythricium* (*Corticium*) *salmonicolor* (fungus)	
		Orthotomicus erosus (bark beetle)		***Orthotomicus erosus* (bark beetle)**

Table 1 Continued. Matrix of representative pest species selected for individual assessments of pest risk potential. Primary combinations of geographical origin, host type, and pest habitat for which pest species were chosen are in bold.

Pest habitat	**Temperate region; Hardwoods**	**Temperate region; Conifers**	**Tropical/subtropical region; Hardwoods**	**Tropical/subtropical region; Conifers**
On bark	***Lymantria dispar* (Asian biotype) (moth)**	*Lymantria dispar* (Asian biotype) (moth)	***Erythricium* (*Corticium*) *salmonicolor* (fungus)**	
	Lymantria monacha (moth)	***Lymantria monacha* (moth)**	***Pterophylla beltrani* (cricket)**	***Pterophylla beltrani* (cricket)**
		***Aradus cinnamomeus* (true bug)**	***Sarsina violascens* (moth)**	

Summary of Current U.S. Regulations for SWPM

Brief History of SWPM Regulations

Before the implementation of the Importation of Logs, Lumber, and Other Unmanufactured Wood Articles regulation (Wood Import Regulation) in 1995, SWPM, along with other wood articles, were not covered under a specific regulation. Before the Wood Import Regulation, APHIS inspectors routinely inspected SWPM at the first port of arrival, and if plant pests were found, the SWPM would be treated, destroyed, or refused entry into the United States.

These actions were taken under the Federal Plant Pest Act, as amended, and the Plant Quarantine Act, as amended, which were superceded on 22 June, 2000 by the Plant Protection Act (P.L. 106–224). These Acts, in part, authorize the Secretary of Agriculture to prevent the dissemination of new plant pests or those not widely distributed throughout the United States. Consequently, APHIS has been delegated the authority to administer these statutes, and has promulgated the Foreign Quarantine Regulations (7 CFR 319) to govern the importation of commodities. However, SWPM were not specifically covered under these regulations until the Wood Import Regulation went into effect. The majority of APHIS policy decisions surrounding SWPM, before the introduction of the Wood Import Regulation, were directed towards identifying which species of exotic organisms should be considered pests warranting regulatory action.

The 1995 Wood Import Regulation was promulgated because APHIS determined that the movement of foreign raw wood into the United States posed a threat of introducing exotic forest pests and pathogens into North America. The Animal and Plant Health Inspection Service noted that inspection at the port of entry (including maritime ports, airports, and land and border crossings) as the only entry requirement for wood and wood products was inadequate in meeting the Agency's goal of protecting U.S. forest resources from exotic pests. Along with the international movement of logs, lumber, and other unmanufactured wood articles, SWPM were identified as a pathway of concern. Solid wood packing materials are covered under the Wood Import Regulation at 7 CFR 319.40–3(b).

Since the Wood Import Regulation went into effect, additional entry requirements for SWPM from China have been found necessary. An interim rule, Solid Wood Packing Material From China, was published on September 18, 1998, and became effective on December 17, 1998. It provides that prior to exportation from the Peoples Republic of China including Hong Kong, any SWPM entering the United States must be heat treated, fumigated and aerated, or treated with preservatives. The interim rule is necessary because of the extensive movement of exotic wood-boring insects into the United States from China on untreated SWPM. In addition, APHIS discovered that the Asian longhorned beetle and other closely related longhorned beetle species were in SWPM imported from China to the United States. The Asian longhorned beetle has resulted in substantial damage to urban trees in Chicago, IL, and the State of New York. Eradication efforts are currently under way in these areas.

APHIS has also proposed that SWPM from States in Mexico adjacent to the U.S. border no longer be imported without restrictions as currently provided in 7 CFR 319.40-3(a). A proposed rule, Importation of Unmanufactured Wood Articles From Mexico, (which in part addresses SWPM from the adjacent States in Mexico) was published in the Federal Register on June 11, 1999. This proposed rule was the outcome of the 1998 USDA Forest Service study entitled, "Pest Risk Assessment of the Importation into the United States of Unprocessed *Pinus* and *Abies* Logs from Mexico" (Tkacz et al. 1998). This assessment documented that several potential pest species with moderate to high risk to U.S. tree resources occur in the bordering States of Mexico but are not present in the United States. Much of the wood currently produced in Mexico comes from bordering States having ecological and geographic features that do not resemble those of the adjoining United States. Because the rationale for the current Wood Import Regulation's exception for the bordering States of Mexico was based on an assumption that the forests of northern Mexico and the United States are contiguous and share similar forest pests, APHIS has had to reconsider the entry status for wood originating from bordering States in Mexico. As proposed, SWPM from the adjacent Mexican States would be subject to the SWPM requirements for the rest of the world except Canada and China, contained in 7 CFR 319.40-3(b).

Current Status of SWPM Regulations

Solid wood packing materials imported with nonwood commodities from anywhere in the world except Canada, China, and the border States of Mexico must be 100 percent free of bark (down to and including the cambium layer) and be apparently free from live plant pests. However, if bark is present, before entry into the United States, the SWPM must be (1) fumigated with methyl bromide, (2) heat treated without moisture reduction at 71.1 ºC for at least 75 minutes, (3) kiln dried in accordance with the Dry Kiln Operations Manual, or at 71.1°C for at least 75 minutes with a reduction of the moisture content to 20 percent, or (4) treated with a preservative product that is registered by the U.S. Environmental Protection Agency. In addition, SWPM are subject to inspection at the port of entry.

Solid wood packing materials free of bark and moving with regulated wood articles (e.g., lumber, logs, woodchips, etc.), except from Canada, China, and Mexican border States, must be either heat treated without moisture reduction, kiln dried, fumigated with methyl bromide, subjected to a preservation pressure treatment, or undergo the same treatment as the regulated wood article, and be apparently free from live plant pests. In addition, SWPM are subject to inspection at the port of entry.

Currently Canada and the Mexican border States are exempt from the entry requirements for SWPM, but SWPM from these countries are subject to inspection at the port of entry. However, in the proposed rule entitled Importation of Unmanufactured Wood Articles From Mexico, APHIS is proposing that the exception for the border States of Mexico for SWPM be removed and that SWPM from the adjacent States of Mexico have entry requirements equivalent to the rest of Mexico and all other countries except Canada and China.

The interim rule Solid Wood Packing Material From China requires that SWPM from China (including the Hong Kong Special Administrative Region) shipped with goods into the United States be heat treated without moisture reduction, kiln dried, fumigated with methyl bromide, or subjected to a preservative pressure treatment.

In all the preceding cases, SWPM moved as the cargo itself (e.g., a container of dunnage) are no longer considered SWPM and must meet the entry requirements for raw lumber under the Wood Import Regulation. However, used pallets are exempt from this requirement if accompanied by an importer document stating that they were previously eligible for importation (100 percent bark-free) and that no new wood has been added to them since that use.

When the proposed Unmanufactured Wood Articles: Solid Wood Packing Materials regulation becomes final, it will supersede all of the current entry requirements for SWPM.

Description of SWPM Pathways

Solid wood packing materials constitute a pathway (i.e., means of transport) posing considerable risk of introducing potential exotic forest pests into the United States. Inspection of SWPM arriving with imported cargo consistently has resulted in numerous pest interceptions over the past few decades. From 1996 through 1998, APHIS inspectors recorded 1,205 interceptions (averaging 402 per year) of live wood pests of quarantine significance associated with SWPM (appendix A). Intercepted cargo with live pests is held for treatment before being released for further transport or is refused entry into the United States. However, many other pests probably escaped detection for reasons that will be discussed in the next section. Not all pests traveling with cargo and escaping detection survive to become established in a new area; however, some exotic forest pests were likely introduced into the U.S. environment via the SWPM pathway (see case histories in appendix B).

Initiation, Approach, and Distribution of Pest Risk in the Pathway

How Pests Enter the SWPM Pathway—Forest pests accompany imported SWPM by becoming associated with the wood in several ways. Pests present on the exterior surface of trees may be transported if bark is not removed (e.g., lymantriid eggs). Those that attack live trees often survive tree felling, rough processing, and shipping when green wood is used to make SWPM (e.g., many bark, long-horned, and buprestid beetles as well as fungal pathogens).

Some pests will attack recently felled wood and often survive processing and shipping (e.g., some bark, long-horned, and buprestid beetles). Still others infest older, even processed wood and survive shipping (e.g., termites and powderpost beetles). APHIS Plant Protection and Quarantine (PPQ) interception records reflect pest taxa having each of these habits (appendix A).

Approach Rates of Shipments with SWPM—Calculating approach rates of SWPM with imported cargo is difficult because cargo manifest and entry documentation usually do not indicate the presence or absence of SWPM in shipments. But, APHIS recently began collecting data on SWPM in its Agricultural Quarantine Inspection Monitoring (AQIM) program. Records in the AQIM data base currently include SWPM data from random inspections of imported cargo conducted at 23 maritime port locations and 8 international airports from October 1998 to March 1999.

AQIM results for these first 6 months indicate that 51.8 percent (502 of 969) of maritime shipments and 8.6 percent (25 of 290) of air shipments included SWPM (APHIS AQIM data base). Chinese Government officials estimate that 30–50 percent of cargo exported to the United States from China may contain SWPM. AQIM data show that many different types of commodities are shipped with SWPM, including more than 250 commodities in the 502 maritime shipments sampled and 18 commodities in the 25 air shipments sampled. Solid wood packing materials arrive in foreign cargo from all regions of the world (table 2).

Distribution of Hazard—Many wood materials used to pack imported cargo accompany the cargo to its final destination, especially in containerized shipments. Foreign SWPM enters the United States through approximately 100 ports en route to numerous destinations. As a result, potential exotic pest organisms associated with SWPM and not detected at ports of entry may be distributed throughout the country via this pathway. Major highways (fig. 1) and railroads crisscross the nation, connecting major cities, and facilitate the redistribution of cargo containers that may contain SWPM.

Table 2. Percentage of imported cargo containing SWPM arriving in the United States by world regions, as determined by random sampling, October 1998–March 1999 (APHIS AQIM data base)

World region	Maritime cargo % (*n* = 502 shipments, from 45 origins)	Air cargo % (*n* = 5 shipments, from 18 origins)
Africa	3	16
Asia	20	8
Australia/New Zealand	2	0
Central America and West Indies	18	0
Europe	43	44
Mideast	4	12
North America	<1	16
South America	10	4

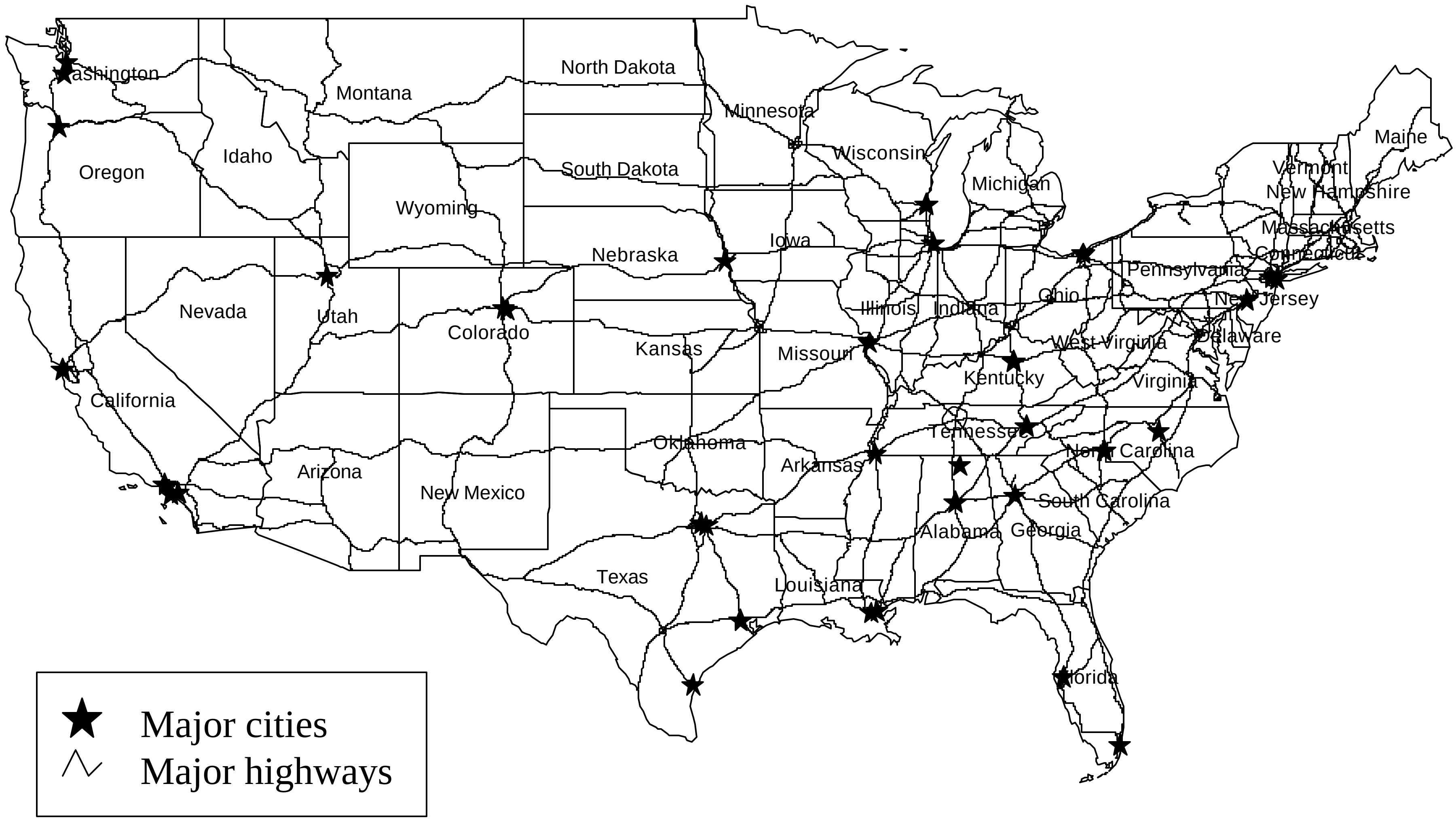


Figure 1. U.S. transportation network of major highways.

Some difficulty arises in accurately determining distribution patterns of imported cargo within the United States. Shipping data frequently record destination addresses for distributors or brokers rather than accurate final destinations. These distributors, and especially brokers, are often located in the port area, whereas the actual destination of the shipments they handle may be anywhere in the country. Consequently, most volume estimates of cargo moving inland from the ports will be low when based on these data. Estimates of inland cargo movement based on APHIS interception data are limited in accuracy also because APHIS records only the destination State. Nonetheless, these sources offer assistance in describing low-end estimates of inland cargo movement.

Most port operations apparently do not divulge inland cargo movement data, but port officials in Seattle, WA, estimate that 70 percent of their cargo is destined for inland markets (Seattle Port Authority, n.d.). APHIS data, for shipments randomly sampled at ports of entry from October 1998 to March 1999, indicate that 39 percent of maritime and 55 percent of air shipments with SWPM were destined for States other than those that include the port of entry (USDA APHIS AQIM data base).

From 1996 to 1998, APHIS found more than 600 import shipments infested with SWPM-related quarantine pests destined for 39 States (USDA APHIS PIN 309 pest interception data base). For imported shipments randomly sampled at ports of entry from October 1998 to March 1999, inspections found that 9 percent (47 of 502) of maritime and 4 percent (1 of 25) of air shipments containing SWPM had bark present and were destined to 11 States. (The presence of bark on SWPM is considered indicative of high pest risk and has been prohibited by APHIS since 1995.)

Records obtained for shipments containing SWPM that required quarantine treatment for pests or presence of bark in 1998–99 also provide an indication of the pathways of entry and distribution within the United States (T. Chanelli 1999, unpublished data from PPQ Form 523: Emergency Action Notifications). These shipments included those that were found to have bark in addition to those in which live pests were detected (i.e., interceptions), and mitigative treatment (usually fumigation) was required before the shipments were allowed to be moved from the port. Because inspectors tend to target cargo expected to be of high risk, the data do not represent random samples but nevertheless provide a good indication of the initial locations of infested SWPM entering the United States. Most shipments found to contain SWPM with bark or live insects arrived at 19 ports of entry, mostly located in coastal areas (fig. 2). Cargo at the ports of entry usually is moved to more interior locations within 1–2 days after arrival in the United States. Importer locations specified on the manifests provide an indication of the initial interior destinations of the cargo, which are often major cities and distribution centers (figs. 3 and 4). Twenty-six importer locations (17 percent of the total) accounted for 55 percent of the shipment interceptions (fig. 5), and 46 importer locations (30 percent of the total) accounted for 68 percent of the shipment interceptions (fig. 6). Importer locations tend to be concentrated in 11 areas of the United States (fig. 7). A similar pattern of initial redistribution is evident when the data are summarized by the frequency of interceptions by importer State (fig. 8). Louisiana (16 percent) and California (13 percent) received the most shipments of intercepted cargo, but States in the Northeast collectively received 16 percent (fig. 9). Cargo destinations, as indicated by importer locations (figs. 3, 4, and 7), generally coincided with the most heavily forested regions of the United States (figs. 10–13). Cargo is likely further redistributed from those locations; however, such information is unavailable.

After imported cargo arrives at a final destination, associated SWPM may be reused, reconditioned for additional use, or discarded. These practices further distribute potentially infested wood to other shipping, receiving, and retail locations; reconditioning manufacturers' sites; landfills; and even private homes.

Some pests remain viable in SWPM transported with cargo—potentially for extended periods. For example, many long-horned beetles require on average 2 to 3 years to develop from egg to adult (Haack and Slansky 1987) but may take considerably longer—even 20–30 years (Linsley 1961)—under abnormal conditions such as excessive desiccation of the wood (Duffy 1953a). APHIS inspectors have repeatedly found live, exotic long-horned beetles in, or emerging from, SWPM with Chinese cargo stored in more than 25 warehouses throughout the United States

Figure 2. Ports of entry with cargo shipments in 1998–99 containing SWPM that required treatment before inland movement owing to the presence of bark or live pest interceptions.

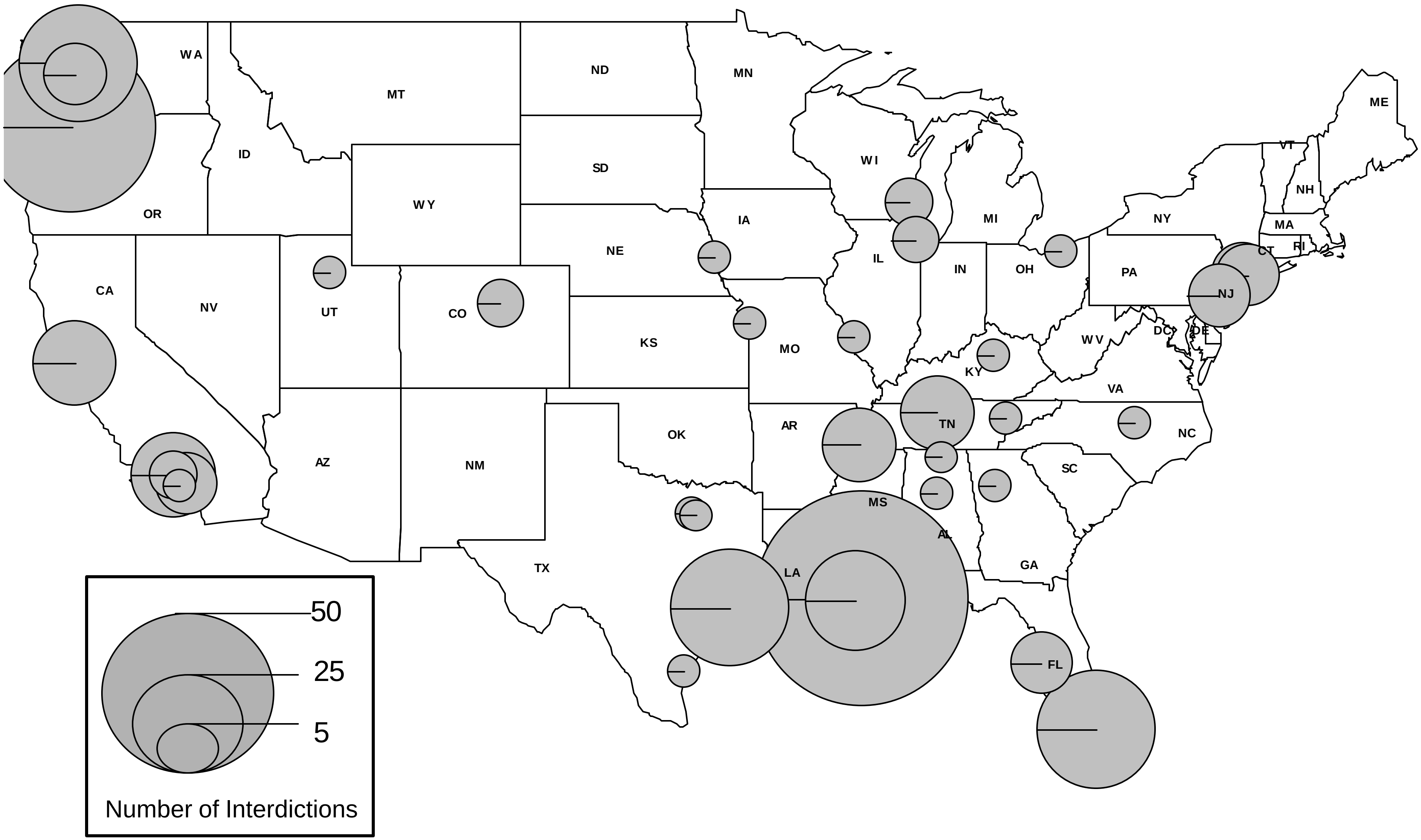


Figure 3. Importer locations (i.e., destinations) for cargo shipments containing SWPM in 1998–99 that required treatment at the port of entry because of the presence of bark or live pest interceptions.

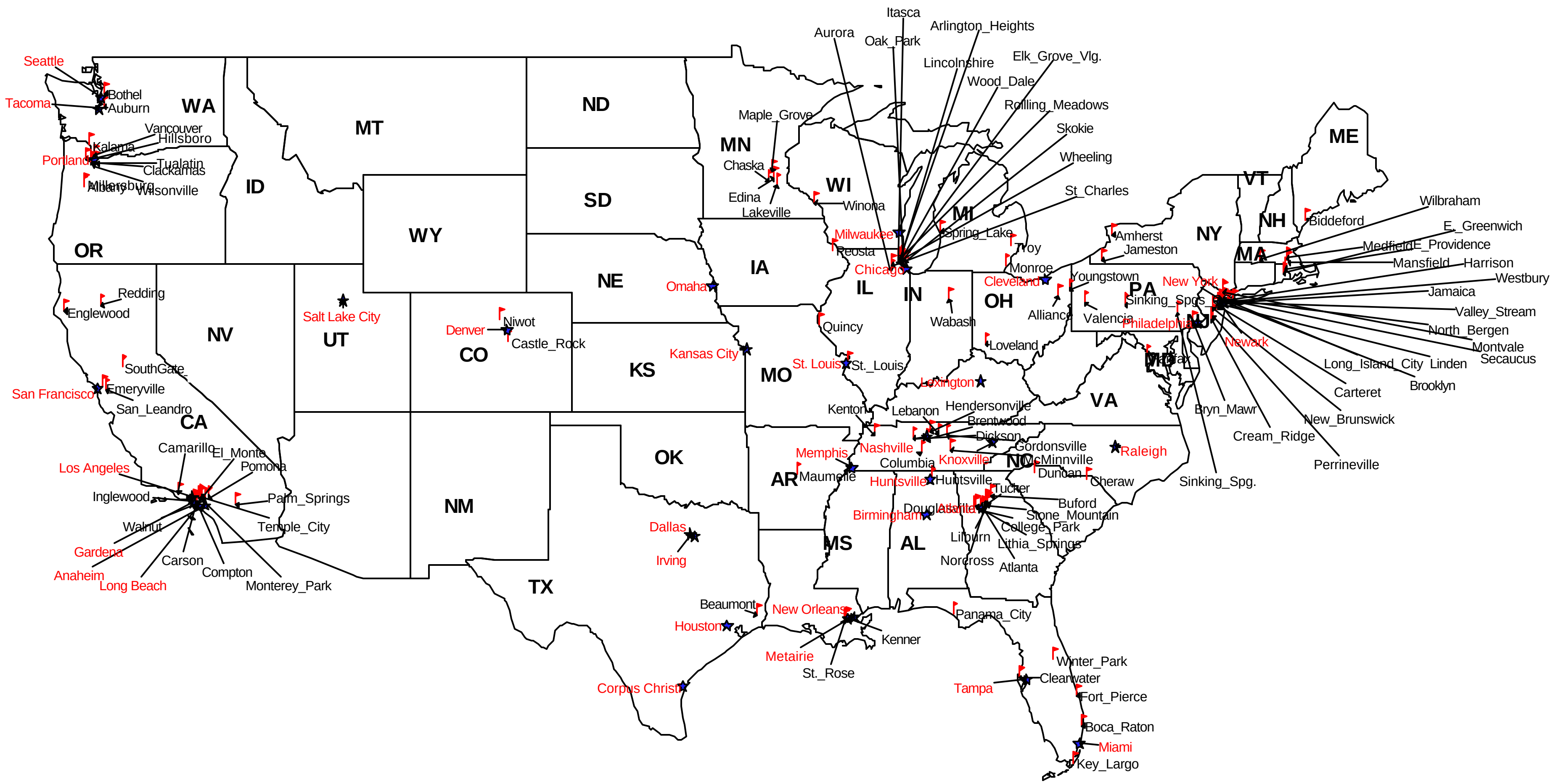


Figure 4. Importer locations for cargo shipments containing SWPM in 1998–99 that required treatment at the port of entry because of the presence of bark or live pest interceptions.

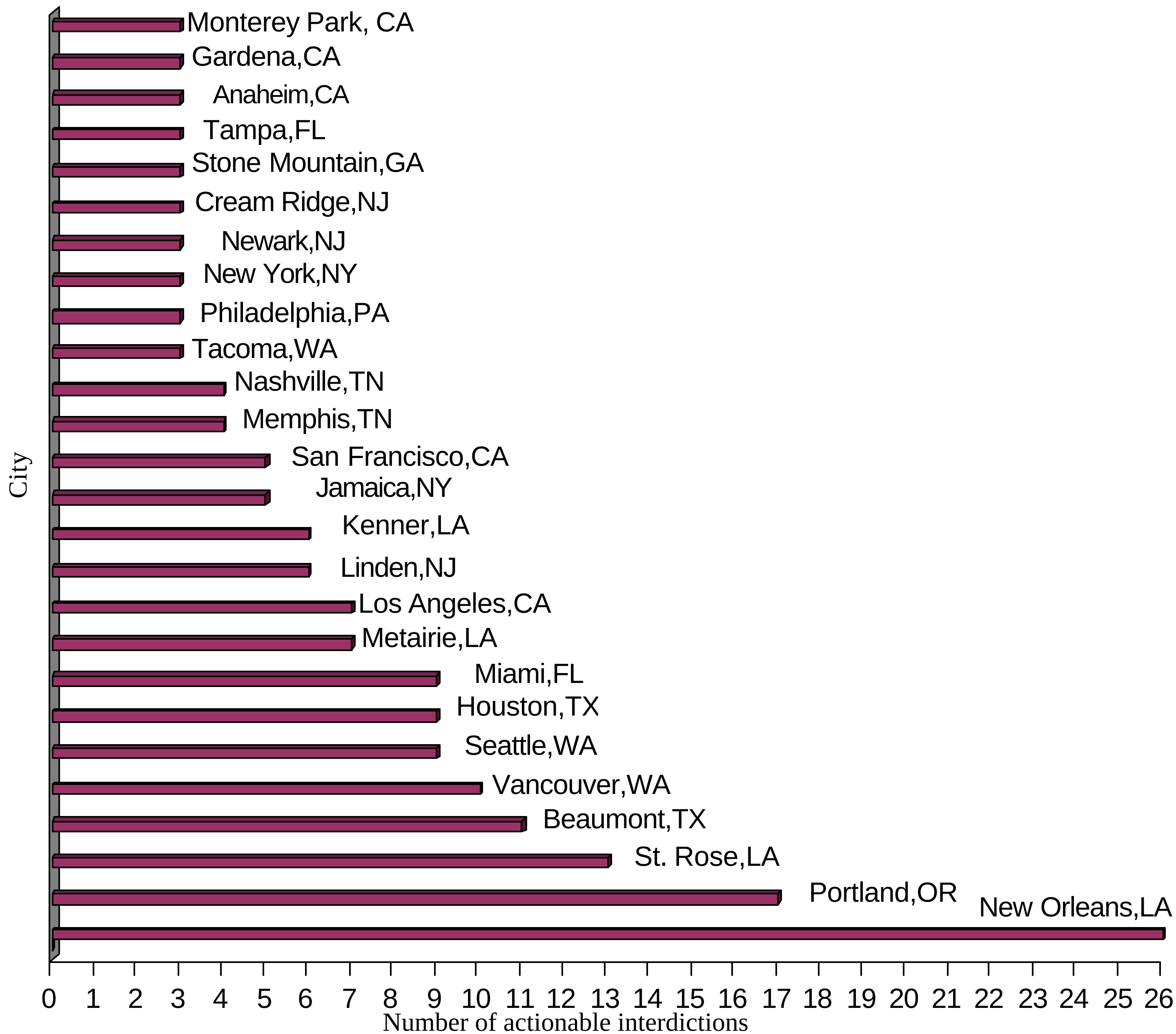


Figure 5. Top importer locations for cargo shipments with SWPM requiring treatment in 1998–99 upon entry because of the presence of bark or live pest interceptions. Twenty-six locations (17 percent) accounted for 55 percent (178/321) of all cargo shipments with SWPM requiring treatment.

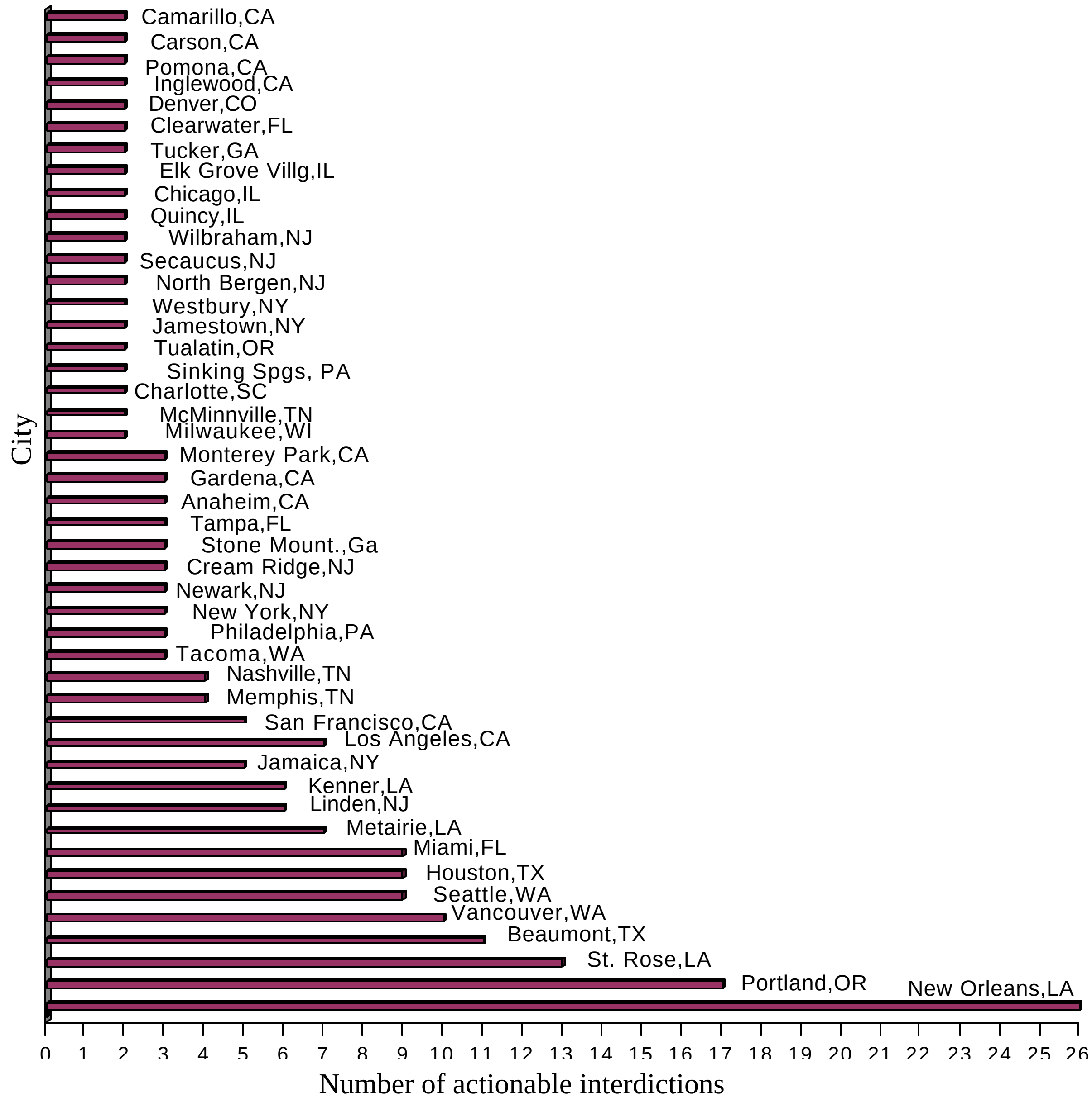


Figure 6. Importer locations for cargo shipments with SWPM requiring treatment in 1998–99 upon entry because of the presence of bark or live pest interceptions. Forty-six importer locations (30 percent) accounted for 68 percent (218/321) of all cargo shipments with SWPM requiring treatments.

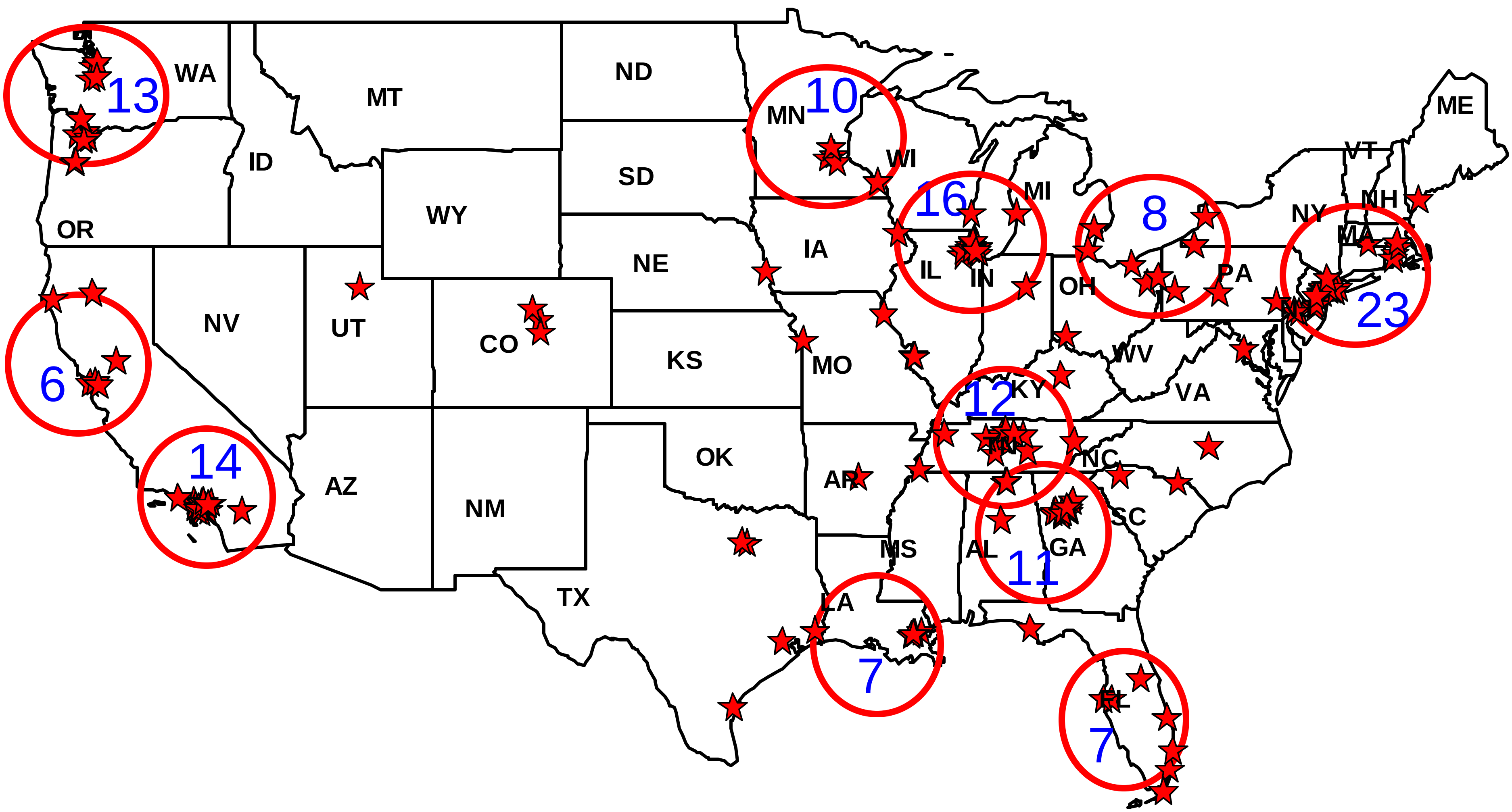


Figure 7. Highest concentrations of importer locations for cargo shipments with SWPM requiring treatment in 1998–99 upon entry because of the presence of bark or live pest interceptions.

