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ALB Hazard Management and Monitoring Version 1.0: An Assessment and Tracking Tool for Asian Longhorned Beetle Eradications in the United States

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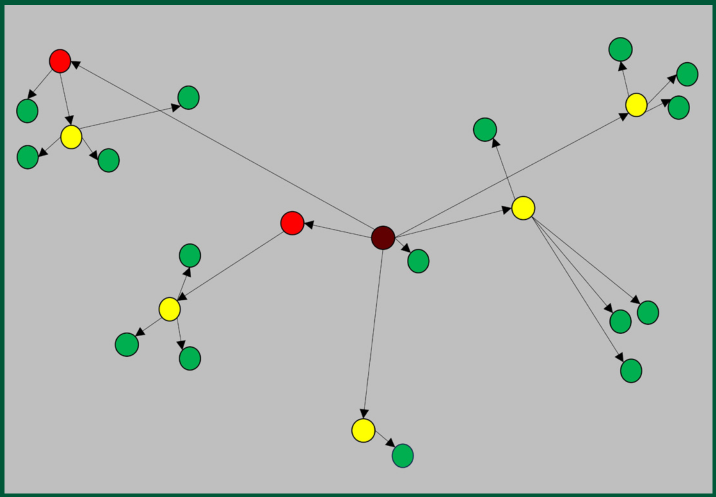

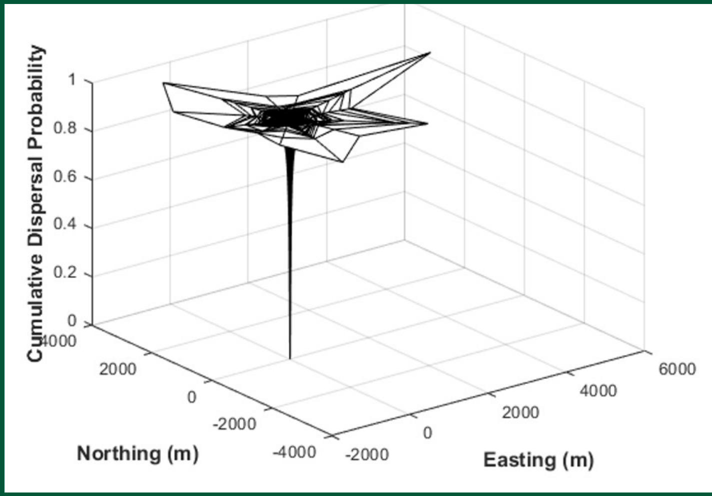

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Abstract

The Asian longhorned beetle (*Anoplophora glabripennis* Motschulsky) poses a significant ecological and economic threat to forested landscapes. Based on the potential cost of uncontrolled infestations, countries in North America and Europe have adopted polices of eradication when breeding populations are found. In the absence of effective traps and remote sensing tools, eradication programs depend on the use of effort intensive visual surveys to identify and remove individual infested host trees. The risk of infestation on the landscape changes as surveys are conducted (reducing risk) and new infested trees are detected (increasing risk), with the method and timing of survey playing roles in risk mitigation. ALB Hazard Management and Monitoring 1.0 is a set of analysis and ArcGIS tools designed to allow managers to track changes in risk as eradication programs work to push beetle populations towards extinction, and to facilitate the analyses of planned survey programs to identify survey strategies that optimize their reduction of risk at a landscape scale.

Keywords: dynamic risk, invasive species, spatial risk, survey optimization, Coleoptera, Cerambycidae

Cover Images

Upper left: Model of Asian longhorned beetle dispersal and movement among trees with varying levels of infestations. **Lower left:** Estimation using ALB Risk version 1.2 of the direction and probability of dispersal of a beetle from a single location. **Right:** Adult Asian longhorned beetle on a poplar tree in China. USDA Forest Service photo by Michael Bohne/Bugwood.org.

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EXECUTIVE SUMMARY

Global risks: The Asian longhorned beetle (ALB) (*Anoplophora glabripennis* Motschulsky) is a wood boring insect native to China and the Korean peninsula. Although the adult beetles are large and visually striking (Fig. 1), the larvae can reside undetected in solid wood packing materials such as the crates and pallets used in international shipping. The ability to stow away in products, cargo, and shipping containers has led to the unintentional introduction of breeding populations of the Asian longhorned beetle to North America and at least nine countries in Europe. The beetle's ability to develop in and destroy trees in more than 22 genera, including the widely distributed *Acer, Populus, Ulmus,* and *Salix,* has earned the beetle seventh position on "100 of the World's Worst Invasive Alien Species," a list published by the International Union for Conservation of Nature (IUCN 2021). In response to the ecological and economic threat posed by the Asian longhorned beetle, the United States, Canada, and members of the European and Mediterranean Plant Protection Organization (EPPO) have adopted policies of eradication when populations of the beetle are found.

Figure 1.—Adult Asian longhorned beetle on a poplar tree in China. USDA Forest Service photo by Michael Bohne/Bugwood.org.

Eradication challenges: Asian longhorned beetle eradication programs in the United States often include two broadly defined phases: delimitation, in which the boundaries of the infestation are identified, and eradication, the process by which individual host trees are surveyed and infested trees are removed and destroyed. The efficacy and application of broad-scale survey tools such as detector dogs and baited traps have been found to be limited. Current eradication programs depend on visual surveys to detect the ~10 mm exit holes and 2 to 10 mm oviposition pits left by adult beetles and identify infested trees (Figs. 2 and 3). In landscapes that can include millions of host trees, the cost and time required to survey a landscape can be substantial; and because visual surveys are imperfect, landscapes may require multiple surveys to achieve an acceptable probability of detection and eradication.

