# Appendix E: Methodologies for Economic Damage Projections

Assumptions for modeling pest spread and damage following introduction of seven representative pest species or groups are detailed in this appendix. Assumptions regarding the potential for spread and damage were developed based upon available scientific information and the judgment of experts consulted. Expert knowledge was elicited based upon the methods reviewed by Morgan and Henrion (1990). The use of high and low expectations (i.e., worst and best cases) was an attempt to capture the range of possibility in the forecasts, given the uncertainties about precise parameters. Biologies for the chosen pest species are described in the individual pest risk assessments contained in appendix D. Assumptions about spread rates, damage potential, time periods for population buildup, primary host species affected, and locations of introduction foci are also summarized in table 4 found elsewhere in this document.

To simulate a buildup period in which the damage gradually increases from zero to a pest's damage potential (i.e., the maximum level for a given scenario), a Weibull function was used to fit the damage rate to the buildup period as function input parameters. Thus, the damage level used in a given year during the buildup period for a given infestation scenario was derived from the Weibull distribution produced by the equation below using damage potential and the time to reach damage potential (see assumptions for specific pest species) as parameters. The cumulative distribution function for the Weibull distribution is

$$F(x;\alpha,\beta)=1-e^{-(x/\beta)^{\alpha}}$$

The probability density function is

$$f(x;\alpha,\beta)=\alpha\beta^{-\alpha}x^{\alpha-1}e^{-(x/\beta)^{\alpha}},$$

where $x$ is the damage potential
and $\alpha$ and $\beta$ are function shape parameters associated with time.

The shape of the Weibull function is illustrated in figure 33 for the *Sirex noctilio* F. scenario.

## Scenario Assumptions for Forest Damage and Loss From Termites

**Sample Pest**—Drywood termite

**Species Name**—*Cryptotermes* spp., *Incisitermes* spp., *Kalotermes* spp., and *Neotermes* spp. (Isoptera: Kalotermitidae)

**Expert Consulted**—Michael Haverty

**Rate of Spread**—The spread of termites of the preceding genera is expected to take 30 to 50 years for distribution throughout an area encompassing southern California and Arizona. This is equivalent to 10 to 16 km per year (6 to 10 miles per year) after initial introduction (or 3,838 to 6,396 mi.$^2$/ yr). These estimates are based on known termite behavior in the United States—particularly experience with introduction of the Formosan subterranean termite into the Southeastern United States. Natural spread is very slow, and most spread is human mediated.

**Damage Potential**—Termites are not expected to cause significant economic loss to forest resources; however, they will attack any hardwood or softwood species in the structure of buildings or any wood product. Losses associated with these termites result from direct damage caused to wood structures and increased costs associated with application of prophylactic treatments required to maintain wooden structures in areas generally infested with