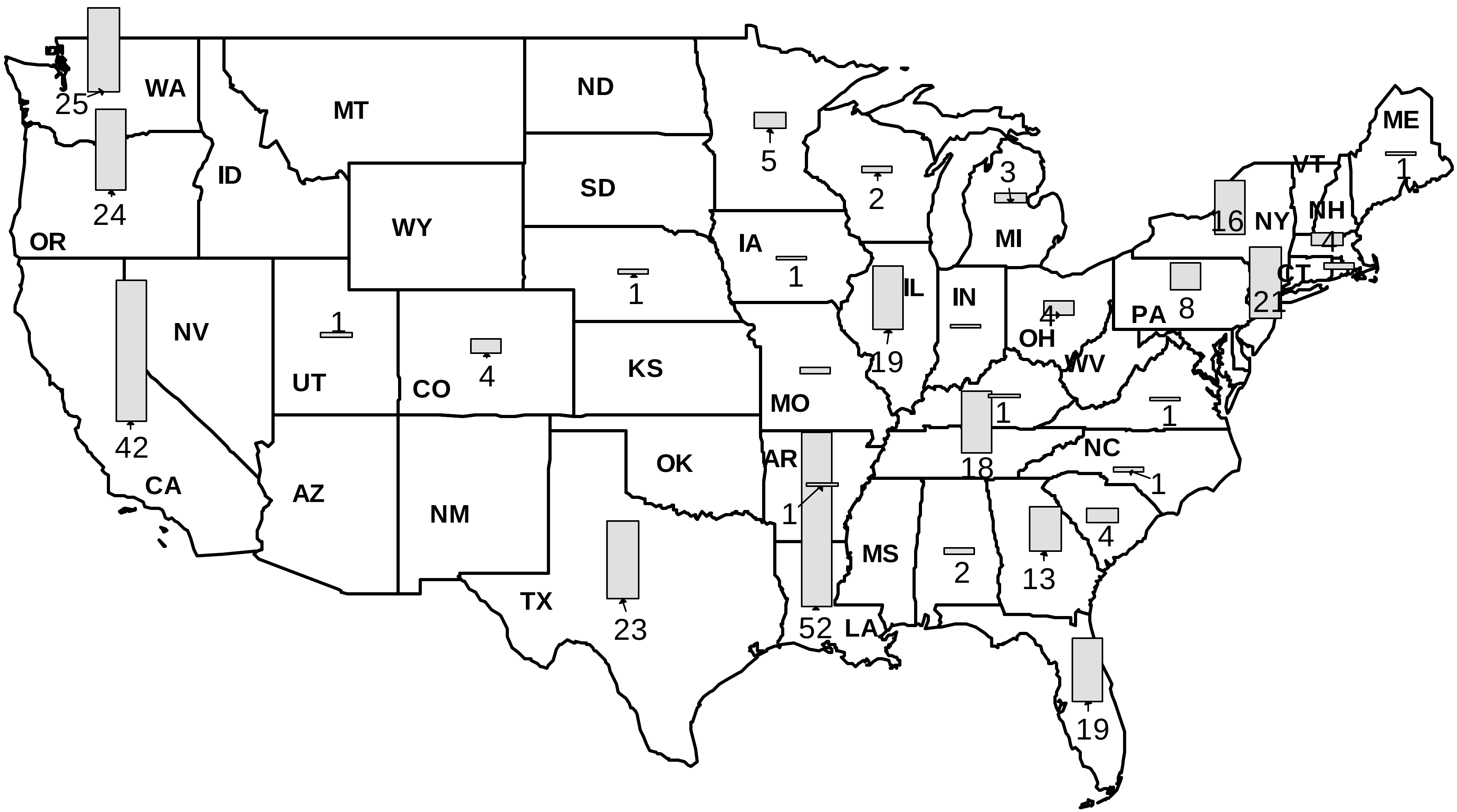


Figure 8. Number of cargo shipments with SWPM in 1998–99 by importer State requiring treatment because of the presence of bark or live pest interceptions.

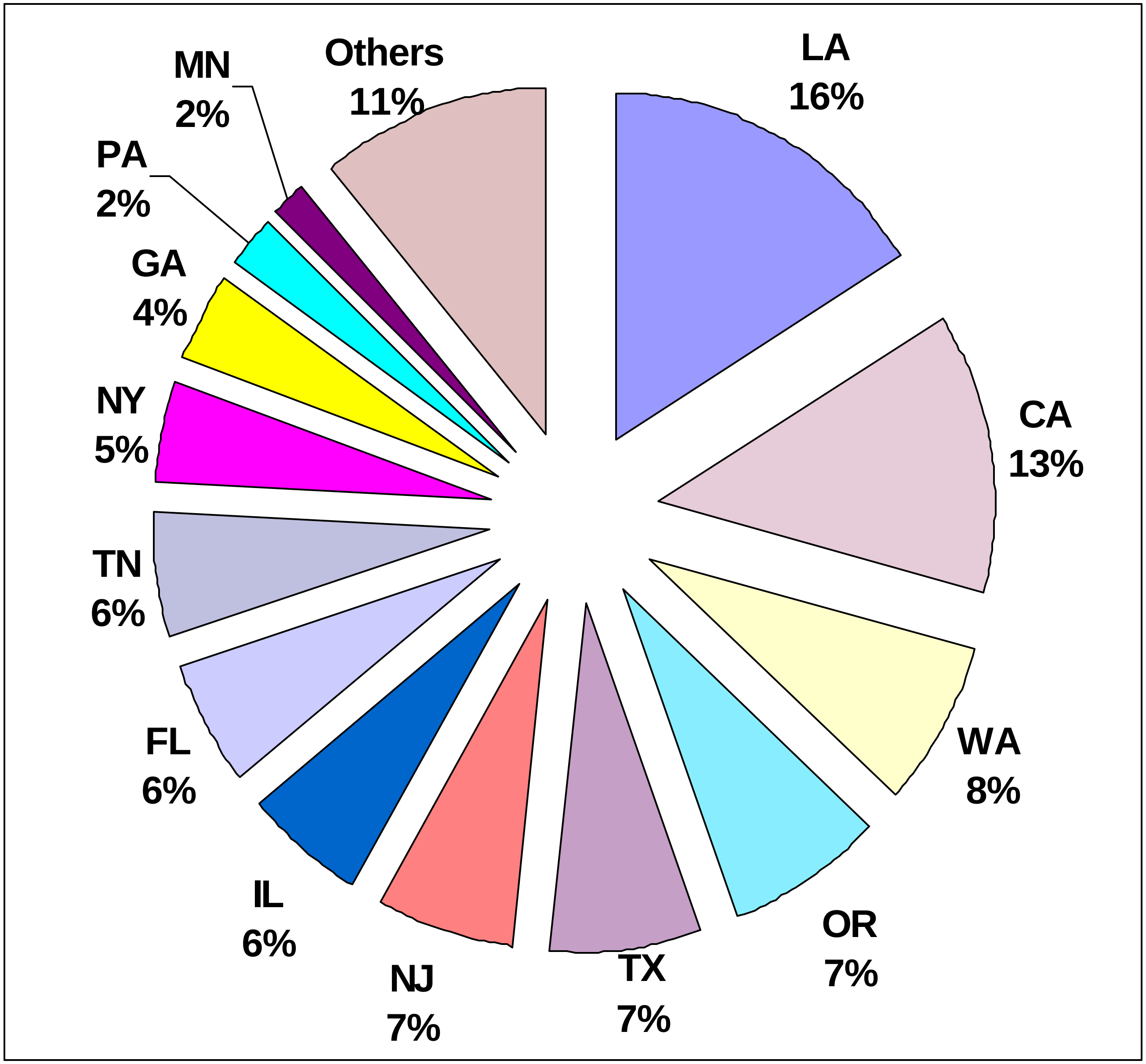


Figure 9. Percentages of cargo shipments with SWPM in 1998–99 by importer State requiring treatment because of the presence of bark or live pest interceptions. Northeastern States collectively comprised 16 percent of interdictions.

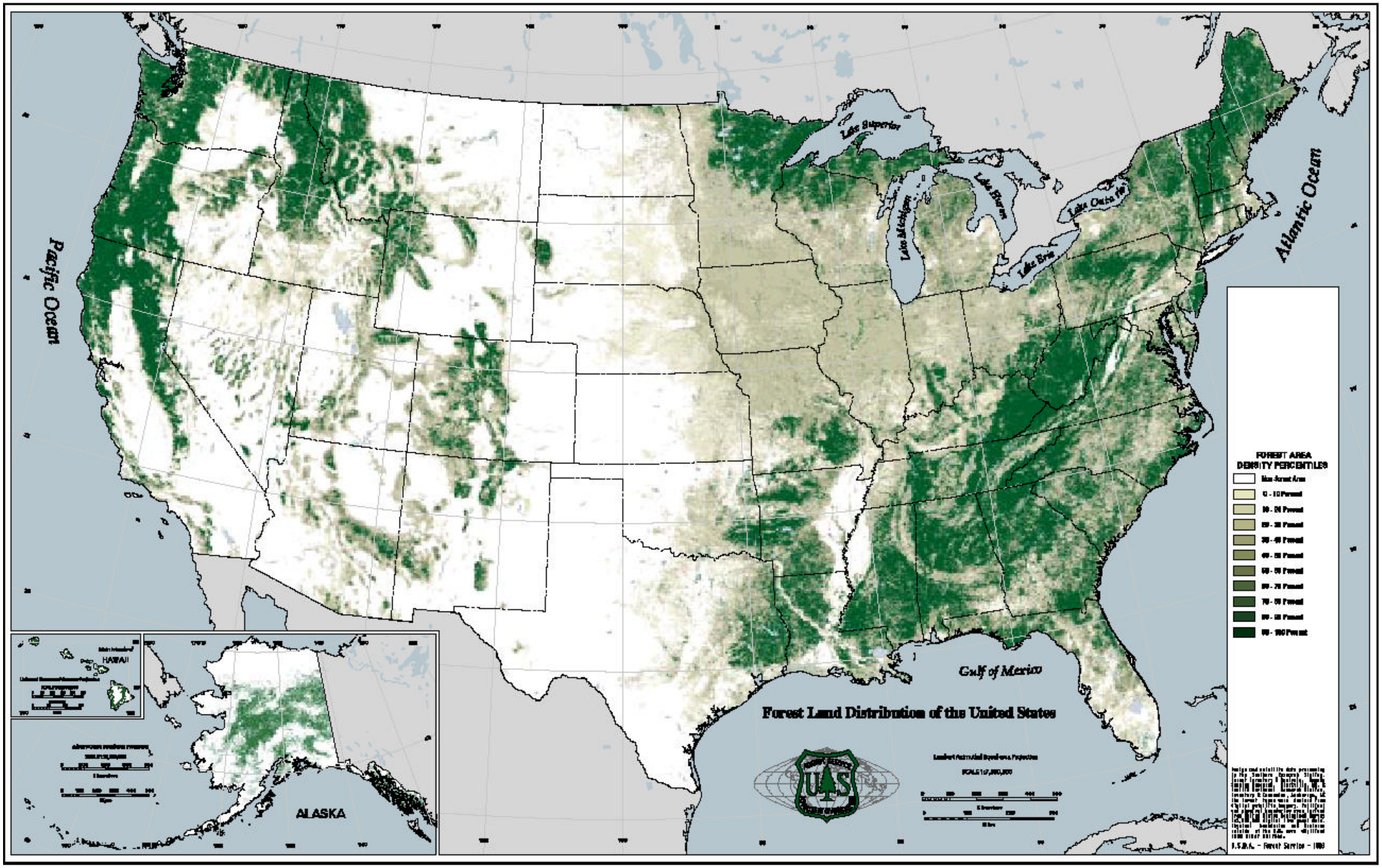


Figure 10. Distribution of U.S. forests by density class (color version available at http://www.srsfia.usfs.msstate.edu/).

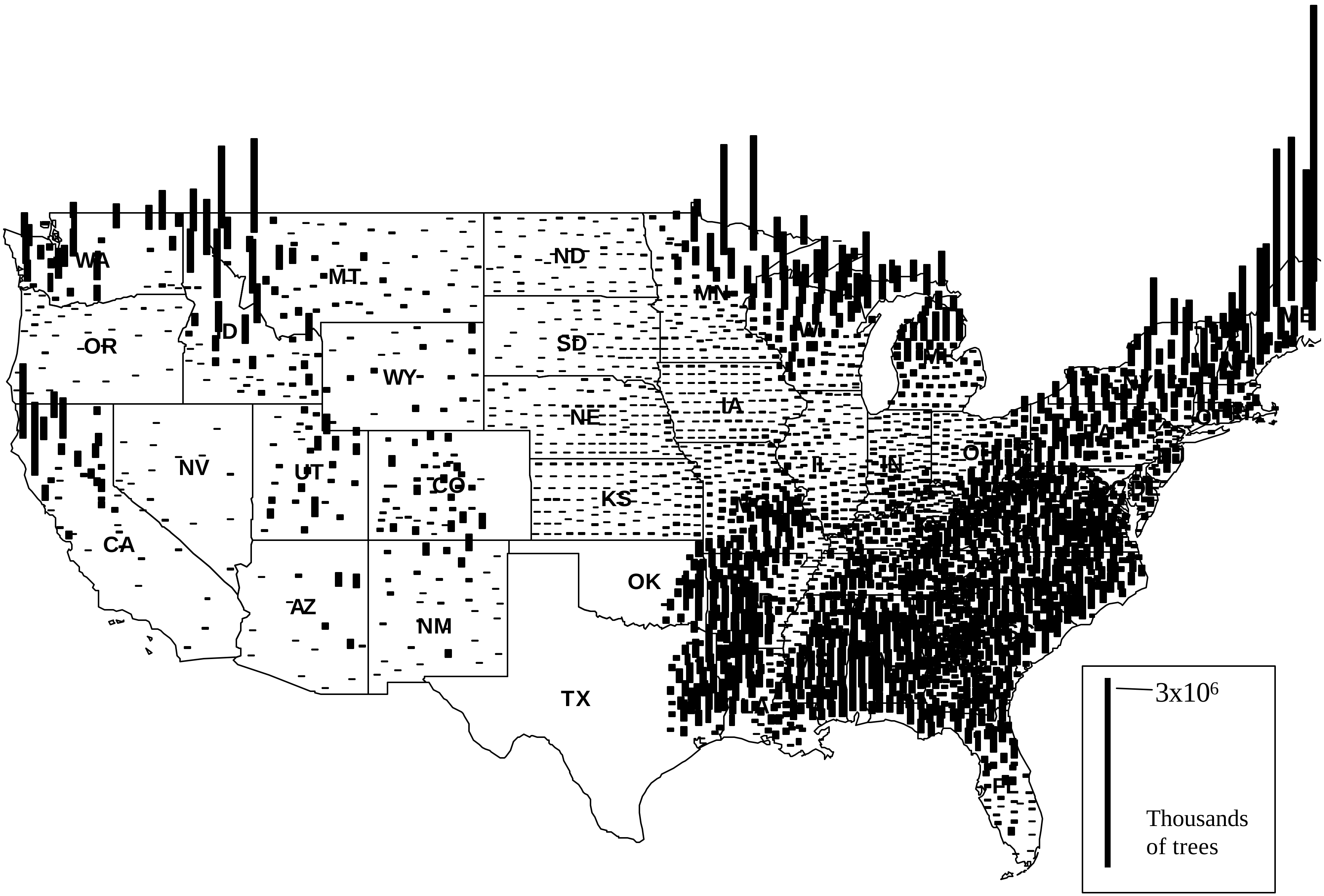


Figure 11. Number of trees (in all diameter classes) by county as derived from Forest Inventory and Analysis data.

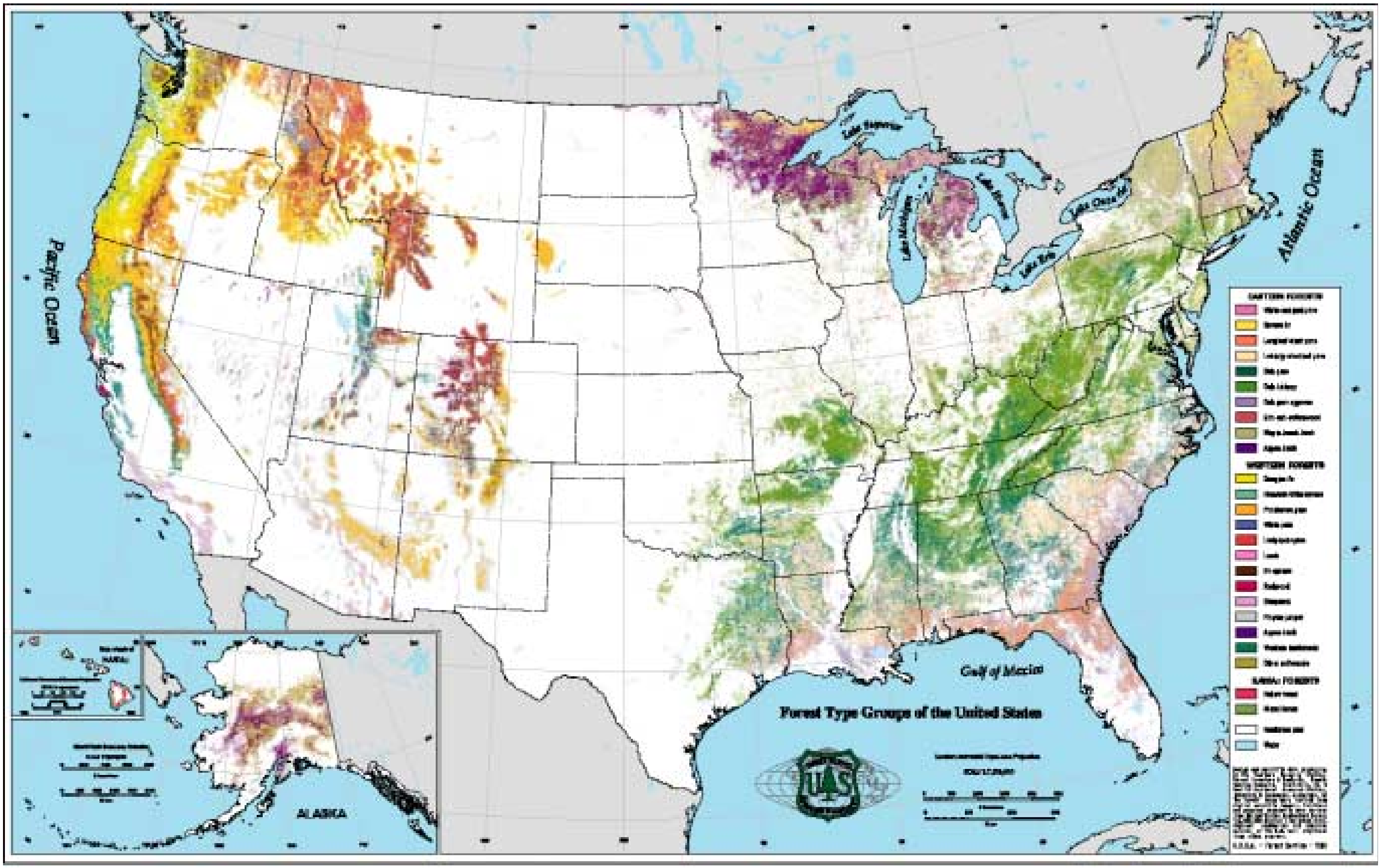


Figure 12. Distribution of U.S. forests by species groups (color version available at http://www.srsfia.usfs.msstate.edu/).

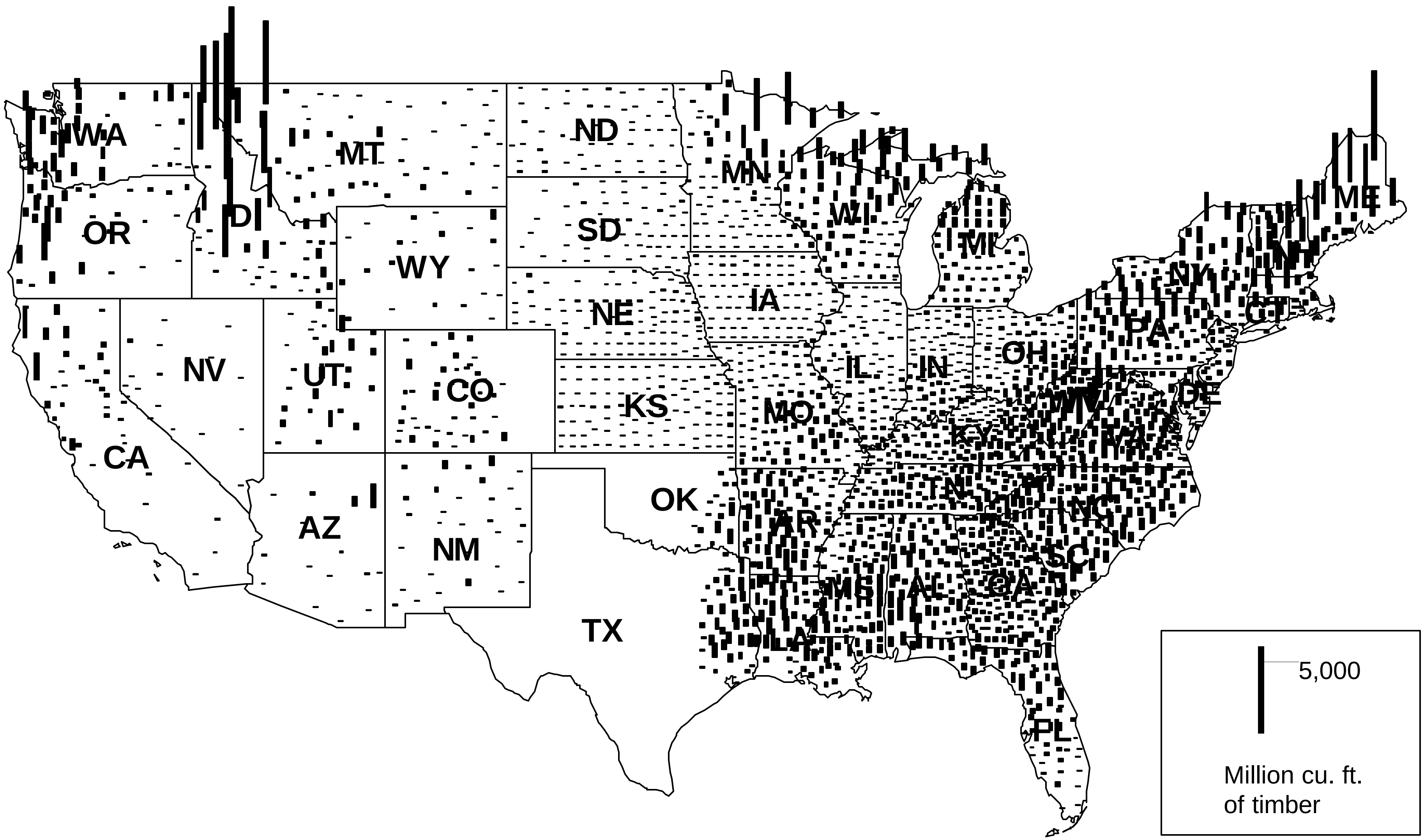


Figure 13. Distribution of timber volumes by county on timberlands in the United States as derived from Forest Inventory and Analysis data.

(USDA APHIS, n.d.). Some of these pests were associated with wood stored 2 to 5 years at the warehouse (Interviews with APHIS, PPQ Officers, February to April 1998).

Evaluation of Inspection as a Mitigation Measure

Infestations by numerous forest pests in the United States (e.g., pine shoot beetle [*Tomicus piniperda* (L.)] and Asian longhorned beetle [*Anoplophora glabripennis* Motchulsky]) and repeated findings at inland warehouses of infested SWPM that escaped detection at ports of entry indicate that the current measures used to mitigate the pest risk presented by the SWPM pathway, that is, inspection of SWPM, are inadequate. Inspection of SWPM at ports of entry poses uniquely difficult problems relative to other imported items regulated by APHIS. These problems include the ubiquitousness of SWPM in arriving cargo, the frequent inability of inspectors to identify shipments containing SWPM or find some types of pests in SWPM, and the impediment that cargo containerization poses to effective SWPM inspection. Characteristics of shipments involving SWPM that contribute to the difficulty of intercepting pests include the large volumes of imported cargo containing SWPM, the absence of information on manifests regarding the presence of SWPM, limited inspection access to cargo packed in shipping containers, and the solid nature of SWPM, which effectively hides many types of pest organisms.

SWPM is Pervasive in Arriving Cargo—The large volume of imported cargo that contains SWPM contributes significantly to inspection problems. About 4.1 million cargo container units arrived in 1998 in Long Beach, CA, the largest U.S. container port (D. Reeves 1999, personal communication). APHIS cannot accurately determine which containers carry SWPM (see the next three sections), but even if this were possible, inspection of all SWPM at Long Beach alone would require unrealistic staffing numbers. If 50 percent of Long Beach import shipments contained SWPM and APHIS attempted to inspect each shipment, APHIS would have to inspect over two million shipments at that port each year, or more than 39,000 each week. With current staffing, APHIS is able to inspect between 125 and 200 shipments for SWPM per week in Long Beach depending on the proportion of "devan" (i.e., unloading of cargo from containers), intensive tailgate (i.e., entering container), and tailgate (i.e, viewing cargo through open doors) inspections performed (D. Reeves 1999, personal communication). These data illustrate the large volume of imported cargo containing SWPM and suggest that current inspection levels are inadequate to prevent pest entry via this pathway. The data further suggest that significant staffing increases may not resolve the problem—especially not in major maritime ports.

Shipments Containing SWPM Cannot Be Identified—Unlike SWPM, other items regulated by APHIS are usually the imported commodity itself (e.g., fruits or vegetables). These commodities are manifested in commerce so that APHIS inspectors become aware of arriving shipments. APHIS port personnel hold and inspect all or some portion of arriving regulated shipments at the port of entry before the shipments are released into U.S. commerce. But, there are no requirements by U.S. Customs or other organizations for shippers or importers to indicate the presence of packing material with imported commodities (except for a recent requirement for a certificate indicating presence or absence of SWPM for shipments arriving from China and Hong Kong). Thus, APHIS inspectors generally cannot determine from shipping manifests which shipments contain SWPM.

Through experience, inspectors learn that certain commodities regularly arrive with SWPM *(*e.g*.,* cast iron items, machinery parts, and quarry tiles). But, virtually any commodity may be supported by wooden pallets, bracing, or crating. In 502 maritime containers randomly sampled by APHIS at ports of entry from October 1998 to March 1999, those carrying cargo with SWPM included more than 250 different commodities (APHIS AQIM data base). Adding to the problem of identifying shipments with SWPM, individual shippers may decide to change their packing procedures (e.g., from using alternative packing materials to SWPM) at any time. Thus, the kinds of commodity shipments containing SWPM are often unpredictable.

Cargo Containerization Hinders Effective SWPM Inspection—In the past two decades, cargo shipping practices have changed considerably. In the past, most maritime cargo was shipped in bulk, but now most arrives in sturdy, sea-worthy trailers called containers.

The worldwide trend of increasing containerization has affected trade in the United States. Los Angeles, CA, experienced growth in arriving containers from 20 in 1958 to 1 million in 1985, over 2 million in 1989, and 3.2 million in 1998 (Los Angeles Port Authority, n.d.). In Long Beach, CA, the number of containers measured in TEU's (a TEU is equivalent to one 20-foot cargo container unit) increased 59 percent from 1994 to 1998 (Long Beach Port Authority, n.d.). The port in Miami, FL handled 761,183 TEU's in 1997, which represents a 104-percent increase since 1990 (Miami Port Authority, n.d.). In Jacksonville, FL, containerized cargo comprised 57 percent (by tonnage) of that transported through the port from 1993 to 1998, as compared with bulk, breakbulk (i.e., packaged but not in shipping containers), and automobile cargo (Jacksonville Port Authority, n.d.).

The change from bulk to containerized cargo affects SWPM inspection effectiveness. Crates and pallet stacks shipped as bulk cargo are usually lifted from the ship's hold and placed on floors of cargo sheds near the pier. Under these circumstances, much of the SWPM is readily visible and accessible, allowing for reasonably effective pest inspection. By contrast, containerized cargo is usually packed tightly in the trailer and often stacked to the roof, preventing inspection of all but a small percentage of the shipment visible at the tailgate (i.e., open doors). Only 1–5 percent of SWPM may be accessible at the tailgate. Importers must pay high fees ranging from $800 to $1,500 per container for removing or devanning cargo to facilitate inspection. Inspectors are often reluctant to impose these additional costs on importers unless there is reasonable certainty pests will be found. Devan inspections are time-consuming, and the limited number of available facilities suitable for devanning at most ports restricts the number of inspections. As a result of these factors, APHIS inspectors do not gain access to most imported SWPM.

Visual Inspection of SWPM for Deep Wood Pests Is Time-Consuming and Often Ineffective—APHIS inspects SWPM primarily by locating bark or evidence of pest damage. APHIS's 1995 wood product regulations prohibit bark on SWPM and thereby facilitate mitigation of arriving pests associated with bark (e.g., bark beetles) because finding bark is easier than finding live pests. However, bark-free SWPM does not protect against other living, deep-wood pathogens and wood-boring pests. Many insects tunnel deep into wood during their life cycle, including Cerambycidae like the Asian longhorned beetle, Buprestidae (Coleoptera), Siricidae (Hymenoptera), and Cossidae (Lepidoptera). APHIS inspectors frequently find these pests surviving in bark-free SWPM.

To intercept deep-wood pests in SWPM, inspectors locate pest damage and carefully split the wood to retrieve live pests without damaging them. The procedure takes time, care, and energy. Inspection efforts are often unproductive; for example, wood planks may be sawed across vacant portions of larval pest tunnels, leading to wasted time spent searching wood in the belief that pests are still present. Visual inspection usually cannot detect pathogens, and culturing of suspect material generally is not done owing to the timelag required for identification. Symptoms of wood pathogens (e.g., stains) resemble those of nonpathogenic organisms and other causal agents or may not be present at all. Thus, traditional inspection for deep-wood pests is labor- and time-intensive and often fails to locate live pests.

Summary—Several factors contribute to reducing the effectiveness of inspection for pests associated with imported SWPM. More than 50 percent of the volume of imported cargo entering the United States may contain SWPM. Virtually any imported commodity may have associated SWPM, and shipping regulations and practices generally do not require identification of which shipments contain these materials. When regulators can identify shipments with wood, over 90 percent of the SWPM may not be readily accessible for inspection because most shipments arrive in containers. Even in cases in which SWPM is accessible, inspection may fail to locate deep-wood insect pests and pathogens. The cumulative effect of these factors suggests that mitigation other than inspection may be necessary to reduce pest risk associated with imported SWPM adequately.

Characterizing Risk in the SWPM Pathway

The SWPM pathway poses unusual difficulty for the characterization of associated pest risk. Unlike SWPM, most items regulated by APHIS are identifiable by type and origin. To determine pest risk presented by a regulated commodity, APHIS assessors usually research pest organisms known to be associated with a specific plant part from a particular country or region (e.g., tomato fruit from country X). They may then eliminate from consideration pests associated with the commodity that are not likely to travel with the commodity in the import pathway. Thus, in the example noted above, if a pest infests tomato roots in country X, but tomato fruit is imported, then that pest is not likely to follow the import pathway.

Using this typical approach, risk assessors narrow the list of pests they rate at several stages by considering only those pests that (1) are associated with the host plant or commodity, (2) occur in the origin country or region considered in the risk assessment, and (3) are likely to arrive with the commodity. This process of elimination often results in a manageable, shortened pest list, thus allowing for reasonably accurate estimates of risk associated with the commodity.

By contrast, commercial practices for handling SWPM differ considerably from those for other regulated items and significantly obscure SWPM type and origin. As a result, assessors have difficulty or are unable to characterize specific associated risks. The following sections elaborate on factors that inhibit the effective characterization of SWPM and, therefore, obscure identification of specific pest risks for any given item.

SWPM Cannot be Characterized by Type—No U.S. import requirements specify the kind of wood to be used for packing materials. Shippers often use low-grade and scrap wood as SWPM to minimize cost. Because cost and availability typically govern choice of SWPM, nearly any and all species of woody plant, from fresh cut to reused seasoned lumber, may be used. Consequently, most pests that feed or occur on or in stems and branches of woody plants may be found in or on SWPM.

Pest interception records indicate that a wide variety of insect borers known to infest different host species, including pine, spruce, oak, and poplar (e.g., *Orthotomicus erosus*, *Ips typographus*, *Phymatodes* sp., and *Anoplophora glabripennis*, respectively) arrive with imported SWPM (appendix A). In Canada, forestry workers identified conifer pests (*Monochamus*) and hardwood pests (*Anoplophora*) from wooden spools used to transport steel wire, which indicates that at least two tree species were used in construction of one spool (Dawson et al., n.d.). These pest interception data and our knowledge of typical commercial practices for selecting raw or green wood for packing materials suggest that cargo containing SWPM may harbor any number and kind of wood pests.

SWPM Cannot Be Characterized by Origin—Solid wood packing materials may be categorized as either limited or multiple use materials. In 1995, 78 percent of pallets were classified as multiple use rather than limited or single use (Bush et al. 1997). Most pallets and some crating, bracing, and dunnage may be used repeatedly. Repeated SWPM use allows wood containing pests from a given country along the trade route to arrive with a commodity manifested and shipped from a different country or continent. This practice frustrates attempts to characterize risk posed by SWPM in virtually any given shipment. Even for limited-use SWPM, information on shipment origin may be unreliable. Countries deficient in materials suitable for constructing SWPM import cheap wood from other countries. For example, Hong Kong purchases wood used for packing materials from other areas, especially mainland China and Malaysia. No conventions or regulations exist that require traders to certify the origin of imported SWPM.

SWPM Cannot Be Characterized by Age—Older, seasoned wood usually presents reduced pest risk compared with fresh cut wood. Although pests like termites, powderpost beetles, and some deep-wood borers and pathogens may survive or prosper in older wood, most forest pests will survive in cut wood for less than 1or 2 years. Export cargo recently packed in wooden crates, pallets, or bracing may be shipped immediately and directly to its destination; it may also remain in storage for unspecified periods before shipping and even transit several countries before arriving at its destination. Shipping records account for only a portion of this movement and do not provide a means for estimating the age of arriving wood. Pest life cycles in wood range from a few months to many years, further confounding attempts to estimate pest survival.

Summary—Wooden pallets offer an example of commercial practice that obscures SWPM type and origin and confuses risk analysis. In the United States, 71 percent of wooden pallets requiring repair or destruction are recycled (repaired or reused) rather than discarded in landfills (29 percent) (Modern Materials Handling and National Wooden Pallet and Container Association 1997), and 87 percent of the wood recovered in 1995 from used pallets was reused in pallets (Bush and Araman 1998). If this is indicative of practice worldwide, then a significant majority of pallets are likely to contain wood of varied type and origin, which is often untraceable.

Thus, any given imported cargo shipment may contain SWPM of varied wood types and age and from unexpected or multiple origins or both. As a result, the likelihood that any given shipment containing SWPM may harbor potential pests cannot be accurately evaluated by PPQ inspectors. Furthermore, because incoming cargo may contain SWPM of varied type and origin, any given shipment may pose the highest level of pest risk offered by the pathway.

Likelihood of Introduction

Past Pest Interceptions and Establishments Associated With SWPM

Estimates of the number of nonindigenous organisms that have become established in the United States (mainland) range from more than 4,500 (U.S. Congress OTA 1993) to over 30,000 (Pimentel et al. 2000). Of these, about 2,000–4,500 are insects, and over 200 are plant pathogens. About a third (35 percent) of the nonindigenous insect species that are known to have become established are considered to have harmful effects, whereas nearly all (91 percent) plant pathogens established have harmful effects (U.S. Congress OTA 1993). Although insects of exotic origin make up about 2 percent of the known insect species in the mainland United States, they constitute about 40 percent of the major pest species of agriculture and forest resources (Kim and McPherson 1993, Pimentel 1986). In Hawaii, nonindigenous species comprise about 32 percent (2598/7998) of the insect fauna (Eldredge and Miller 1998). Over 400 of the nonindigenous insect species and about 20 of the plant pathogens known to occur primarily in the U.S. mainland affect trees or shrubs (Bridges 1995, Haack and Cavey 1997, Haack et al. 1997a, Mattson et al. 1994b, Niemelä and Mattson 1996). Pimentel (1986) estimated that 27 percent of the major forest insect pests in the United States are nonnative, including some of the most damaging species.

Many exotic pest introductions occurred before implementation of stringent safeguarding regulations; however, today's international trade activities continue to facilitate movement of exotic organisms. Although nonnative organisms have arrived via many different pathways and on various hosts (e.g., nursery stock, seeds, logs, SWPM), recent interceptions of forest pests (mostly insects) have been far more common on SWPM than on other cargo items. Between August 1995 and March 1998, approximately 500 shipments were found to harbor forest pests of quarantine significance, and 97 percent of those were associated with SWPM (USDA APHIS 1999).

Although pest interception data indicate that infested SWPM arrive with a wide variety of commodities, import commodities most likely to be associated with SWPM that may harbor exotic forest pests are usually heavy, such as machinery, stone, and metal (table 3). Canadian researchers discovered that wooden spools designed to carry steel wire and cable are particularly risky. In a 1997 port survey conducted in Canada, bark was found to be present and usually hidden within wood layers in 90 percent of wooden spools shipped from China, Korea, and Malaysia, and 14 percent of the spools contained live insects (Dawson et al., n.d.). Surveys of Chinese wooden spools in 1997 and 1998 revealed that 22–24 percent contained live insects and that 37 percent of damage was likely to be nonvisible externally (Allen et al., n.d.). Another Canadian survey of wooden packing materials used to brace granite blocks

Table 3. Commodities associated with multiple interceptions of pests with solid wood packing materials imported into the United States and Canada (from Government of Canada, Canadian Food Inspection Service)

Aluminum	Pallets
Appliances	Personal effects/household goods
Ball bearings	Pipe
Bathroom accessories	Plexiglass
Batteries	Pottery
Brake rotors	Pumps
Ceramics	Sheet metal
Chain	Silicon
Cutlery	Slate
Electrical ballasts	Statues
Furniture	Steel (bars)
Gaskets	Steel (ingots)
Gears/sprockets	Steel (rolled)
Glass products	Steel (manufactured)
Granite	Stone (cut)
Iron (bars)	Tile
Iron (cast)	Titanium
Iron (rolled)	Tools
Machine parts	Sports equipment (weightlifting)
Machinery	Wire/cable (no spool)
Magnesium (ingots)	Wire/cable (with spool)
Marble	Wood baskets
Molybdenum	Wood picture frames

found that 32 percent of the wood packing pieces contained live insects and 50 percent had bluestain fungi (Allen et al., n.d.).

From 1996 through 1998, APHIS inspectors recorded 1,205 interceptions (averaging 402 per year) of live exotic forest pests arriving with SWPM entering the United States (table A–1 in appendix A). These interceptions represented 156 taxa (but not species because many organisms, particularly immatures, could not be identified beyond genus or family levels). The interception records probably provide a good representation of the kinds of insect pests that may enter with SWPM; however, most plant pathogens in cargo shipments are not often or easily detected, isolated, and identified. Thus, pathogenic organisms are infrequently intercepted and reported. Members of the order Coleoptera (beetles) accounted for 94 percent (1,134/1,205) of all interceptions. The most common family of pests intercepted, both within the order Coleoptera (48 percent) and within all taxa intercepted (45 percent), was the Scolytidae (bark beetles) despite implementation of regulation changes in 1995 prohibiting bark on imported materials (table A–2 in appendix A). The next most common group was the wood borers of the family Cerambycidae, which made up 35 percent of all interceptions. The orders Hymenoptera and Lepidoptera accounted for 3 percent and 2 percent, respectively, of all interceptions.

The bark beetles (Scolytidae) made up 48 percent of Coleoptera interceptions in 1996–98 compared with 72 percent of the Coleoptera interceptions reported from all wood articles between 1985 and 1996 (Haack and Cavey 1997). The continued prevalence of bark beetle interceptions indicates that wood material is still arriving at ports of entry that is not 100 percent bark-free and is therefore able to harbor and protect these insects; however, the diminished percentage in 1996–98 may indicate that some reduction in pest numbers has occurred as a result of the bark-free regulations, changing trade patterns, or both. The reduction may also reflect increased emphasis by APHIS inspectors on detecting cerambycids in cargo since the first discovery of the Asian longhorned beetle in New York in 1996. The percentage of Coleoptera interceptions represented by Cerambycidae wood borers, on the other hand, appears to have increased from 7 percent for wood articles inspected in 1985–96 (Haack and Cavey 1997) to 37 percent for shipments with SWPM in 1996–98.