Management needs: For survey and eradication programs to be both effective and efficient, program managers need tools that can:

- Map the distribution of infestation risk on the landscape, where risk is the estimated probability that at least some trees in a defined area are infested. Such tools can help identify regulatory boundaries, estimate the resources needed to conduct adequate surveys, achieve eradication, and identify high risk and high priority management areas within the infested landscape. Ideally, the estimated distribution of risk should be based on the patterns of beetle dispersal specific to the infested area.

Figure 2.—Asian longhorned beetle exit holes in tree bark. USDA Forest Service photo by Dennis Haugen/ Bugwood.org.

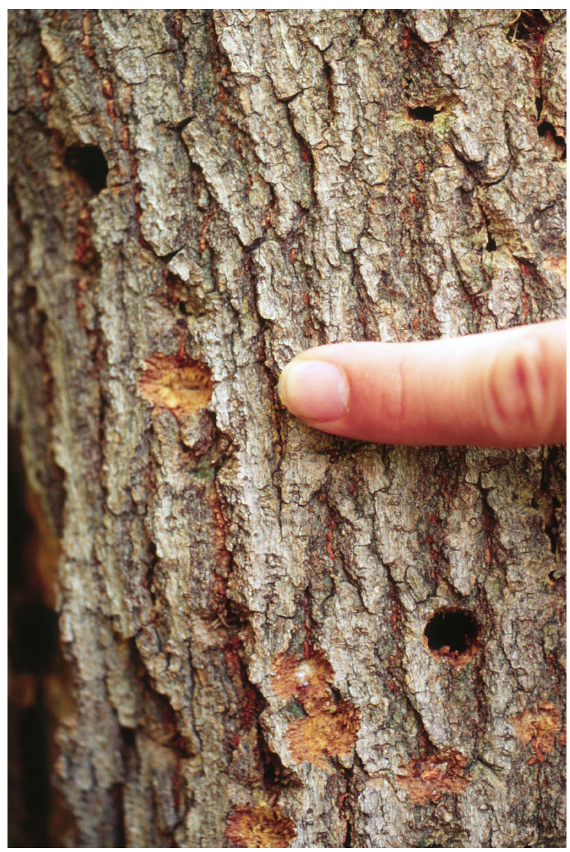

Figure 3.—Oviposition pits chewed into bark by female Asian longhorned beetles. The pits allow the female to insert individual eggs into the cambium, where the larvae hatch and feed before moving further into the xylem. Note the presence of exit holes. USDA Forest Service photo by Dennis Haugen/Bugwood.org.

- Quantify and track progress toward achieving eradication as surveys are carried out and as host trees are removed.

- Allow managers to explore, compare, and evaluate multiple management strategies and identify actions that maximize eradication progress using available resources.

ALB Risk: ALB Risk is a tool that provides managers with an estimate of the distribution of the risk based on local patterns of dispersal. Within the context of these tools and this document, risk is defined as the estimated probability that at least one tree within a given area (e.g., hectare) is infested by at least one beetle. This task is carried out using ALB Risk 1.2, a Windows™ based, stand-alone executable program that uses a graph-based approach to reconstruct patterns of beetle dispersal based on the locations and infestation levels of known infested trees. The reconstructed patterns of beetle dispersal are used to estimate the two-dimensional dispersal kernel describing the probability of beetle dispersal by both distance and direction. By laying the dispersal kernel on the locations of each known infested tree and compiling the cumulative dispersal risk from each tree, the tool estimates the probability of beetle infestation for each hectare in a defined region (typically a 40 km × 40 km area). ALB Risk can be used independent of ALB Hazard Management and Monitoring and should be used prior to running ALB Hazard Management and Monitoring to estimate the distribution of infestation risk on the landscape. A detailed description of its structure and function can be found in Trotter and Hull-Sanders (2015), Trotter et al. (2018), and Trotter et al. (2021).

ALB Hazard Management and Monitoring 1.0: ALB Hazard Management and Monitoring is a tool that provides methods to track changes in risk as areas are surveyed, host trees are removed, and new infested trees are found as well as a process to evaluate and compare the effects of future management strategies on eradication progress. ALB Hazard Management and Monitoring is run within ArcGIS Desktop™ (ESRI™) as a Python script or as a tool that can be added to ArcToolbox. Using the dispersal and infestation risk maps generated by ALB Risk as a starting point, ALB Hazard Management and Monitoring estimates changes in infestation risk on a hectare-by-hectare basis resulting from management activities such as surveys and host removals. Risk within a hectare may decrease following negative surveys and host plant removals or may increase as new infested trees are found. Variation in survey methods (aerial or ground based), the sequence in which surveys are carried out, and the timing between surveys can interact to modify infestation risk. Loading records of completed management actions allows managers to track changes in landscape risk and progress towards eradication, and loading future management actions allows managers to compare and explore the costs and impacts of future management strategies, methods, and priorities.

Tools and user guides: At the time of publication, 1.2 was the current version of ALB Risk and 1.0 was the current version of ALB Hazard Management and Monitoring. Users are encouraged to check for updated versions.

- The ALB Risk user guide and tool are available at https://doi.org/10.2737/NRS-GTR-201.

- The ALB Hazard Management and Monitoring tool is available at https://doi.org/10.2737/NRS-GTR-222. The ALB Hazard Management and Monitoring Python script may be adapted for use with open-source GIS platforms such as QGIS by modifying the arcpy-dependent functions embedded in the Python script for use outside ArcGIS. In these situations, if the logic structure in the ALB Hazard Management and Monitoring Python script is used, the original script source should be acknowledged.