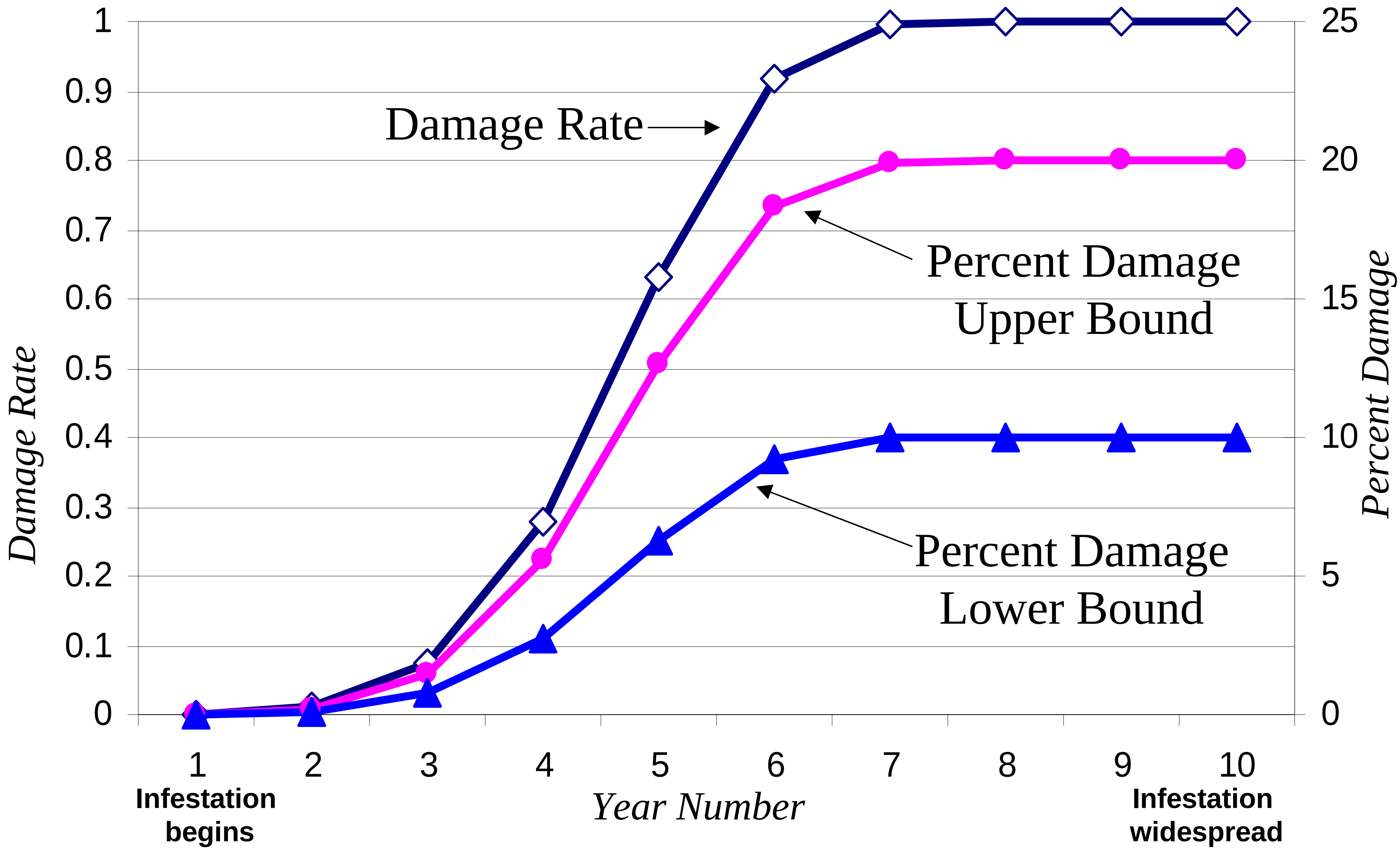


Figure 33. Weibull function for estimating pest damage potential during population buildup period as developed for the *Sirex noctilio* scenario.

termites.  Once a termite species is established, the economic losses continue to accrue indefinitely.

**Time Period (To Reach Potential Damage Levels)**—It is expected that termites such as the kalotermitid species are capable of becoming widespread throughout an area such as southern California in a period of 30–50 years.

**Primary Hosts Attacked**—Most softwoods and hardwoods present in buildings and other structures can be attacked.

**Introductions**—One introduction focus (location) in San Diego, CA, was selected as a starting point for loss projections.

**Expected Range—**Drywood termites are expected to be most damaging in the Southern States and in the southern coastal areas along the west and east of the continental United States.

## Scenario Assumptions for Forest Damage and Loss From a Tropical Disease (Tree Canker)

**Sample Pest—**Pink disease fungus

**Species Name—***Erythricium salmonicolor* (Berk. & Broome) Burdsall (Basidiomycota: Hyphodermataceae)

**Expert Consulted**— Charles Hodges

**Rate of Spread**—Pink disease is expected to spread rapidly within Hawaiian island groups.  The expected time to spread within an island group is 1 year.  Maui, Molokai, and Oahu islands can be expected to behave as one island group.  The Big Island would be a second island group, with Kauai considered a third island group.  Thus if the pink disease fungus were to be introduced into any of these island groups, the disease would spread throughout that group after 1year.