Pest interceptions associated with SWPM were recorded from 64 countries of origin in 1996–98 (table A–3 in appendix A). In 1998, primary trading partners included western Europe (21 percent of import value), Canada (19.2 percent), Japan (13.4 percent), and Mexico (10.2 percent) (U.S. Bureau of Census, n.d. b). However, imports have increased in recent years from other countries around the world as markets have opened up and trade restrictions have declined. This trend is expected to continue, thereby influencing additional shifts in the kinds and numbers of potential exotic forest pests that may arrive at U.S. ports of entry. As an example, the proportion of total imports into the United States in terms of monetary value doubled for China between 1991 (3.9 percent) and 1998 (7.8 percent) (U.S. Bureau of Census, n.d. a, b). Although the amount of cargo containing SWPM (see table 2) and the pest risks associated with those shipments are not directly proportional to the value of imports from any particular country or region, trade patterns can significantly influence the levels of pest interceptions and entries into the United States. China was the primary source of interceptions of Cerambycidae (74 percent) found with SWPM in 1996–98, whereas European countries contributed 14 percent. Haack and Cavey (1997) noted that interceptions of forest pests from China increased from 1.2 percent of all interceptions on wood articles in 1985 to 21.2 percent in 1996. This trend appeared to continue in 1996–98, for 39 percent of interceptions associated with SWPM originated in China (table A–3 in appendix A). In addition to shipments with pest interceptions, when shipments are considered on which bark was found but no live pests of any taxa were detected, 50 percent of the shipments requiring treatment at U.S. ports of entry were from China (fig. 14). Asia has recently supplanted Europe as the region contributing the most interceptions of exotic forest pests to the United States (table A–4 in appendix A). However, European countries were collectively responsible for 37 percent of all intercepted pests found with SWPM in 1996–98, and contributed 56 percent of the Scolytidae (bark beetle) interceptions. Shipments from China contributed 18 percent of the Scolytidae interceptions. The relative shift in numbers of Cerambycidae versus Scolytidae intercepted in wood items in recent years probably reflects changing trade patterns in which Asian countries (especially China) are shipping more cargo to the United States. Although the majority of interceptions of pests in SWPM in 1996–98 were found in cargo originating from Europe and Asia, 38 interceptions occurred in shipments arriving from other North American countries, 34 came from South America, 30 arrived from Africa, and 4 were from Oceania (table A–4 in appendix A).

About 72 percent of the nonindigenous forest insects that have become established in the United States have origins in Europe, whereas 18 percent came from Asia (Mattson et al. 1994b), reflecting past trade patterns. About half of the recognized nonnative tree pathogens have origins in Europe, and the remainder came from Asia (Bridges 1995). This probably resulted not only from a long history of trade between Europe and North America but also because the continents are similar biogeographically (Niemelä and Mattson 1996). Many more species of forest insects of European origin have successfully become established in North America than the reverse (Mattson et al. 1994b). This phenomenon may be the result of the greater diversity of congeneric and confamilial plant species that may be adopted as hosts, the greater abundance of these potential host plants, the less fragmented distributions of potential hosts, and the longer growing seasons or phenological windows for pest adaptation in North America compared with Europe (Niemelä and Mattson 1992, 1996). The most common woody plant genera (i.e., *Prunus, Malus, Betula, Populus, Salix, Pinus, Quercus, Pyrus, Crataegus, Acer, Ulmus, Alnus,* and *Picea*) for establishment of nonnative forest insects in North America are common in Europe, whereas the least common genera (e.g., *Carya, Chamaecyparis, Robinia, Pseudotsuga, Thuja,* and *Tsuga*) do not occur naturally in Europe (Niemelä and Mattson 1996). Additionally, it has been argued that European pest species tend to have competitive advantages and superior invasive abilities (i.e., lower extinction rates of founder populations) relative to North American species owing to the former's catastrophic evolutionary history of glaciation and severe disturbances (Niemelä and Mattson 1992, 1996). Similar comparisons of the invasive potential of tree pests of Asian origin have not been conducted.

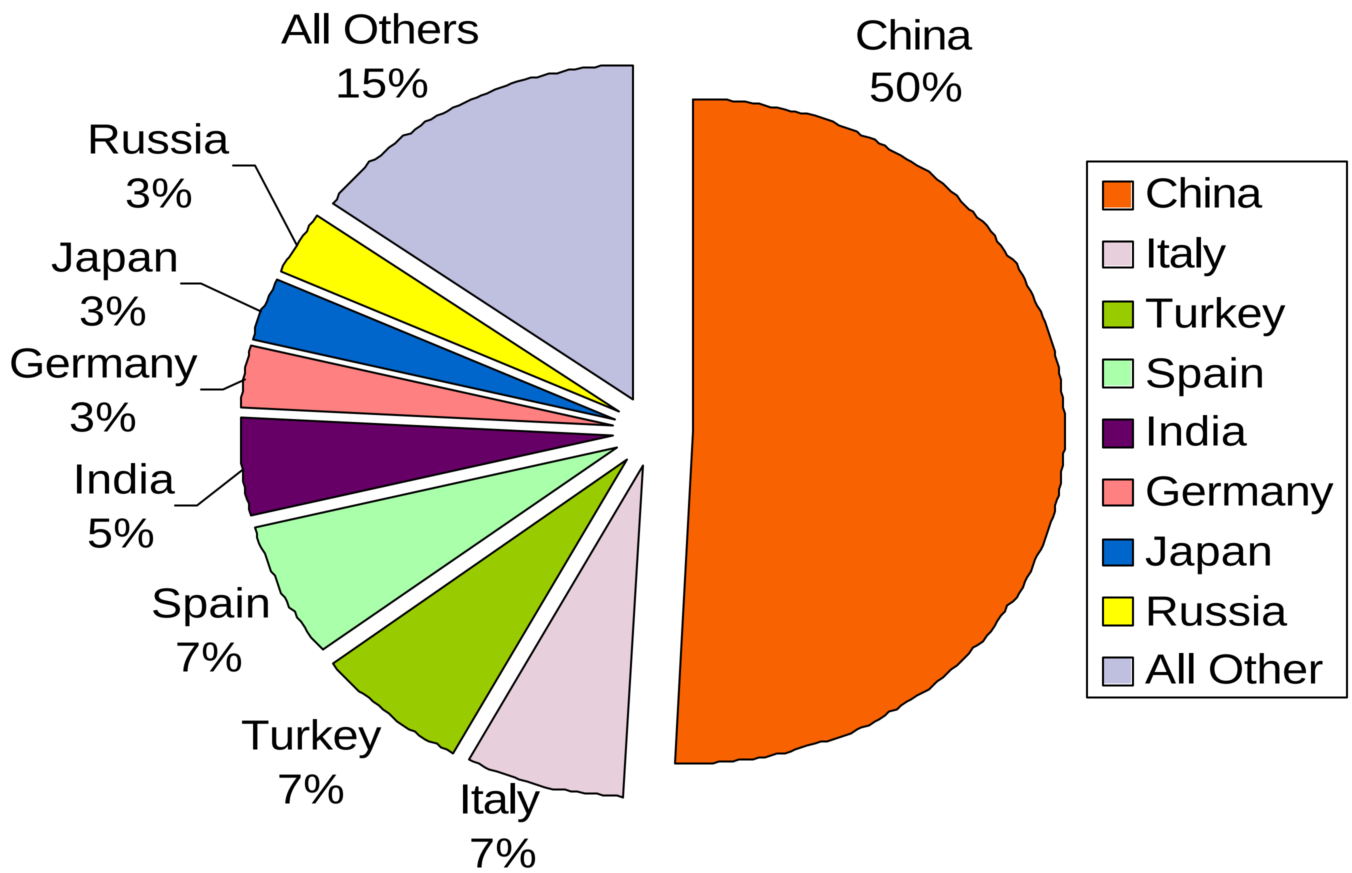


Figure 14. Percentages of cargo shipments by country of origin with SWPM in 1998–99 requiring treatment because of the presence of bark or live pest interceptions.

Although the most frequent destination States for shipments containing SWPM found to harbor exotic forest pests were in California, Florida, and Texas (table A–5), the majority of exotic forest pests have become established in the Northeastern and Northwestern regions of the United States (Mattson et al. 1994b; W. Wallner 1999, personal communication). The rank order of destination States changes somewhat when shipments containing bark but with no reported live pests are also included (fig. 9). Regions with the most recorded introductions of nonindigenous forest pests correspond to areas of active commercial seaports at which favorable climates and an abundance of diverse forest tree species exist (figs. 10–13).

Examples of past introductions into the United States of forest pest species that can travel with SWPM include the Asian longhorned beetle, chestnut blight fungus, Dutch elm disease fungus, Formosan subterranean termite, gypsy moth (European biotype), pine shoot beetle, and the smaller Japanese cedar longhorned beetle. Although several of these species were initially introduced by means other than SWPM (e.g., logs, nursery stock, research colonies), SWPM can serve as a vehicle of additional human-assisted transport. The case histories of these introductions, which are detailed in appendix B, are representative of the types and magnitudes of damage that can result from introduction of forest pests transportable with SWPM. A case history of the introduction to Japan (likely from the United States) of the pinewood nematode, which causes pine wilt disease is also presented in appendix B, to illustrate the potential effects of a type of organism not otherwise represented among those mentioned previously.

Potential for Entry and Establishment of Pests Transported With SWPM

The likelihood that an organism will move to, and become established in, a new environment is related to the chance of the organism's being associated with the host or commodity being moved, its survivability during transport, its ability to locate and colonize suitable hosts in its new environment, and its ability to reproduce and spread. If the likelihood of any one of these steps is low, the overall risk of introduction will be low. The likelihood of introduction (i.e., entry and establishment) will vary with biologies, origin, time, and destination.

For untreated or ineffectively treated wood (e.g., wood that has not been properly fumigated, kiln dried, or otherwise handled in a way likely to kill insects and pathogenic organisms), the likelihood of a potential pest's being associated with the host or wood material being moved depends upon population levels in the country of origin and the habits and seasonalities of life stages of the organism. Potential pests may already be present in or on host material at the time of harvest, or they may colonize after harvest but before shipment. Many species of bark beetles and wood borers are particularly attracted to recently cut wood. In some countries of origin, SWPM (especially single-use materials) are more likely to be constructed out of infested materials because of general unsuitability for other uses. Forest insects and pathogens that have life stages closely associated with tree trunks, especially those that remain with the host for long periods (e.g., wood-borers, bark beetles, deep wood pathogens), may pose the greatest risks of infesting wood materials to be exported. Although some organisms spend most of their lifespan associated with tree trunks, others are present only in certain life stages and seasons (e.g., eggs of some lepidopterous species such as the Asian gypsy moth). Organisms that maintain stable populations in the country of origin may be intercepted on a regular basis at ports of entry (provided the pests are readily detectable by visual examination), whereas organisms with cyclical population levels may only be intercepted in years when epidemics occur at exporting locations. Therefore, the absence of interceptions of a given pest species in any given year or span of years does not necessarily indicate that risk of entry is low. Given fluctuations in population levels through time and space, assessments of pest risk need to consider whether introduction is likely over a long period rather than at any specific point in time.

Harvesting, handling, and pest mitigation practices can result in incomplete destruction of organisms residing in wood materials. For example, debarking may be incomplete, leaving remnants in depressions. Problems also exist with adequate penetration of fumigants beyond a few inches' depth into wood materials (a particular concern for deep-wood pathogens) and into large or tightly packed cargo shipments. The effectiveness of possible mitigation strategies will be addressed in the pest risk reduction analysis and is not considered further here.

A potential pest organism infesting SWPM destined for the United States must be able to survive conditions of transit in order to gain entry. The lengthy list of live insect pests intercepted with SWPM at U.S. ports of entry with origins from around the world (table A–1 in appendix A) suggests that environmental conditions in shipping containers and airplane cargo holds are favorable for survival of many organisms. Even small pieces of wood material may be sufficient to provide enough habitat and protection for organisms transported; an adult cerambycid beetle was successfully reared from a 2.5-cm^2 piece of crating containing bark following importation to Canada (Dawson et al., n.d.). The survivability of pathogenic organisms may vary with moisture requirements—particularly for vegetative stages of the organisms. However, certain dormant stages (e.g., spores) can be very resistant to fluctuations in moisture and temperature conditions. Depending on time in transit, survivability on SWPM may be lower for certain potential pest species and life stages that are dependent upon living plant tissue for sustenance (e.g., sap feeders such as Homoptera, the dominant order of previous introductions of forest insects into North America [Mattson et al. 1994a]).

The likelihood of a species' becoming established in a new location may increase in relation to the numbers of individuals imported at a given time or with repeated instances of entry; however, the relationship is not necessarily linear. Other factors that may influence likelihood of establishment include availability of suitable hosts and environmental conditions (e.g., weather) at the destination location and ability of the organism to disperse and locate new hosts. Therefore, the most frequently intercepted organisms at ports of entry are not necessarily the most likely to become established in the United States over time. Virtually all nonnative insect species that have colonized in North America have either adopted new host species in the same genus as their native hosts or became established on native host species that were planted (as exotics) in North America (Mattson et al. 1994b). Non-native insect and pathogen species with broad host ranges may have more opportunities for locating suitable hosts in a new environment; however, examples exist of species with limited host ranges that have become established in the United States with devastating results (e.g., pathogens causing chestnut blight and Dutch elm disease). Among nonnative forest insect pests successfully established in the United States (via all pathways), 37 percent were classified as polyphagous, 18 percent were oligophagous, and 44 percent were monophagous (Mattson et al. 1994b). Those pest species with narrow host preferences that have become successfully established in North America generally have come from native environments similar to those they have colonized (Gibbs and Wainhouse 1986, Niemela and Mattson 1992). Similarity of climatic conditions also helps ensure synchrony of the pest with its hosts' phenologies. Species adapted to high latitudes are more likely to be able to adapt to temperature and light regimes of low and midlatitudes than the reverse (Niemelä and Mattson 1996). However, tropical and subtropical environments, such as occur in Hawaii and Florida, may be favorable for establishment of greater numbers of exotic species than harsher regions. An estimated 2,582 exotic invertebrates have been introduced to Hawaii compared with about 2,000 for the continental United States (Pimentel et al. 2000). Habitat disturbances also may enhance the ability of founder populations to colonize a site (Liebhold et al. 1993, 1995).

Most arrivals of nonnative species do not result in permanent establishment because of the high likelihood of extinction of small populations (Liebhold et al. 1993, 1995). New arrivals may have to compete with native species that utilize similar niches. Introduced pests may even have a competitive advantage relative to North American counterparts, as has been suggested for European insects in general (Niemelä and Mattson 1992, 1996). Certain plant pathogens may require the presence of wounds to become established; others are dependent on the presence of insect vectors. Once a viable population has become established, typically it will expand to fill adjoining areas of suitable habitat. Biological characteristics of an organism for reproduction and spread influence its ability to become successfully established in a new environment. Species that reproduce asexually (or vegetatively) may be able to become established in the absence of males (or cross-fertilization) in the founding population or even from the introduction of a single female (or propagule). About 40 percent of exotic forest insects established in North America have parthenogenetic capabilities, compared with an estimated 11 percent of native phytophagous taxa (Niemelä and Mattson 1996). Although population increase and spread will be influenced by variations in the environment colonized, diffusion models that predict a constant rate of spread in all directions (i.e., radially) from a point of origin have been found to describe range expansion parameters of exotic pests adequately (Liebhold et al. 1993, 1995). The extent of population expansion of an invader species is governed by the spatial distribution of suitable habitat and the accessibility of suitable habitats to the population (Liebhold et al. 1995). Regions with the greatest risk of pest entry are those with high levels of human mobility and trade; therefore, urban areas may be more at risk than isolated forests for introduction of exotic forest pests (Liebhold et al. 1995). Exotic species are more commonly found around ports of entry, agricultural trade centers, metropolitan areas, locales (such as Hawaii) that support human populations of international origin, and disturbed areas (U.S. Congress OTA 1993).

Consequences of Introduction

Resources at Risk

Representatives of almost every type of vegetation that occurs in the world can be found somewhere in the United States or its protectorates (Smith 1995). Although closed canopies of conifers and broad-leaved deciduous trees typical of the humid parts of the Temperate Zone predominate in forests of the continental United States, tropical forests exist in Hawaii, southern Florida, Puerto Rico, and the Pacific Islands. Forest patterns and compositions are shaped by a variety of land forms, latitudinal positions, and climatic differences.

Forest land covers about 737 million acres (298 million ha), or about 33 percent of the land area of the United States (USDA Forest Service 1993a). This translates to just over 1 ha per person, which is slightly ahead of the global mean of 0.66 ha per capita. Forested land is widely but unevenly distributed and ranges from the sparse scrub forests of the arid interior West to the highly productive forests of the Pacific Coast and South (figs. 10 and 11). Forested lands of the Pacific Coast, Rocky Mountains, North (east and central), and South (east and central) encompass 87,625,000 ha; 56,522,000 ha; 68,154,000 ha; and 85,690,000 ha, respectively (Powell et al. 1993). Composition ranges from pure hardwood to multispecies mixtures to conifer forests (fig. 12). About 500 native species of trees in 73 plant families occur in the continental United States; about 100 of these are tropical (Little 1979). Genera with the greatest number of species, in descending order, include *Quercus* (oak), *Pinus* (pine), *Crataegus* (hawthorn), *Salix* (willow), *Prunus* (cherry, plum), *Fraxinus* (ash), *Ilex* (holly), *Acer* (maple), *Juniperus* (juniper), *Yucca* (yucca), *Cornus* (dogwood), *Carya* (hickory), and *Populus* (cottonwood, poplar, aspen). Some other tree genera are widely distributed although limited in number of species (e.g., *Pseudotsuga* [Douglas-fir], *Tsuga* [hemlock], and *Thuja* [arborvitae]). Hundreds of species of native and introduced trees occur in tropical and subtropical locations, but most species are limited in distribution (Little and Skolmen 1989).

About 66 percent of all forest land (about 490 million acres) is classified as timberland capable of producing more than 20 cubic feet per acre per year and not withdrawn from timber production (USDA Forest Service 1993a). About 70 percent of the timberland is located in the Eastern United States (fig. 13). Nationally, about 57percent of the volume of growing stock is softwoods, and 43 percent is hardwoods. About 90 percent of the hardwood timber volume is located in the Eastern United States. For softwoods, 66 percent of the timber volume is located in the Western United States, and 23 percent is in the South. Primary uses of harvested wood include sawlogs for lumber (41 percent by volume), veneer logs (8 percent), pulpwood for paper (28 percent), fuelwood (18 percent), and other products (e.g., poles, posts, shakes) (5 percent). Timber production was valued at over $19 billion in 1991 (.$22 billion in 1998 dollars), and secondary timber-related products added about $40 billion (.$46 billion in 1998 dollars) in production value (McKeever and Howard 1996). This represented 17 percent of combined forest and agricultural products produced in the United States. Primary timber production was the highest value crop produced in the Southern and Pacific Coast States and was fourth highest in the Northern and Rocky Mountain States.

The dominant natural tree-cover types at risk for exotic pest introduction within various regions of the United States are briefly described below. More detailed descriptions of these regions can be found in Barrett (1995), USDA Forest Service (1993a), and USDA APHIS (1994). Numerous understory and riparian tree species, too numerous to describe herein, that comprise important ecological components of U.S. forest ecosystems are also at risk.

Eastern Deciduous Forest Region—This region, which covers the Mid-Atlantic States, the Northeast, and parts of the Southeast, is composed of a complicated array of hundreds of tree species, most of which are hardwoods. However, the comparatively small number of conifer species cover substantial areas. Dominant forest-cover types include oak–pine–hickory, oak–hickory, sugar maple–beech (*Acer saccharum* Marsh.–*Fagus grandifolia* Ehrh.), hemlock (*Tsuga*), eastern white pine (*Pinus strobus* L.), spruce (*Picea*), and the northern hardwoods.

Southeast Region—The southeastern coastal plain region extends from the Texas Gulf Coast to southern New Jersey, including the lower Mississippi River Basin. Pine, oak, and mixed oak–pine forests are characteristic.

North Central and Great Plains Regions—These regions extend from northeast Mexico to south-central Canada. The predominant forest types include aspen–birch (*Betula*), oak–hickory, northern hardwoods (maple, beech, basswood [*Tilia*]), lowland hardwoods (elm [*Ulmus*], cottonwood, oak, maple), lowland conifers (black spruce [*Picea mariana* (Mill.) B.S.P.], northern white cedar [*Thuja occidentalis* L.], larch [*Larix*]), and mixed pines.

Pacific Northwest Region—Extending from midcoastal California to southern Alaska, this region is characterized by predominantly mixed conifer forests composed of pines, true fir (*Abies*), hemlock, and Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco]. Pure pine forests occur in the southern Cascades and on the eastern slope of the Sierra Nevada. Other softwoods, including western larch (*Larix occidentalis* Nutt.), western red cedar (*Thuja plicata* Donn ex. D. Don), redwood [*Sequoia sempervirens* (D. Don) Endl.], and other minor species occur in localized areas.

Pacific Southwest Region—Although mostly desert and shrubland, the area making up midcoastal California south and east into the desert of the Southwest contains several pine species, Douglas-fir, and incense-cedar (*Libocedrus decurrens* Torr.).

Rocky Mountain Region—At lower elevations, the dominant trees are broad-leaved deciduous species. Higher elevations are characterized by ponderosa pine (*Pinus ponderosa* Dougl. ex Laws) woodlands, mixed pine–oak woodlands, and Douglas-fir and spruce–fir–hemlock forests.

Tropical and Subtropical Regions—Tropical habitats occur in the southern tip of Florida, Hawaii, Puerto Rico, the Virgin Islands, Guam, the Northern Mariana Islands, American Samoa, and Palau. Forest land on 43 tropical islands of the State of Hawaii and the territories of the United States is estimated to encompass about 17 percent of the total land area and includes over 1.1 million acres (United States Forest Service, unpublished data). The vegetation composition of each island is distinct. Although more than 300 native tree species occur in the Hawaiian islands, most species occur on only one or a few of the six major islands and are scattered or uncommon and small (Little and Skolmen 1989). Most species are endemic with 95 percent occurring nowhere else in the world. The dominant native forest types in the Hawaiian islands, which are also commercially important, are ‘Çhi’a lehua [*Metrosideros polymorpha* Gaudich. in the family Myrtaceae] and koa (*Acacia koa* Gray in the family Leguminosae). Introduced *Eucalyptus* spp. dominate commercial plantations. Puerto Rico and the Virgin Islands have over 500 native tree species each. About 25 percent of the species in Puerto Rico occur nowhere else, and some widespread tropical or subtropical species are noticeably absent from the island. Forest types in Puerto Rico can be divided into secondary forest (79 percent) and coffee shade forests (21 percent), with 77 percent of the coffee shade forests being abandoned (Franco et al. 1997). Ten tree species account for about half of the live basal area: *Spathodea companulata* Beauv., *Guarea guidonia* (L.) Sleumer, *Inga vera* Willd., *Cercopia peltata* L., *Andira inermis* (W. Wright) Kunth ex DC., *Tabebuia heterophylla* (DC.) Britton, *Eugenia jambos* L., *Inga fagifolia* (L.), *Erythrina poeppegiana* (Walp.) O. F. Cook*, and Mangifera indica* L. Upland rain forests composed of many tropical species dominate the native vegetation of American Samoa, and accessible areas have been converted to production of coconuts (*Cocos nucifera* L.), breadfruit [*Artocarpus altilis* (Park) Fosb.], bananas (*Musa* spp.), mango (*Mangifera indica* L.), and other agricultural crops (Cole et al. 1988). Saltwater-adapted mangrove forests occur in the wet coastal areas of southern Florida and American Samoa, whereas palm trees are characteristic in freshwater swamps of southern Florida (Cole et al. 1988, Spurr and Barnes 1973).

In addition to extensive natural stands of conifers and hardwoods in the United States, 27 percent of the 281,000 km^2 of urban areas (cities, towns, and villages) in the coterminous United States is covered by trees (Dwyer et al., in press). An estimated 3.8 billion trees exist in these urban areas. Nonindigenous species of woody plants are commonly planted in urban settings, which increases the likelihood that an exotic pest organism will be able to locate a suitable host upon entry. Urban tree resources vary within and between regions of the country. Areas with the largest populations of urban trees occur in the South and Northeast. Cities that developed in forested areas have the highest percentage of land occupied by tree cover at an average of 34.4 percent, compared with grasslands (17.8 percent) and deserts (9.3 percent). The highest concentrations of tree cover are typically found in park and residential areas and on vacant lands within cities located within forest ecotypes. Urban tree cover is sparsest in commercial and industrial areas and on vacant lands within desert ecotypes. Urban land areas doubled in size between the late 1960's and the early 1990's.

A very sizable industry exists in the United States devoted to the production of ornamentals and Christmas trees that could be affected by pests introduced through SWPM. In 1997, nursery crops were produced on nearly 350 thousand acres of open ground in addition to greenhouse production, and the retail value of all nursery crops (figures not available for woody plants alone) totaled almost $3.4 billion dollars (USDA Economic Research Service 1999b). The United States is both the world's largest producer and consumer market for greenhouse and nursery crops (USDA Economic Research Service 1999a). Floriculture and environmental horticulture (including nursery production) are also the fastest growing segments of U.S. agriculture and rank second in economic output behind beef and beef products and seventh in grower cash receipts. Nursery and greenhouse production is concentrated in the West and South, primarily owing to favorable climatic conditions, but is also important in the Northeast and Midwest. The top 10 producing states—California, Florida, Texas, North Carolina, Ohio, Oregon, Michigan, Pennsylvania, New York, and Oklahoma—collectively account for more than two-thirds of output. In 1999, 35.4 million Christmas trees were sold in the retail market at a value of $1.1 billion dollars (National Christmas Tree Association, personal communication). Over 98 percent come from plantations rather than natural forests (National Christmas Tree Association 2000b). Christmas trees are grown in all 50 States on a total of about one million acres, but the top producing states are Oregon, Michigan, Wisconsin, Pennsylvania, California, and North Carolina (National Christmas Tree Association 2000a). The top-selling species of Christmas trees are balsam fir [*Abies balsamea* (L.) Mill.], Douglas-fir, Fraser fir [*Abies fraseri* (Pursh) Poir.], noble fir (*Abies procera* Rehd.), Scotch pine (*Pinus sylvestris* L.), Virginia pine (*Pinus virginiana* Mill.), and eastern white pine (*Pinus strobus* L.) (National Christmas Tree Association 2000a). Additionally, over 3.4 million acres in the United States are planted for tree fruit and nut production with a value in 1997 of over $10 billion (USDA National Agricultural Statistics Service, n.d.). Production is greatest for oranges, grapes, apples, almonds, grapefruit, walnuts, and peaches. In addition to tree hosts, some potential pest organisms (for example, rust fungi) that may be transported with SWPM use nonwoody (i.e., herbaceous) plant species as alternate hosts. Some of the potential nonwoody hosts include commercially grown agricultural crops such as sugar cane, avocado, sweet potato, corn, and grains.

Serious adverse impacts on the economic and ecological value of U.S. forests and trees (including urban, ornamental, fruit, and nut) could result from the introduction of destructive tree pests with SWPM. Because SWPM may be transported throughout the United States or its protectorates, the assessment team considers the forest and tree resources throughout the United States and its protectorates to be at risk for pest introduction. Although this risk assessment generally uses specific examples from limited regions when discussing impacts associated with introduced pests, we recognize that forests and trees throughout the United States and its protectorates are potentially at risk and that, in addition to economic values that are easily quantifiable, intrinsic values (e.g., esthetic, recreational, ecological, social) are often even more important. The potential impact on trees with limited range or genetic variability, as well as impacts on trees in the urban environment, could also be significant.

Potential Environmental Impacts of Pests Transported With SWPM

Considering Ecological Values at Risk—The forests of the United States, which contain about 600 species of trees (native and introduced), are remarkable for their abundance and variety. Tree-dominated ecosystems and landscapes are obviously more than just trees. They contain and sustain tens of thousands of species of terrestrial and aquatic animals and lesser plants, the majority of which truly depend upon forests for their existence. For example, forests provide crucial habitat for probably at least half of both the 100,000 species of insects and the 18,000 species of vascular plants native to North America (Niemelä and Mattson 1996). It is better known, however, that forests sustain most of the important game species as well as many more nongame species such as the rich avifauna, including dozens of threatened and endangered species. Some highly prized forest game animals include deer, elk, moose, woodland caribou, bears, bighorn sheep, cougars, mountain goats, turkeys, and many species of grouse, rabbits, hares, quail, doves, squirrels, pigeons, and a variety of forest-dwelling waterfowl. Important forest-dwelling furbearers include such species as beavers, raccoon, bobcats, lynx, coyotes, foxes, mink, fishers, marten, and otters. Some of the best known forest-dwelling threatened and endangered species include Columbian white-tailed deer, timber wolves, grizzly bears, wolverines, tassel-eared squirrels, northern and Mexican spotted owls, peregrine falcon, and several accipiter hawks. Almost all important game fish, such as the many species of trout (e.g., rainbow, eastern brook, brown, Dolly Varden, and cutthroat), and many species of amphibians and invertebrates live in streams, rivers, and lakes whose health is intricately intertwined with that of their forested watersheds. For example, much of the spawning and rearing habitats for anadromous fish in the Pacific Northwest, the Atlantic Northeast, and many salmonids in the Great Lakes are located on public forests. The Pacific salmon fishery depends on the quality of the streams that run throughout American and Canadian forests. Besides providing stable stream and river banks and retaining soils and soil nutrients that would otherwise flush downstream and ultimately into the seas, riparian trees and shrubs provide the majority of the life-giving organic matter input (leaves) necessary for the stream invertebrates and microbes that are at the base of riparian food chains (Anderson and Sedell 1979). Forests also provide the streams and rivers with critically important coarse woody debris (i.e., downed trees) that create crucial biodiversity-generating structure and micro habitats (Naiman and Decamps 1997).

Though most humans live apart from forests in densely populated urban centers, trees and forests are no less important to humans than they are to the myriad forest-dwelling creatures. From a purely spiritual level, tree-covered yards, streets, parks, and forests have immense value and importance to the psychological well-being of people. Trees can provide those crucial environments and opportunities for fleeting escape and restorative meditation and have historically inspired reflection and artistic creation. Humans also depend upon trees and forests to fulfill vital biological needs, although this function is usually taken for granted. The generation of life-giving oxygen and the sequestration of carbon are important functions that result from the ecological processes of global nutrient and hydrological cycling and the global atomospheric gas–heat balance (Abramovitz 1997). In addition, all manner of tree and wood products are woven into our daily lives, our culture, and our human ecology. The people of the United States consume more wood products than most, about 2.4 m^3 per yr per capita, which is twice the average for the entire “developed” world (Brooks 1993). But forests also affect human ecology at the sociopolitical level. There is an undeniable correlation between the health and the abundance of a nation’s natural resources and its sociopolitical stability. Correlation does not imply simple cause and effect, but ecological stresses inevitably bring about social and political consequences, typically strife, leading to a reinforcing negative feedback loop (Brown 1995).

Impacts From Exotic Pest Establishment—Indigenous plant-eating insects and pathogens are a normal and essential feature of all forest ecosystems. At low-to-moderate population levels they play a positive role in cycling nutrients, energy transfers, pollination, and biodiversity generation. Even the periodic outbreaks of some indigenous insect species are normal phenomena that generally have positive, long-term impacts on forest health and succession (Mattson and Addy 1975). However, when outbreak cycles intensify or population numbers remain chronically high, insects and pathogens can become highly destructive forces capable of drastically changing the normative ecological order within ecosystems and across landscapes. This typically happens when one or more ecological constraints on insect and pathogen population growth and dispersal are removed or rendered inoperative, often under circumstances created by humans.

Perhaps the most damaging, the most persistent, and hence the most serious pest problems are those generated by nonindigenous or exotic organisms. The most successful ones typically operate with fewer and different constraints than do indigenous insects and pathogens (Holway et al. 1998, Adler 1999, Holway 1999). There are today more than 400 exotic insects and 24 exotic pathogens that have been purposely or accidently imported into North America and have become permanently established in its forests and woodlands (Niemelä and Mattson 1996, Mattson et al. 1994b, Liebhold et al. 1995). About 5 percent of the insects and half of the pathogens have become such serious pests that they threaten the health, productivity, stability, merchantability, and even the very existence of some trees and forests (Liebhold et al. 1995, Mattson 1998). The chestnut blight fungus [*Cryphonectria parasitica* (Murr.) Barr], Dutch elm disease fungus [*Ophiostoma ulmi* (Buisman) Nannf. sensu lato], white pine blister rust (caused by *Cronartium ribicola* J. C. Fisch.), gypsy moth [*Lymantria dispar* (L.)], balsam woolly adelgid [*Adelges piceae* (Ratzeburg)], hemlock woolly adelgid (*Adelges tsugae* Annand), beech bark scale (*Cryptococcus fagisuga* Lindinger), larch casebearer [*Coleophora laricella* (Hubner)], larch sawfly [*Pristiphora erichsonii* (Hartig)], European pine shoot moth [*Rhyacionia buoliana* (Schiffermüller)], European spruce aphid [*Elatobium abietinum* (Walker)], and most recently, the Asian longhorned beetle [*Anoplophora glabripennis* (Motschulsky)] are but a few of the introduced pathogens and insects that have caused economic and ecological disruption in urban and rural forests of the United States (Drooz 1985, Furniss and Carolin 1977, Liebhold et al. 1995, Mattson 1998). The remaining 95 percent of the forest insect exotics in North America also have ecological and economic impacts, but the nature and magnitude of such impacts have not been assessed. Many of these less notorious exotics could be having impacts as great or greater, though less dramatic, than those of the better known immigrants. For example, there are about two dozen species of introduced weevils in North America that feed underground as larvae primarily on fine roots of trees and shrubs. Their impact on the root systems of nursery stock plants is well known and has forced nursery operators to adopt the routine use of pesticides to protect their investments (Drooz 1985). The weevils are also commonly abundant in some forest soils—as many as 1,000 per m^2 (Mattson, unpublished). But, with no other data, it is only possible to wonder about their important ecological impacts. Have they displaced any of the native soil-dwelling fauna? Have they changed the growth rates of the trees and lesser vegetation impacted by their underground herbivory? Have they diminished the carbon sequestration capacity of our North American forests (i.e., their capacity to buffer the increases in atomospheric CO_2)? Have they altered the relative competitive abilities of native forest flora? Many of the same serious questions are being raised about the impacts of exotic earthworms in northern Minnesota forests (Alban and Berry 1994; Frelich, personal communication). Just because there is little knowledge of, or data about, an exotic, it is erroneous to assume that its establishment and its continued presence are without ecological risk and cost, and the long-term consequences are sometimes so far-reaching and nonintuitive. For example, no one could have predicted 100 years ago when the causal agent of Asian white pine blister rust was introduced into North America that its presence would eventually threaten the food resources of grizzly bears in selected areas of the Western United States (Mattson et al. 1991a, 1992).

The potential ecological and economic risks associated with introduced species remain high and continue to grow in spite of our best efforts to limit and arrest invasions. One reason is that owing to the "globalization" of world economies, the movement of products and people around the world has been rapidly escalating, seriously outpacing our collective capacities to detect and prevent unwanted pest entries (Haack and Cavey 1997). Secondly, every exotic phytophagous species in a new environment has the potential (though, some much more than others) to become ecologically disruptive because introduced species usually have diminished or ineffective natural controls in their new environment, including the antiherbivore defense systems of their new hosts. For example, the old natural enemies and competitors of introduced species are absent, and new natural enemies may adopt them as hosts or food rather slowly. Compounding the problem, new host trees in the adopted environment may not have effective natural defenses against the new pests in contrast to those pests with which they have coevolved for tens of thousands if not millions of years. To give an example, two factors contributed to the European pine shoot moth's becoming a greater pest in the United States than in its native Europe: (a) in contrast to its native habitat, the moth had no endoparasites in the United States, and (b) trees were less resistant to this moth in the United States (Miller 1967). Though not common knowledge, it is often the case that trees that have not coevolved with a given plant-feeding organism are highly susceptible to, and easily injured by, new pests. For example, Eurasian birches are more susceptible in North America to the native bronze birch borer, *Agrilus anxius* Gory, than are native birches (Miller et al. 1991; Herms, personal communication). Likewise, Eurasian spruces are more susceptible to the native shoot-boring weevil, *Pissodes strobi* (Peck), in North America than are native spruces, especially the white spruce, *Picea glauca* (Moench) Voss (Mattson, personal observation; G. Kiss, personal communication). And, North American white spruces are more susceptible to the European gall-forming adelgid, *Adelges abietis* (L.) than is the Norway spruce, *Picea abies* (L.) Karst. (Mattson et al. 1994a; Mattson, unpublished). Furthermore, in many cases involving exotic sucking insects such as aphids, scales, and bugs feeding on phloem, xylem, and cell sap, the host plant defense systems may react inappropriately, leading to plugged vascular tissues, rapid tissue death, and abscission of plant parts (Ciesla 1998; Mattson, personal observation).

Once an exotic species becomes established, controlling its populations is never simple or cheap. There are never any quick fixes. Attempts to control the European pine shoot moth by introducing its parasites from Europe failed, perhaps because the introduced parasites did not have suitable alternate hosts in the United States (Miller 1967). Similarly, it has been difficult to establish European parasites for the gypsy moth in North America. Of 40 or so natural enemies introduced, only 10 became established, and only 1 of these has provided a measure of control (Pimentel 1986). This is not an indictment of attempts to control exotic pests by introducing their natural enemies, though this approach can become a double-edged sword through its unwanted effects on other native organisms (Malakoff 1999, Louda et al. 1997). For the most part, such a method is a potentially worthwhile control measure (compared with pesticides) that has yielded many successes (Ryan 1987, Ryan et al. 1987, Quednau 1990). However, successes usually come very slowly because they require careful study, selection, and release of the "best" biological control agents—a process usually requiring 10 or more years (Elton 1958, Pimentel 1986). Even then, the chances of success can be frustratingly unpredictable. For example, *Entomophaga maimaiga*, a fungal parasite of the gypsy moth, was released in the United States in 1910 and 1911 and apparently failed to become established. However, 79 years later, in 1989, the fungus suddenly reappeared, killing large numbers of gypsy moths. Three years later, by 1992, this virulent pathogen had apparently spread to cover the gypsy moth's entire distribution in Eastern North America. No one yet knows why (Hajek et al. 1995, Hajek 1998).

Vulnerability of North American Forests—North American forests are highly vulnerable to invasion by exotic species. As testimony to this statement, we already have more than 400 exotic insects permanently established (Mattson et al. 1994b, Niemelä and Mattson 1996), whereas all of Europe probably has no more than about 50 exotic insects in its forests, half coming from North America (Mattson and Niemela, unpublished). The extensive forests in nearly every region of the United States and the large number of tree genera (159) also common to Eurasia and elsewhere will provide ideal colonization opportunities for many immigrant forest insects. Moreover, once having found appropriate host materials, the immigrants will likely be able to wedge themselves into the existing community of insects because, as a rule, North American insect communities are not so tightly packed as, for example, those in Europe (Niemelä and Spence 1994, Niemelä and Mattson 1996, Louda et al. 1997); however, the assembly rules for communities and ecosystems are really not well understood (Tilman 1999). Because all immigrants must also adjust to the new photoperiodic regimes of their adopted environment, the United States will be most suitable for invasion by insects coming from regions with equivalent photoperiodic regimes (i.e., midlatitudinal regions of the world). But in addition, Niemelä and Mattson (1996) reasoned that the United States is highly susceptible to invasion by insects from high latitudes because long-day, high-latitude (Northern and Southern hemispheres) insects can very likely adjust to a shorter day environment, but the reverse may not be so. In fact, about 75 percent of exotic forest insects in North America have been derived from the higher latitudes of Europe and Asia.