CONTENTS

INTRODUCTION

Domestic and International Populations of the Invasive Asian Longhorned Beetle

Following is a short summary of the history of the Asian longhorned beetle (ALB) as a global invasive species. The events leading to the introduction of the Asian longhorned beetle to North America and Europe have been presented in detail in other documents, including Pan (2005) and Haack et al. (2010), and we refer the reader to these sources.

The Asian longhorned beetle (*Anoplophora glabripennis* Motschulsky) is a large cerambycid wood borer native to China and the Korean peninsula, where it is also called the Starry Night Beetle. The Asian longhorned beetle and its relatives have long been known in Asia and have appeared in both modern and traditional art, such as Japanese netsuke. According to Pan (2005), the beetle has been known since the Qing Dynasty (1644–1912). Prior to the middle of the 20th century, there is no indication the beetle was considered a pest of economic or ecological importance. In the middle of the last century, however, landscape conditions changed in ways that have favored the beetle, leading to outbreaks in China and opportunities for the beetle to be transported internationally.

By the late 1950s much of China's forested land had been cleared, which led to soil erosion, a lack of wood resources, desertification, and massive dust storms. In response, the government in China began large-scale tree planting efforts in the 1960s. In 1978, the government expanded the tree planting efforts and formally initiated the Three North Shelter Forest Program. Also called the Great Green Wall, the Three North Shelter Forest Program is a massive reforestation and afforestation effort designed to generate wood resources, stabilize soils, reduce dust storms, and slow the expansion of the Gobi Desert by establishing large-scale tree plantings and windbreaks. The program is the world's largest reforestation and afforestation program, and since its start more than 150 million hectares of agricultural lands have been affected by afforestation efforts, including an estimated 66 billion trees planted across more than 7 million hectares of windrows (Qui et al. 2017). The program is scheduled to continue through 2050, with a goal of creating a 4,500-km-long shelter belt that crosses northeast China.

This massive planting effort in China has encountered challenges. The emphasis on planting large quantities of trees quickly has led to monocultures of species such as *Populus dakuanensis* and North American hybrid poplars selected for their rapid growth. Many of these species have been found to be highly susceptible to infestation by the Asian longhorned beetle, and the use of monoculture plantings (Fig. 4) led to large outbreaks of the Asian longhorned beetle in China in the 1980s and 1990s (Haack et al. 2010). Today the beetle is a significant management challenge for planted trees in agricultural and urban environments across much of China.

As infestations develop within trees, beetle larvae tunnel through the phloem and the xylem, exposing the tree to secondary pests and pathogens and weakening the physical structure of the tree as wood is removed. Broken branches and trunks are common in infested trees, particularly in windy conditions (Pan 2005). To control outbreaks and manage hazardous trees, provinces in China initiated large tree cutting programs. By the mid-1980s, more than 80 million beetle-infested trees had been felled in Ningxia Province alone, where the first outbreaks were documented. The aggressive cutting of infested trees has produced large quantities of low-quality wood that is unsuitable for commodities such as furniture, veneer, and high value dimensional lumber but structurally adequate for commodities such as pallets, crates, and dunnage, where the appearance of the wood is not as important. The use of infested wood to produce solid wood packing material (Fig. 5) combined with the ability of late instars and pupae

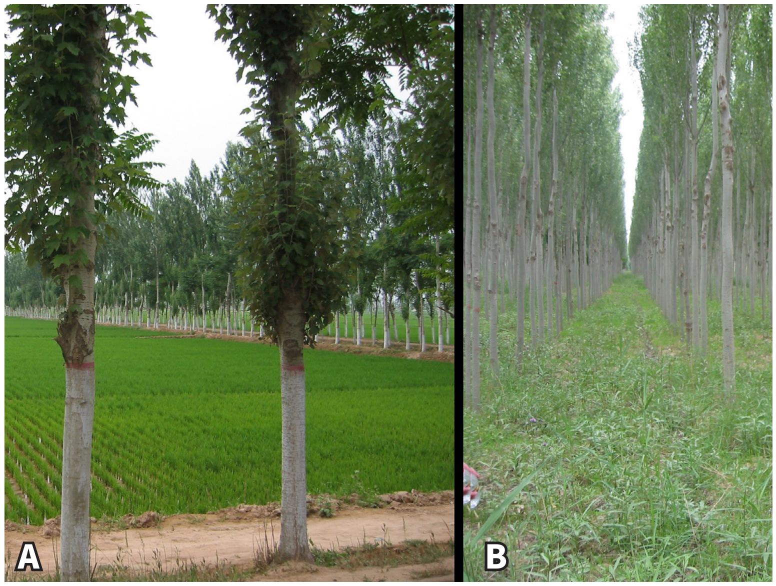

Figure 4.—Windbreaks (A) and monoculture plantings (B) of poplars in China infested by native populations of the Asian longhorned beetle. USDA Forest Service photo.

Figure 5.—Solid wood packing materials such as pallets, crates, and dunnage (material used to keep cargo from shifting in transit) provide a pathway for the spread of nonnative, wood boring species such as Asian longhorned beetle. USDA Forest Service photo by Larry R. Barber/Bugwood.org.

to survive inside the cut wood during transport led to the introduction of the Asian longhorned beetle to novel landscapes around the globe.