**Damage potential—**Tree mortality is not expected;  rather, a reduction of growth and loss of fruit production are the anticipated outcomes.  Pink disease is notable in that not only is the forest resource affected but cultivated fruit trees as well.  Growth reduction in forest trees is expected to vary between 40 and 50 percent.  Loss of fruit production is expected to vary between 50 and 70 percent in areas where climatic conditions are most favorable for infection and spread (i.e., >2,000 mm rainfall per year).  On the basis of rainfall levels typical for the Hawaiian islands, disease development is expected to be less than optimal, and thus a range of 25–40-percent loss of fruit production was assumed.

**Time Period (To Reach Potential Damage Levels)**—Pink disease is expected to cover an entire island group within the first year of pathogen introduction.  The disease is also expected to reach damaging potential after the initial year of infestation.

**Primary Hosts Attacked**—Hardwoods and fruit trees.  Forest hosts include *Eucalyptus* spp., *Acacia* spp, and *Paraserianthes falcataria*.  Cultivated hosts include rubber, coffee, cocoa, citrus, *Malus* spp., and *Litchi chinensis.*

**Introductions**—It was assumed that an introduction would occur in the Hawaiian islands.

**Expected Range—**The potential ecological range for pink disease includes Hawaii, Puerto Rico, and the Pacific territories (Guam, Marianas, American Samoa).  Pink disease is already present in the Southeastern United States but is not a serious problem because of the pathogen's moisture requirements.

## Scenario Assumptions for Forest Damage and Loss From a Wood Borer

**Sample Pest**—Asian longhorned beetle

**Species Name—***Anoplophora glabripennis* (Motschulsky) (Coleoptera: Cerambycidae)

**Experts consulted**—Joseph Cavey, Vic Mastro

**Rate of Spread**—The Asian longhorned beetle (ALB) is expected to spread at 300 m to 3 km per year after it becomes established in the United States. The lower rate is predicated on mostly natural spread; the higher rate is based on human-mediated spread such as movement of infested firewood within a local area.

**Damage potential**—Once the ALB becomes established, it is expected to reduce the productivity of trees by 80 to 100 percent. Trees killed by this pest will have very little to no salvage value.

**Time Period (To Reach Potential Damage Levels)—**The damage potential is expected to be observed within 3 to 4 years after initial pest introduction with tree mortality levels approaching 100 percent observable after 10 years.

**Primary Hosts Attacked**—The ALB attacks many hardwoods found in the United States. Hosts include maple, poplar, buckeye, alder, birch, ash, mulberry, sycamore, cherry, plum, pear, willow, locust, and elm.

**Introductions—**The strongest evidence for establishment potential is provided by the known current infestations of this pest in at least two locations (New York, NY, and Chicago, IL) over the past 10 years. Three introduction foci (locations) were selected as starting points for loss projections: Chicago, IL, New York, NY, and Atlanta, GA.

**Expected Range—**There are no known constraints to the widespread distribution of the ALB throughout the ranges of potential hosts within the continental United States.

## Scenario Assumptions for Forest Damage and Loss From a Woodwasp

**Sample Pest**—A sirex woodwasp

**Species Name—***Sirex noctilio* F. (Hymenoptera: Siricidae)

**Expert Consulted**—Dennis Haugen

**Rate of Spread—***Sirex snoctilio* has a flight potential of 100 miles, but initial dispersal flights are usually less than 2 miles. The spread rate is expected to be within 5 to 15 miles per year based on the behavior of this pest after it was introduced outside of its native range into Australia.