The history of biological invasions clearly shows that exotic species establish themselves most readily in ecosystems that have previously been altered or stressed (Elton 1958, Orians 1986, Tilman 1999). Forest fragmentation, simplification, single-species plantations, improper forest management, elevated tropospheric ozone, CO_2, UV–B, acid rain, nitrogen pollution, and global climate change are among the many anthropogenic influences that may further facilitate the establishment of exotic species in North American urban and rural forests (Jefferies and Maron 1997, Rozema et al. 1997, Dukes and Mooney 1999, Harrington et al. 1999, Parmesan et al. 1999).

Forest fragmentation and simplification are important because both often result in fewer birds and other vertebrate (small mammals) and invertebrate (insects, mites, spiders, nematodes, etc.) natural enemies that might provide some degree of control for a new immigrant. The same is true for large, single-species forest plantations, which in addition provide a wealth of host material for pest propagation if that tree species is within the natural host range of the immigrant. Modified habitats have increased the risk associated with introduced pests because the uniformity of managed forest landscapes can facilitate the spread of pests (Perry 1988). The habitat for many natural enemies has been reduced by forest fragmentation and structural simplification such as the removal of key structural elements like snags, coarse woody debris, and multistructured canopies (Wilcove 1985, Torgersen et al. 1990). Declining numbers of songbirds, important consumers of forest insects, have been well documented in parts of the United States, Canada, and the world (Wilcove 1985, James et al. 1996, Vitousek et al. 1997). Holling (1988) concluded that, although the presence of fewer insect-eating birds alone is unlikely to trigger insect outbreaks, one important line of defense has clearly been weakened, and forests have consequently become more vulnerable to pests.

Air pollution (e.g., ozone, sulphur and nitrogen deposition, etc.) along with possible effects of global climate change (elevated temperature, moisture stress, and CO_2) may significantly alter the competitive abilities of various species of plants and their capacity to produce defensive responses and chemicals against pest organisms (James et al. 1980, Hain 1987, Dukes and Mooney 1999). The consequences are difficult to generalize because the defenses are so varied and respond differently to different stresses and growing conditions. The concern is that pollution and greenhouse gases may change community and ecosystem structure and debilitate important lines of natural defenses, thereby increasing the invasion potential of exotic pests. Although we have no substantive knowledge about the impact of air quality, this factor does introduce an additional level of worrisome uncertainty in attempting to predict the environmental impacts of new exotics.

In summary, although the issue is exceedingly complex and yet unresolved, evidence indicates that trees and forests may be more vulnerable to both native and introduced pests in a changing climate. Note especially that trees stressed by one agent can often become more vulnerable to others. For example, balsam fir [*Abies balsamea* (L.) Mill.] attacked by the introduced insect, the balsam woolly adelgid, became more susceptible to the root pathogen *Armillaria mellea* (Vahl:Fr.) P. Kumm. (Hudak and Singh 1970). Likewise, native beech trees attacked by the introduced beech bark scale became highly susceptible to *Nectria* fungi. It is possible that changing climate, increased incidence of established pests, and the introduction of new pests could act synergistically to intensify the overall effect (Mattson 1998).

Factors Affecting Potential Ecological Impacts—The potential ecological impacts of pest introductions are difficult to assess because of the complexity of forest ecosystems and the mostly unknown potential and undefined plasticity of the potential pest in a new environment. For example, although Mattson et al. (1994b) concluded that most exotic insects adopted host plants in North America that were close to their ancestral hosts, there is the possibility that these insects may attack new and very different hosts. It is likely, though, that most such new hosts will be in the same family, or if not, at least in the same order as their ancestral ones. However, as the number of potential plant hosts increases, so does the potential ecological impact of the exotic organism, which very likely will intensify exponentially with host number. Thus, doubts about the potential host range of the exotic organism in the new environment increase the difficulty and uncertainty of realistic assessment of its potential impact.

Despite these uncertainties and caveats, there are some general guidelines that can be employed for predicting immigrant establishment and potential general impact. One strategy is to consider the key traits of the immigrant organism and those of its preferred host plants. It is important to be able to predict an organism's capacity to establish itself, disperse, increase in population size, and inflict serious host damage (diminished growth, reproduction, and death). There are several levels or scales at which to consider ecological impacts: first, the level of the individual plant and how it responds physiologically; second, the level of the plant population and how it fares ecologically when attacked by an exotic; and third, how the effects cascade through the community, ecosystem, and landscape and what may be significantly changed as the result of the exotic's impact on the tree species in question.

Parthenogenesis and Polyploidy: Effects on Survival, Growth, and Adaptability of Introduced Pests—Obviously, not all exotics are equal in their likelihood of successful establishment, rates of spread, and population growth. Besides the breadth of an invader's host plant preferences, Niemelä and Mattson (1996) argued that two other traits may also be valuable for predicting high establishment success and hence possibly also high spread and eventual ecological impact: (1) parthenogenesis, and (2) polyploidy. Parthenogenesis, for example, permits reproduction and thus survival in the absence of males, as might be crucial during multiple founder events or during drastic reductions in the founder colonies caused perhaps by stochastic events such as severe weather or even human-delivered pesticides or biocides. Parthenogenesis also permits a greater rate of population growth because every individual may be a reproductive unit. Asexual reproduction leads to multiple clonal lines that permit rapid exploitation of suitable resources but perhaps at the cost of limited genetic variability in populations owing to the absence of recombination. This could result in limited evolutionary potential but is probably not a serious handicap in the short run. Polyploidy, on the other hand, confers upon a species the capacity for greater ecological amplitudes than its diploid or haploid equivalents and hence can lead to higher survival, reproductive, and dispersal potential across a wider range of environments (Niemelä and Mattson 1996). In fact, many immigrant insects may be both parthenogenetic and polyploid. Coleopterans, homopterans, hymenopterans, and thysanopterans may be the groups most likely to have these traits.

Feeding Guild: Effects on Plant Capacity to Recover Physiologically From Feeding and Oviposition Damage—Certain kinds of pest feeding and oviposition injuries (tissue intrusions, removal) are clearly more damaging than other kinds because not all plant injuries are repaired or compensated for physiologically to the same degree. Mattson et al. (1988) ranked 13 insect feeding guilds (or habits) according to their physiological impact on the host, that is, the plant's likely ability to recover rapidly from, or compensate for, insect injuries. At the top of the list (i.e., high plant recovery capacity and low insect impact) were gall-formers on leaves and twigs followed by end-of-growing season and then early-season defoliators. At the very bottom (very low recovery capacity and very high impact) were borers in the inner bark (phloem, cambium) and sapwood of the roots, root crowns, and main stems.

In the case of exotics, the consequences of introduction are likely to be severe for those organisms that invade living vascular tissues, such as phloem and sapwood, because these exotics may induce hypersensitive reactions in the plant, leading to plugging of the tissues and death. In addition to wood-invading beetles and fungi, nematodes, true aphids, and adelgids can also trigger such severe defense reactions by plants. Moreover, any herbivore that transmits plant fungi, bacteria, mycoplasma, and viruses should receive a high risk rating for the same reason.

Lacking in the preceding list is the herbivore guild that directly attacks reproductive parts. This guild is obviously very important in permitting successful reproduction and thus continued existence of the host over ecological time and would be a high-impact, high-risk feeding guild.

Host Plant Feeding Range: Effects on the Proportion of the Landscape Susceptible to Attack—Ecological disruption from an exotic pest can increase exponentially as the proportion of plants susceptible in a landscape increases. This can result from a pest with very broad host plant preferences (e.g., gypsy moth), or it can also result from a pest with narrow host preferences when the host trees have vast, nearly pure populations, as is typical for many species of early successional trees (e.g., aspen, paper birch, various pines) and even some very late successional trees (e.g., sugar maple, beech, eastern and western hemlocks, balsam and alpine firs, etc.) (Mattson et al. 1991b). Obviously, the more potential host plants there are in the new environment, the faster an insect or pathogen will spread and increase in number, thus intensifying its potential for ecological impacts.

Role of the Susceptible Plant Species in the Ecosystem: Effects at the Ecosystem and Landscape Levels—Besides the mere abundance and numerical dominance of an exotic pest's host plants, there is another suite of factors to be considered: the host plants' ecological roles. These ecological contributions, especially the unique ones for which there may be little or no redundancy in the system, ought to be evaluated carefully. Several species of riparian deciduous hardwoods shade streams, stabilize channels, and provide the life-giving organic matter to aquatic food webs (Cummins 1980). Nitrogen-fixing plants, such as the various species of alders and ceanothus, are critical to long-term soil fertility. A plant species need not be very abundant or dominant numerically but may still play a vital ecological role. Whitebark pine (*Pinus albicaulis* Engelm.), long under siege from white pine blister rust, has a limited distribution but provides important, if not irreplaceable, overwinter food reserves for bears and birds where this tree does occur (Mattson et al. 1991a). Unfortunately, knowledge of most ecological systems is still so incomplete that it would be difficult to go beyond quartile rankings of species of plants based on their ecological contributions. The cautious approach argues that every species has intrinsic value and provides significant ecological services, although roles will vary with environmental context. For example, whitebark pines located within the range of grizzly bears may provide higher ecological value than those growing elsewhere because of the importance of the pine seed as an overwintering food source for this endangered species.

Describing Ecological Impacts of Exotic Infestations—Measuring the ecological impact of exotic phytophagous pests on forests is not a trivial task. Ideally, measurements should be made both before and after exotic infestations to address such important, fundamental factors as the following:

- The amount of energy captured and stored by the various plant strata of the forest;
- The allocation of that captured energy to all important plant processes (growth, reproduction, defense, storage, respiration);
- The amount, rates, and fate of critical nutrients cycled and stored by the vegetation and soil-litter system and that entering and lost from the ecosystem;
- The detailed complexity of energy and nutrient fluxes through the entire food webs and a description of their attendant biodiversity in every trophic category, and;
- Response curves of the key ecosystem processes to common stressors such as prolonged and repeated moisture deficits, air pollution episodes, nitrogen deposition, and human management regimes.

Complexity of ecological systems handicaps efforts to predict potential ecological impacts of exotic pests accurately. Additions of new plant-feeding organisms to ecosystems do not constitute a simple linear augmentation of existing phytophagous organism effects (Mattson 1998). In the absence of detailed and comprehensive data on impacts of exotic pests on ecological processes, inferences can be made from case histories of past introductions about impacts in general.

*Biodiversity Erosion and Alteration***—**

<u>Range-Wide Virtual Extinction of Attacked Plant Species</u>—Among the legendary ecological losses from exotic pests has been the virtual extinction of American chestnut, once an abundant, fast-growing, dominant tree, from the Eastern United States' deciduous forest (Hepting 1974). Not only was a photosynthesizing tree lost but one that was a structurally and chemically unique species providing unique ecological services and products. Tree species are not simple carbon copies of one another. Each has its own ecological niche, resilience in the face of stresses, and ecological contributions. One such obvious product was chestnuts, upon which many animals depended. Among these were humans, bears, deer, turkeys, grouse, and many species of squirrels and woodland mice. Several other plant species now stand in the American chestnut's place but may not provide similar ecological functions and roles. Most American elms (*Ulmus americana* L.) have been lost from urban, rural, and eastern mixed, deciduous forests (Mattson 1998). The presence of American elms as urban forest ornamentals has continued to decline with the spread of the pathogens that cause Dutch elm disease. As other tree species fill in where elms once grew, the forest appears to recover, but the important roles and characteristics of the departed elms may be forever lost. One can only wonder how far up and down the ecological scales these alterations have been transmitted. North American butternut (*Juglans cinerea* L.), like American elm, is currently being eliminated in vast numbers from its entire natural range because of an apparently introduced pathogen (unknown 30 years ago) that causes butternut canker, *Sirococcus clavigignenti-juglandacearum* N. B. Nair, Kostichka & Kuntz. Three exotic pests have caused three native trees to be reduced to insignificant, residual components in the ecology of eastern urban and rural forests. This is an enormous loss of biodiversity, the consequences of which are a story largely untold.

<u>Limited and Localized Extinctions of Attacked Plant Species</u>—Short of near extinctions of species, depredations of

exotics may alter typical plant abundance and distribution patterns. Probably the most common case is that of attacked plants' being gradually eliminated from certain localized areas that are highly favorable for the exotic's capacity for infestation. For example, eastern white pine (*Pinus strobus* L.) is generally highly susceptible to Asian white pine blister rust but is most heavily infested and impacted in those special bioclimatic regions having high humidity during key late summer periods when the infective stages of the pathogen are dispersing (Van Arsdel et al. 1956, Manion 1981). This means that formerly highly suitable areas for white pine around the shores of the Great Lakes and other localized bioclimatic zones in the Northern Great Lakes States and Canada are now highly prone to disease, and thus white pines in these regions are gradually and inexorably being eliminated by disease and competition as well as prudently rejected by foresters for use in reforestation in such regions. If white pine blister rust were not enough of an added burden to white pine, it acquired another imported pest, the introduced pine sawfly [*Diprion similis* (Hartig)], which can frequently be observed in those same areas where white pine is most infested by blister rust. When multiple exotic phytophages attack a plant (on top of its normal load of indigenous phytophages), the species can be pushed into a chronic decline spiral from which recovery may be impossible (Mattson 1998). For example, if there are fewer and fewer trees producing fewer and fewer cones, then there is little likelihood that there will ever be large enough crops of cones and seeds to escape predators through "masting" (i.e., crops so large that usual insect, bird, and mammalian predators cannot eat them all, and thus enough propagules escape to begin new generations of trees). As tree numbers decline even further, they eventually reach the extinction threshold (different for each tree species) at which there no longer is any possibility for recovery.

Diminished General Abundance of Attacked Plant Species—Infestations by exotics on their preferred hosts may eventually cover the entire host geographic range and thereby significantly alter the usual competitive balance among plants by lowering the competitive abilities of attacked trees. Sometimes suddenly, but usually gradually, attacked species are hobbled into positions of lesser and lesser abundance within the environments in which they are capable of growing. However, the natural ecological range of the plant may remain virtually unchanged. Abundance of the beech tree (*Fagus grandifolia* Ehrh.) has been, and continues to be, diminished by infestations of beech bark scale and *Nectria* spp. fungi (Runkle 2000). As the scale invades beech forests, it renders the bark of most beeches suitable for colonization by *Nectria* fungi, which then trigger an initial explosion of beech mortality (Houston 1998). This early wave of mortality releases competing tree species. Moreover, the long-term continuing interaction of beeches with the scale and the fungi further erodes the vigor and competitive ability of beeches as an evolutionary struggle plays itself out: the more resistant beech genotypes are being sorted out, and they slowly begin enlarging their numbers (Houston 1998). The changes are not just limited to the tree stratum. Just as for chestnut and the chestnut blight fungus, the beech bark scale and the *Nectria* fungi lower the capacity of beech to mast, and thus affect the entire community of nut-consuming insects, birds, and mammals. As a consequence, there are major changes cascading through the community and ecosystem.

Diminished General Abundance of Competing and Phenologically Later Phytophagous Species—As exotic phytophages establish themselves in an ecosystem, they may out compete and hence push native phytophages into declining abundance. This may happen through direct scramble competition, in which one competitively superior species displaces contemporaneous native species (Holway 1999). Another possibility is that exotics trigger alterations in plant tissue abundance and biochemistry that adversely influence native species. Sometimes, plant-feeding exotics are slightly earlier phenologically than their North American equivalents, thus giving them a competitive edge (Niemelä and Mattson 1996). Just one example may illustrate the point. The recently introduced Eurasian bark beetle, *Tomicus piniperda* L., is known to fly weeks ahead of the native North American beetles with which it competes for stressed and dying trees for breeding. This first-at-the-table advantage may allow this beetle to succeed at the expense of native species (Haack 1996).

Diminished Forest Productivity; Diminished Carbon Sequestration—Added herbivory derived from exotics is unlikely to increase forest net primary production, but there is little hard data on the extent to which it may diminish the mean primary production capacity of trees and forests. Reduction of primary productivity in infested stands lowers carbon sequestration capacity. Undoubtedly, more frequent pest outbreaks lower forest productivity. Haack and Mattson (1993) concluded that outbreaks of exotic sawfly species are more frequent than those of equivalent

North American native sawflies.

There is a general rule that defoliation by herbivores that does not exceed approximately 30 percent is compensated for by the plant in its remaining leaves in such a way that there is no net loss in net primary production (Kulman 1971). Thus, one may ask if the addition of exotics to a plant's herbivore load pushes total herbivory beyond the 30 percent defoliation tolerance threshold, more often than usual. If this is true, then exotics are diminishing tree and forest productivity based on the assumption that co-occurring unattacked plant species are not perfectly linearly increasing their productivity in response to that lost by the attacked plants. Compensatory growth by competing plants is less likely to happen in monocultures than in polycultures, and even in polycultures there is unlikely to be perfect compensation during episodes of elevated herbivory (Mattson et al. 1991b). The net result, then, is a high probability for diminished forest production capacity owing to exotic defoliators. The gypsy moth in North America has elevated the mean or "background" level of herbivory in susceptible forests since its introduction in 1868 and in doing so has precipitated reductions in tree growth and elevated tree mortality (Cambell and Valentine 1972; Herrick and Ganser 1987, 1988; Quimby 1987; Witter and Stoyenoff 1992). Owing to the gypsy moth's very polyphagous feeding habits, few plants are left unscathed during peak defoliation episodes (Witter and Stoyenoff 1992), and hence there is virtually no compensatory capacity remaining during outbreaks that last in individual stands for about 2 years (Elkinton and Liebhold 1990). After a bout of severe defoliation, trees take about 3 years to recover (Witter and Stoyenoff 1992). As trees die from heightened defoliation or other exotic-induced injuries, how quickly do the surviving plants recoup the lost space and abiotic flux and thus recover the lost net primary production? Three to five years is likely based on ecosystem recovery rates following disturbances (Fahey and Hughes 1992).

Altered Nutrient Cycling and Hydrology: Increased Nutrient Export From Impacted Ecosystems—If the invasions of exotic species lead to heightened levels of defoliation, root mortality, plant mortality, and diminished reproduction, there are bound to be changes in nutrient cycling and retention by affected ecosystems (Mattson and Addy 1975). Defoliation, for example, can change the chemical distribution by substantially increasing the amount of dissolved organic carbon and other compounds (e.g., dissolved organic nitrogen) leaching from injured foliage (Kimmins 1972). Defoliation thereby influences the whole community of epiphytic microogranisms (Stadler and Muller 1996). Furthermore, it substantially increases greenfall (green leaf fragments) input to the soil-litter system and also the amount of insect frass and bodies (Lovett and Reusink 1995). Much of the pest-driven, heightened input of organic matter with high levels of nutrients, however, may be taken up by soil microbial biomass (Lerdau 1996). Typically increased nitrous oxide, nitrate, phosphorus, and trace metal loadings are observed in the watersheds following clearcuts and high defoliation episodes (Bowden and Bormann 1986, Swank et al. 1981, Webb et al. 1995, Eshleman et al. 1998, Jenkins et al. 1999).

Usually, there are also increased water yields owing to reduced transpiration by the vegetation (Corbett 1987, Cheng 1989). With regard to aquatic habitat, the combination of more water moving through the soil and reduced root strength will increase the probability of surface erosion and mass soil movements, which will in turn pulse more sediment to streams (Swanson et al. 1989). This can impact both the aquatic invertebrates and vertebrates. Salmonid species are particularly sensitive to sediments, which reduce aeration within spawning gravels. One study found that the 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 substantially altered if trees were heavily defoliated and eventually 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), whereas rainfall in downwind areas could decrease because less water would be cycled back to the atmosphere (Andre et al. 1989, Newson and Calder 1989). Without the modulating effects of up slope forests, stream flows would probably become more variable with greater peak flows in the spring and lower summer water levels.

System Recovery—System recovery from exotic pest attack will depend heavily upon a favorable confluence of biotic and abiotic factors. Although the reality of global climate change is nearly certain, it is instructive to consider its implications relative to potential pest introductions. Successful seedling establishment is very likely to become even more difficult if the trees occupying a given site become increasingly maladapted to their local climate. Drought already hampers reforestation throughout many parts of North America—especially the interior West and from southern Oregon into California. Increasing dryness would only exacerbate that problem, making it more pervasive. Heavy fuel loads would make young stands particularly vulnerable to wildfire (Franklin et al. 1989, Gottschalk 1990), and a warmer, drier climate would greatly exacerbate fire danger. A combination of unusual stresses could push forested landscapes into becoming grasslands, savannah, 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, as has happened over and over again in the development of civilization in all parts of the world (Perry et al. 1989). Depending on the nature and the extent of damage and losses, recovery may take millennia and longer (i.e., evolutionary time scales; Quammen 1998).

Summary—Exotic pests pose a substantial threat to the ecological integrity of urban and rural forests in North America because exotics are generally free of the usual biological constraints with which they have coevolved in their native habitat. Ecological risks associated with all pests are higher now than in the past because of pervasive, multiple stresses associated with disturbed habitats, reduced populations of indigenous natural enemies, increased anthropogenic stressing agents (e.g., elevated ozone, CO_2, sulphur and nitrogen deposition, altered climates, etc.), and growing numbers and populations of previously established exotics. The ecological effects of a new and different pest depend on its rate of spread, its host range, the degree to which its hosts play keystone roles, the existing load of indigenous and exotic phytophagous organisms already in place, and the rate at which attacked ecosystems can recover, if at all. In the most severe cases, extensive tree mortality might benefit some animals but threaten others, lower water quality, alter regional hydrology, increase the probability of wildfire, and reduce the carbon storage capacity of North American forests. The combined effects of environmental stress, greater abundance and outbreaks of native and exotic pests already present, and the introduction of new pests might create an irreversible death–decline scenario for many tree species whereby the ecology of many North American urban and rural forests would be rapidly altered and degraded. As history has repeatedly shown, the loss of important native tree species from our forests due to exotic pests has not generally prevented other, different forests from eventually replacing the assaulted ones. This, we can take comfort in. However, whether this replacement process should be properly considered and labeled “recovery” is open to serious debate. We know so little about the nature and magnitude of the myriad ecological processes that are altered by exotic-imposed losses that it is therefore exceedingly difficult to measure and assess recovery to former, preexotic conditions. We need to be ever mindful of the empty forest syndrome: Although the shell of a forest is obviously there, what about all of the rest of the important but not so apparent components (Redford 1992)?

Potential Economic Impacts of Pests Transported With SWPM

Activity by forest pest species can result in a variety of economic losses due to damage to trees, forests, or wooden structures. Depending upon the pest species and the hosts attacked, economic losses may be reflected in

- tree mortality and timber volume loss;
- wood defect and degrade;
- tree growth loss;
- reduction in production of products such as maple syrup, fruits, nuts, or seed;
- reduction in property values;
- damage to property due to tree failures;
- losses in recreation visitor days and tourism;
- increased human health problems (e.g., allergic reactions to pests, injuries from tree failures);
- increased energy costs (e.g., resulting from loss of shade);

- increased costs for mitigating pest damage or restoring habitat;
- and several other indirect effects.

Pimentel et al. (2000) estimated that established nonindigenous insects and pathogens cause about $4 billion in monetary loss of forest products each year in the United States. Additionally, the USDA Forest Service alone spends about $11 million (. $12 million in 1998 dollars) annually to control European gypsy moth (Campbell and Schlarbaum 1994), and total annual costs since 1980 may have exceeded $35 million (Wallner 1996a). Eradication of the Asian gypsy moth over 4 years in Seattle, WA, Portland, OR, and Vancouver, BC, cost approximately $17 million, and the 3-year eradication effort in Wilmington, NC, cost about $6 million (W. Wallner 1999, personal communication). Removal of elm trees because of infection by the Dutch elm disease fungus costs owners in the United States about $100 million (. $107 million in 1998 dollars) each year (Campbell and Schlarbaum 1994). Eradication costs for Asian longhorned beetle infestations in the New York and Chicago areas between 1996 and March 2000 already total over $25 million, and the programs are continuing for the foreseeable future (M. Stefan, personal communication). Because the nursery and Christmas tree industries typically ship plants long distances from production sites, the introduction of exotic pests often results in imposition of new regulations for nursery stock and Christmas trees that can pose financial burdens on the affected industries.

Given biological and ecological uncertainties, the potential for economic damage can be difficult to quantify or predict—especially for those pest species that threaten but have not yet become established in a new environment. Even when substantial information is available regarding economic impacts of the species in its native environment, the magnitude of potential harm in a new environment can vary widely. Often, an introduced pest will cause more harm in a new environment owing to inadequacy of natural control factors (i.e., natural enemies may not be relocated along with the pest). Also, the species may adopt new host species and habits in its new environment that are unanticipated or unpredictable.

The effect of a newly introduced pest species is a function of the characteristics of the pest organism, characteristics of the host(s), the nature of the pest–host interaction, and interactions of the pest–host complex with the surrounding biological and physical environment. Even when potential damage can adequately be described, the complexities of natural ecosystems makes it difficult to quantify potential economic impacts adequately. Most of the following assessments of potential economic losses due to introduction of selected exotic pests that may be transported with SWPM concentrate on quantifying timber values associated with tree mortality. An example also was developed for tree mortality in urban settings using calculations of compensatory tree values. Potential impacts to plantation crops in Hawaii were estimated for one plant pathogen. One example of potential impacts to wooden structures was also estimated based upon control expenditures. This limited analysis does not negate the importance of other types of economic losses that are usually less readily quantifiable but is meant to give an indication of the magnitudes of impacts possible. The examples, therefore, likely underestimate potential cumulative economic impacts resulting from direct and indirect damage caused by exotic pest introductions.

Because the specific timing of pest introductions, their points of entry and establishment, the species involved, and other characteristics (such as whether multiple entries of single or multiple pest species will occur) are not predictable, assumptions that describe potential scenarios must be devised to develop quantitative projections of resource and monetary losses. These uncertainties as well as unknown interaction effects (e.g., competition) between multiple exotic species, make predictions of cumulative pest effects of multiple species introductions into any given location unrealistic. Therefore, scenarios for introduction into the United States were developed individually for seven forest pest species or groups. Potential impacts to U.S. resources were developed for these pests using available forest inventory information supplied by the USDA Forest Service and economic statistics. The organisms selected are intended to serve as examples of the damage potential of some types of exotic forest pests that may be introduced with SWPM (e.g., wood borers, bark beetles, defoliators, wood pathogens); analyses are not comprehensive or additive. The collaborators in this pest risk assessment consulted scientists with expertise in biological characteristics of the pest species to be analyzed to develop assumptions regarding likely spread rates, intensity of damage, primary hosts attacked, population buildup period (before damage becomes noticeable), and possible locations of independent introductions. Assumptions used in the economic impact analyses are summarized in table 4 and discussed in more detail in appendix E. The low and high extremes of potential spread rates and damage potentials defined the best-case and worst-case scenarios, respectively, for each pest. The use of these high and low expectations was an attempt to capture the range of possibility in the forecasts given the uncertainties about precise parameters. Economic loss values were developed based upon the value of commodities affected and the assumption that no eradication or control measures were implemented following detection of a new pest establishment (except for drywood termites). The seven representative species groups selected for quantitative economic loss analyses included the following:

Pest Species	Pest Type
Drywood termites (Kalotermitidae spp.)	Wood-boring termites
Pink disease pathogen [*Erythricium salmonicolor* (Berk. & Broome) Burdsall]	Tropical canker disease
Asian longhorned beetle [*Anoplophora glabripennis* (Motschulsky)]	Wood-boring beetle
A sirex woodwasp (*Sirex noctilio* F.)	Wood-boring siricid
Eurasian spruce bark beetle [*Ips typographus* (L.)]	Conifer bark beetle
Nun moth (*Lymantria monacha* L.)	Conifer and hardwood tree defoliator
Heterobasidion spp. root-rot pathogens (nonindigenous species or strains)	Temperate wood pathogens

Structural Damage Impacts—Drywood Termites—The risk assessment collaborators estimated potential economic impacts caused by introduction of an exotic species of drywood termite based upon costs to control existing populations of termites in wooden structures in the United States. Total yearly control costs were divided by the area encompassed by termite populations to derive a yearly cost estimate per square mile. The area of termite population spread from an introduction point in San Diego, CA, was determined for each year following introduction up to 30 years. Best- and worst-case scenarios were estimated by using the low and high extremes of the expected spread rate of 6–10 miles per year (10–16 km/yr), which assumes human-assisted spread. At 10 miles per year (16 km/yr), drywood termite populations would spread to a radius of 300 miles (483 km) in 30 years (fig. 15). The cost estimate for control per square mile each year was multiplied by the area encompassed by the expanding infestation and discounted by 7 percent per year (U.S. Office of Management and Budget 1996; see appendix E) to estimate potential damage impacts on a yearly and cumulative basis (table 5). Annual control costs are expected to exceed $1 million after 17 years given the worst-case scenario and after 24 years given the best-case scenario. At the faster rate of spread (worst case), drywood termites are expected to spread throughout their potential range within 30 years, and cumulative control costs would exceed $109 million. Cumulative control costs after 30 years under the best-case scenario would exceed $17 million.

Tropical Plantation Impacts—Pink Disease—Commercial plantations of eucalyptus and coffee grown in the Hawaiian islands are likely to be most affected economically by introduction of *Erythricium salmonicolor* (Berk. & Broome) Burdsall, which causes pink disease. The Hawaiian islands were divided into three groups for analysis: (1) Hawaii, including the Big Island, Molokai, and Maui; (2) Kauai, along with Niihau; and (3) Oahu. Any of the island groups could become infested without the pathogen necessarily spreading to the other island groups; however, the area within a given island group is expected to become infested quickly upon introduction of the pink disease pathogen. Yearly damage impact projections were based upon estimates of total acres of eucalyptus (C. Masaki 1999, personal communication) and coffee (Martin 1998) planted on the various islands (fig. 16).

For eucalyptus, timber volumes affected were then estimated based upon average growth rates per unit area per year. The pink disease pathogen is expected to spread throughout eucalyptus plantations within 7 years of introduction for the worst-case scenario and within 12 years for the best-case scenario. Once an island group is totally infested, rotation age (i.e., years to harvest) would increase because of reduced growth rates from an average of 7 years to 12 years for the best-case scenario or 14 years for the worst-case scenario. These figures are based on

Table 4. Summary of assumptions used to develop economic loss projections for some representative pest species that could be introduced to the United States with SWPM. Ranges are given to span likely best- and worse-case scenarios. Detailed discussion of the basis for the assumptions is presented in appendix E.

Pest species	Spread rates (Linear distance/yr)	Damage potential (% mortality or damage)	Buildup period	Primary hosts attacked	Introduction foci
Drywood termites Kalotermitidae	6–10 mi/yr (10–16 km/yr)	Structural damage	30–50 yr	All wooden structures	San Diego, CA
Pink disease fungus *Erythricium* (*Corticium*) *salmonicolor*	2 yr per HI island group	40–50% growth loss 25–40% fruit loss	3–5 yr	eucalyptus (*Eucalyptus*); coffee (*Coffea*); fruit trees	Hawaii
Asian longhorned beetle *Anoplophora glabripennis*	0.2–2 mi/yr (0.3–3 km/yr)	80–100%	3–4 yr	maple (*Acer*); poplar (*Populus*); buckeye (*Aesculus*); alder (*Alnus*); birch (*Betula*); ash (*Fraxinus*); mulberry (*Morus*); sycamore (*Platanus*); cherry and plum (*Prunus*); pear (*Pyrus*); willow (*Salix*); locust (*Robinia*); elm (*Ulmus*)	Chicago, IL New York, NY Atlanta, GA
A sirex woodwasp *Sirex noctilio*	5–15 mi/yr (8-24 km/yr)	10–20%	7–10 yr	pines (*Pinus*); esp. Monterey, loblolly, and slash	San Francisco, CA Minneapolis, MN Atlanta, GA
European spruce bark beetle *Ips typographus*	1–30 mi/yr (2–48 km/yr)	10–80%	7–10 yr	spruce (*Picea*)	Seattle, WA Minneapolis, MN Newark, NJ

Table 4 Continued. Summary of assumptions used to develop economic loss projections for some representative pest species that could be introduced to the United States with SWPM. Ranges are given to span likely best- and worse-case scenarios. Detailed discussion of the basis for the assumptions is presented in appendix E.

Pest species	**Spread rates** (Linear distance/yr)	**Damage potential** (% mortality or damage)	**Buildup period**	**Primary hosts attacked**	**Introduction foci**
Nun moth *Lymantria monacha*	3–15 mi/yr (5–25 km/yr)	50–100%	5(NE)–10(S) yr	spruce (*Picea*); larch (*Larix*); fir (*Abies*); oak (*Quercus*); elm (*Ulmus*); maple (*Acer*); birch (*Betula*); beech (*Fagus*)	Seattle, WA Minneapolis, MN New York, NY
Root rot *Heterobasidion* spp.	0.1–0.6 mi/yr (0.1–1 km/yr)	30–40%: conifers 10%: hardwoods	15–20 yr	pine (*Pinus*); Douglas-fir (*Pseudotsuga*); spruce (*Picea*); larch (*Larix*); juniper (*Juniperus*); birch (*Betula*); fir (*Abies*); hemlock (*Tsuga*)	Nashville, TN Charleston, SC Atlanta, GA Portland, OR

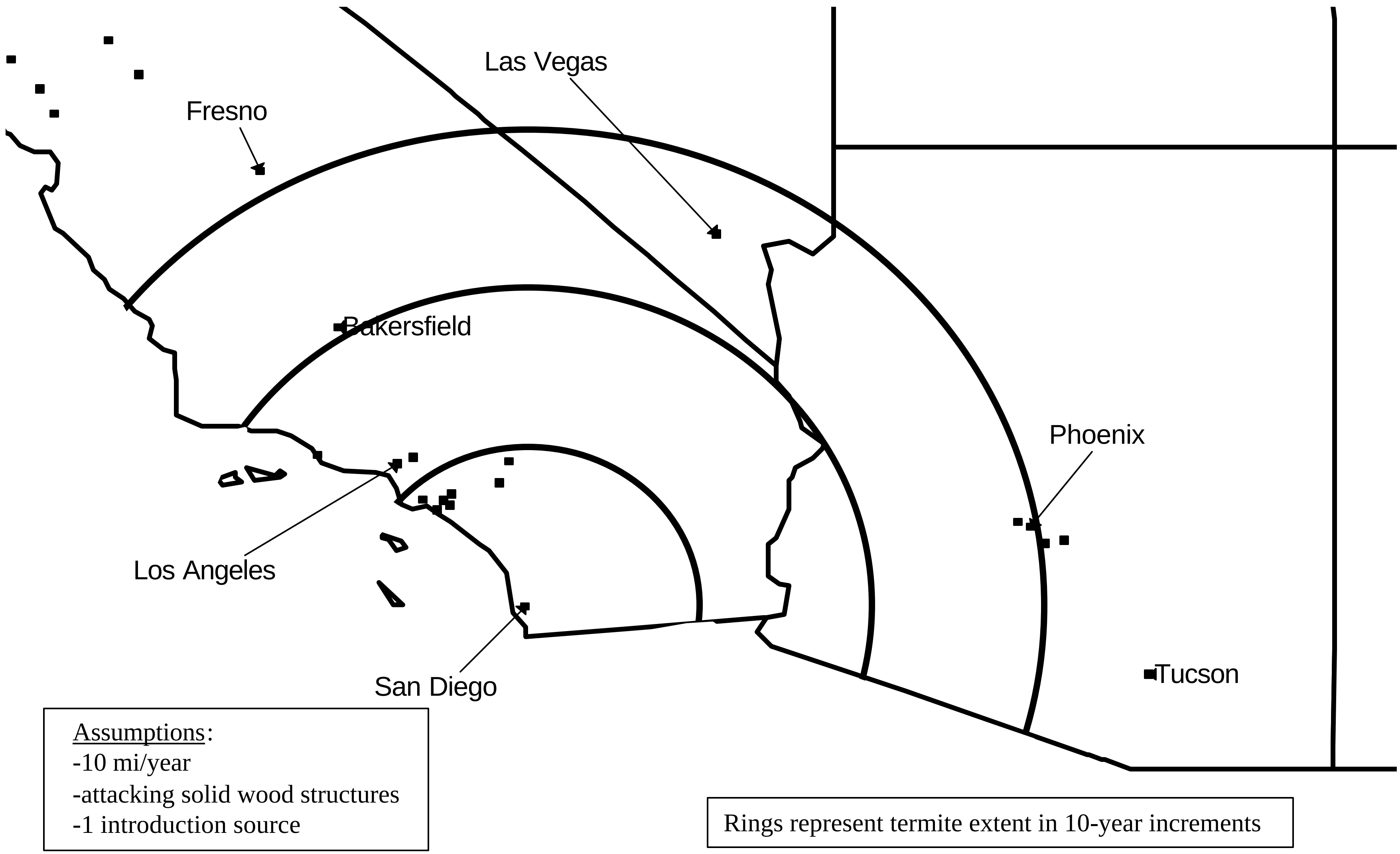


Figure 15. Expansion forecast over 30 years for introduction of exotic drywood termites into San Diego, CA.