In the early 1990s, the USDA Animal and Plant Health Inspection Service (APHIS) identified the beetle as a high-risk species for introduction to the United States, and in 1992 the first Asian longhorned beetles were found in shipping warehouses in Canada and the United States (Haack et al. 1997). In 1996 the first breeding population outside of Asia was found in New York City, where it had infested street trees. Between the 1996 Brooklyn discovery and 2022, breeding populations of the beetle have been identified in Austria, Belgium, Canada, Finland, France, Germany, Italy, Turkey, the Netherlands, and the United Kingdom (Branco et al. 2022). If infestations are left to spread unchecked, the Asian longhorned beetle has the potential to cause significant ecological and economic harm in both urban and forested settings across North America and Europe. An early study carried out by Nowak et al. (2001) found that infestations in urban settings could cost the U.S. economy more than $660 billion, with additional costs to other economic sectors such as lumber, maple syrup production, and tourism.

Following the 1996 detection, the Animal and Plant Health Inspection Service formed a science advisory committee to review available research on the biology and control of the beetle. The committee recommended eradication as a primary and priority strategy due to the scale of the potential economic and ecological costs of uncontrolled infestations, and the United States, Canada, and members of the European and Mediterranean Plant Protection Organization (EPPO) have adopted policies of eradication. Eradication programs typically focus on eliminating the beetle by finding individual infested trees and destroying them by felling and chipping (Fig. 6).

Figure 6.—Trees infested with Asian longhorned beetles are felled and destroyed (A), usually by chipping the entire tree (B), to prevent the emergence of beetles and the spread of an infestation. USDA Animal and Plant Health Inspection Service photo.

The Biology and Life History of the Asian Longhorned Beetle

In the summer and early fall, mated females crawl on the trunk and branches of host trees searching for suitable oviposition sites. Females chew a pit in the bark, during which they may assess the quality of the oviposition site. If the location is acceptable, the female turns 180 degrees to bring her ovipositor to the freshly chewed pit and insert a single egg through the bark into the phloem (Fig. 7). After hatching, beetle larvae feed on cambial tissues, which leads to necrosis and potential bark loss from the feeding zone. After developing through three instars, the larvae turn inward to chew through the xylem and heartwood, which leaves tunnels approximately 10 mm in diameter. Beetles within the xylem continue to develop through at least two additional instars while growing to a weight of 1 to 2 g; under suboptimal conditions, larvae may molt through more than 14 instars (Keena and Moore 2010). In the spring and summer, larvae that are ready to pupate chew horizontally through the wood toward the bark, stopping about 2 cm below the surface. Here the beetles chew a pupal chamber, pupate, and emerge as adults (Fig. 8). Adults remain in the pupal chamber while they sclerotize, a process than can take several weeks (Sánchez and Keena 2013). Adults then chew through the remaining wood to emerge from the tree, leaving a circular hole in the bark about 1 cm in diameter (Fig. 9). Emerged adults spend up to 2 weeks feeding on leaves and twig bark (Fig. 10), after which they are ready to mate. For most native and introduced populations, complete development takes roughly 2 years, although variation among beetles, hosts trees, and climates can lead to development times ranging from 1 to more than 6 years (Trotter and Keena 2016). The Asian longhorned beetle feeds on a wide range of host trees, including members of the genera *Acer, Aesculus, Albizia, Betula, Carpinus, Cercidiphyllum, Crataegus, Elaegnus, Fagus, Firmiana, Fraxinus, Koelreuteria, Malus, Platanus, Populus, Prunus, Salix, Sorbus, Tilia, Ulmus,* and *Xanthoceras,* and there is one record of a single infested hickory (*Carya*) (Meng et al. 2015).

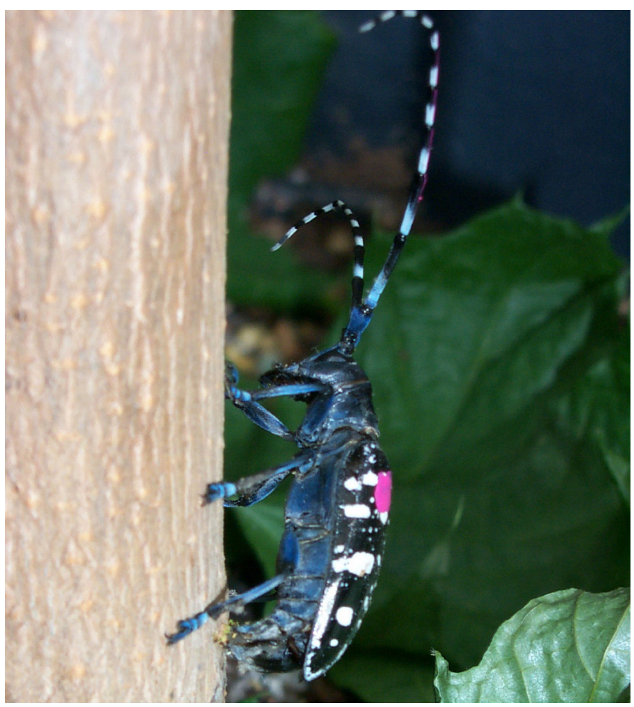

Figure 7.—A female Asian longhorned beetle inserting an egg into the phloem of the host tree. After chewing pits in the bark to reach the phloem, the female turns 180 degrees and inserts the egg. This beetle has been marked with paint as an identifying mark in a study. Licensed photo by Dean Morewood, Health Canada/Bugwood.org.

Figure 8.— Cutaway view of an adult Asian longhorned beetle in a pupal chamber preparing to chew an exit tunnel. When larvae are ready to pupate, they chew horizontally to create a chamber. After pupation, the adult emerges in the chamber, where it sclerotizes. USDA Forest Service photo by Michael Bohne/Bugwood.org.