**Damage potential**—Unlike other wood wasp species, *S. noctilio* aggressively kills pine trees. Larvae tunnel in the trunks of trees, beginning in the sapwood and sometimes reaching the center of the tree. *S. noctilio* exists in symbiotic association with a fungus, *Amylostereum areolatum*.

Overstocked, stressed plantations between 10 and 30 years old are most susceptible to attack. In Australia, the most severely impacted plantations of Monterey pine (*Pinus radiata* D. Don) exceeded 80-percent tree mortality. In Brazil, tree mortality has exceeded 50 percent in loblolly pine (*Pinus taeda* L.) plantations. Plantations are expected to have a higher level of tree mortality than natural pine stands. The Southeastern region is expected to have a higher damage potential than the Western region because of the abundance of pine plantations in the Southeastern United States. For this analysis, *Sirex* is estimated to kill an average of 10 to 20 percent of the trees over a given area.

**Time Period (To Reach Potential Damage Levels)**—The time required to achieve potential damage levels is expected to be between 7 to 10 years following introduction.

**Primary Hosts Attacked**—*S. noctilio* may attack all species of pine (*Pinus* spp.). Monterey, loblolly, and slash pines (all native to the United States) have been heavily attacked in other countries (New Zealand, Australia, Brazil, Argentina, Uruguay, and South Africa).

**Introductions**—Three introduction foci (locations) were selected as starting points for loss projections: San Francisco, CA, Minneapolis, MN, and Atlanta, GA.

**Expected Range**—All pine-growing regions in the United States are expected to be susceptible; thus, no ecological restrictions in the continental United States are assumed.

## Scenario Assumptions for Forest Damage and Loss From Bark Beetles

**Sample Pest**—European spruce bark beetle

**Species Name**—*Ips typographus* (L.) (Coleoptera: Scolytidae)

**Expert Consulted**—Andris Eglitis.

**Rate of Spread**—The European spruce bark beetle (ESBB) is normally associated with felled trees but moves to standing trees once populations build up. The ESBB may spread from 1 to 30 mi/yr from an initial colonization site, but the expected rate of population spread is 5 to 10 mi/yr. This expectation is based on information and evidence about the behavior of the beetle and its associated fungi in Europe and Asia.

**Damage Potential**—Damage by the ESBB can be severe and includes 10- to 80-percent tree mortality in average stands. The ESBB has several associated fungi. At least one fungus, *Ceratocystis polonica* (Siemaszko ) Moreau, is known to be highly virulent and capable of killing healthy hosts once transmitted by a vector such as the ESBB. Owing to the nature of damage, trees killed by this beetle will have an initial salvage value of 30 percent of "green" value.

**Time Period (To Reach Potential Damage Levels)**—The ESBB is expected to require 7 to 10 years to build up damaging populations once introduced into a specific area. After this period, the beetle would be expected to be widespread and to cause significant damage within its initial infestation focus and within a radius of 50 km of that focus. Because the beetle is capable of two generations per year in southern latitudes, whereas it has a single generation in its more northerly range, this pest would be expected to move more rapidly if an infestation began in southern latitudes in the United States. However because the preferred spruce hosts occur only in northern latitudes in the United States, this distinction in biology may be moot.

**Primary Hosts Attacked**—Spruces are preferred hosts, although the ESBB can also attack pines and larches. The key species attacked in North America are expected to be spruces.

**Introductions**—Likely areas for new introductions and colonization include the New England States, the West Coast, the Lake States, the Rocky Mountains, and coastal Oregon, Washington, and Alaska. Three introduction foci (locations) were selected as starting points for loss projections: Seattle, WA, Minneapolis, MN, and Newark, NJ.

**Expected Range**—Establishment is likely to be limited to northern latitudes and higher elevations where the primary spruce hosts occur.