Table 5. Projected yearly and cumulative monetary losses discounted 7 percent per year (in thousands of dollars) owing to costs to control a new drywood termite in wooden structures based on the assumption of introduction into San Diego, CA

Year	Worst-Case Scenario		Best-Case Scenario	
	Yearly	Cumulative	Yearly	Cumulative
1	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0
6	0.6	0.6	0.0	0.0
7	1.8	2.4	0.2	0.2
8	5.0	7.4	0.5	0.6
9	12.0	19.4	1.1	1.7
10	26.0	45.4	2.4	4.2
11	52.2	97.6	4.8	9.0
12	97.7	195.3	9.1	18.1
13	173.1	368.4	16.1	34.2
14	292.2	660.6	27.2	61.3
15	473.0	1,113.7	44.1	105.4
16	737.8	1,871.5	69.1	174.5
17	1,112.8	2,984.4	104.8	279.3
18	1,627.3	4,611.6	154.5	433.8
19	2,311.0	6,922.6	222.3	656.1
20	3,190.2	10,112.8	312.6	968.7
21	4,281.1	14,393.9	430.4	1,399.1
22	5,581.1	19,975.0	581.4	1,980.5
23	7,058.4	27,033.4	771.4	2,752.0
24	8,642.3	35,675.7	1,006.3	3,758.3
25	10,220.5	45,896.2	1,291.6	5,050.0
26	11,646.8	57,543.0	1,631.8	6,681.7
27	12,766.5	70,309.5	2,029.7	8,711.5
28	13,457.1	83,766.7	2,485.6	11,197.1
29	12,775.4	96,542.0	2,800.0	13,997.1
30	12,569.2	109,111.2	3,320.3	17,317.5

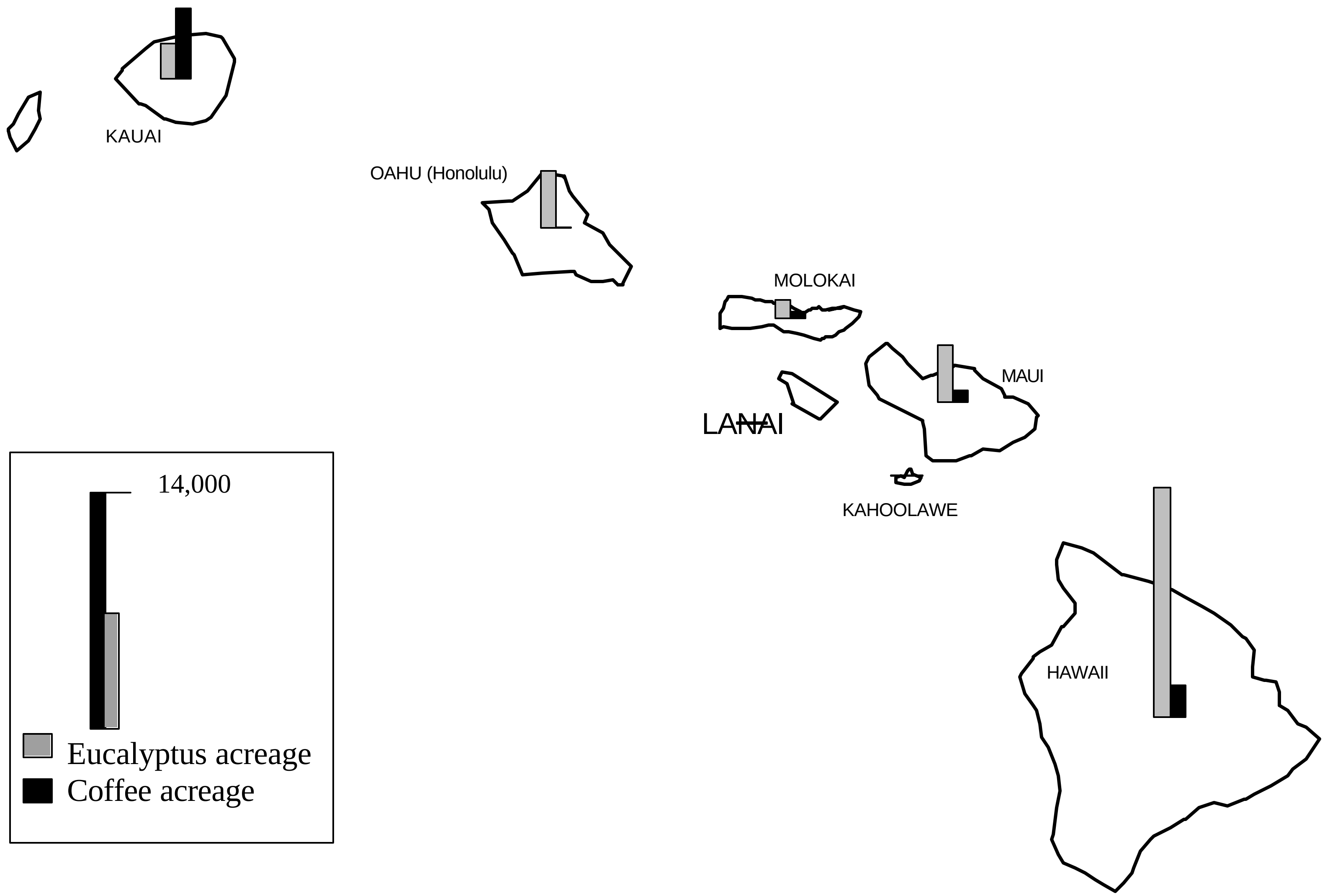


Figure 16. Acreages of eucalyptus and coffee plantations in the Hawaiian islands potentially at risk for introduction of the pathogen that causes pink disease, *Erythricium salmonicolor*.

a conservative estimate of growth rates for established species and a rotation age typical for pulp production. Production would gradually decline during the population buildup periods until maximum annual damage levels are reached, ranging from 372 thousand cubic feet of volume loss in the best case for Kauai to nearly 4 million cubic feet of volume loss in the worst-case scenario for Hawaii (table 6). Cumulative discounted monetary losses due to growth reduction caused by pink disease are estimated to range from about $3 million to $25 million after 12 years for the best-case scenario and from about $4 million to $39 million after 7 years for the worst-case scenario, depending upon island group and growth reduction rates (table 7).

For coffee, pink disease is expected to spread throughout the island groups within 7 years of pathogen introduction for the worst-case scenario and within 13 years for the best-case scenario (table 8). Average prices per acre were calculated by dividing total value of coffee harvest by total acres harvested in the 1996–97 growing season for Hawaii and Kauai (Martin 1998). Average loss values per acre were then calculated for best-case (25 percent loss) and worst-case (40 percent loss) scenarios and applied to the projected acres affected by pink disease (table 9). Coffee production would be severely impacted within a short time under the worst-case scenario (cumulative discounted losses of about $6–14 million after 7 years) and seriously impacted under the best-case scenario (cumulative discounted losses of about $3–6 million after 13 years).

Urban Tree Impacts—Asian Longhorned Beetle—New introductions of exotic forest pests transported with SWPM are likely to occur in urban areas because of the concentration of trade and transportation at these locations. Recent introductions of the Asian longhorned beetle (ALB), *Anoplophora glabripennis* (Motschulsky), into New York and Chicago follow this pattern. The potential impact of introduction of the ALB populations, in terms of tree mortality and monetary value, on urban trees was estimated quantitatively for eight cities for which urban tree inventory information is available: Atlanta, GA; Baltimore, MD; Boston, MA; Chicago, IL; Jersey City, NJ; New York, NY; Oakland, CA; and Philadelphia, PA. Data on urban forest structure collected and analyzed using the Urban Forest Effects (UFORE) model (Nowak and Crane, in press; Nowak et al., in review) were combined with ALB feeding preferences (table 10) to quantify the potential number of trees, percentage of total canopy cover (leaf area), and potential monetary loss associated with ALB infestation scenarios.

The Asian longhorned beetle was modeled to spread at two rates: 300 m/yr and 3 km/yr. The slower spread rate is based upon the natural spread rate of beetles (Thier 1997), whereas the upper spread rate is dependent on human-assisted transport of infested wood, such as firewood. ALB infestation was assumed to start at the center of the city and to spread outward until the entire city area was encompassed. The ALB infestation was assumed to spread at equal rates through all land uses proportional to the city land use distribution and tree composition in the land use (e.g., if 50 percent of the city was residential land, then 50 percent of the ALB infestation occurred on residential land each year). All susceptible trees (preferred class) would be killed within 4 years of attack in natural areas (e.g., forests, vacant lands). On all other land uses, it was assumed that susceptible trees would be removed within 2 years of attack owing to increased maintenance and hazard liability for these land uses.

The value of the trees in each ALB susceptibility class was calculated based on the compensatory value of trees prescribed by the Council of Tree and Landscape Appraisers (1992). Compensatory values are used for monetary settlement for damage or death of plants through litigation, insurance claims of direct payment, and loss of property value for income tax deduction. Compensatory value is based on the replacement cost of a similar tree and is an estimate of the amount of money the tree owner should be compensated for tree loss. Compensatory value is based on four tree and site characteristics: tree trunk area (cross-sectional area at 1.37 m in height), species, condition, and location. Tree trunk area and species are used to determine the basic value, which is then multiplied by condition and location ratings (0–1) to determine the final tree compensatory value. A more detailed description of the methodology used to calculate compensatory values is given in appendix E.

Tree resources at risk (i.e., preferred hosts) for ALB attack range from a high of 63 percent of the trees in Chicago (2.6 million trees) to 12 percent in Oakland (182,600 trees) (table 11). If all preferred hosts were eventually killed,

Table 6. Projected yearly timber volume loss (in thousand cubic feet) of eucalyptus plantations in Hawaiian island groups expected to be affected by pink disease following introduction of *Erythricium salmonicolor*[1]

	Worst-Case Scenario			Best Case Scenario		
Year	**Oahu, HI** Island group	**Kauai, HI** Island group	**Hawaii, HI** Island group	**Oahu, HI** Island group	**Kauai, HI** Island group	**Hawaii, HI** Island group
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.4	0.4	2.6	0.0	0.0	0.0
3	12.4	7.7	66.0	0.0	0.0	0.0
4	115.0	72.9	612.9	0.4	0.4	2.1
5	469.7	298.1	2,508.3	2.1	1.3	12.4
6	733.0	465.0	3,914.3	9.9	6.4	52.8
7	742.9	471.4	3,967.9	33.4	21.0	177.6
8				91.8	58.3	490.2
9				208.0	132.1	1,110.5
10				375.7	238.5	2,006.5
11				525.0	332.8	2,802.1
12				586.3	371.9	3,131.1

[1] Based upon total acreage estimates for eucalyptus plantations: Hawaii (Big Island) 13,983 acres; Oahu 3,615 acres; Maui 3,465 acres; Kauai 2,198 acres; Molokai 1,055 acres (C. Masaki 1999, personal communication) and average growth rate of 30 cubic meters per hectare per year (C. Hodges 1999, personal communication).

Table 7. Projected cumulative monetary loss discounted 7 percent per year (in thousands of dollars) for eucalyptus plantations by Hawaiian island group owing to damage by pink disease following introduction of *Erythricium salmonicolor*[1]

	Worst-Case Scenario			Best-Case Scenario		
Year	**Oahu, HI** Island group	**Kauai, HI** Island group	**Hawaii, HI** Island group	**Oahu, HI** Island group	**Kauai, HI** Island group	**Hawaii, HI** Island group
1	0.0	0.0	0.0	0.0	0.0	0.0
2	1.9	2.0	12.0	0.0	0.0	0.0
3	55.8	35.4	297.8	0.0	0.0	0.0
4	520.6	330.2	2,776.6	1.8	1.8	8.7
5	2,295.8	1,457.0	12,257.1	9.9	6.7	55.7
6	4,885.1	3,099.3	26,083.9	44.7	29.4	242.1
7	7,337.6	4,655.5	39,183.1	155.2	98.8	828.3
8				438.4	278.8	2,340.9
9				1,038.3	659.7	5,542.9
10				2,050.8	1,302.3	10,950.0
11				3,373.0	2,140.6	18,007.3
12				4,753.1	3,015.9	25,337.1

[1] Based upon average stumpage value of $25 per cubic meter (= $708 per thousand cubic feet) (C. Hodges 1999, personal communication).

Table 8. Projected yearly acreage of coffee plantations by Hawaiian island group expected to be affected by pink disease following introduction of *Erythricium salmonicolor*

	Worst-Case Scenario			Best-Case Scenario		
Year	**Oahu, HI** Island group	**Kauai, HI** Island group	**Hawaii, HI** Island group	**Oahu, HI** Island group	**Kauai, HI** Island group	**Hawaii, HI** Island group
1	0	0	0	0	0	0
2	0	2	1	0	0	0
3	0	50	36	0	0	0
4	0	465	330	0	1	1
5	0	1,903	1,350	0	7	5
6	0	2,969	2,106	0	29	20
7	0	3,010	2,135	0	96	68
8				0	266	188
9				0	602	427
10				0	1,087	771
11				0	1,518	1,077
12				0	1,697	1,203
13				0	1,720	1,220

Table 9. Projected cumulative monetary crop loss discounted 7 percent per year (in thousands of dollars) for coffee plantations by Hawaiian island group owing to damage by pink disease following introduction of *Erythricium salmonicolor*

	Worst-Case Scenario			Best-Case Scenario		
Year	**Oahu, HI** Island group	**Kauai, HI**[1] Island group	**Hawaii, HI**[2] Island group	**Oahu, HI** Island group	**Kauai, HI**[1] Island group	**Hawaii, HI**[2] Island group
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	2.0	3.0	0.0	0.0	0.0
3	0.0	49.4	104.6	0.0	0.0	0.0
4	0.0	461.7	974.7	0.0	0.6	1.6
5	0.0	2,038.3	4,301.3	0.0	4.2	9.3
6	0.0	4,337.2	9,151.3	0.0	18.2	38.1
7	0.0	6,515.4	13,746.4	0.0	61.6	129.6
8				0.0	173.9	365.8
9				0.0	411.4	867.3
10				0.0	840.4	1,772.9
11				0.0	1,439.4	3,037.8
12				0.0	2,109.0	4,450.7
13				0.0	2,743.3	5,789.8

[1] Reported harvest values for Kauai also included harvests from Maui and Molokai to avoid disclosure of individual operations. Average price was $2,715 per acre harvested for the 1996–97 crop year (Martin 1998).
[2] Average price for Hawaii (Big Island) was $8,075 per acre harvested for the 1996–97 crop year (Martin 1998).

Table 10. Genera and species assignments in Asian longhorned beetle (ALB) preference classes (V. Mastro 1999, personal communication). Preferred class indicates trees that are known hosts in the United States, China, or both countries on the basis of literature or verified ALB exit holes. Oviposition–genera class indicates (a) that the tree species has been attacked but ALB development in the tree has not yet been confirmed, (b) a genera with only one known host species, or (c) both of these occurrences.

Genera/species	**Preference class**
Acer spp.	Preferred
Aesculus spp.	Preferred
Ailanthus altissima	Oviposition/genera
Albizzia julibrissin	Preferred
Alnus spp.	Preferred
Betula populifolia	Preferred
Betula spp.	Oviposition/genera
Elaeagnus angustifolia	Preferred
Elaeagnus spp.	Oviposition/genera
Fraxinus spp.	Preferred
Hibiscus syriacus	Preferred
Hibiscus spp.	Oviposition/genera
Melia spp.	Preferred
Morus spp.	Preferred
Platanus spp.	Oviposition/genera
Populus spp.	Preferred
Prunus spp.	Preferred
Pyrus spp.	Preferred
Quercus spp.	Oviposition/genera
Robinia spp.	Oviposition/genera
Salix spp.	Preferred
Ulmus spp.	Preferred

Table 11. Estimated tree resources at risk for infestation by Asian longhorned beetle (ALB) in eight cities

City	Area	Years to infest entire city		Resources at risk for ALB attack in preferred host classes				
		@ 300 *m/yr*	@ 3 *km/yr*	No. of trees preferred by ALB	% of all trees preferred	% of total canopy cover preferred	Total value (in thousand $) of preferred trees (in year 1)	$ value per tree (year 1)
Chicago, IL	588	46	5	2,615,600	63	61.2	1,001,770[a]	na
Boston, MA	143	23	3	654,400	57	56.7	730,970	1,117
Philadelphia, PA	342	35	4	1,061,000	55	40.9	587,470	554
Baltimore, MD	238	30	3	1,200,500	48	45.6	1,289,560	1,074
New York, NY	800	54	6	2,032,100	43	40.3	1,587,060	781
Jersey City, NJ	38	12	2	48,500	37	40.6	39,960	824
Atlanta, GA	341	35	4	1,675,500	19	17.0	355,480	212
Oakland, CA	145	23	3	182,600	12	11.6[b]	87,070[c]	477[c]

[a] Estimate based on median dollar value per tree from Atlanta and Philadelphia, for Chicago's tree diameter distribution was similar to the distributions of trees in these cities. These cities have similar values and are among the lowest values in the table.
[b] Percentage of total tree cover.
[c] Based on original estimates (1.587 million trees; $385 million) (Nowak 1993) using a basic price of $27 per in^2 that was adjusted upward based on a more recent basic price of $53 per in^2 for California (ACRT 1997).
na = not analyzed

the corresponding percentage of canopy cover loss[1] would range from 61 percent in Chicago to 12 percent in Oakland. The total value of tree resources at risk in 1997 dollars ranges from $1.6 billion in New York to $40 million in Jersey City. Differences among cities in total number of trees that could be attacked and killed by the ALB and the value of those trees are related to city size, percentage of land covered by trees (i.e., total number of trees in the city), and the proportion of the tree population that is in preferred host species or genera (% of Trees in table 11).

The potential tree resources at risk for ALB attack reveal patterns among cities that may be related to region of the country. In the Northeast–North Central (NE–NC) region, the percentage of trees preferred as hosts and the corresponding percentage of the total canopy cover appear to be significantly greater than in cities found in the South (Atlanta) and West (Oakland). The median percentage of trees in the preferred host class (51.5 percent) and the percentage of canopy cover that could be lost (43 percent) for the NE–NC cities were greater than the median values for Atlanta and Oakland (15.5 percent of trees and 14.6 percent of canopy cover), which were used to represent the area outside of the NC–NE region (i.e., the rest of the United States). Though the sample size is small, it is likely that regional differences in tree species composition will affect the overall potential magnitude of ALB impact. Therefore, relatively high proportions of preferred ALB host species in the NE–NC region will likely lead to greater ALB impacts in this area. Other regions of the country (e.g., the Pacific Northwest) may also have relatively high proportions of preferred host species, but urban tree species compositions in these areas remain to be investigated. Given the probability that forest types similar to those in the NE–NC region exist in the "rest of United States" region, the regional extrapolation procedure for this region is probably conservative.

The median compensatory value (in 1997 dollars) of tree resources at risk for ALB attack per preferred host tree (NE–NC = $824; rest of United States = $345) also varies by region. These differences are primarily due to amounts and proportions of preferred host species as well as diameter and land use distributions of these species. Median basic price (in 1997 dollars) for the rest of United States was actually higher than in the NE–NC cities analyzed ($5.42 per cm^2 versus $3.49 per cm^2). Median species values used in the valuation formula appeared to be similar among regions (e.g., NE–NC *Acer rubrum* = 0.8; rest of United States *A. rubrum* = 0.815).

The time until ALB would infest the entire city ranged from 12 years in Jersey City to 54 years in New York at a 300 m/yr spread rate (table 11). At a faster rate of spread (3 km/yr), city-wide infestation would drop to 2–6 years for all cities (tables 11 and 12). Five years following ALB introduction, the percentage of infested city land area, given a natural spread rate of 300 m/yr, was projected to range from 0.9 percent in New York to 18.4 percent in Jersey City (table 13). After 20 years at that spread rate, the ALB-infested land area would range from 14.1 percent in New York to 100 percent in Jersey City. The lower spread rate of 300 m/yr may provide a reasonably good benchmark for ALB impacts over time for the cities analyzed, although spread rate can be reduced with implementation of eradication or control efforts and may be accelerated by human-assisted transport of infested wood. Actual ALB spread after establishment likely will not follow an even pattern, and spot infestations will occur ahead of the main front owing to human-assisted transport that eventually will coalesce with the primary population. The faster rate of spread of 3 km/yr more likely represents a worst-case scenario and would not be expected where eradication or control measures were implemented.

At the faster spread rate of 3 km/yr, infestation of all preferred host trees within 6 years of pest introduction would range from 48,500 trees in Jersey City to 2.6 million trees in Chicago (table 14). For trees affected, corresponding cumulative compensatory values discounted at 7 percent per year (U.S. Office of Management and Budget 1996; see appendix E) would range from about $39 million to $1.3 billion per city (table 15). The cumulative percentage tree mortality would equal that of the total resources at risk 3 years after all trees became infested, occurring at 5 to 9 years, depending upon location (tables 11 and 16). The cumulative number of preferred host trees that would be

[1]Canopy cover as measured by leaf area is used as an indication of the plant's dominance in the landscape.

Table 12. Projected percentage of city area potentially affected following introduction of Asian longhorned beetle (ALB) for eight U.S. cities at a spread rate of 3 km/yr (worst-case scenario).

	Percent of city area encompassed by ALB infestation							
Year	**Chicago, IL**	**Boston, MA**	**Philadelphia, PA**	**Baltimore, MD**	**New York, NY**	**Jersey City, NJ**	**Atlanta, GA**	**Oakland, CA**
1	4.8	19.8	8.3	11.9	3.5	73.7	8.3	19.5
2	19.2	79.2	33.1	47.5	14.1	100.0	33.1	77.9
3	43.2	100.0	74.5	100.0	31.8		74.5	100.0
4	76.9		100.0		56.6		100.0	
5	100.0				88.4			
6					100.0			

Table 13. Projected percentage of city area potentially affected following introduction of the Asian longhorned beetle at a spread rate of 300 m/yr (best case)

Year	Percent of city area encompassed by ALB infestation							
	Chicago, IL	**Boston, MA**	**Philadelphia, PA**	**Baltimore, MD**	**New York, NY**	**Jersey City, NJ**	**Atlanta, GA**	**Oakland, CA**
1	0.0	0.2	0.1	0.1	0.0	0.7	0.1	0.2
2	0.2	0.8	0.3	0.5	0.1	2.9	0.3	0.8
3	0.4	1.8	0.7	1.1	0.3	6.6	0.7	1.8
4	0.8	3.2	1.3	1.9	0.6	11.8	1.3	3.1
5	1.2	5.0	2.1	3.0	0.9	18.4	2.1	4.9
6	1.7	7.1	3.0	4.3	1.3	26.5	3.0	7.0
7	2.4	9.7	4.1	5.8	1.7	36.1	4.1	9.5
8	3.1	12.7	5.3	7.6	2.3	47.2	5.3	12.5
9	3.9	16.0	6.7	9.6	2.9	59.7	6.7	15.8
10	4.8	19.8	8.3	11.9	3.5	73.7	8.3	19.5
11	5.8	24.0	10.0	14.4	4.3	89.2	10.0	23.6
12	6.9	28.5	11.9	17.1	5.1	100.0	11.9	28.1
13	8.1	33.5	14.0	20.1	6.0		14.0	32.9
14	9.4	38.8	16.2	23.3	6.9		16.2	38.2
15	10.8	44.6	18.6	26.7	8.0		18.6	43.8
16	12.3	50.7	21.2	30.4	9.1		21.2	49.9
17	13.9	57.2	23.9	34.3	10.2		23.9	56.3
18	15.6	64.2	26.8	38.5	11.5		26.8	63.1
19	17.3	71.5	29.9	42.9	12.8		29.9	70.3
20	19.2	79.2	33.1	47.5	14.1		33.1	77.9
21	21.2	87.3	36.5	52.4	15.6		36.5	85.9
22	23.3	95.8	40.1	57.5	17.1		40.1	94.3
23	25.4	100.0	43.8	62.8	18.7		43.8	100.0
24	27.7		47.7	68.4	20.4		47.7	
25	30.0		51.7	74.2	22.1		51.8	
26	32.5		56.0	80.3	23.9		56.0	
27	35.0		60.4	86.6	25.8		60.4	
28	37.7		64.9	93.1	27.7		64.9	
29	40.4		69.6	99.9	29.7		69.7	
30	43.2		74.5	100.0	31.8		74.5	

Table 14. Estimated cumulative number of preferred host trees potentially infested following introduction of ALB at a spread rate of 3 km/yr (worst case)

	Cumulative number of trees (x 1,000) infested by ALB							
Year	**Chicago, IL**	**Boston, MA**	**Philadelphia, PA**	**Baltimore, MD**	**New York, NY**	**Jersey City, NJ**	**Atlanta, GA**	**Oakland, CA**
1	125.7	129.6	87.8	142.6	71.9	35.7	138.8	35.6
2	502.7	518.3	351.4	570.2	287.5	48.5	555.1	142.3
3	1,131.0	654.4	790.5	1,200.5	646.9		1,248.9	182.6
4	2,010.7		1,061.0		1,150.1		1,675.5	
5	2,615.6				1,797.1			
6					2,032.1			

Table 15. Estimated cumulative compensatory value (discounted 7percent per year) of preferred host trees potentially infested by ALB following introduction at a spread rate of 3 km/yr (worst-case scenario); (na = not analyzed)

	Cumulative compensatory value (in thousand $) of trees infested by ALB							
Year	**Chicago, IL**	**Boston, MA**	**Philadelphia, PA**	**Baltimore, MD**	**New York, NY**	**Jersey City, NJ**	**Atlanta, GA**	**Oakland, CA**
1	na	144,740	48,640	153,130	56,140	29,450	29,440	na
2		543,107	182,493	574,580	210,654	39,092	110,477	
3		675,878	394,896	1,165,941	455,828		239,047	
4			517,137		776,625		312,930	
5					1,162,085			
6					1,292,954			

Table 16. Estimated cumulative percentage of tree mortality potentially caused by ALB following introduction at a spread rate of 3 km/yr (worst-case scenario); (na = not analyzed)

	Cumulative percent of tree mortality caused by ALB							
Year	**Chicago, IL**	**Boston, MA**	**Philadelphia, PA**	**Baltimore, MD**	**New York, NY**	**Jersey City, NJ**	**Atlanta, GA**	**Oakland, CA**
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	2.2	8.5	2.5	3.7	1.1	19.3	0.6	1.2
3	8.7	33.9	9.9	14.7	4.6	26.3	2.6	4.6
4	20.5	45.5	24.3	33.0	10.6	34.0	6.7	7.0
5	38.3	53.7	38.1	39.2	19.7	36.8	11.3	10.3
6	53.1	56.6	48.3	48.2	31.9		15.8	11.5
7	59.2		54.6		38.2		18.6	
8	63.4				41.6			
9					42.8			

ALB-infested after 5 years at the 300 m/yr spread rate would range from 8,900 in Jersey City and Oakland to 35,600 in Baltimore and from 48,500 in Jersey City to 570,200 in Baltimore after 20 years (table 17). Corresponding cumulative compensatory values discounted at 7 percent per year of the affected trees would range from about $6 million in Jersey City and Atlanta to $32 million in Baltimore after 5 years and from $25 million in Jersey City to $403 million in Baltimore after 30 years (table 18). These compensatory values, although high, likely underestimate the total potential ALB impact because they do not include costs of regulation, eradication, or control and do not account for secondary costs (such as higher energy costs for cooling buildings because of lost shade) or intrinsic values (such as quality of recreational experiences or loss of wildlife habitat). In addition, trees in the oviposition–genera host class could actually be preferred hosts but are currently awaiting research confirmation. If trees in this class actually are preferred hosts, tree resources at risk for ALB attack could increase from an additional 34,000 trees in Jersey City ($40.6 million in 1997 dollars) to 1,378,000 trees in New York ($2.4 billion in 1997 dollars) (table 19). The percentage of all city trees that would be killed at the lower spread rate of 300 m/yr (given a delay of 2 to 4 years following initial attack) would range from 0.1 percent in Atlanta to 3.4 percent in Jersey City after 5 years and from 4.9 percent in Atlanta to 38.5 percent in Boston after 20 years (table 20).

Chicago and New York, two cities that have ALB infestations, are located in areas where the impact of ALB is potentially large. The number of infested trees removed in Chicago during 1999 eradication efforts (about 1,250) roughly corresponds to the amount projected to be affected within 1 year following pest introduction, if a single point of entry and a spread rate of 300 m/yr are assumed. For New York, the number of infested trees removed in the first 2 years after detection (about 2,300) corresponds to the number of trees expected to be affected 2 years following pest introduction; however, the number of trees removed within 4 years (about 4,300) was 37 percent of the number projected for a no-control scenario. Because populations in both cities are estimated to have been present for several years before initial detection (1996 for New York and 1998 for Chicago), there likely is a short lag time necessary for population buildup before spread becomes noticeable. This buildup would likely delay the actual progression of tree infestation and mortality by a few years compared with that projected in the scenario calculations.

Other cities in the NE–NC region also have the potential for significant ALB impact on the city's tree resources (e.g., Boston, Baltimore, Jersey City, Philadelphia) should the pest become established in those locales. Cities in other areas of the United States may also be significantly affected by a city-wide ALB infestation (e.g., cities in the Pacific Northwest), but additional data are needed to provide a more detailed analysis of variation across the country. Conservatively, a widespread ALB infestation across the United States will likely kill at least 10 percent of the urban tree population (based on an extrapolation of data from the most conservative city estimate—Oakland).

The estimated potential national ALB impact if every urban place in the coterminous United States eventually becomes totally infested with this insect is a loss of 26.5 percent of the canopy cover, 30.7 percent of the trees (1.2 billion trees). The compensatory value of these trees totals $522 billion (in 1997 dollars).

Forest Timber Production Impacts—Necessary data to estimate the damage impact of a pest on timber resources include distributions of tree resources at risk, average volumes of tree resources at risk (generally calculated from size and density measures), expanding fronts of the hypothetical infestations over time (including estimates of number and location of entries and rate of spread of pest populations), natural mortality and harvest rates, pest-induced mortality or damage levels, average projected forest growth, and any significant modifiers of the preceding variables. The general approach for predicting timber losses due to introduction of exotic forest pests is illustrated in figure 17. Timber loss estimates for the pests analyzed used county-level timber volumes for forest land

Table 17. Estimated cumulative number of preferred host trees potentially infested following introduction of the ALB at a spread rate of 300 m/yr (best case)

	Cumulative number of trees (× 1,000) infested by ALB							
Year	**Chicago, IL**	**Boston, MA**	**Philadelphia, PA**	**Baltimore, MD**	**New York, NY**	**Jersey City, NJ**	**Atlanta, GA**	**Oakland, CA**
1	1.3	1.3	0.9	1.4	0.7	0.4	1.4	0.4
2	5.0	5.2	3.5	5.7	2.9	1.4	5.6	1.4
3	11.3	11.7	7.9	12.8	6.5	3.2	12.5	3.2
4	20.1	20.7	14.1	22.8	11.5	5.7	22.2	5.7
5	31.4	32.4	22.0	35.6	18.0	8.9	34.7	8.9
6	45.2	46.6	31.6	51.3	25.9	12.9	50.0	12.8
7	61.6	63.5	43.0	69.8	35.2	17.5	68.0	17.4
8	80.4	82.9	56.2	91.2	46.0	22.9	88.8	22.8
9	101.8	105.0	71.1	115.5	58.2	29.0	112.4	28.8
10	125.7	129.6	87.8	142.6	71.9	35.7	138.8	35.6
11	152.1	156.8	106.3	172.5	87.0	43.3	167.9	43.1
12	181.0	186.6	126.5	205.3	103.5	48.5	199.8	51.2
13	212.4	219.0	148.4	240.9	121.5		234.5	60.1
14	246.3	254.0	172.2	279.4	140.9		272.0	69.7
15	282.7	291.6	197.6	320.7	161.7		312.2	80.1
16	321.7	331.7	224.9	364.9	184.0		355.2	91.1
17	363.2	374.5	253.9	412.0	207.7		401.0	102.8
18	407.2	419.8	284.6	461.9	232.9		449.6	115.3
19	453.7	467.8	317.1	514.6	259.5		500.9	128.4
20	502.7	518.3	351.4	570.2	287.5		555.1	142.3
21	554.2	571.4	387.4	628.6	317.0		612.0	156.9
22	608.2	627.2	425.1	689.9	347.9		671.6	172.2
23	664.8	654.4	464.7	754.1	380.3		734.1	182.6
24	723.8		505.9	821.1	414.0		799.3	
25	785.4		549.0	890.9	449.3		867.3	
26	849.5		593.8	963.6	485.9		938.1	
27	916.1		640.3	1,039.2	524.0		1,011.6	
28	985.2		688.6	1,117.6	563.6		1,087.9	
29	1,056.8		738.7	1,198.9	604.5		1,167.0	
30	1,131.0		790.5	1,200.5	646.9		1,248.9	

Table 18. Estimated cumulative compensatory value (discounted 7 percent per year) of preferred hosts potentially infested by the ALB following introduction at a spread rate of 300 m/yr (best-case scenario); (na = not analyzed)

	Cumulative compensatory value (in thousand $) of trees infested by ALB							
Year	**Chicago, IL**	**Boston, MA**	**Philadelphia, PA**	**Baltimore, MD**	**New York, NY**	**Jersey City, NJ**	**Atlanta, GA**	**Oakland, CA**
1	na	1,450	490	1,530	560	290	290	na
2		5,432	1,829	5,750	2,110	1,107	1,107	
3		11,755	3,952	12,432	4,556	2,390	2,390	
4		20,024	6,727	21,183	7,764	4,072	4,072	
5		29,957	10,069	31,695	11,624	6,094	6,094	
6		41,315	13,883	43,709	16,024	8,404	8,404	
7		53,849	18,095	56,969	20,888	10,956	10,956	
8		67,369	22,641	71,274	26,131	13,708	13,702	
9		81,692	27,448	86,424	31,684	16,624	16,618	
10		96,650	32,479	102,252	37,488	19,665	19,659	
11		112,099	37,670	118,596	43,481	22,812	22,800	
12		127,915	42,981	135,328	49,614	24,864	26,021	
13		143,984	48,380	152,325	55,848		29,289	
14		160,201	53,833	169,484	62,139		32,588	
15		176,477	59,301	186,703	68,453		35,896	
16		192,740	64,767	203,908	74,759		39,205	
17		208,922	70,204	221,028	81,036		42,498	
18		224,959	75,592	237,993	87,257		45,759	
19		240,803	80,914	254,757	93,402		48,981	
20		256,412	86,160	271,270	99,455		52,158	
21		271,746	91,313	287,493	105,404		55,277	
22		286,778	96,365	303,395	111,234		58,334	
23		293,646	101,304	318,949	116,935		61,325	
24			106,126	334,130	122,502		64,243	
25			110,824	348,922	127,926		67,087	
26			115,395	363,312	133,201		69,853	
27			119,833	377,286	138,323		72,541	
28			124,137	390,839	143,293		75,146	
29			128,034	403,108	147,791		77,505	
30			131,804	403,340	152,142		79,787	

Table 19. Asian longhorned beetle (ALB) host preference class differences in eight cities based on number of live trees[a] and associated current compensatory value

City	Number of trees (× 1,000)				Total value (× $1,000,000) in year 1			
	PREF	OVI–G	CONF	UNK	PREF	OVI–G	CONF	UNK
Chicago, IL	2,615.6	236.6	287.2	988.7	1,001.8[b]	90.6[b]	110.0[b]	378.7[b]
Boston, MA	654.4	263.0	105.0	134.0	731.0	255.3	115.0	151.4
Baltimore, MD	1,200.5	492.7	175.0	611.4	1,289.5	1,037.3	208.3	891.1
New York, NY	2,032.1	1,378.7	102.5	1,236.1	1,587.1	2,402.8	119.9	1,079.5
Jersey City, NJ	48.5	34.2	10.4	38.7	40.0	40.6	4.3	16.0
Philadelphia, PA	1,061.0	289.9	167.8	425.8	587.5	446.8	178.8	538.1
Atlanta, GA	1,675.5	1,280.0	1,398.6	4,670.5	335.5	1,082.6	1,003.4	1,269.5
Oakland, CA	182.6	223.9	277.8	903.4	na	na	na	na

[a] Except Chicago and Oakland, where all trees (living and dead) were analyzed.

[b] Estimate based on median dollar value per tree from Atlanta and Philadelphia (table 11) for Chicago's tree diameter distribution was similar to the distributions of trees in these cities.

PREF = known ALB host.

OVI–G = (a) a host that is known to have been attacked in the field or in the laboratory but is currently not a confirmed host pending completion of life cycle; (b) tree genera with only one known host species, or both.

CONF = conifer species (no known conifer hosts).

UNK = hardwood genera with no ALB host data.

Table 20. Percentage of tree mortality potentially caused by the ALB following introduction at a spread rate of 300 m/yr (best-case scenario); (na = not analyzed).

	Cumulative percent tree mortality caused by ALB							
Year	**Chicago, IL**	**Boston, MA**	**Philadelphia, PA**	**Baltimore, MD**	**New York, NY**	**Jersey City, NJ**	**Atlanta, GA**	**Oakland, CA**
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.1	0.0	0.0	0.0	0.2	0.0	0.0
3	0.1	0.3	0.1	0.1	0.0	0.8	0.0	0.0
4	0.2	0.8	0.2	0.3	0.1	1.8	0.1	0.1
5	0.4	1.5	0.5	0.7	0.2	3.4	0.1	0.2
6	0.6	2.4	0.8	1.1	0.3	5.5	0.2	0.4
7	0.9	3.5	1.2	1.6	0.5	8.3	0.4	0.6
8	1.3	4.8	1.7	2.3	0.7	11.5	0.5	0.8
9	1.7	6.4	2.3	3.1	0.9	15.3	0.7	1.1
10	2.2	8.2	3.0	4.0	1.1	19.6	1.0	1.5
11	2.7	10.2	3.8	5.0	1.4	24.4	1.2	1.8
12	3.3	12.5	4.6	6.1	1.7	29.8	1.5	2.3
13	4.0	14.9	5.6	7.4	2.0	34.1	1.8	2.7
14	4.7	17.6	6.7	8.7	2.4	35.7	2.2	3.3
15	5.5	20.5	7.8	10.2	2.8	36.8	2.5	3.8
16	6.4	23.7	9.0	11.8	3.2		3.0	4.4
17	7.3	27.0	10.3	13.4	3.7		3.4	5.1
18	8.3	30.6	11.8	15.3	4.1		3.9	5.8
19	9.3	34.4	13.3	17.2	4.7		4.4	6.5
20	10.4	38.5	14.8	19.2	5.2		4.9	7.3
21	11.5	42.7	16.5	21.4	5.8		5.5	8.1
22	12.7	47.2	18.3	23.7	6.4		6.1	9.0
23	14.0	51.9	20.2	26.1	7.0		6.7	9.9
24	15.4	54.8	22.1	28.6	7.7		7.3	10.7
25	16.8	56.0	24.1	31.2	8.4		8.0	11.2
26	18.2	56.6	26.3	33.9	9.1		8.7	11.5
27	19.7		28.5	36.8	9.9		9.5	
28	21.3		30.8	39.7	10.6		10.3	
29	22.9		33.2	42.8	11.5		11.1	
30	24.9		35.7	46.0	12.3		11.9	

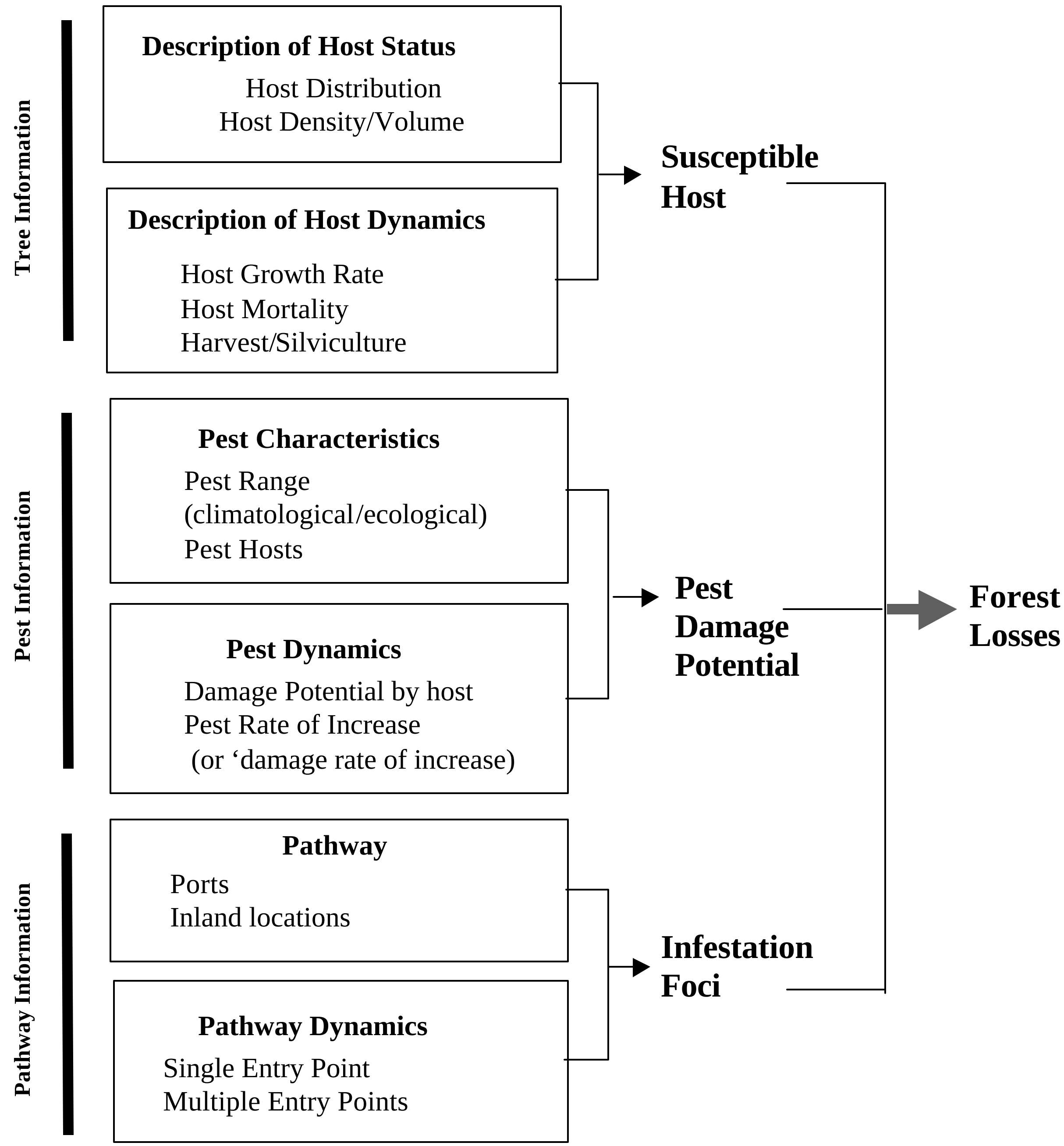


Figure 17. General approach to estimating forest economic losses.

classified as timberland[2] generated from forest inventory and analysis (FIA) data (found at http://www.srsfia.usfs.msstate.edu/; described by Hansen et al. 1992, Woudenberg and Farrenkopf 1995). Urban tree populations are not included in the FIA data set; however, potential impacts on urban trees were estimated separately (using different methodology) for the Asian longhorned beetle (above).