Figure 9.—Adult Asian longhorned beetle finishing the round exit hole to emerge from the tree. USDA Forest Service photo by R. Talbot Trotter.

Figure 10.—Adult Asian longhorned beetles feed on the bark of twigs and on the midribs and petioles of leaves. Licensed photo by Dean Morewood, Health Canada/Bugwood.org.

Survey Methods and Estimates of Their Efficacy

When the Asian longhorned beetle was first detected in the United States in 1996, research programs were initiated by federal, state, and local agencies; private industry; and universities to develop survey methods to find infested trees on the landscape. Survey and research programs have explored the use of detector dogs (Errico 2013), pheromone and kairomone baited traps (Crook et al. 2014; Meng et al. 2014; Nehme et al. 2010, 2014; Zhang et al. 2002), audio equipment capable of detecting the sounds made by beetles as they chew through the wood, and visual surveys conducted both from the ground and within tree canopies by tree climbers. Although these methods have progressed, they have been found to be unsuitable for conducting cost-effective surveys at a landscape scale. For example, pheromone and kairomone baited traps have an effective distance of less than 100 meters and limited draw strength. Detector dogs have been effective in controlled settings but may be less effective and more expensive to apply in urban and rural landscapes. Detecting the sounds of chewing beetles requires substantial equipment, and the approach is currently not practical for landscape-scale surveys. Because of these limitations, most eradication programs in North America and Europe continue to depend on visual surveys conducted by trained field crews to find infested trees on the landscape (Haack et al. 2010, Turgeon et al. 2022).

Ground Survey and Management Methods and Efficacy

Ground survey crews are tasked with conducting visual surveys of individual trees using binoculars and spotting scopes to find beetles' exit holes and oviposition pits (Figs. 2 and 3), which can occur in any part of the canopy where the diameter is greater than about 3 cm. The efficacy of these ground-based surveys is influenced by multiple factors: the height, type, and abundance of damage (Turgeon et al. 2010); the portions of the tree visible from the ground; irregular bark surfaces; snow- or ice-covered bark; views blocked by intersecting canopies; lighting; season (leaf on or leaf off); and the skill and experience of the surveyor.

Estimating the efficacy of ground surveys is difficult, and the probability of detecting or failing to detect an infestation varies among trees and surveyors. An experimental analysis of detectability by Turgeon et al. (2010) found a rate of 73 percent detection success with a single oviposition pit and 66 percent success when a single exit hole is present, when damage is visible from the ground and the visibility of damage is standardized. Preliminary estimates indicate an average of 30 percent of the bark on a tree is visible from the ground, and while detection rates may be higher due to the distribution of exit holes and oviposition pits in the lower canopy and upper bole, the assumed (default) detection efficacy used is 30 percent with a corresponding 70 percent probability of failing to detect an infestation. Actual detection rates may be higher, and managers may elect to apply modified rates. Despite the limitations of ground-based visual surveys, this method has been effectively used to eradicate several Asian longhorned beetle breeding populations, including infestations in New Jersey, Boston (MA), Chicago (IL), Toronto (Canada), and Kent (United Kingdom).

Tree Climbing Survey Methods and Efficacy

Surveys conducted from within the canopy by tree climbers face some of the same limitations as ground surveys, including lighting, season (leaf on or leaf off), the accessibility of the tree, and surveyor experience. However, the ability to move through the canopy of the tree allows surveyors to access a larger portion of the tree, including upward-facing surfaces. Climbers can also make close-up inspections of damage to confirm or reject suspected damage that cannot be verified from the ground. With increased access to the canopy, climbing staff have estimated that 70 percent or more of the surface of the trunk and branches are visible, making the survey efficacy for tree climbers estimated to be 70 percent (with a corresponding 30 percent probability of failing to detect an infestation).

Aerial Survey Methods and Efficacy

Surveyors may use lifting equipment such as bucket trucks and personnel lifts (Fig. 11) to access tree canopies (unmanned aerial systems, such as drones, are also under evaluation but are not yet used on an operational scale and are not discussed here). Lifting equipment allows surveyors to move quickly through a canopy and examine branches that are too small to be climbed safely. Lifting equipment also provides access to trees that might otherwise be too dangerous to survey due to tree defects or the presence of power lines. For the purposes of estimating the efficacy of surveys carried out using bucket trucks and personnel lifts, these methods are assumed to have the same 70 percent detection efficacy as tree climbing and are combined in the general category of aerial surveys.

Full Host Removal

In some instances, areas of the landscape may be effectively managed by removing all host material. Full host removal activities have several advantages, including a high probability of eradication, low risk of reinfestation, and a reduced or eliminated need to revisit or resurvey the location. In cases where managers are confident all material has been removed from an area, the removal of 100 percent of the host material is equivalent to carrying out a negative survey with a 100 percent detection efficacy rate. In some cases, however, managers may decide that there is the potential for some host material to remain or for host plants to resprout or reestablish. Under these conditions, an assumed efficacy rate lower than 100 percent may be considered suitable.

Figure 11.—Lifting equipment such as bucket trucks facilitate canopy inspection surveys. Licensed photo by Thomas B. Denholm, New Jersey Department of Agriculture/Bugwood.org.