## Scenario Assumptions for Forest Damage and Loss From a Lymantriid Forest Defoliator

**Sample Pest**—Nun Moth

**Species Name—***Lymantria monacha* L. (Lepidoptera: Lymantriidae)

**Expert Consulted—**William Wallner

**Rate of Spread**—The rate of spread is expected to vary between 3 and 15 miles per year.

**Damage potential**—Mortality of up to 100 percent may be expected in spruce and pine following heavy defoliation because of the inability to refoliate. Mortality may vary from 50 to 100 percent of an average stand. Trees killed by this pest will have an initial salvage value of 75 percent of "green" value.

**Time Period (To Reach Potential Damage Levels)**—The time required to achieve potential damage levels is expected to be between 5 and 10 years following introduction.

**Primary Hosts Attacked**—Most species of spruce and pine are expected to be susceptible to nun moth attack. Many hardwoods are also readily attacked. Hosts include spruce (*Picea*), larch (*Larix*), fir (*Abies*), oak (*Quercus*), elm (*Ulmus*), maple (*Acer*), birch (*Betula*), and beech (*Fagus*).

**Introductions—**Likely points of entry based on interception data for the related species, *Lymantria dispar* (gypsy moth), may include Portland, OR; Wilmington, NC; Seattle, WA; Detroit, MI; Chicago, IL; Los Angeles, San Francisco, and San Diego, CA; Mississippi river shores; and New Orleans, LA. Three introduction foci (locations) were selected as starting points for loss projections: Seattle, WA, Minneapolis, MN, and New York, NY.

**Expected Range—**Damage is expected to be greater in the northern parts of the United States and less in the southern regions; however, the entire host range is presumed susceptible to nun moth, for the continental United States does not present an ecological constraint to pest dissemination.

## Scenario Assumptions for Forest Damage and Loss From a Root Disease

**Sample Pest—**Heterobasidion root rot fungi

**Species Name**—*Heterobasidion* spp. group (Basidomycetes: Holobasidiomycetidae)

**Expert consulted—**Harold Burdsall

**Rate of Spread**—Although spores of this pathogen group have been found up to 300 km from the nearest source, it is expected to move slowly at 0.1 to 1 km per year.

**Damage Potential**—Heterobasidion root rots are expected to cause tree mortality and reduced growth. Thirty to 40 percent mortality is expected on pine, and 10-percent mortality may be expected on hardwoods.

**Time Period (To Reach Potential Damage Levels)—**Species in this pathogen group are expected to build up slowly, requiring 15 to 20 years to reach their damage potential.

**Primary Hosts Attacked—**Hosts for Heterobasidion root rots include pines, Douglas-firs, spruces, larches, junipers, birchs, firs, and hemlocks.

**Introductions**—Four introduction foci (locations) were selected as starting points for loss projections: Nashville, TN, Charleston, SC, Atlanta, GA, and Portland, OR.

**Expected Range**—Most of the continental United States is likely to support an infestation. The Southeastern United States may be at higher risk owing to higher moisture levels.

## Discounting

Values for economic loss projections were discounted for all scenarios at 7 percent per year in accordance with guidelines for economic analyses conducted in support of significant regulatory actions of the United States (U.S. Office of Management and Budget 1996). "Discounting takes account of the fact that resources (goods and services) that are available in a given year are worth more than the identical resources available in a later year. . . . Constant-dollar benefits and costs must be discounted to present values before benefits and costs in different years can be added together to determine overall net benefits. To obtain constant dollar estimates, benefit and cost streams in nominal dollars should be adjusted to correct for inflation. . . . In general, the discount rate should not be adjusted to account for uncertainty of future benefits and costs." The formula used to calculate the cumulative present value is

$$PresentValueofLoss = L_0 + \left(\frac{L_1}{1+r_1}\right) + \left(\frac{L_2}{(1+r_1)(1+r_2)}\right) + \ldots + \left(\frac{L_T}{(1+r_1)\ldots(1+r_T)}\right)$$

where $L_t$ represents loss experienced in future years, $t$ refers to the year, and $r$ is the discount rate (0.07 in this case).