Timber volumes for the primary host species of a given pest were extracted from the FIA data base. When the FIA data base used combination categories for cover type (such as oak–pine), and if the combination included a nonpreferred host, an estimate was made as to the proportion of the area represented by one host species versus the other. Only the estimated volume of the preferred host species was used then to calculate total host resource available. For most of the species considered in this analysis, this breakdown between lumped categories was not necessary. For pests with multiple hosts, an average damage potential was used for the combined host tree species. Average expected growth rates, mortality, and harvests given in the FIA data base were used to adjust tree volumes through time to simulate the dynamics of the available forest resource. In other words, the host volume available for pest infestation did not remain constant from year to year for each county potentially affected.

The locations of introduction foci for infestation scenarios were selected based on recommendations from experts and APHIS–PPQ interception data. Rates of spread were applied from these initial foci each year for 30 years, resulting in delineation of concentric areas. FIA timber data for hosts (including natural growth and mortality projections) for counties intersected by the area potentially infested each year (i.e., those counties contained completely or nearly so within the maximum extent of circular expansion for each year of pest spread) were tallied. The Geographic Information Systems (GIS) tools were used for analysis to represent the infestation expansion area and locations of affected counties and tree resources spatially. Where contiguous hosts were not present (that is, where there was a county with no hosts next to an affected county), the pest infestation was assumed to stop spreading in that direction once the area of expansion reached a no-host county. Pest damage levels (i.e., tree mortality rates) were progressively applied to the host resources available each year to derive projected timber losses for the area affected through time. Less than maximum damage potential for each scenario was used during an assumed population buildup period following pest introduction based upon a calculated Weibull function (see appendix E). Thus, a yearly accounting was made of the iterative losses that would be induced by each pest species as the area (and associated forest resource) covered by the pest increased. In some circumstances the spread "radii" from contiguous infestations coalesced. For simplicity, only the initial tree mortalities were counted in these cases, and the "reinfestations" were not considered to cause additional damage (because trees cannot be killed more than once, and stand characteristics for remaining trees likely would be altered enough to affect sustainability of subsequent infestations). In most cases, no more than three foci were modeled for any given pest scenario to limit the instances of overlapping infestations because little information is available on potential interactions between different populations.

Once tree volume losses were estimated for each pest by introduction location and best-case and worst-case scenarios, the values of those losses in 1998 dollars were calculated. Average 1994 stumpage prices per thousand board foot by tree species (Howard 1997) were inflated to 1998 prices using the producer price index (C. Klocek 1999, personal communication), and average prices were calculated for each scenario based upon the host tree species mix used. Because timber volumes in the FIA data base were measured in cubic feet (cf) (owing to recent conversion in measurement methodology by the USDA Forest Service), whereas the most recent published timber prices were based upon board feet (bf), an average conversion factor of 5.5 bf = 1 cf was used (J. Lewis, personal communication); however, actual relationships between the volume measures vary by tree species and location. Yearly monetary values were then discounted at 7 percent per year according to guidelines of the United States

[2] Timberland is land capable of producing commercial wood with at least 10 percent stocking of forest trees and that is not developed for nonforest uses or otherwise withdrawn from timber production. Stocking is a measure of the proportion of growth potential utilized or stand density relative to standards for the number of trees per acre by diameter class.

Office of Management and Budget (1996) to obtain the present value (see Appendix E).

The projected volumes of timber affected by expanding populations of introduced forest pests vary yearly depending upon the distribution of timber inventories available in potentially infested counties (because most other variables were applied at constant rates for simplicity of modeling). Values of affected timber likewise vary from year to year.

Depending upon location and rate of spread, Asian longhorned beetle populations may take from 4 to 30 or more years to expand beyond the bounds of the city (and county) affected, and therefore the urban tree resources, before beginning to affect commercial timberlands (table 21). In the best-case scenarios, Asian longhorned beetles would not reach beyond the urban tree resources of Chicago (i.e., Cook County) and New York within 30 years (fig. 18), and thus little or no commercial timber production would be affected in that time period. In the best case, damage to commercial timberlands outside Atlanta exceeding 100,000 cubic feet of timber would begin in year 5, and annual damage levels could rise to 19 million cubic feet by year 15 before declining. Cumulative discounted monetary losses around Atlanta might range from $2 million to $29 million after 30 years for best and worst cases, respectively (table 22). In the worst-case scenario, infestations could spread 90 km (nearly 60 miles) from the initial entry points in 30 years (fig. 19). Infestations would expand beyond the urban areas to begin affecting commercial forests outside Chicago and New York after 15 years under the worst-case scenario. Annual commercial timber volume losses could reach as high as 319 million cubic feet in New York within 7 years after ALB expansion beyond the urban core (i.e., year 21) (table 21). Cumulative discounted monetary losses for the timber resources around Chicago and New York would range from $1 million to $10 million, respectively, 30 years after introduction under the worst-case scenario (table 22). The majority of timberland resources at risk for ALB infestation are concentrated in the Eastern United States, although suitable hosts also occur in the Northwest (fig. 20). County level distributions of available timberland resources suitable for ALB colonization are shown in relation to infestation foci modeled at the faster spread rate in figure 21.

Distribution of timberland resources at risk for infestation by a sirex woodwasp (*Sirex noctilio* F.) are shown in figure 22. Only pines were considered to be viable hosts for this analysis. Spread from the point of entry after 30 years was assumed to reach a radius of 150 miles (241 km) for the best-case scenario and 450 miles (724 km) for the worst-case scenario (figs. 23 and 24). Of the three locations modeled, Atlanta, GA, would sustain the greatest damage levels with maximum annual volume losses of 550 million cubic feet to more than 6 billion cubic feet for the best and worst cases, respectively (table 23). Cumulative discounted values for timber losses after 30 years would range from $48 million to $607 million (table 24). For Minneapolis, MN, maximum annual damage within 30 years of introduction is expected to range from 81 million cubic feet to 688 million cubic feet for best and worst cases, respectively (table 23). Cumulative discounted timber losses after 30 years would be between $7 million and $76 million (table 24). For San Francisco, CA, maximum annual volume loss would be somewhat lower, ranging from 36 to 372 million cubic feet (table 23); however, cumulative discounted values of timber loss after 30 years would be similar to those of Minneapolis at nearly $7 million to $77 million because of regional differences in stumpage values of pine (table 24).

The European spruce bark beetle, *Ips typographus* (L.), was assumed to attack only spruce, which is limited to areas of the Northern United States and high elevations in the mountainous west (fig. 25). At the slower rate of spread, populations are expected to remain localized (fig. 26), but spread may reach up to 900 miles (1,448 km) from the point of origin after 30 years for the fastest spread rate (fig. 27). Economic impacts are likely to be minimal under the best-case scenario for all three locations modeled (tables 25 and 26). However, significant damage could be expected under the worst-case scenario. Annual volume loss could range up to 919 million cubic feet for

Table 21. Projected yearly timber volume losses (in million cubic feet) for forested lands due to damage by the Asian longhorned beetle

	Worst-Case Scenario			Best-Case Scenario		
Year	**Chicago, IL**	**New York, NY**	**Atlanta, GA**	**Chicago, IL**	**New York, NY**	**Atlanta, GA**
1	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	28.35	0.00	0.00	0.13
6	0.00	0.00	66.69	0.00	0.00	0.35
7	0.00	0.00	46.65	0.00	0.00	0.79
8	0.00	0.00	14.55	0.00	0.00	1.60
9	0.00	0.00	3.18	0.00	0.00	2.92
10	0.00	0.00	36.32	0.00	0.00	4.92
11	0.00	0.00	244.12	0.00	0.00	7.68
12	0.00	0.00	29.00	0.00	0.00	11.08
13	0.00	0.00	18.32	0.00	0.00	14.70
14	0.00	0.00	4.00	0.00	0.00	17.70
15	3.36	12.93	74.50	0.00	0.00	19.00
16	7.91	30.42	173.48	0.00	0.00	17.74
17	5.53	21.28	121.28	0.00	0.00	13.97
18	1.72	6.64	37.84	0.00	0.00	8.92
19	0.38	1.45	8.26	0.00	0.00	4.40
20	4.81	136.18	109.13	0.00	0.00	1.59
21	11.15	319.67	253.10	0.00	0.00	0.40
22	7.79	223.60	176.89	0.00	0.00	0.06
23	2.43	69.76	55.18	0.00	0.00	0.00
24	0.53	15.22	67.00	0.00	0.00	0.00
25	9.08	3.07	295.30	0.00	0.00	0.00
26	21.12	0.61	176.00	0.00	0.00	0.00
27	14.77	0.12	122.01	0.00	0.00	0.00
28	4.61	0.02	38.00	0.00	0.00	0.00
29	1.00	0.00	8.29	0.00	0.00	0.00
30	14.17	191.17	116.09	0.00	0.00	0.00

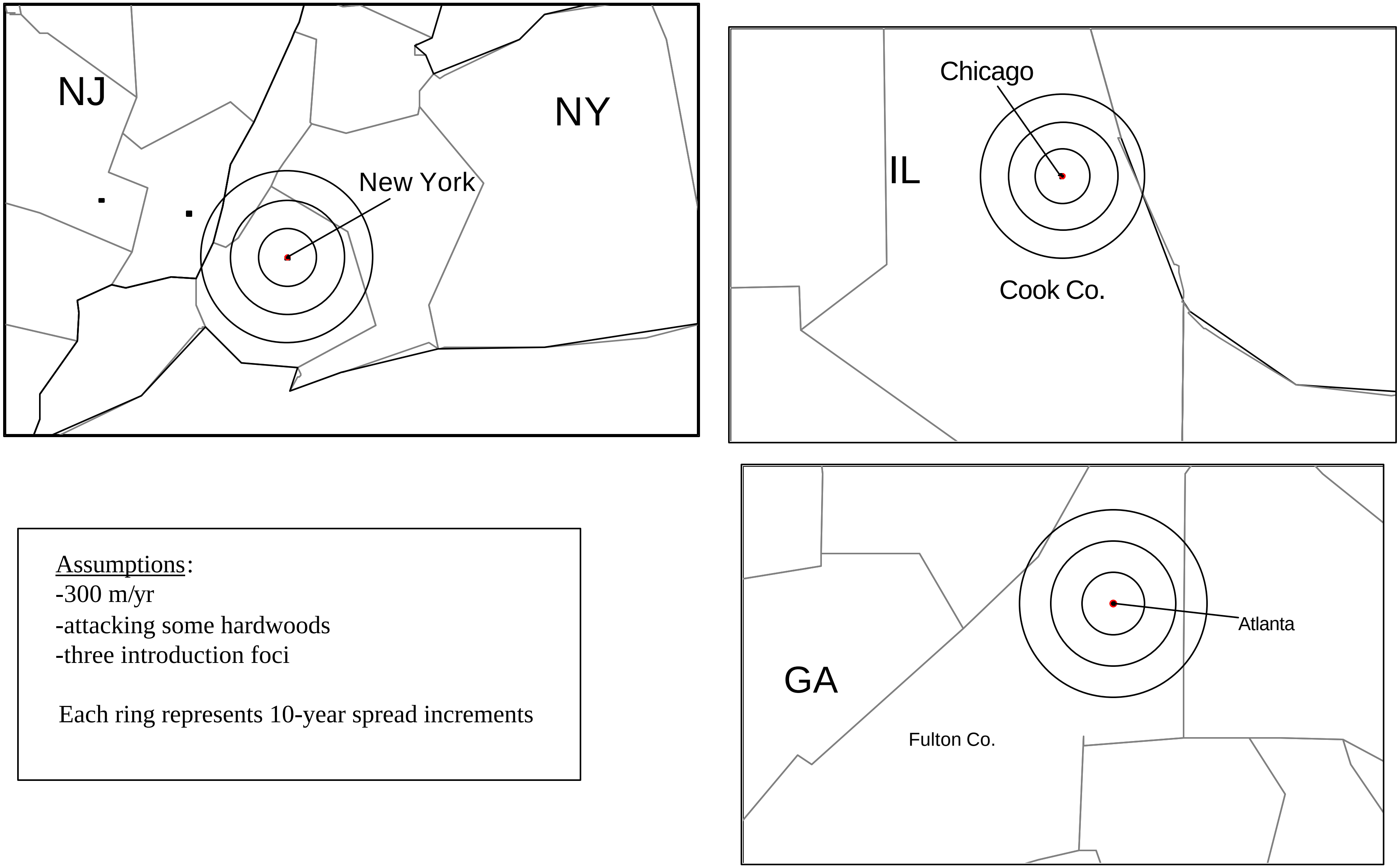


Figure 18. Expansion forecast over 30 years for Asian longhorned beetle introduction into New York, NY, Chicago IL, and Atlanta, GA, on the assumption of the best-case (slow spread rate) scenario. Circles represent the maximum extent of spread for the specified years; however, timber losses were based upon timber inventory (FIA) data for counties encompassed within the annual rings of hypothetical infestation spread.

Table 22. Projected cumulative monetary timber losses (in thousands of 1997 dollars discounted 7 percent) for the Asian longhorned beetle.

	Worst-Case Scenario			Best-Case Scenario		
Year	**Chicago, IL**	**New York, NY**	**Atlanta, GA**	**Chicago, IL**	**New York, NY**	**Atlanta, GA**
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	889.5	0.0	0.0	4.1
6	0.0	0.0	2,844.9	0.0	0.0	14.2
7	0.0	0.0	4,123.3	0.0	0.0	36.0
8	0.0	0.0	4,496.0	0.0	0.0	76.8
9	0.0	0.0	4,572.0	0.0	0.0	146.8
10	0.0	0.0	5,384.5	0.0	0.0	256.9
11	0.0	0.0	10,487.9	0.0	0.0	417.4
12	0.0	0.0	11,054.5	0.0	0.0	633.9
13	0.0	0.0	11,389.0	0.0	0.0	902.3
14	0.0	0.0	11,457.2	0.0	0.0	1,204.3
15	53.6	206.3	12,645.4	0.0	0.0	1,507.3
16	171.5	659.8	15,231.1	0.0	0.0	1,771.8
17	248.6	956.3	16,920.6	0.0	0.0	1,966.3
18	271.0	1,042.7	17,413.1	0.0	0.0	2,082.4
19	275.6	1,060.3	17,513.6	0.0	0.0	2,136.0
20	330.3	2,608.9	18,754.5	0.0	0.0	2,154.1
21	448.8	6,006.0	21,444.2	0.0	0.0	2,158.3
22	526.2	8,226.8	23,201.0	0.0	0.0	2,158.9
23	548.8	8,874.3	23,713.2	0.0	0.0	2,159.0
24	553.4	9,006.4	24,294.4	0.0	0.0	2,159.0
25	627.0	9,031.3	26,688.5	0.0	0.0	2,159.0
26	787.1	9,036.0	28,022.0	0.0	0.0	2,159.0
27	891.6	9,036.8	28,886.0	0.0	0.0	2,159.0
28	922.1	9,037.0	29,137.4	0.0	0.0	2,159.0
29	927.9	9,037.0	29,185.3	0.0	0.0	2,159.0
30	1,004.5	10,069.8	29,233.9	0.0	0.0	2,159.0

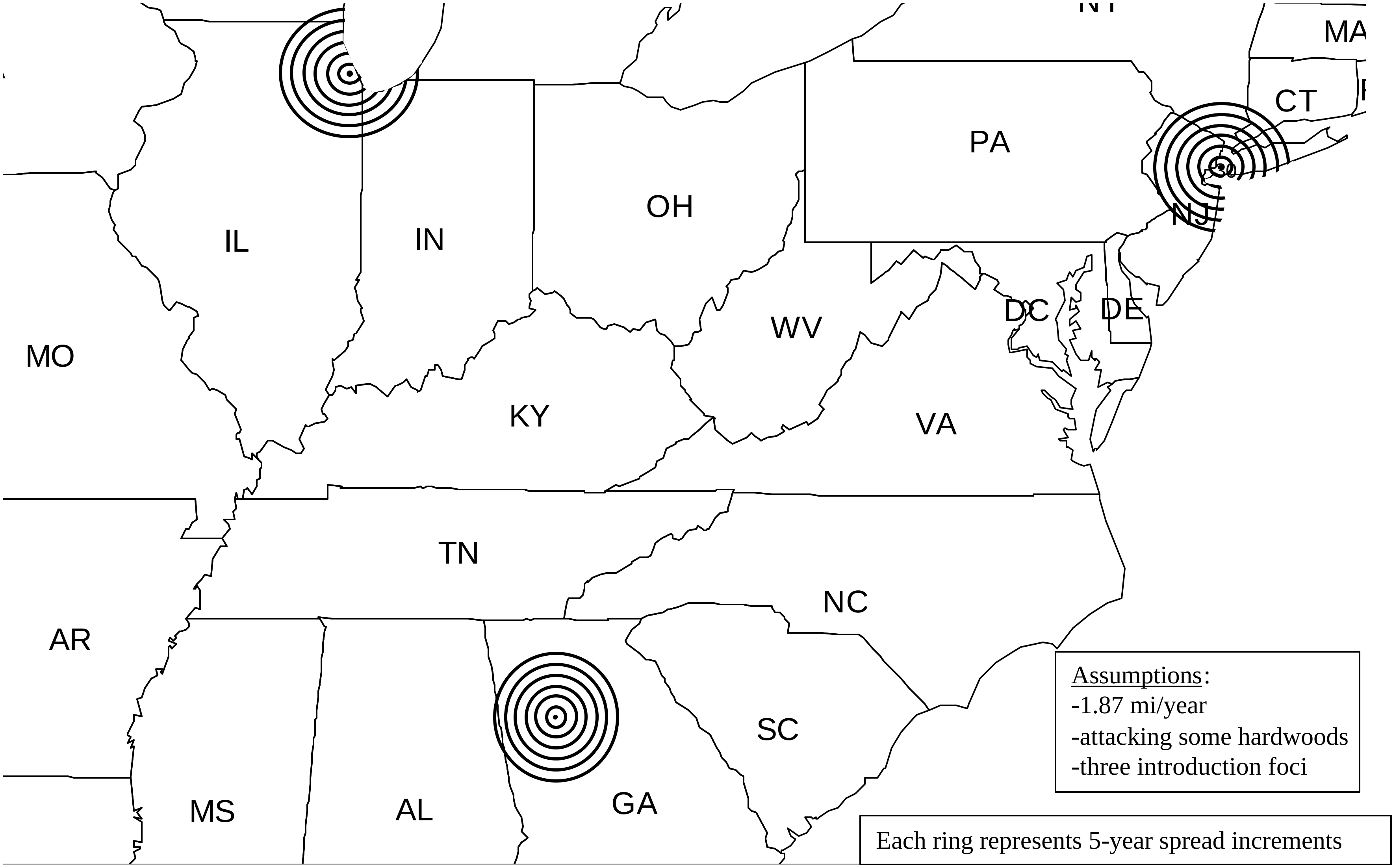


Figure 19. Expansion forecast over 30 years for Asian longhorned beetle introduction into New York, NY, Chicago, IL, and Atlanta, GA, on the assumption of the worst-case (faster spread rate) scenario. Circles represent the maximum extent of spread for the specified years; however, timber losses were based upon timber inventory (FIA) data for counties (boundaries not shown) encompassed within the annual rings of hypothetical infestation spread.

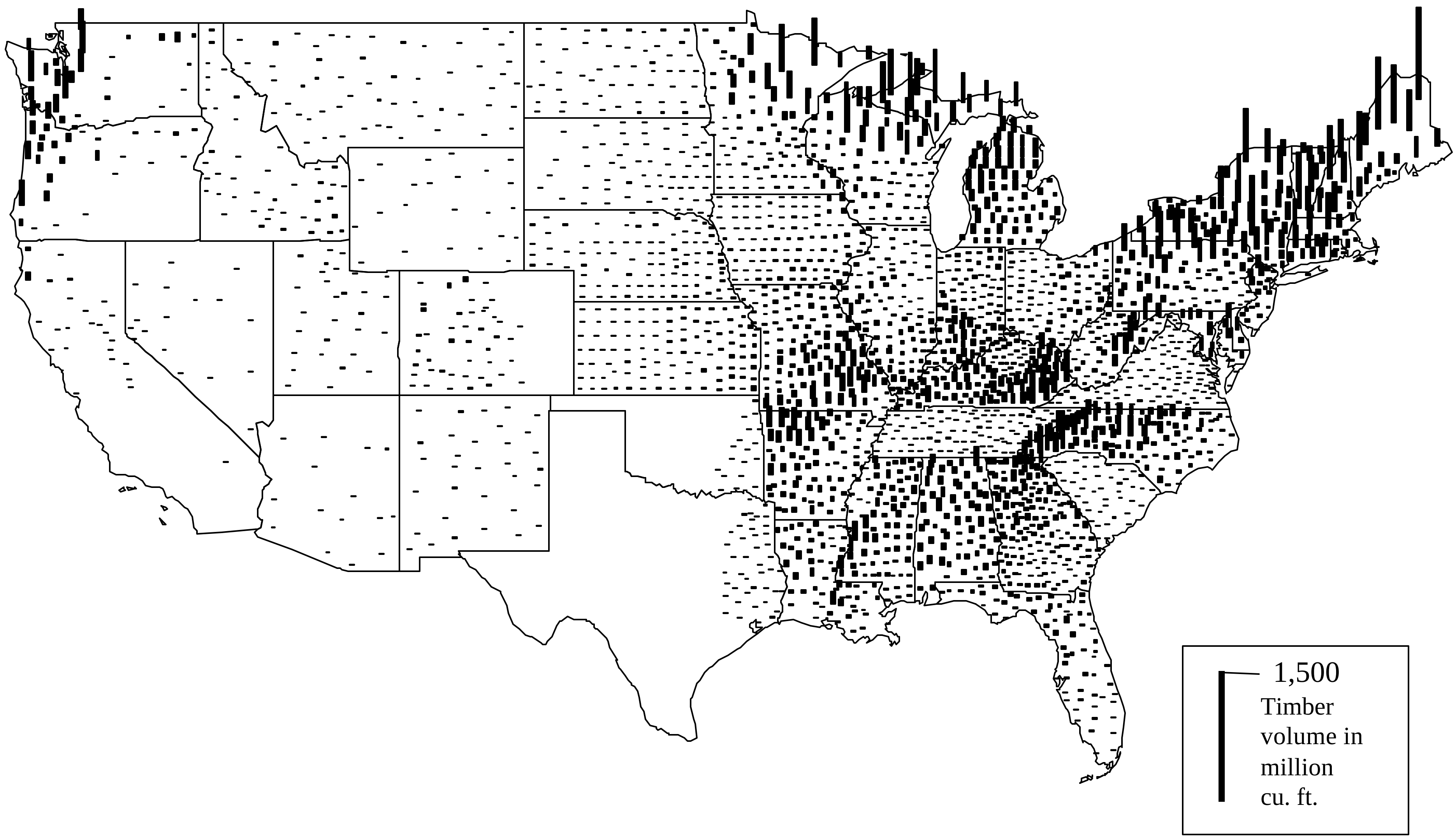


Figure 20. Distribution of timber volumes (by county) of potential tree hosts at risk for infestation by the Asian longhorned beetle on timberlands in the continental United States.

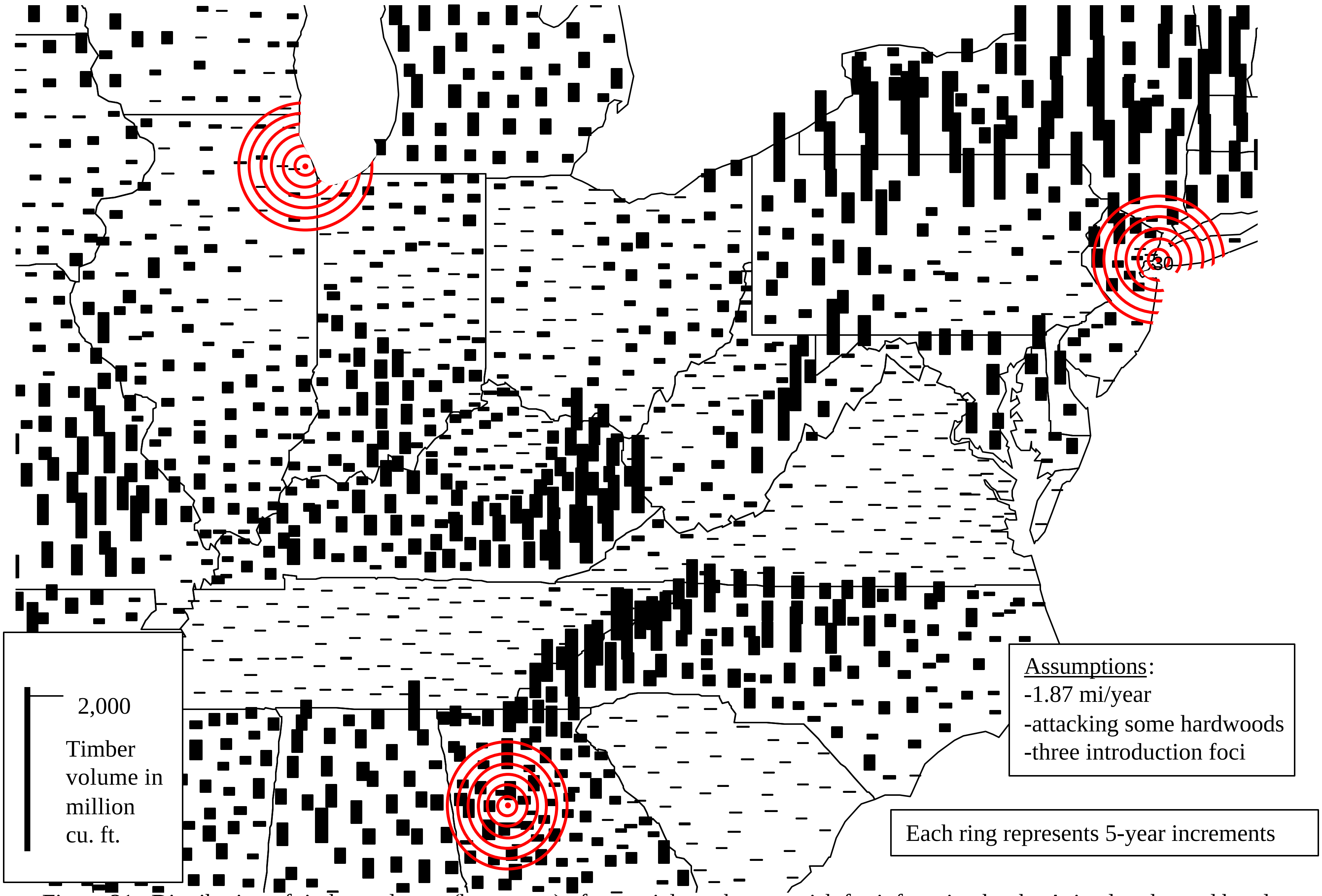


Figure 21. Distribution of timber volumes (by county) of potential tree hosts at risk for infestation by the Asian longhorned beetle on timberlands in relation to hypothetical spread from New York, NY, Chicago, IL, and Atlanta, GA. Circles represent the maximum extent of spread for the specified years; however, timber losses were based upon timber inventory (FIA) data for counties encompassed within the annual rings of hypothetical infestation spread.

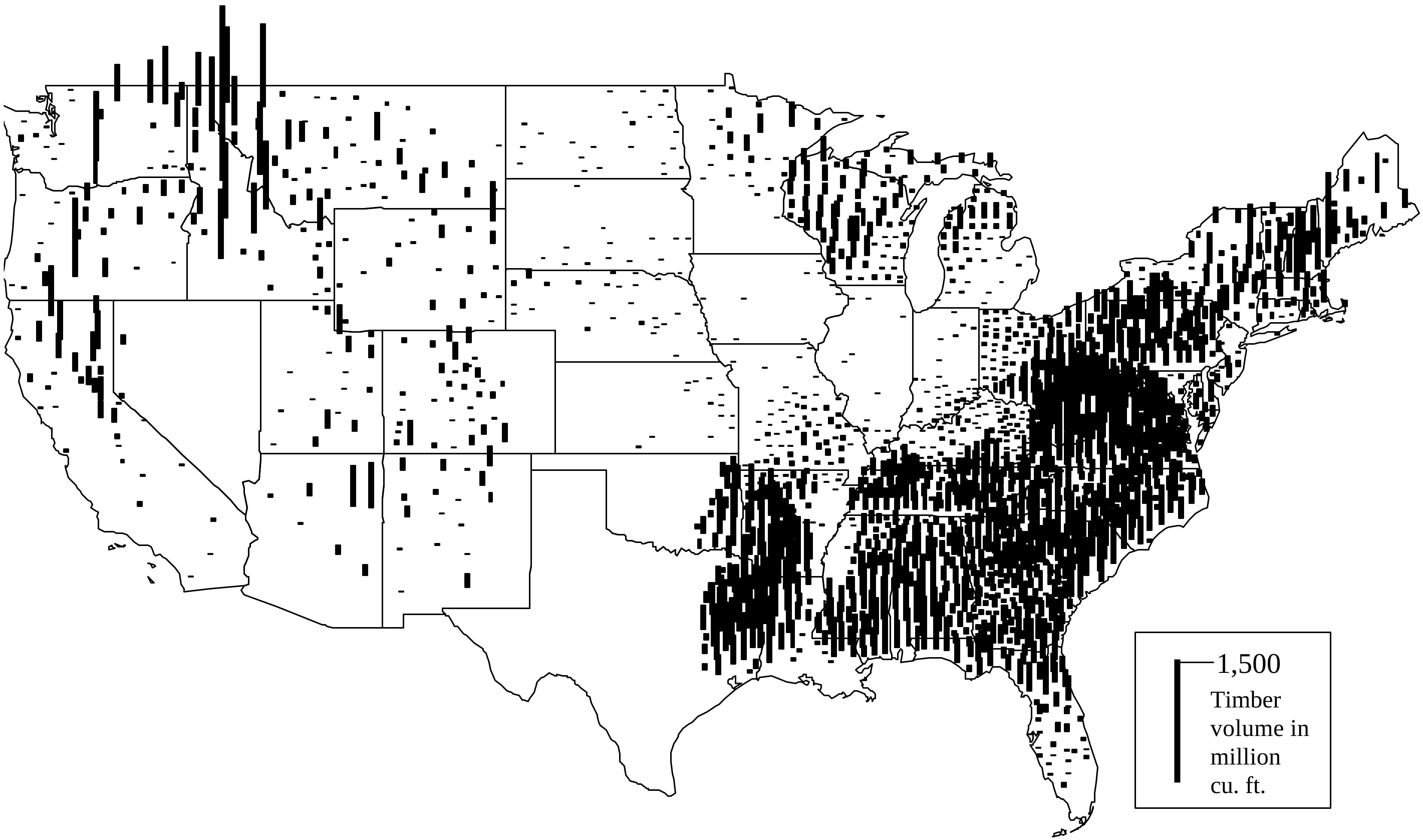


Figure 22. Distribution of timber volumes (by county) of potential tree hosts at risk for infestation by a sirex woodwasp (*Sirex noctilio*) on timberlands in the continental United States.

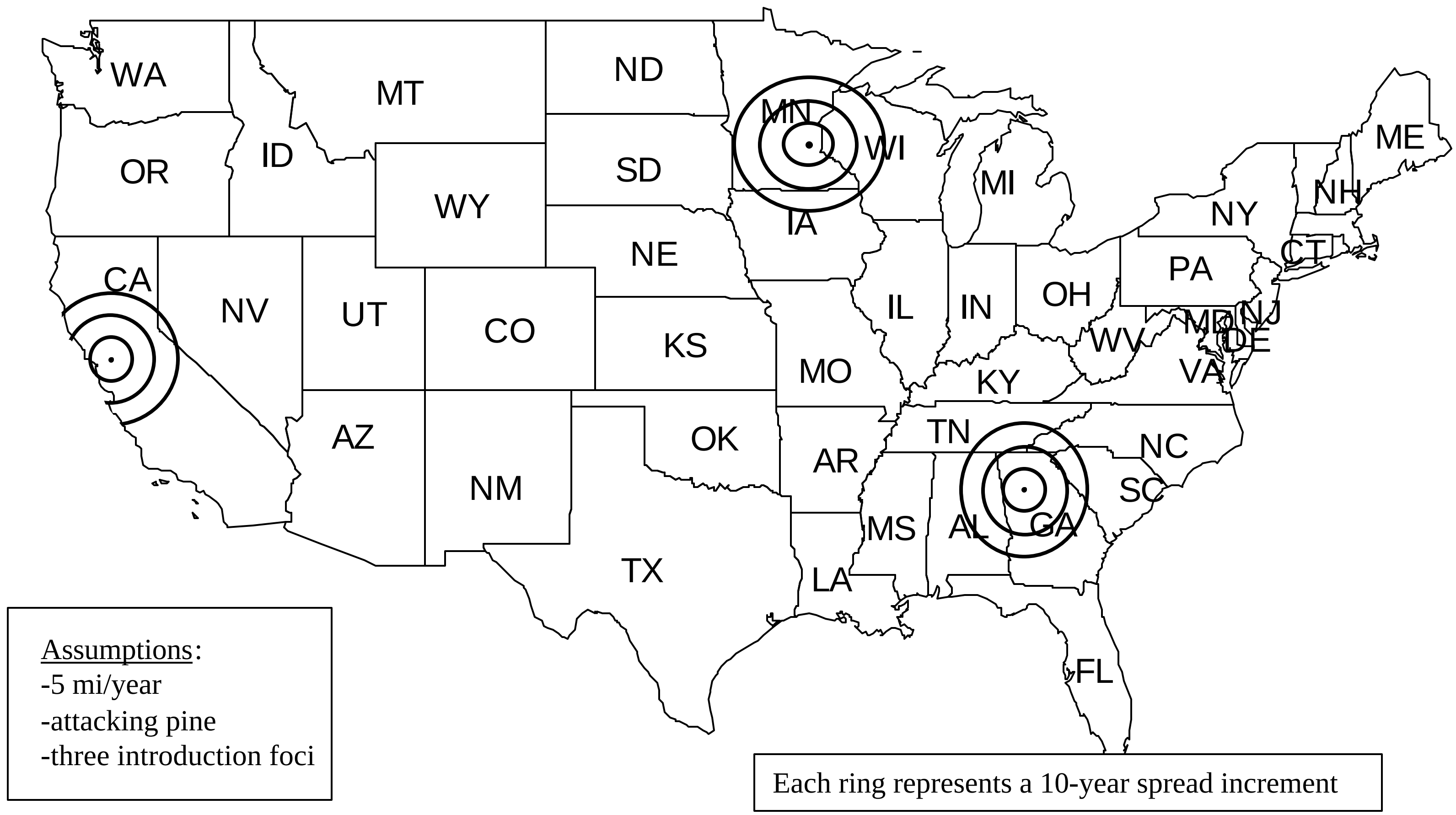


Figure 23. Expansion forecast over 30 years for a sirex woodwasp (*Sirex noctilio*) on the assumption of the best-case (slow spread rate) scenario. Circles represent the maximum extent of spread for the specified years; however, timber losses were based upon timber inventory (FIA) data for counties (boundaries not shown) encompassed within the annual rings of hypothetical infestation spread.