ALB HAZARD MANAGEMENT AND MONITORING 1.0: OVERVIEW

ALB Hazard Management and Monitoring 1.0 provides a method to calculate changes in infestation risk on the landscape due to management activities and is the second step in a two-step process. The first step is estimating the distribution of infestation risk on the landscape due to beetle dispersal and the distribution of known infested trees and is carried out using ALB Risk as described in Trotter et al. (2018, 2021).

The second step uses the mapped estimate of infestation risk generated by ALB Risk as a starting point and calculates changes in risk due to management activities such as the removal of infested trees and the completion of surveys. The tool can track changes in risk due to past management activities and evaluate future potential changes in risk resulting from planned management actions. This process is carried out using ALB Hazard Management and Monitoring, which can be freely downloaded as either a packaged tool for use in ArcGIS ArcToolbox or as a Python script available at https://doi.org/10.2737/NRS-GTR-222.

Estimating Landscape Risk Based on Trees and Landscape Units

Risk is a broad term. In this document and the model it describes, risk is used specifically to describe the probability that a unit of assessment (a tree, area, or landscape) is infested with the Asian longhorned beetle at a given point in time. For an individual tree, risk is the probability that the tree is infested, and infestation is assumed to be a binary condition (infested or not infested). Risk for an area such as a specified hectare (or region) is the probability that at least one tree within that area is infested. Risk in this situation does not indicate the severity or intensity of an infestation; rather, it indicates the probability that at least one infested tree is present.

Using this definition, risk at multiple scales can be estimated. Consider a hypothetical landscape that contains 10 trees. The probability that none of the trees are infested (and the landscape is therefore free of infestation) is calculated as the product of the probabilities that each individual tree is not infested. If the probability that an individual tree is not infested is 80 percent, then the probability that no trees are infested is 10.7 percent ($0.8^{10} = 0.107$), and the concomitant probability that at least one of the trees (and therefore the landscape) is infested is 89.3 percent.

Computing risk this way has the advantages of being computationally simple and using a unit of measure (the individual tree) at which both the biology of the beetle and surveys ultimately operate. However, using a tree-scale approach to assess landscapes may only be feasible on small landscapes with few trees. On landscapes with millions of host trees, data describing the risk for each tree are likely not available, and collecting the data would be time-consuming and cost prohibitive. To accommodate these data limits, the method used by ALB Hazard Management and Monitoring computes changes in risk on a per hectare basis rather than a per tree basis. This hectare-based approach reduces data requirements, aligns with the spatial scale of dispersal risk estimates generated by ALB Risk, and uses a landscape unit that scales with management activities.

The shift in scale from individual trees to hectares, however, requires two assumptions that users should consider. First, breaking the landscape into individual hectares requires the assumption that management activities such as surveys and full host removals are adequately described at a hectare scale. If units of management on the landscape are significantly smaller than a hectare, recording data at this scale may not adequately capture relevant spatial information. Generally, eradication efforts in the United States have operated at scales that make a hectare a reasonable choice, although managers should be aware of the potential role that spatial scale may play and the need to evaluate its suitability for local landscape patterns and management activities. In situations in which different scales may be more appropriate, it may be necessary to change the scaling value used by ALB Hazard Management and Monitoring (for more information contact Robert.T.Trotter@usda.gov).

Second is the assumption that the detection rates used for ground and aerial surveys of individual trees (30 percent and 70 percent detection efficacy, respectively) can be translated to the efficacy of a survey within a hectare, when the actual number of trees within the hectare may vary. One simplifying approach is to recognize that the 30 percent and 70 percent survey efficacy values are based on estimations of the total surface area of a tree that is visible. If this assumption is extended to a given hectare, then regardless of the number of trees within a hectare, 30 percent (or 70 percent) of the total tree surface area within a hectare is likely to be visible to surveyors. However, this approach does not account for potential changes in the detectability of an infestation within a given hectare as the number of infested trees increases (described in the following section).

Using Tree-Based Estimates of Survey Efficacy at Larger Spatial Scales: A Thought Experiment

To explore the effect of changes in the number of trees surveyed on the probability of detecting an infestation, it is helpful to consider several extreme scenarios. Consider a hectare that contains only one tree, which is lightly infested. In this situation, the probability that the infestation will be detected when the hectare is surveyed is simply the probability that the infestation will be detected when the single tree is surveyed, or 30 percent (assuming ground surveys are used). Now consider a situation in which there are 10 trees within the hectare, all of which are infested. In this situation the probability that *at least one* infested tree will be detected is 1 minus the probability of failing to detect the infestation in all 10 trees ($1 - 0.7^{10}$), or 97 percent. As the number of infested trees increases, the probability of detecting at least one of the infested trees (and therefore correctly identifying the hectare as infested) increases rapidly. The efficacy of a survey (or the probability that it will successfully detect an infestation) is therefore bounded at the low end by the probability of detecting a sole infested tree (30 percent for ground surveys and 70 percent for aerial surveys) and an upper bound that approaches 100 percent as infestations include more trees. Under these conditions, the use of the single tree rates of detection (30 percent and 70 percent) is likely to be conservative. Under real world conditions where, if a hectare is infested, it is likely multiple trees are infested, the use of the single tree detection may underestimate the effective survey efficacy. Because the probability of detecting an infestation in an uninfested tree is assumed to be zero, the total number of uninfested trees within the hectare does not change the estimated survey efficacy because it does not alter the probability of detection within the single infested tree, even though tree abundance and density will play a substantial role in the time required to complete a survey.