The potential economic impacts estimated for introductions of the representative exotic forest pests modeled in this pest risk assessment help to define the benefits of proposed regulations in that they represent the avoided losses that would result from prevention of pest entry. This information can be used in an economic analysis for the proposed regulation (outside the scope of this document).

Because the time of introduction of various exotic pests is unpredictable, the hypothetical introduction scenarios were developed with the assumption of introduction in year 1, and with initial monetary values set at those known or estimated for 1998 (unless otherwise indicated). Because of the effect of discounting, cumulative monetary values for a similar span of time for any given scenario would be different (i.e., less, if all other assumptions remained constant) if an infestation began in a later year. Also, because introductions of various pest species or multiple introductions of a given species are likely to occur in different years, and the number and kinds of introductions of different pests are unpredictable, projections of the potential economic impacts of exotic forest pests to the United States are not additive.

## Methods for Calculating Compensatory Values of Urban Tree Resources

Details of methods used to calculate compensatory values of urban tree resources potentially affected by spread of the Asian longhorned beetle are described herein.

Field data were used to determine urban forest structure of the entire city (e.g., tree species composition, number of trees) for eight cities: Atlanta, GA, Baltimore, MD, Boston, MA, Chicago, IL (Nowak 1994), Jersey City, NJ[4], New York, NY, Oakland, CA (Nowak 1993), and Philadelphia, PA. City data (except for Oakland and Chicago) were recently collected and analyzed using the Urban Forest Effects (UFORE) model based on a stratified random sample of approximately two hundred 0.04-ha plots per city (Nowak and Crane, in press; Nowak et al., in review). The ALB data analyses for these cities are in relation to live trees; data from Oakland and Chicago refer to the entire city population (including 2.9 percent dead trees in Oakland and 5 percent dead trees in Chicago).

Data on urban forest structure were combined with ALB feeding preferences (table 10) to quantify the potential number of trees, percent of total canopy cover (leaf area), and potential monetary loss associated with ALB-infestation scenarios. ALB feeding preferences were divided into four classes:

1. Preferred—known ALB host;
2. Oviposition–genera—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; or b. tree genera with only one known host species; or both;
3. Conifer—conifer species (no known conifer hosts); and
4. Unknown—hardwood genera with no ALB host data.

On the basis of assumptions developed by the USDA Animal and Plant Health Inspection Service (APHIS), the ALB 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, whereas the upper spread rate is dependent upon human-assisted transport of infested wood such as firewood. The slower spread rate provides a conservative estimate of potential impacts over time for situations in which effective programs to restrict movement of infested wood are implemented. The faster spread rate represents a worst-case scenario in which no quarantine restrictions or sanitation practices are adopted and people actively move infested materials. The spread rates were assumed to be averages for the described scenarios, and no modeling of beetle population fluctuations was attempted. However, given an expanding radius of infestation, beetle populations would need to increase exponentially over time to maintain the spread rates. 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. No trees were assumed to be killed by the ALB in other host preference classes.

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 were residential land, then 50 percent of the ALB infestation would occur on residential land each year). ALB infestation was assumed to start at the center of the city and spread outward until the entire city area was encompassed.

The value of the trees in each ALB susceptibility class was calculated based on compensatory value of trees as 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. Other values can be ascribed to trees based on such factors as increases in local property values or environmental functions provided (e.g., air pollution reduction), but the compensatory valuation method is one of the most direct means of establishing the value of compensation 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

[4] Data were collected and analyzed in cooperation with the State of New Jersey, Department of Environmental Protection and Energy, Division of Parks and Forestry.

then multiplied by condition and location ratings (0–1) to determine the final tree compensatory value.