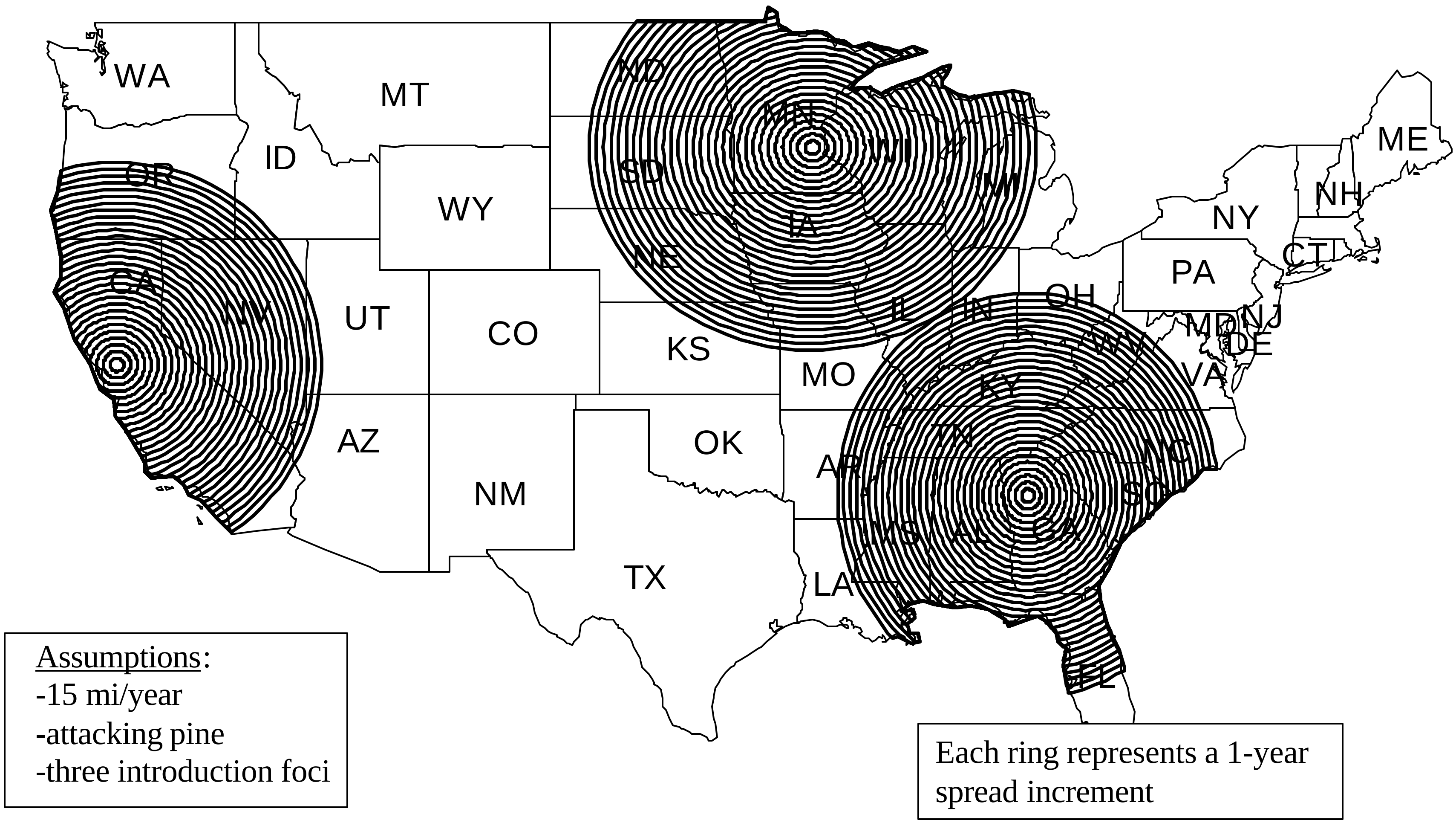


Figure 24. Expansion forecast over 30 years for a sirex woodwasp (*Sirex noctilio*) on the assumption of the worst-case (faster spread rate) scenario. Circles represent the maximum extent of spread for the specified years; however, timber losses were based upon timber inventory (FIA) data for counties (boundaries not shown) encompassed within the annual rings of hypothetical infestation spread.

Table 23. Projected yearly timber volume losses (in million cubic feet) due to damage by *Sirex noctilio*

Year	Worst-Case Scenario			Best-Case Scenario		
	Minneapolis, MN	Atlanta, GA	San Francisco, CA	Minneapolis, MN	Atlanta, GA	San Francisco, CA
1	0.00	0.02	0.00	0.00	0.00	0.00
2	0.10	0.70	0.00	0.00	0.01	0.00
3	0.10	1.86	0.00	0.01	0.09	0.00
4	1.38	7.84	0.00	0.06	0.44	0.03
5	4.26	26.77	0.01	0.22	1.50	0.10
6	13.61	65.48	0.35	0.60	4.05	0.27
7	21.76	135.71	2.59	1.37	9.25	0.61
8	35.04	243.22	10.78	2.78	18.77	1.24
9	61.62	394.55	30.37	5.16	34.78	2.31
10	101.92	616.77	63.33	8.88	59.86	3.97
11	150.24	902.12	105.55	14.36	96.78	6.42
12	185.46	1,226.54	139.37	21.95	147.96	9.82
13	230.81	1,686.32	159.57	31.81	214.44	14.22
14	280.18	1,737.04	176.53	43.69	294.54	19.54
15	325.43	1,818.62	188.59	56.69	382.18	25.35
16	418.43	2,430.52	202.10	69.07	465.66	30.89
17	553.63	2,823.38	224.67	78.33	528.02	35.03
18	688.05	3,390.58	237.53	81.69	550.70	36.53
19	543.34	3,836.16	226.60	77.20	520.39	34.52
20	620.14	4,162.39	216.03	64.89	437.44	29.02
21	565.58	4,305.53	220.39	47.47	319.98	21.23
22	520.52	4,738.46	220.76	29.44	198.46	13.17
23	487.60	4,844.16	372.01	15.02	101.28	6.72
24	433.02	4,997.20	176.64	6.09	41.09	2.72
25	432.98	4,965.46	162.53	1.89	12.74	0.84
26	367.57	6,028.55	170.98	0.43	2.89	0.19
27	329.92	5,791.71	194.72	0.07	0.45	0.03
28	340.30	5,336.43	211.57	0.01	0.05	0.00
29	390.00	5,532.41	253.52	0.00	0.00	0.00
30	616.91	6,415.86	162.79	0.00	0.00	0.00

Table 24. Projected cumulative monetary losses in timber production (in thousands of 1998 dollars discounted 7 percent) for *Sirex noctilio*

	Worst-Case Scenario			Best-Case Scenario		
Year	**Minneapolis, MN**	**Atlanta, GA**	**San Francisco, CA**	**Minneapolis, MN**	**Atlanta, GA**	**San Francisco, CA**
1	0.0	0.7	0.0	0.0	0.0	0.0
2	2.9	20.9	0.0	0.0	0.2	0.0
3	5.7	72.2	0.0	0.4	2.6	0.0
4	41.3	274.0	0.0	2.1	14.0	1.6
5	143.9	918.0	0.8	7.4	50.2	6.6
6	449.9	2,390.2	17.5	21.0	141.2	19.3
7	907.2	5,241.5	131.9	49.8	335.7	46.4
8	1,595.2	10,017.6	576.9	104.5	704.3	97.8
9	2,725.9	17,258.5	1,748.4	199.1	1,342.5	186.8
10	4,474.0	27,837.0	4,031.2	351.4	2,369.2	330.0
11	6,882.2	42,297.5	7,587.3	581.6	3,920.6	546.3
12	9,660.5	60,672.0	11,975.6	910.4	6,137.1	855.4
13	12,892.0	84,281.7	16,671.3	1,355.8	9,139.4	1,274.0
14	16,558.1	107,010.5	21,526.2	1,927.5	12,993.4	1,811.4
15	20,537.8	129,250.0	26,373.6	2,620.8	17,667.0	2,463.0
16	25,319.9	157,027.8	31,228.4	3,410.2	22,988.7	3,205.0
17	31,233.2	187,184.4	36,272.2	4,246.8	28,628.5	3,991.4
18	38,101.6	221,030.2	41,255.9	5,062.3	34,125.8	4,757.9
19	43,170.6	256,818.8	45,699.2	5,782.4	38,980.7	5,434.9
20	48,577.6	293,110.4	49,658.2	6,348.2	42,794.8	5,966.7
21	53,186.2	328,194.2	53,432.7	6,735.0	45,402.1	6,330.2
22	57,150.2	364,279.8	56,966.3	6,959.2	46,913.5	6,541.0
23	60,620.6	398,756.9	62,531.3	7,066.2	47,634.4	6,641.5
24	63,500.9	431,996.4	65,000.8	7,106.7	47,907.7	6,679.6
25	66,192.5	462,864.1	67,124.4	7,118.4	47,986.9	6,690.6
26	68,328.1	497,888.8	69,212.3	7,120.9	48,003.6	6,693.0
27	70,119.4	529,336.2	71,434.5	7,121.3	48,006.1	6,693.3
28	71,846.3	556,415.9	73,691.1	7,121.3	48,006.3	6,693.3
29	73,574.8	580,937.1	76,052.8	7,121.3	48,006.4	6,693.4
30	76,130.3	607,513.5	77,470.1	7,121.3	48,006.4	6,693.4

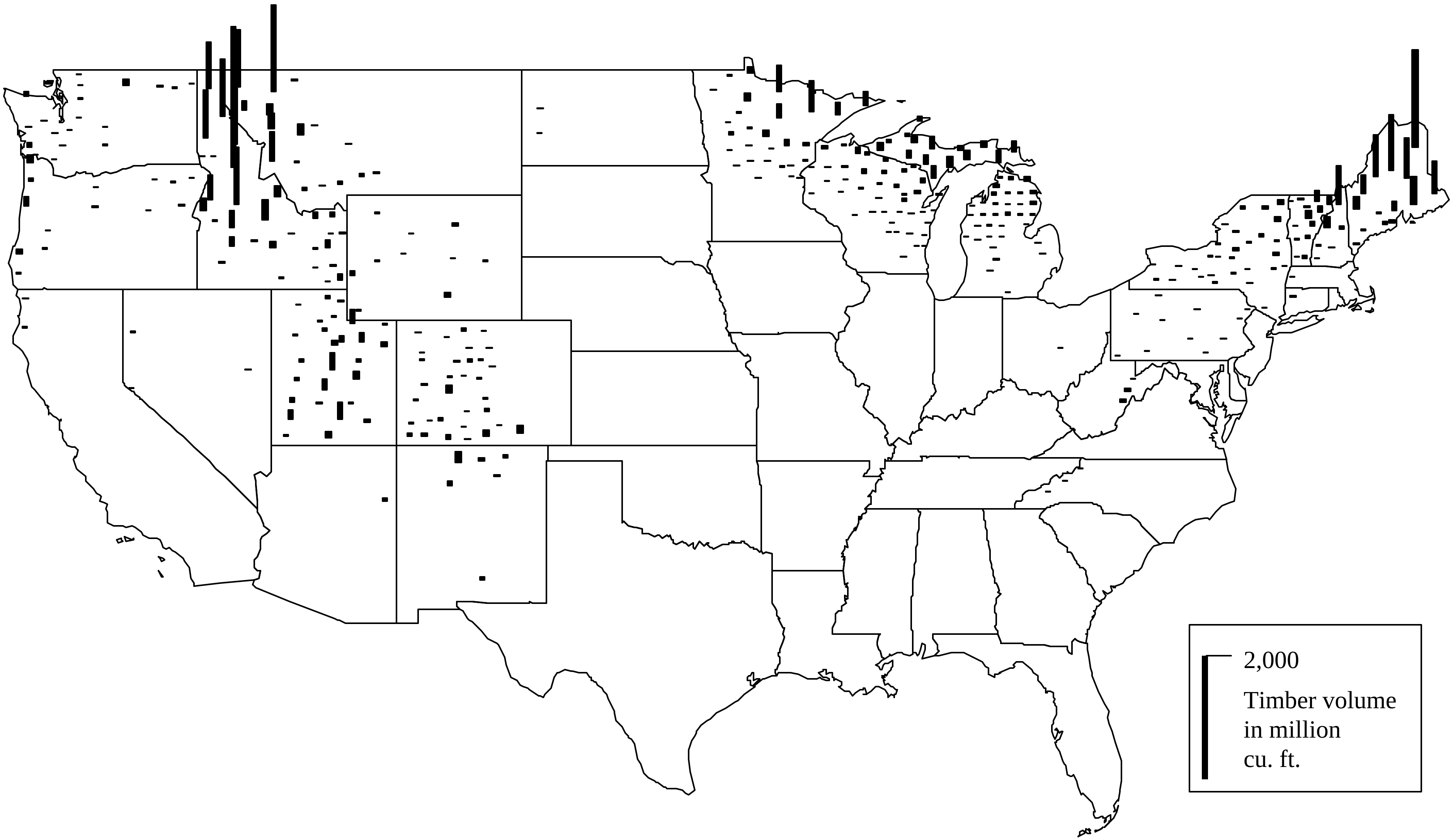


Figure 25. Distribution of timber volumes (by county) of potential tree hosts at risk for infestation by the European spruce bark beetle (*Ips typographus*) on timberlands in the continental United States.

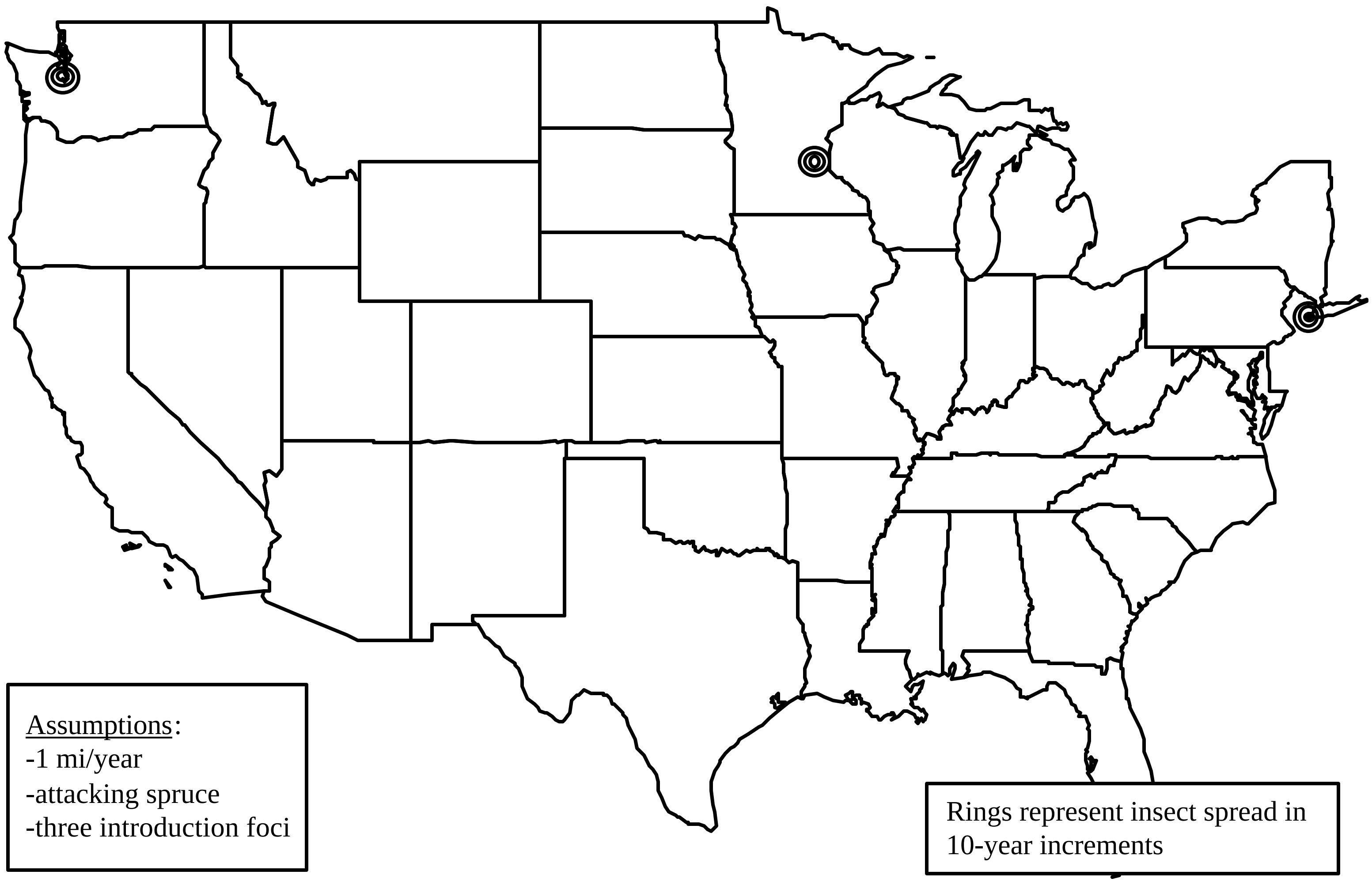


Figure 26. Expansion forecast over 30 years for the European spruce bark beetle (*Ips typographus*) on the assumption of the best-case (slow spread rate) scenario.

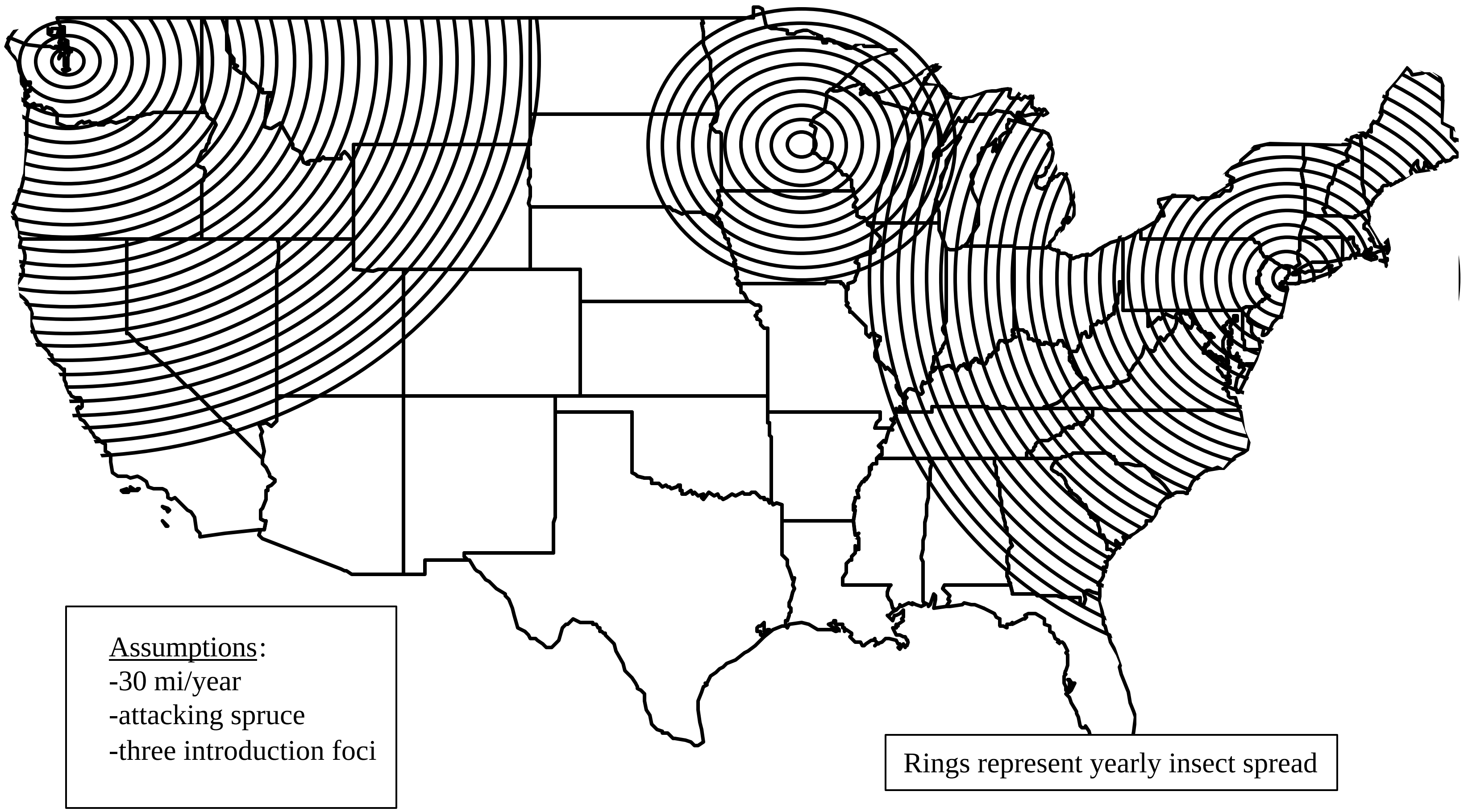


Figure 27. Expansion forecast over 30 years for the European spruce bark beetle (*Ips typographus*) on the assumption of the worst-case (faster spread rate) scenario. Circles represent the maximum extent of spread for the specified years; however, timber losses were based upon timber inventory (FIA) data for counties (boundaries not shown) encompassed within the annual rings of hypothetical infestation spread.

Table 25. Projected yearly timber volume losses (in million cubic feet) due to damage by the European spruce bark beetle

Year	Worst-Case Scenario			Best-Case Scenario		
	Minneapolis, MN	New York, NY	Seattle, WA	Minneapolis, MN	New York, NY	Seattle, WA
1	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.02	0.00	0.00	0.00
3	0.00	0.05	0.25	0.00	0.00	0.00
4	0.00	0.40	1.80	0.00	0.00	0.00
5	0.03	1.53	8.10	0.00	0.00	0.00
6	0.41	3.60	24.77	0.00	0.00	0.00
7	39.75	7.55	53.56	0.00	0.00	0.00
8	14.66	72.60	84.68	0.00	0.00	0.00
9	46.87	189.80	98.94	0.00	0.00	0.00
10	109.31	134.06	80.35	0.00	0.00	0.01
11	291.73	193.66	61.06	0.00	0.01	0.01
12	626.43	273.19	60.13	0.00	0.01	0.02
13	370.80	357.91	44.01	0.00	0.01	0.02
14	243.71	405.80	21.43	0.00	0.01	0.02
15	271.61	369.37	23.17	0.00	0.02	0.03
16	824.27	393.93	16.24	0.00	0.02	0.03
17	108.81	603.25	9.09	0.00	0.02	0.04
18	129.25	758.59	5.25	0.00	0.02	0.04
19	387.41	704.95	2.63	0.00	0.03	0.05
20	120.96	611.28	3.22	0.00	0.03	0.05
21	919.39	345.95	4.98	0.00	0.03	0.05
22	561.94	134.64	3.53	0.00	0.03	0.05
23	345.37	102.88	1.02	0.00	0.03	0.05
24	503.34	103.98	0.21	0.00	0.03	0.05
25	642.81	165.63	0.04	0.00	0.02	0.04
26	631.92	47.38	0.01	0.00	0.02	0.04
27	221.00	28.60	0.00	0.00	0.02	0.04
28	0.00	1.00	0.00	0.00	0.02	0.03
29	0.00	0.40	0.00	0.00	0.01	0.02
30	0.00	2.00	0.00	0.00	0.01	0.02

Table 26. Projected cumulative monetary timber losses (in thousands of 1998 dollars discounted 7 percent) for the European spruce bark beetle

Year	Worst-Case Scenario			Best-Case Scenario		
	Minneapolis, MN	New York, NY	Seattle, WA	Minneapolis, MN	New York, NY	Seattle, WA
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.1	0.8	0.0	0.0	0.0
3	0.0	2.1	10.5	0.0	0.0	0.0
4	0.0	16.3	75.1	0.0	0.0	0.0
5	1.0	67.4	346.5	0.0	0.0	0.0
6	13.8	180.1	1,121.9	0.0	0.1	0.1
7	1,176.9	401.1	2,689.0	0.0	0.1	0.2
8	1,577.8	2,386.3	5,004.7	0.0	0.2	0.3
9	2,775.7	7,237.1	7,533.3	0.0	0.3	0.5
10	5,386.6	10,439.0	9,452.5	0.0	0.4	0.7
11	11,898.7	14,761.8	10,815.6	0.0	0.6	1.0
12	24,967.2	20,461.0	12,070.0	0.0	0.8	1.3
13	32,196.6	27,439.1	12,928.2	0.0	1.0	1.7
14	36,637.5	34,833.5	13,318.7	0.0	1.2	2.2
15	41,262.8	41,123.7	13,713.3	0.0	1.5	2.7
16	54,381.3	47,393.2	13,971.8	0.0	1.8	3.2
17	55,999.8	56,366.0	14,107.0	0.0	2.1	3.8
18	57,796.4	66,911.3	14,180.0	0.0	2.5	4.4
19	62,829.6	76,069.8	14,214.2	0.0	2.8	5.0
20	64,298.2	83,491.9	14,253.3	0.0	3.1	5.6
21	74,730.9	87,417.5	14,309.8	0.0	3.5	6.1
22	80,690.3	88,845.3	14,347.2	0.0	3.8	6.7
23	84,113.4	89,865.0	14,357.3	0.0	4.1	7.2
24	88,775.7	91,078.3	14,359.2	0.0	4.3	7.6
25	94,340.4	92,512.2	14,359.6	0.0	4.5	8.0
26	99,453.0	92,895.6	14,359.6	0.0	4.7	8.4
27	101,124.1	93,111.8	14,359.7	0.0	4.9	8.6
28	101,124.1	93,118.8	14,359.7	0.0	5.0	8.8
29	101,124.1	93,121.3	14,359.7	0.0	5.1	9.0
30	101,124.1	93,132.9	14,359.7	0.0	5.1	9.1

introduction into Minneapolis, 758 million cubic feet for introduction into New York, and 98 million cubic feet for introduction into Seattle (table 25). Cumulative discounted values for timber loss after 30 years would be $101 million for Minneapolis, $93 million for New York, and $14 million for Seattle (table 26).

Although nun moth (*Lymantria monacha* L.) prefers many conifer hosts, it also will attack a variety of hardwoods. Timberland resources at risk are largely concentrated in the East, Great Lakes region, and Northwest (fig. 28). In the best-case scenario, spread would reach a radius of only 90 miles (145 km) after 30 years (fig. 29); however, spread could extend 450 miles (724 km) from the point of origin under the worst-case scenario (fig. 30). For the best-case scenario, maximum annual volume losses are expected to be about 100 million cubic feet for introductions into New York and Minneapolis and about 700 million cubic feet for Seattle (table 27). Cumulative discounted timber loss values after 30 years would be about $28–30 million for New York and Minneapolis and about $169 million for Seattle (table 28). Affected timber volumes would generally be more variable from year to year for the worst-case scenario at all three locations modeled because of uneven distributions of host trees (table 27). Maximum annual damage could reach nearly 8 billion cubic feet for introduction into New York, nearly 7 billion cubic feet for Minneapolis, and 3 billion cubic feet for Seattle. For the worst case scenarios, cumulative discounted timber loss values after 30 years would be about $721 million for Minneapolis, $891 million for Seattle, and $921 million for New York (table 28).

Several nonindigenous species or strains of *Heterobasidion* cause root rots that may affect a variety of conifer and hardwood hosts. Timberland resources at risk for introduction occur in the East, Great Lakes region, and West (fig. 31). Spread is expected to be slow, extending only 30 km (18 miles) from the point of origin within 30 years under the worst-case scenario (fig. 32). Economic damage levels are expected to be relatively low under all scenarios and locations modeled (tables 29 and 30). Even under the worst-case scenario, maximum annual volume losses would likely only reach 16 million cubic feet. Cumulative discounted timber value losses after 30 years are expected to range from about $266,500 in Portland, OR, to $1.8 million in Atlanta, GA (table 30). Past introductions of other forest pathogens with faster spread rates demonstrate the high potential for economic damage for some wood pathogens, however.

Pest Risk Potential for Selected Pests That May Be Transported With SWPM

Evaluations of the likelihood of introduction and consequences of introduction, when combined for a given organism, result in an assessment of pest risk potential, which is often expressed qualitatively with ratings of low, moderate, or high risk. Pest risk potential varies with pathway or mode of conveyance, biological characteristics of the organism, environmental requirements, host range, and availability of potential hosts in a new environment.

Nineteen potential pest species or groups that may be transported with SWPM were selected for detailed qualitative risk assessment and were chosen to represent combinations of geographic origin (i.e., temperate or tropical and subtropical), host type (i.e., conifers or hardwoods), and pest habitat (i.e., in deep wood, under bark, or on bark) (appendix C). The selected species or groups included an array of insects, fungi, and insect vector–pathogen associations (table D–1 in appendix D). The selected organisms are meant to serve as examples of the kinds of exotic pest threats that exist in relation to importation of SWPM into the United States and do not constitute a comprehensive listing or assessment of the organisms likely to pose some level of threat to U.S. tree resources. Each selected pest species or group was assessed separately by describing background information about the organism and assigning risk ratings to seven elements that were combined into an overall rating for pest risk potential.

Four elements were rated to describe the likelihood of pest introduction: presence with host at origin potential, entry potential, establishment potential, and spread potential. Consequences of introduction were described by three additional elements: economic impact potential, environmental impact potential, and social and political

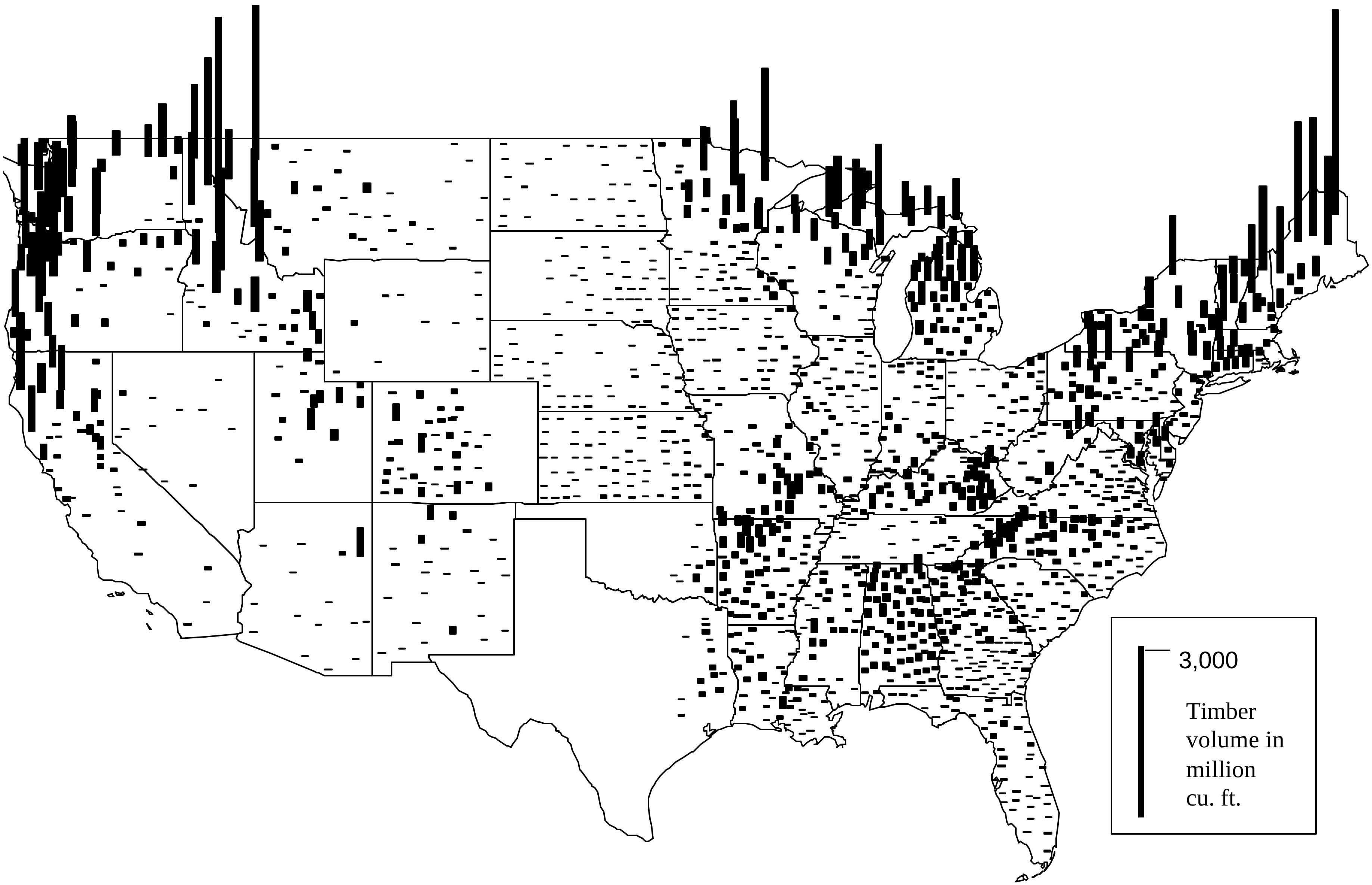


Figure 28. Distribution of timber volumes (by county) of potential tree hosts at risk for infestation by the nun moth (*Lymantria monacha*) on timberlands in the continental United States.

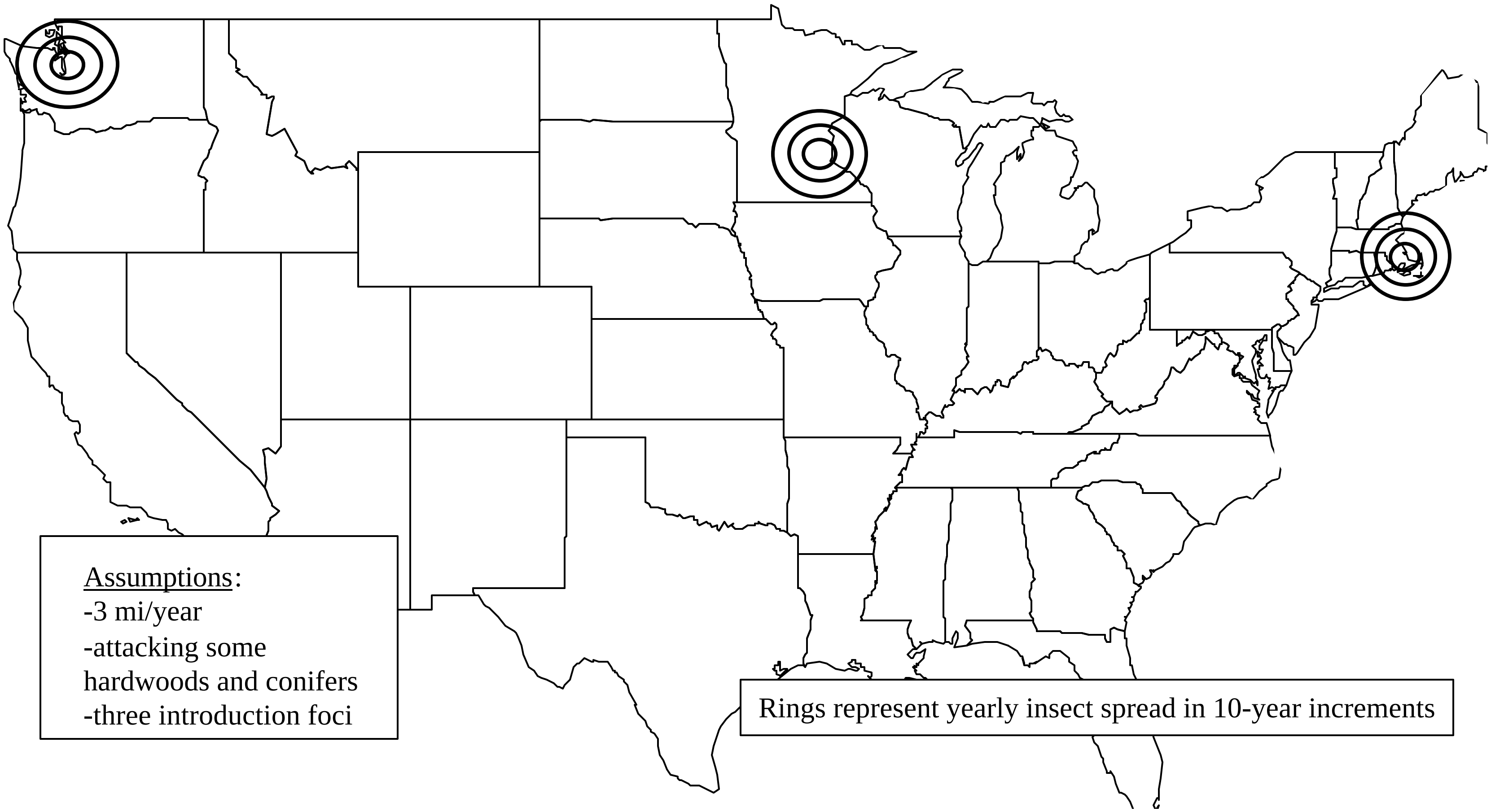


Figure 29. Expansion forecast over 30 years for the nun moth (*Lymantria monacha*) on the assumption of the best-case (slow spread rate) scenario. Circles represent the maximum extent of spread for the specified years; however, timber losses were based upon timber inventory (FIA) data for counties (boundaries not shown) encompassed within the annual rings of hypothetical infestation spread.

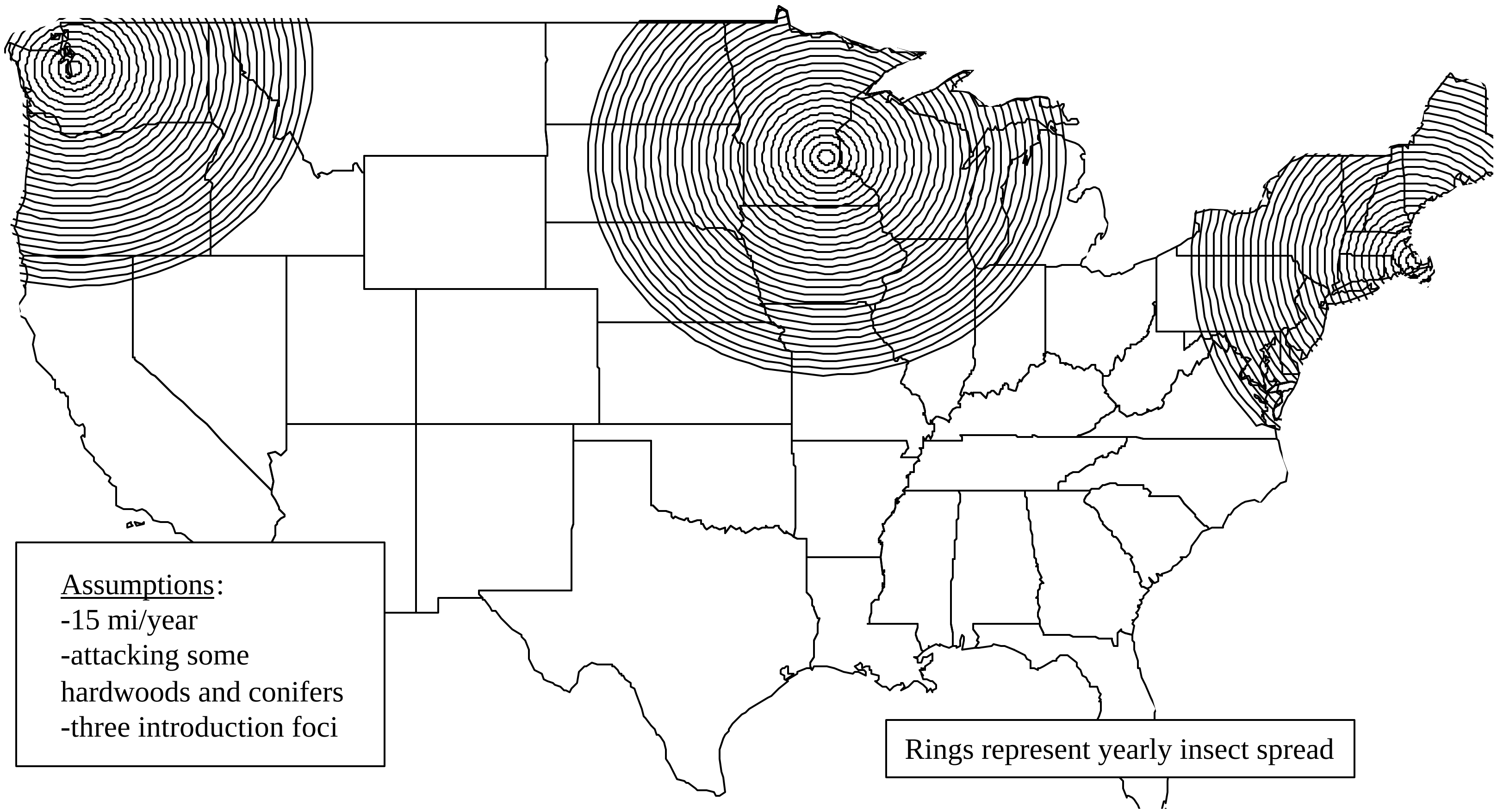


Figure 30. Expansion forecast over 30 years for the nun moth (*Lymantria monacha*) on the assumption of the worst-case (faster spread rate) scenario. Circles represent the maximum extent of spread for the specified years; however, timber losses were based upon timber inventory (FIA) data for counties (boundaries not shown) encompassed within the annual rings of hypothetical infestation spread.