The Effect of Landscape Unit Size on Estimated Survey Efficacy: A Thought Experiment

Although the preceding example provides a logical justification for applying the tree-specific estimates of survey efficacy to a given hectare, there is an important interaction between the estimated probability of detection and the size of the landscape unit. Some of the effects of changing the size of the landscape unit can be explored by considering situations in which the unit is very small or very large. At the extreme end of small landscape units, consider a situation in which units are so small that they contain only one tree. Under these conditions, the probability of detecting an infestation within that unit is once again the probability of detecting an infestation within a single tree. If, however, the landscape unit is very large and the entire landscape is analyzed as a single unit, then the probability of detecting the infestation on the landscape again becomes a function of the number of infested trees and the survey method used. Between these two extremes, there may be interactions between the total landscape scale risk (based on the product of the risk within landscape units) and the size of the units, and this issue merits further exploration. Based on these extremes, selecting a landscape unit that is practical for management may be a reasonable tradeoff, and within these analyses a standard hectare is used.

The Effect of Time Between Surveys on Survey Efficacy

Left unmanaged, a small population of the Asian longhorned beetle in a stand with adequate host material is expected to increase over time. As the population increases, the abundance and visibility of damage within the tree and the number of infested trees are expected to increase. Because the detectability of an infestation is linked to both the amount of damage within trees and the number of infested trees, the detectability of an infestation would be expected to increase the longer the population infests a given location.

Two simple scenarios highlight this process. Consider a situation in which one lightly infested tree is surveyed from the ground and the infestation is not detected. If the same tree is surveyed again the following year, the beetle population may have increased very little, and the probability of detecting the infestation remains nearly as low as it was during the previous survey (i.e., 30 percent). Then consider a situation in which the second survey of the lightly infested is conducted eight years after the first. Over the eight-year period, both the quantity of damage to the single infested tree missed in the initial survey and the number of infested trees around it would be expected to increase, making the infestation more apparent and therefore more likely to be detected. By similar logic, two negative surveys carried out with a substantial time lag between them may provide a high level of confidence that an area is not infested.

To integrate the assumed increase in detectability of infestations with the passage of time, the model decreases the probability that a survey (ground or aerial) will fail to detect an infestation by 5 percent for each year that passes between surveys starting in the second year. The assumption of an annual and constant 5 percent increase in the detectability in the period between surveys is currently based on field experience by surveyors and program managers, and additional research is needed to refine this estimate. The user can explore the effect of this value on landscape estimates by running multiple scenarios using multiple and varying rates as described in section 4.

Calculating Changes in Hectare Risk Following Management Activities

To calculate changes in risk for each hectare on the landscape, ALB Hazard Management and Monitoring starts with the estimated probability that the hectare is infested based on the output generated by ALB Risk. Then, for each year for which there is data, the probability of infestation (risk value) is multiplied by the probability that a given survey method will fail to detect the infestation. For example, if a hectare has a 75 percent probability of infestation and is surveyed once from the ground (with a 70 percent probability of survey failure), the updated infestation probability is

$$0.75 \times 0.70 = 0.525$$

or 52.5 percent. As subsequent surveys and host removals are completed, the new risk value is again multiplied by the probability that the survey method will fail to detect (or in the case of host removal, fail to remove) the infestation. If multiple management actions are carried out within a single year, their effects are included following the sequence (1) ground survey, (2) aerial survey, (3) host removal. To accommodate the effect of beetle population growth over time, the probability of survey failure is reduced by 5 percent for each year between surveys, as described in the preceding section.

The above method allows the estimated risk (probability of infestation) to be updated for each hectare in each year that the landscape is managed. However, this approach assumes that no new infested trees are detected during the surveys. The detection of new infested trees in an area that had previously been surveyed suggests several possible scenarios, the two most likely of which are (1) the infestation was there during the previous survey(s) but was not detected, or (2) the area was not infested during the previous survey(s) but has since become infested by newly arrived beetles. Both scenarios merit further study to identify reasonable methods for calculating the conditional odds that either has occurred and the impact of these events on the estimated risk for the given hectare. Currently, however, the model uses the simple approach of reassigning the starting risk value for the hectare (prior to any management activity). Using the above example, if the single hectare started with a risk estimate of 75 percent and had one negative survey (thus bringing the risk to 52.5 percent), the detection of an infested tree during a second survey would return the hectare risk estimate to 75 percent (note that this is the risk value assigned *after* the newly identified infested tree(s) have been removed). This method has the effect of highlighting areas where infestations have been found during multiple surveys and applies a conservative approach to estimating risk.

ALB HAZARD MANAGEMENT AND MONITORING 1.0: USER GUIDE

This user guide uses the following fonts to highlight names and actions:

- *Italic text* denotes names of files and default layers.
- **Bold black** indicates input text and options to be selected by the user.
- `Courier font` indicates text and input prompts generated by the tool.

1 Downloading and Installing the Tools

ALB Hazard Management and Monitoring 1.0 uses multiple sources of input data, including an estimate of the pre-management distribution of infestation risk on the landscape generated by the tool ALB Risk. Both tools (ALB Hazard Management and Monitoring and ALB Risk) are freely available for download and are installed separately.

1.1 Installing ALB Risk 1.2

ALB Risk calculates a raster dataset that provides an estimate for the distribution of infestation risk prior to management activities. Both the tool and the user guide describing its installation and use are available for download at https://doi.org/10.2737/NRS-GTR-201. In brief, ALB Risk uses the locations of known infested trees and the estimated level of infestation within trees to reconstruct patterns of beetle spread on the landscape. These estimates of dispersal risk are then re-applied to the locations of known trees on the landscape to produce a hectare-by-hectare estimate of the probability that a location has been infested by a beetle arriving from at least one of the infested trees on the landscape.