For transplantable trees, average replacement cost and transplantable size were obtained from local International Society of Arboriculture publications (ACRT 1997) to determine the basic replacement price (\$ per cm$^2$ of cross-sectional area) for the tree. Basic replacement price was multiplied by tree trunk area and species factor (0–1) to determine the tree's basic value. Minimum basic value, prior to species adjustment, was set at \$150. Local species values (0–1) were obtained from International Society of Arboriculture publications (ACRT 1997). If no data were available for the State, data from the closest State were used.

For trees larger than transplantable size,

$$\text{Basic Value} = \text{Replacement Cost} + (\text{Basic Price} \times [TA_A - TA_R] \times \text{Species}),$$

where replacement cost is the cost of a tree at the largest transplantable size, basic price is the local average cost per unit trunk area (\$ per cm$^2$), $TA_A$ is trunk area of the tree being appraised, and $TA_R$ is trunk area of the largest transplantable tree. Local average replacement cost, transplantable size, basic price, and species values (0–1) were obtained from International Society of Arboriculture publications (ACRT 1997). If no data were available for the State, data from the closest State were used.

For trees larger than 76.2 cm in trunk diameter, trunk area was adjusted downward based on the premise that a large mature tree would not increase in value as rapidly as its trunk area would increase. The following adjusted trunk area formula was determined empirically based on the perceived increase in tree size, expected longevity, anticipated maintenance, and structural safety (Council of Tree and Landscape Appraisers 1992):

$$\text{Adjusted Trunk Area} = -0.335d^2 + 69.3d - 1087,$$

where $d$ = trunk diameter in inches.

The basic value was multiplied by condition and location factors (0–1) to determine the tree's compensatory value. Condition factors are based on crown dieback: Excellent (<1-percent dieback) = 1.0; Good (1–10-percent dieback) = 0.95; Fair (11–25-percent dieback) = 0.82; Poor (26–50-percent dieback) = 0.62; Critical (51–75-percent dieback) = 0.37; Dying (76–99-percent dieback) = 0.13; Dead (100-percent dieback) = 0.0.

Available data required using location factors based on land use type (International Society of Arboriculture 1988): Golf course = 0.8, Commercial–industrial = 0.75, Cemetery = 0.75, Institutional = 0.75, Parks = 0.6, Residential = 0.6, Transportation = 0.5, Forest = 0.5, Agriculture = 0.4, Vacant = 0.2, Wetland = 0.1.

As an example of compensatory value calculations, if a 40.6-cm-diameter tree (1,297 cm$^2$ trunk area) has a species rating of 0.5, a condition rating of 0.82, a location rating of 0.4, a basic price of \$7 per cm$^2$, and a replacement cost of \$1,300 for a 12.7-cm-diameter tree (126 cm$^2$ trunk area), the compensatory value would equal

$$\{1{,}300 + [7 * (1297 - 126) * 0.5]\} * 0.82 * 0.4 = \$1{,}771$$

Data for individual trees in each city were used to determine the compensatory value of trees in the ALB-preferred host class. To estimate the potential total loss in value of urban forests nationally due to the ALB, total compensatory value of trees in each city was divided by total tree cover (m$^2$) to determine average compensatory value per unit tree cover (\$ per m$^2$). Extrapolation of city data to estimate national ALB effects was done by region owing to the regional divergence in ALB effects. Extrapolation to urban areas in the Northeast–North Central region (Connecticut, Delaware, Illinois, Indiana, Kentucky, Massachusetts, Maryland, Maine, Michigan, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Virginia, Vermont, Wisconsin, and West Virginia) was based on median data from Boston, Baltimore, Chicago, Jersey City, New York, and Philadelphia.

Extrapolation to the rest of the United States was based on median data from Atlanta and Oakland. The standardized compensatory value ($ per $m^2$) was multiplied by total urban tree cover in the region (Dwyer et al., in press) to estimate the current monetary value of resources at risk (i.e., likely hosts) for attack by ALB.