Table 27. Projected yearly timber volume losses (in million cubic feet) due to damage by the nun moth

Year	Worst-Case Scenario			Best-Case Scenario		
	New York, NY	**Minneapolis, MN**	**Seattle, WA**	**New York, NY**	**Minneapolis, MN**	**Seattle, WA**
1	0.00	0.01	0.00	0.00	0.01	0.00
2	0.00	1.68	0.00	0.00	0.11	0.00
3	119.26	51.39	5.60	0.36	0.46	2.56
4	111.74	260.28	93.31	0.98	1.24	6.89
5	130.90	360.06	477.52	2.06	2.61	14.51
6	4.20	6.50	2,706.39	3.74	4.74	26.33
7	23.98	777.34	1,613.23	6.14	7.77	43.23
8	42.15	7.66	1,724.72	9.37	11.87	65.98
9	1,456.52	1,744.43	2,286.86	13.53	17.13	95.24
10	2,047.25	1,031.68	2,403.26	18.68	23.65	131.48
11	5,500.58	2,017.38	3,052.50	24.85	31.45	174.89
12	169.48	63.61	2,252.33	32.02	40.52	225.32
13	1,034.69	2,872.58	2,114.44	40.10	50.75	282.17
14	530.43	1,690.01	876.25	48.93	61.93	344.33
15	0.98	1,024.88	1,002.74	58.28	73.76	410.10
16	1,133.45	6,930.92	1,162.25	67.81	85.82	477.19
17	5,885.42	907.74	1,658.00	77.13	97.61	542.74
18	7,701.56	2,369.00	2,185.87	85.75	108.53	603.44
19	641.16	1,625.34	1,483.76	93.18	117.94	655.74
20	801.97	2,028.20	1,005.34	98.91	125.19	696.06
21	482.71	633.41	1,203.30	102.49	129.71	721.21
22	892.98	179.71	872.79	103.55	131.06	728.72
23	115.39	285.50	1,060.36	101.92	128.99	717.22
24	5,306.27	2,455.62	1,233.37	97.58	123.50	686.69
25	3,373.75	1,000.00	1,138.34	90.75	114.86	638.63
26	651.18	0.00	631.17	81.85	103.60	576.00
27	762.72	200.00	545.19	71.47	90.46	502.95
28	44.01	900.00	402.79	60.30	76.32	424.36
29	352.94	1,338.03	146.32	49.07	62.10	345.30
30	127.17	3,353.14	109.75	38.42	48.63	270.39

Table 28. Projected cumulative timber losses (in thousands of 1998 dollars discounted 7 percent) due to damage by the nun moth

	Worst-Case Scenario			Best-Case Scenario		
Year	**New York, NY**	**Minneapolis, MN**	**Seattle, WA**	**New York, NY**	**Minneapolis, MN**	**Seattle, WA**
1	0.0	5.2	0.0	0.0	0.4	0.0
2	0.0	94.6	0.0	0.0	6.0	0.0
3	7,062.7	2,689.2	282.5	21.5	29.3	129.2
4	13,247.1	14,969.9	4,685.2	75.7	87.7	454.2
5	20,018.1	30,847.2	25,742.5	182.3	202.8	1,093.9
6	20,221.2	31,115.0	137,277.6	363.2	398.0	2,179.2
7	21,304.8	61,054.7	199,412.3	640.8	697.4	3,844.1
8	23,084.4	61,330.5	261,495.1	1,036.6	1,124.6	6,219.1
9	80,560.4	120,014.9	338,427.5	1,570.7	1,700.8	9,423.0
10	156,062.0	152,451.2	413,986.7	2,259.8	2,444.3	13,556.8
11	345,650.2	211,728.9	503,679.7	3,116.4	3,368.5	18,695.6
12	351,109.7	213,475.7	565,531.3	4,147.8	4,481.4	24,883.2
13	382,258.7	287,199.5	619,797.6	5,354.9	5,783.9	32,125.1
14	397,182.6	327,735.4	640,815.0	6,731.6	7,269.3	40,384.1
15	397,208.4	350,709.5	663,292.8	8,264.0	8,922.7	49,577.1
16	425,062.3	495,912.2	687,642.0	9,930.4	10,720.8	59,574.3
17	560,231.4	513,685.2	720,104.5	11,701.8	12,632.0	70,200.8
18	725,539.7	557,034.4	760,102.8	13,542.4	14,618.0	81,243.0
19	738,401.5	584,830.0	785,477.3	15,411.7	16,634.9	92,457.0
20	753,436.7	617,246.1	801,545.3	17,266.1	18,635.7	103,581.8
21	761,894.3	626,707.3	819,519.1	19,061.8	20,573.2	114,354.4
22	776,516.9	629,216.0	831,703.1	20,757.5	22,402.9	124,527.3
23	778,282.8	632,940.9	845,537.2	22,317.2	24,085.8	133,884.5
24	854,175.9	662,882.5	860,575.7	23,712.9	25,591.7	142,257.3
25	899,272.4	674,277.9	873,547.6	24,926.0	26,900.6	149,534.8
26	907,407.3	674,288.6	880,269.5	25,948.5	28,003.9	155,669.2
27	916,312.1	676,279.2	885,695.9	26,783.0	28,904.2	160,675.1
28	916,792.3	684,651.0	889,442.7	27,441.0	29,614.2	164,622.6
29	920,155.9	695,522.2	890,631.5	27,908.6	30,118.8	167,428.1
30	921,288.6	720,983.4	891,464.9	28,250.9	30,488.1	169,481.2

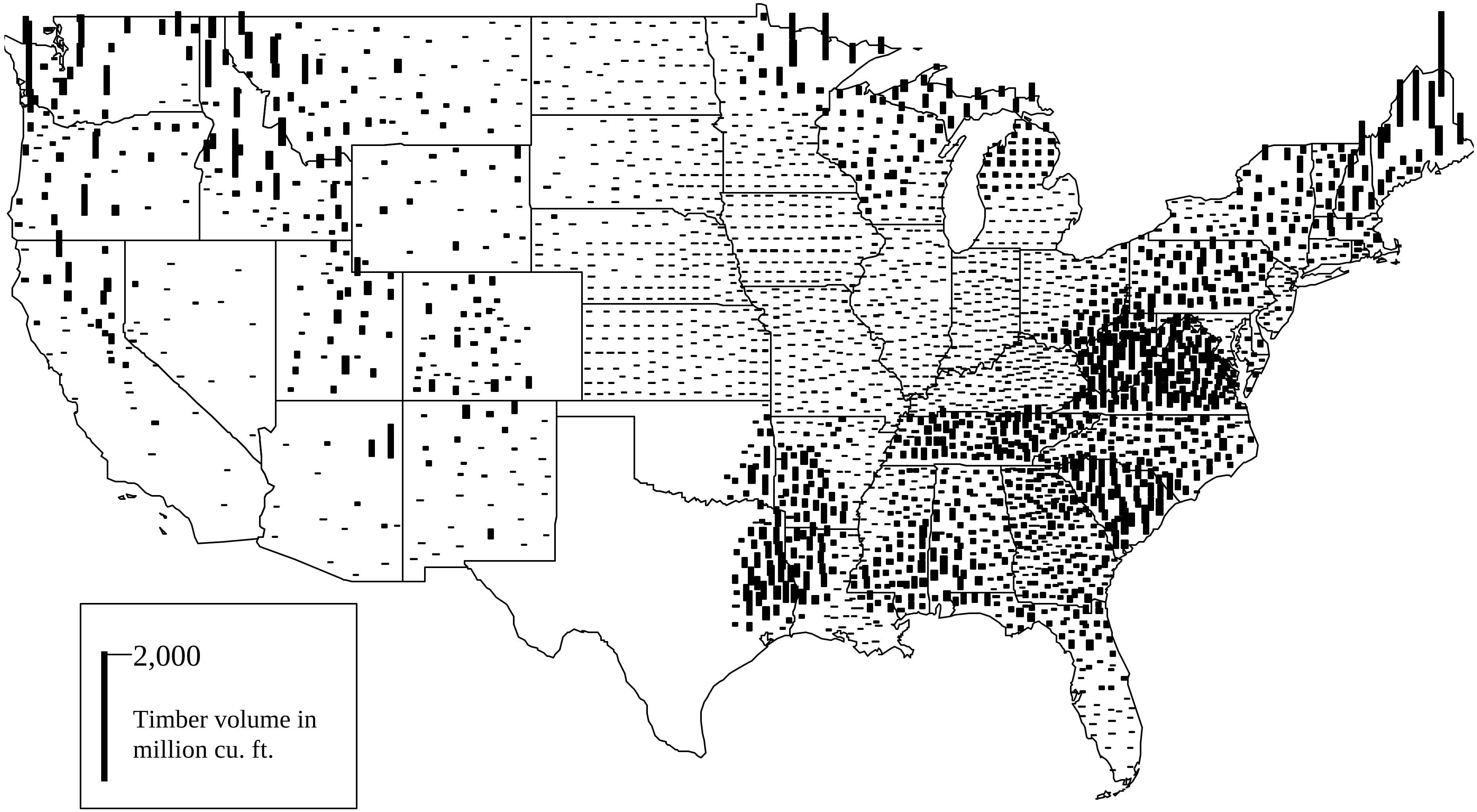
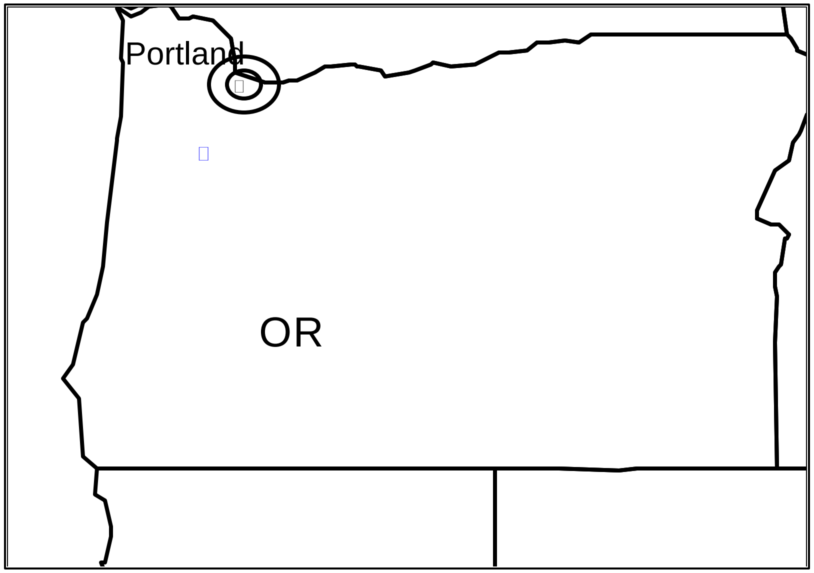


Figure 31. Distribution of timber volumes (by county) of potential tree hosts at risk for infestation by heterobasidion root rots on timberlands in the continental United States.



<u>Assumptions</u>:
-0.6 mi/year
-attacking several conifers
-five introduction foci

**Slow-spread diagram not shown. At the slow rate (100 m/yr [0.1 mi/yr]) this pest does not move beyond the confines of any given county for the 30- year period considered.*

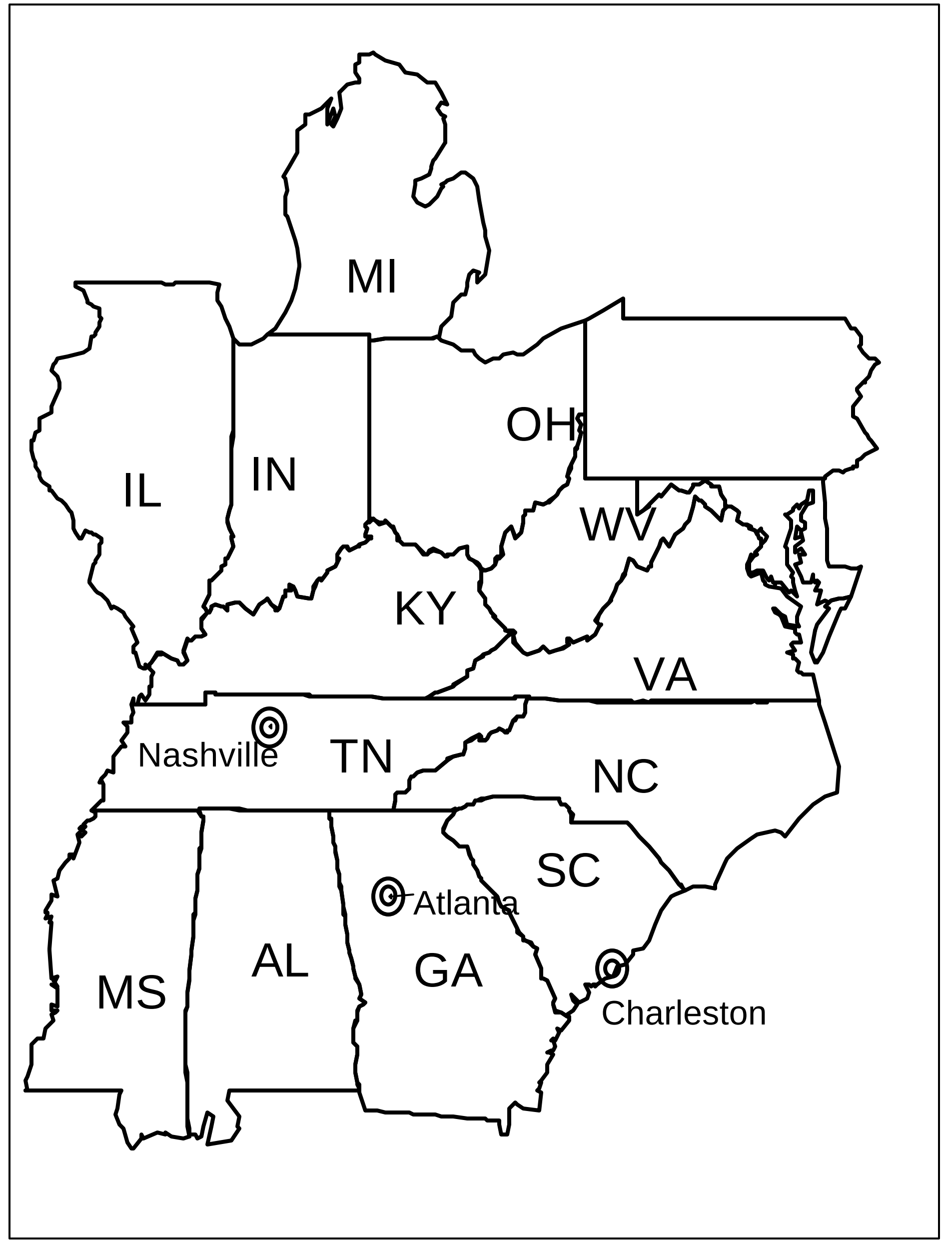


Figure 32. Expansion forecast over 30 years for heterobasidion root rots on the assumption of the worst-case (faster spread rate) scenario. Rings represent disease extent after 15 and 30 years.

Table 29. Projected yearly timber volume losses (in million cubic feet) due to damage by heterobasidion root rot

Year	Worst-Case Scenario				Best-Case Scenario			
	Nashville TN	**Charleston SC**	**Atlanta GA**	**Portland OR**	**Nashville TN**	**Charleston SC**	**Atlanta GA**	**Portland OR**
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.01	0.01	0.02	0.00	0.00	0.01	0.00	0.00
3	0.05	0.06	0.07	0.00	0.01	0.03	0.01	0.00
4	0.13	0.16	0.18	0.01	0.03	0.08	0.04	0.00
5	0.28	0.33	0.37	0.02	0.06	0.16	0.08	0.00
6	0.51	0.59	0.68	0.05	0.12	0.30	0.14	0.00
7	0.83	0.97	1.11	0.08	0.19	0.49	0.23	0.00
8	1.27	1.48	1.70	0.11	0.29	0.74	0.35	0.00
9	1.83	2.14	2.45	0.17	0.42	1.07	0.51	0.00
10	2.52	2.95	3.38	0.23	0.58	1.48	0.70	0.00
11	3.35	3.91	4.48	0.30	0.77	1.96	0.92	0.00
12	4.30	5.02	5.75	0.39	0.99	2.51	1.19	0.00
13	5.36	6.26	7.16	0.49	1.23	3.13	1.48	0.00
14	6.50	7.59	8.69	0.59	1.50	3.80	1.79	0.00
15	7.68	8.97	10.27	0.70	1.77	4.49	2.12	0.00
16	8.85	10.34	11.83	0.81	2.04	5.17	2.44	0.00
17	9.96	11.63	13.31	0.91	2.30	5.82	2.75	0.00
18	10.92	12.76	14.59	0.99	2.52	6.38	3.01	0.00
19	11.67	13.64	15.60	1.06	2.69	6.82	3.22	0.00
20	12.16	14.20	16.25	1.11	2.80	7.10	3.36	0.00
21	12.32	14.39	16.47	1.12	2.84	7.20	3.40	0.00
22	12.13	14.17	16.22	1.10	2.80	7.09	3.35	0.00
23	11.59	13.54	15.50	1.06	2.67	6.77	3.20	0.00
24	10.73	12.54	14.34	0.98	2.47	6.27	2.96	0.00
25	9.60	11.22	12.83	0.88	2.21	5.61	2.65	0.00
26	8.30	9.69	11.09	0.76	1.91	4.84	2.29	0.00
27	6.90	8.06	9.22	0.63	1.59	4.03	1.90	0.00
28	5.51	6.44	7.37	0.50	1.27	3.22	1.52	0.00
29	4.22	4.93	5.64	0.38	0.97	2.46	1.16	0.00
30	3.09	3.61	4.13	0.28	0.71	1.80	0.85	0.00

Table 30. Projected cumulative monetary timber losses (in thousands of 1998 dollars discounted 7 percent) for heterobasidion root rot

Year	Worst-Case Scenario				Best-Case Scenario			
	Nashville TN	Charleston SC	Atlanta GA	Portland OR	Nashville TN	Charleston SC	Atlanta GA	Portland OR
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.3	0.4	0.4	0.0	0.1	0.2	0.1	0.0
3	1.4	1.7	1.9	0.3	0.3	0.8	0.4	0.0
4	4.3	5.1	5.8	0.8	1.0	2.5	1.2	0.0
5	10.0	11.7	13.4	2.0	2.3	5.9	2.8	0.0
6	19.7	23.0	26.3	3.9	4.5	11.5	5.4	0.0
7	34.5	40.3	46.1	6.8	8.0	20.2	9.5	0.0
8	55.6	65.0	74.4	11.0	12.8	32.5	15.3	0.0
9	84.1	98.2	112.4	16.6	19.4	49.1	23.2	0.0
10	120.7	141.0	161.3	23.8	27.8	70.5	33.3	0.0
11	166.1	194.0	222.0	32.8	38.3	97.0	45.8	0.0
12	220.5	257.6	294.8	43.5	50.9	128.8	60.9	0.0
13	283.9	331.7	379.6	56.0	65.5	165.9	78.4	0.0
14	355.8	415.7	475.6	70.2	82.1	207.9	98.2	0.0
15	435.2	508.5	581.8	85.9	100.4	254.2	120.2	0.0
16	520.8	608.4	696.1	102.8	120.1	304.2	143.8	0.0
17	610.7	713.5	816.3	120.5	140.8	356.7	168.6	0.0
18	702.8	821.1	939.4	138.7	162.1	410.6	194.0	0.0
19	794.9	928.7	1,062.5	156.8	183.3	464.4	219.5	0.0
20	884.5	1,033.4	1,182.3	174.5	204.0	516.7	244.2	0.0
21	969.4	1,132.6	1,295.7	191.3	223.6	566.3	267.6	0.0
22	1,047.5	1,223.8	1,400.1	206.7	241.6	611.9	289.2	0.0
23	1,117.2	1,305.3	1,493.4	220.4	257.7	652.6	308.5	0.0
24	1,177.6	1,375.8	1,574.0	232.4	271.6	687.9	325.1	0.0
25	1,228.0	1,434.8	1,641.5	242.3	283.2	717.4	339.0	0.0
26	1,268.8	1,482.4	1,696.0	250.4	292.6	741.2	350.3	0.0
27	1,300.4	1,519.4	1,738.3	256.6	299.9	759.7	359.0	0.0
28	1,324.1	1,547.0	1,769.9	261.3	305.4	773.5	365.6	0.0
29	1,339.9	1,565.5	1,791.0	264.4	309.0	782.7	369.9	0.0
30	1,350.7	1,578.1	1,805.5	266.5	311.5	789.0	372.9	0.0

considerations. Criteria based upon characteristics of the organism being evaluated and environmental influences were developed for each of the seven elements to help define categories of low, moderate, and high risk. A detailed description of the pest risk assessment process is given in appendix C. Risk ratings were developed to assess pest risks that occur under current regulations and import practices irrespective of any particular mitigation strategies that might be proposed during development of a rule change for SWPM.

In table 31, risk ratings for the 7 elements and the overall pest risk potential rating derived from the 7 elements are summarized for the 19 pest species or groups assessed. The pests are grouped by combinations of geographic region of origin and pest habitat (e.g., temperate regions in deep wood); some pests occur in more than one such category. Rationales for the assignment of risk ratings are detailed in individual pest data sheets compiled in appendix D.

Pest risk potential was rated as high for most organisms evaluated, although root and stem rots (*Armillaria* spp., *Phellinus* spp., *Ganoderma* spp.) and the orthopteran, *Pterophylla beltrani*, were rated as only moderate risk. Representative pests were deliberately selected to illustrate that organisms exist that may both traverse the SWPM pathway and pose potential damage to U.S. resources; therefore, none of the organisms assessed resulted in a rating of low pest risk potential. All but one of the assessed organisms rated high for both presence with host at origin potential and entry potential, which indicates that the SWPM pathway is a viable route of entry to the United States for these organisms. Establishment potential, spread potential, and types of potential damage varied with biological characteristics of the organisms rated.

Organisms that utilize the interior portions of wood (such as fungi that cause root rots, stains, and wilts; and wood-boring beetles, wasps, and termites) represent a wide array of taxa with varied biologies; however, they all have a survival advantage in being physically protected within the host material and difficult to detect in SWPM. Damage caused by organisms that inhabit interior portions of wood often results in defects and degradation that can cause tree failure and tree mortality or structural damage in the case of wood buildings. The greatest differences in the potentials of these kinds of organisms to become established in a new environment likely result from variations in the ability to move from SWPM to new host tree material, rates of population increase, and rates of spread. Adult insects in this group generally have flight capabilities and can actively search for new hosts. Some pathogenic organisms are dependent upon insect vectors for dispersal to new hosts; therefore, the likelihood of introduction will vary subject to whether the pathogenic organism is introduced along with its vector or not. Other pathogenic organisms that rely more on passive dispersal of spores (such as by wind) tend to compensate by producing massive levels of inoculum, thereby increasing the chances of encountering a suitable new host tree. Differences in pest risk potential for these types of pathogenic organisms likely are more dependent upon availability of suitable environmental conditions for reproduction (e.g., sporulation, germination). Potential pest species that utilize deep-wood material are common in conifer and hardwood host groups.

Bark beetles and some plant pathogens (such as those causing canker diseases) utilize the nutrient-rich inner bark and cambium of trees and are frequently transported with SWPM. Bark beetles characteristically have a high potential for dispersal, colonization, population increase, and spread; therefore, as a group they have a high likelihood of introduction. Those bark beetle species that have the ability to attack, colonize, and kill live trees, consequently, will have high pest risk potentials. Bark beetles are also characteristically associated with fungi that they transport to new hosts. Some of these fungi are pathogenic. Destructive species of bark beetles are generally more common in conifer hosts, but some of the most destructive bark beetle–fungal associations that have become established in North America have utilized hardwood hosts. Destructive bark beetles are also most characteristic of temperate regions; however, some species have become established in high-elevation forests in tropical and subtropical regions. SWPM produced and shipped from these areas can pose a significant threat to temperate areas (generally the continental United States). Those pathogenic organisms that occur beneath bark but are not transmitted by insects may have dispersal capabilities similar to deep-wood pathogens that rely on passive spread mechanisms.

Table 31. Summary of pest risk potentials for 19 representative pests of concern that may be transported with solid wood packing materials (in deep wood, under bark, or on bark)

	Likelihood of introduction				Consequences of introduction			Pest risk potential[1]
Pest common name (*Scientific name*)	Presence with host or commodity at origin potential	Entry potential	Establishment potential	Spread potential	Economic damage Potential	Environmental damage potential	Social and political considerations	
Temperate regions in deep wood								
Root and stem rot fungi (*Armillaria* spp., *Phellinus* spp., *Ganoderma* spp.)	H[2]	H	M	M	M	M	M	M
Heterobasidion root rot fungi (*Heterobasidion* spp.)	H	H	H	H	M	M	H	H
Stain and wilt fungi (*Ophiostoma* spp., *Ceratocystis* spp.)	H	H	H	H	H	H	M	H
Asian longhorned beetle (*Anoplophora glabripennis*)	H	H	H	M	H	H	H	H
A sirex woodwasp (*Sirex noctilio*)	H	H	H	H	H	H	H	H
Drywood termites (Kalotermitidae spp.)	H	H	H	H	M	L	M	H
Subterranean termites (Rhinotermitidae spp.)	H	H	H	H	H	L	M	H

Table 31 Continued. Summary of pest risk potentials for 20 representative pests of concern that may be transported with solid wood packing materials (in deep wood, under bark, or on bark)

	Likelihood of introduction				Consequences of introduction			Pest risk potential[1]
Pest common name (*Scientific name*)	Presence with host or commodity at origin potential	Entry potential	Establishment potential	Spread potential	Economic damage potential	Environmental damage potential	Social and political considerations	
Temperate regions under bark								
Stain and wilt fungi (*Ophiostoma* spp., *Ceratocystis* spp.)	H	H	H	H	H	H	M	H
Red-haired pine bark beetle (*Hylurgus ligniperda*)	H[2]	H	H	H	H	M	M	H
European spruce bark beetle (*Ips typographus*)	H	H	H	H	H	H	H	H
Mediterranean pine engraver beetle (*Orthotomicus erosus*)	H	H	H	H	H	H	L	H
European oak bark beetle (*Scolytus intricatus*)	H	H	H	H	H	H	H	H
Temperate regions on bark								
Asian gypsy moth (*Lymantria dispar*, Asian biotype)	H	H	H	H	H	H	H	H
Nun moth (*Lymantria monacha*)	H	H	H	H	H	H	H	H
Pine flat bug (*Aradus cinnamomeus*)	H	H	H	H	H	H	H	H

Table 31 Continued. Summary of pest risk potentials for 20 representative pests of concern that may be transported with solid wood packing materials (in deep wood, under bark, or on bark)

	Likelihood of introduction				Consequences of introduction			Pest risk potential[1]
Pest common name (*Scientific name*)	Presence with host or commodity at origin potential	Entry ptential	Establishment potential	Spread potential	Economic damage potential	Environmental damage potential	Social and political considerations	
Tropical and subtropical regions in deep wood								
Root and stem rot fungi (*Armillaria* spp., *Phellinus* spp., *Ganoderma* spp.)	H[2]	H	M	M	M	M	M	M
Brown root rot fungus (*Phellinus noxious*)	H	H	H	M	M	H	H	H
Stain and wilt fungi (*Ophiostoma* spp., *Ceratocystis* spp.)	H	H	H	H	H	H	M	H
Canker stain fungus (*Ceratocystis* [*Corticium*] *fimbriata*)	H	H	H	H	H	M	H	H
Pink disease fungus (*Erythricium salmonicolor*)	H	H	H	M	M	H	H	H
Drywood termites (Kalotermitidae spp.)	H	H	H	H	M	L	M	H
Subterranean termites (Rhinotermitidae spp.)	H	H	H	H	H	L	M	H

Table 31 Continued. Summary of pest risk potentials for 20 representative pests of concern that may be transported with solid wood packing materials (in deep wood, under bark, or on bark)

	Likelihood of introduction				Consequences of introduction			Pest risk potential[1]
Pest common name (*Scientific name*)	Presence with host or commodity at origin potential	Entry potential	Establishment potential	Spread potential	Economic damage potential	Environmental damage potential	Social and political considerations	
Tropical and subtropical regions under bark								
Stain and wilt fungi (*Ophiostoma* spp., *Ceratocystis* spp.)	H	H	H	H	H	H	M	H
Canker stain fungus (*Ceratocystis fimbriata*)	H[2]	H	H	H	H	M	H	H
Pink disease fungus (*Erythricium salmonicolor*)	H	H	H	M	M	H	H	H
Mediterranean pine engraver beetle (*Orthotomicus erosus*)	H	H	H	H	H	H	L	H
Tropical and subtropical regions on bark								
Pink disease fungus (*Erythricium salmonicolor*)	H	H	H	M	M	H	H	H
Purple moth (*Sarsina violascens*)	H	H	H	H	M	M	M	H
La Grilleta (*Pterophylla beltrani*)	M	H	H	M	M	M	M	M

[1/] Pest risk potential ratings combine values for likelihood of introduction and consequences of introduction as defined by the seven risk rating elements. Methodology for assigning and combining ratings is detailed in appendix C.
[2/] H = high risk potential; M = moderate risk potential; L = low risk potential.

Potential tree pests that may be transported on bark attached to SWPM may include a variety of taxa and pest habits. Life stages may be sessile, hidden in bark crevices, or adherent to the bark with gluelike substances (e.g., egg masses). Many are difficult to detect owing to cryptic coloration, concealment in cracks, or small size. Survivability during transport may be high because of a dormant or environmentally resistant state (e.g., eggs or spores). Although some potential pests that may be transported on the bark of SWPM can cause damage by sucking plant juices out of stems and tree trunks (e.g., some bark-inhabiting Hemiptera and Homoptera), others may be more damaging to additional plant parts once established in a suitable environment. For example, many defoliators (e.g., Lepidoptera and Orthoptera) lay their eggs on bark but do not remain there to feed. The consequences of introduction are probably more varied for pests that may occur on bark for this reason and range from cosmetic injury to growth reduction to tree mortality.

The continental United States provides ample tree host species and environmental conditions to support a diversity of potential pest species originating from temperate regions outside its borders. Numerous examples exist of potentially damaging temperate organisms that pose significant threats of introduction via the SWPM pathway, some of which are listed in table 31. Although the expanse of tree resources in tropical and subtropical environments that are under U.S. jurisdiction (i.e., Hawaii, Puerto Rico, Pacific Islands, etc.) makes up a small percentage of the potential resources that may be attacked by exotic tree pests, the importance of these resources is heightened by their uniqueness and limited quantities. Several potential tree pests of tropical and subtropical origin may pose significant threats of introduction to tropical and subtropical locations under the protection of the United States, a few of which are listed in table 31. Additionally, some temperate tree pests may occur in high-elevation forests of tropical and subtropical regions that could pose significant pest risks for the continental United States.

Evaluation of the 19 selected potential pest species or groups demonstrates that significant pest risk potential currently exists for certain types of organisms that may be transported with SWPM into the United States and its territories. Examples of high pest risk potential for the SWPM pathway may be encountered in temperate and tropical and subtropical regions of origin, conifer and hardwood host types, and the three primary niches (in deep wood, under bark, and on bark) of the SWPM host material being transported. Organisms with high pest risk potential are unlikely to be excluded adequately solely through inspections at ports of entry. This contention is further supported by historical instances of entry, establishment, and damage caused by pests moving into the United States with SWPM.

Conclusions

The SWPM pathway poses considerable risk for introducing exotic forest pests to the United States, as evidenced by numerous pest interceptions at ports of entry and recent breaches in the safeguarding system that resulted in entry and establishment of exotic forest pests (e.g., Asian longhorned beetle, pine shoot beetle). Any given imported cargo shipment may contain SWPM of varied wood types and age, with unexpected or multiple origins or both. Because of the variability in SWPM content and the inability to identify these differences readily, any given shipment may pose the highest level of pest risk offered by the pathway. SWPM may be associated with importations of over 250 different commodities shipped from virtually anywhere in the world. SWPM accompany about 52 percent of maritime shipments and 9 percent of air shipments imported into the United States. SWPM may reach the United States through approximately 100 ports of entry and often accompany the cargo to its final destination, which may be anywhere in the United States.

The vast majority (97 percent) of port interceptions of quarantine-significant forest pests in recent years have been associated with imports of SWPM. The cumulative barriers (vast quantities on imported cargo, difficulties in identifying shipments that contain SWPM, inaccessibility of cargo in containers, concealment of pests in wood materials, etc.) to detecting pests arriving with SWPM readily indicate that port inspections and associated interdiction actions are inadequate to reduce the pest risk associated with SWPM. Furthermore, the bark-free requirement enacted in 1995 has not been sufficient to limit entry of bark beetles and provides little or no protection against deep-wood pests such as wood borers and deep-wood pathogens. About 9 percent of maritime and 4 percent of air shipments contain SWPM with bark present in violation of import regulations. Bark beetles (family Scolytidae) are still the most commonly (45 percent) intercepted group of pest organisms associated with shipments containing SWPM. Wood borers of the family Cerambycidae are the next most frequently (35 percent) intercepted pest group.

Most organisms that feed or occur in or on stems and branches of woody plants may be found in or on SWPM. In 1996–98, 156 taxa of quarantine-significant tree pests were detected in imports of SWPM to the United States; others likely escaped detection, particularly plant pathogens. Forest insects and pathogens that have life stages closely associated with tree trunks, especially those that remain there for long periods (e.g., wood borers, bark beetles, deep-wood pathogens), may pose the greatest risks of infesting wood materials to be exported. Other potential pests may be present only in certain life stages and seasons (e.g., eggs of some lepidopterous species such as the Asian gypsy moth).

The lengthy list of quarantine-significant insect pests intercepted with SWPM indicates that environmental conditions in shipping containers and airplane cargo holds are suitable for survival of these organisms. Owing to the extensive forests in almost every region of the United States and that encompass a very large number of tree genera—many shared in common with Asia, Europe, and elsewhere—U.S. forests will provide ideal establishment opportunities for many, if not most, immigrant tree-infesting organisms.

North American forests are highly vulnerable to the invasion of exotic pests. Many past introductions of nonindigenous forest pests that may be transported with SWPM into the United States illustrate the high potential for establishment and the potential consequences from similar pest introductions.

Many exotic forest insects and pathogens have the potential to become such serious pests that they threaten the health, productivity, stability, merchantability, and even the very existence of some trees and forests. Certain kinds of pest damage are clearly more serious than others because not all plant injuries are repaired or compensated for physiologically to the same degree. Among 13 insect feeding guilds, those with the lowest recovery capacity and highest impact are borers in the inner bark (phloem, cambium) and sapwood of the roots, root crowns, and main stems. In addition to stem- and wood-invading beetles and fungi, nematodes, true aphids, and adelgids can also trigger a severe reaction by plants, leading to tree mortality. Moreover, any herbivore that transmits or acts as a vector for plant pathogenic fungi, bacteria, phytoplasms, and viruses may have high potential for plant injury.

Ecological disruption from an exotic species increases exponentially as the proportion of plants that are susceptible in a landscape increases. This can result from a pest with very broad host plant preferences or from a pest with narrow host preferences for trees having vast, nearly pure populations, as is typical for many species of early successional (e.g., aspen, paper birch, various pines) and even some very late successional trees (e.g., sugar maple, beech, eastern and western hemlocks, balsam and alpine firs, etc.). Ecological impact can also be significant for pests that attack hosts with limited distributions but that play vital ecological roles. The most devastating impact that may result from the introduction of exotic forest pests is the extinction of ecologically dominant plant species, such as occurred for the American chestnut following introduction of chestnut blight. Biodiversity may be reduced not only because of loss of the tree species, but the wildlife and other organisms that depend upon the vegetative habitat as well. Depredations of exotics may alter typical plant abundance and distribution patterns, and attacked plants may gradually be eliminated from certain localized areas. Selective infestation by exotics on their preferred hosts can significantly alter the usual competitive balance in plant communities by lowering the competitive abilities of attacked trees. Exotics may diminish tree and forest productivity if their addition pushes total herbivory by native and exotic species over the tolerance threshold beyond which plants generally are unable to compensate with growth. Pest damage in turn may effect substantial changes in nutrient cycling and retention, hydrology, soil erosion, and capacity for reforestation. Extensive tree mortality would benefit some animals and threaten others, lower water quality, alter regional hydrology, increase the probability of wildfires, and reduce the carbon storage capacity of North American forests. As exotic plant-feeding organisms establish themselves in an ecosystem, they also may outcompete native insects and microorganisms, causing their populations to decline.

Activity by forest pest species can result in a variety of economic losses due to damage to trees, forests, or wooden structures. Economic losses will vary by the pest species and the hosts attacked, but may be reflected in

- tree mortality and timber volume loss;
- wood defects and degradation;
- tree growth loss;
- reduction in production of products such as maple syrup, fruits, nuts, or seed;
- reduction in property values;
- damage to property due to tree failures;
- losses in recreation visitor days and tourism;
- increased human health problems (e.g., allergic reactions to pests, injuries from tree failures);
- increased energy costs (e.g., resulting from loss of shade);
- increased costs for mitigating pest damage or restoring habitat;
- and many other indirect effects.

Once a new pest becomes established, controlling its populations is never simple or cheap. Introduction of a significantly damaging forest pest can lead to cumulative monetary losses over 30 years in the tens of millions to billions of dollars subject to availability of host resources at the location of the infestation.

For the 19 potential pest species or groups evaluated qualitatively for pest risk potential, most rated as high in risk. All but one of the assessed organisms rated high for both presence with host or commodity at origin potential and entry potential, which indicates that the SWPM pathway is a viable route of entry to the United States for these organisms. Establishment potential, spread potential, and types of potential damage varied with biological characteristics of the organisms rated.

Evaluation of the 19 selected potential pest species or groups demonstrates that significant pest risk potential currently exists for many types of organisms transportable with SWPM into the United States and its territories. Examples of high pest risk potential for the SWPM pathway are present in both temperate and tropical and subtropical regions of origin, both conifer and hardwood host types, and for the three primary niches (in deep wood, under bark, and on bark) of the SWPM host material being transported. Organisms with high pest risk potential are unlikely to be excluded adequately solely through inspections and associated interdiction actions at ports of entry.

Given the ubiquity of the SWPM pathway and associated pests as well as difficulties in tracing SWPM origins and identifying SWPM compositions, worldwide application of more stringent importation requirements appears to be warranted. Employment of effective mitigation measures that can reduce the likelihood that live pests will be transported with SWPM has the potential to reduce greatly the risk of introduction of destructive exotic forest pests into the United States. Development of new U.S. import requirements and regulations for SWPM requires additional analyses beyond the scope of this pest risk assessment to evaluate potential mitigation strategies for effectiveness in reducing pest risk potentials, expected environmental effects of proposed actions, and impacts on global economies.

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