1.2 Downloading and Installing ALB Hazard Management and Monitoring 1.0

ALB Hazard Management and Monitoring is a tool that can be added to the ArcToolbox used in ArcGIS Desktop or ArcGIS Online. Start by downloading the zipped file called *ALB Hazard Management and Monitoring Tool v1_0.zip* (or the file providing the most current version), which is available at https://doi.org/10.2737/NRS-GTR-222. Users can unpack the files using *winzip, zip7,* or any other suitable program. The user can place the unpacked files in any location that is convenient, but the location used will need to be accessible to the user. Once unpacked, the user should have a directory called ALB Hazard Management and Monitoring. To install the tools into ArcToolbox, follow these steps:

1. Open ArcMap.
2. Click on the ArcToolbox icon to open the ArcToolbox window (Fig. 12).
3. Right click on the uppermost directory, ArcToolbox, and select the option **Add Toolbox**.
4. Navigate to the ALB Hazard Management and Monitoring directory, and then select **ALB Tools**.
5. ArcToolbox should now include a tool directory for ALB Tools (Fig. 13).
6. Right click on the ALB Tools directory, select **Add**, and then select **Script**.
7. Navigate to the ALB Hazard Management and Monitoring directory, and then select **ALB Hazard Management and Monitoring 1.0** (or current version).
8. Repeat this process (Add Script) to add ALB Hazard Management and Monitoring and Data Reformat scripts

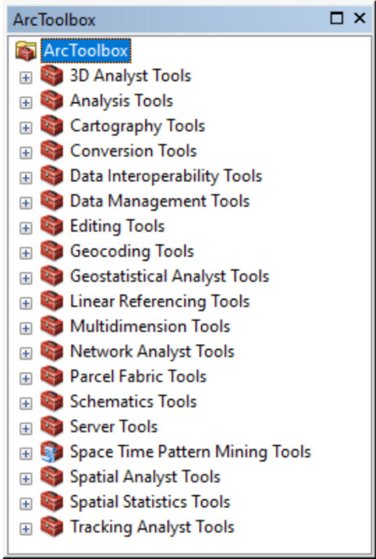

Figure 12.—ArcToolbox window.

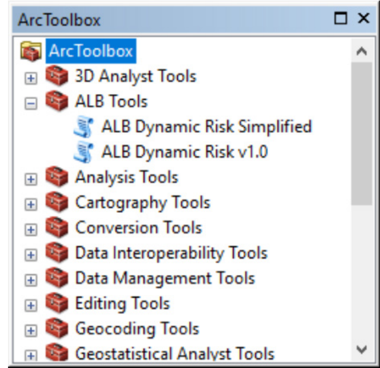

Figure 13.—ArcToolbox window with ALB Tools added and open.

With the three tools within ALB Tools loaded into ArcToolbox, ALB Hazard Management and Monitoring is ready to use.

2 Organizing and Formatting Input Data

Input data are provided as four layers within a single geodatabase. The layers should include the following, each of which is described below: a point layer that provides the level of infestation, location, and year detected for each known infested tree (2.1); a polygon layer documenting the areas included in ground surveys and the year that each survey was completed (2.2); a polygon layer documenting the areas that have been surveyed by climbers and the year that each survey was completed (2.3); and a polygon layer documenting the areas where full host removal has been conducted and the year that the host material was removed (2.4). The names of the geodatabase and the individual layers can be defined by the user, although as noted below, using the recommended names reduces the number of parameters the user will need to set when running the tool.

2.1 Formatting the Infested Tree Data Input Layer

The geodatabase used should include a point layer documenting the known infested trees. For each tree in the database, the data table should include four fields providing the X coordinate, Y coordinate, a numeric integer (1 to 5) indicating the level of infestation within the tree, and a numeric four-digit value recording the year that the infested tree was detected. The order of the fields in the data table is not important, and the table can include additional fields (although the additional fields will be ignored by the tool). Following are additional details on the required fields.

Naming the infested tree data layer: Any name can be used to identify the layer containing the infested tree records. However, the tool will use the default layer name *InfestedTrees* unless an alternative is provided by the user. Using the default layer name can simplify analyses by reducing the number of parameters the user will need to set when running ALB Hazard Management and Monitoring. Note that although any name can be used, the name of the layer in the geodatabase needs to match the name of the layer as it is shown in ArcMap. Once a layer is loaded into ArcMap, users can change the name of the layer in the Table of Contents within

ArcMap (without changing the name of the layer in the geodatabase). While this is a useful feature, changing the name or label in the Table of Contents can cause an error when ALB Hazard Management and Monitoring is run, so renaming layers in the map is discouraged.

Tree coordinates: The tree coordinates table must include an X and Y coordinate for each tree. These values should be based on a cartesian coordinate system such as the Universal Transverse Mercator (UTM) projection. If X and Y coordinates are not included in the table, they can be added using ArcToolbox. First, the coordinate system for the layer must be reprojected (if necessary) to UTM. Once the coordinate system is in UTM, X and Y values can be added by opening ArcToolbox, opening **Data Management Tools**, opening **Features**, and selecting **Add XY Coordinates**. The tool will add two columns to the data called *Point_X and Point_Y*. ALB Hazard Management and Monitoring assumes the X and Y data are included in fields with these default names. If X and Y data are already in the table but are provided under different field names, the fields will need to be either renamed or replicated with the required names. The field type containing the X and Y coordinates should be numeric, and values should be provided for each tree. Missing values for trees will generate an error when the tool is run.

Infestation levels: The model requires each tree be assigned to one of five numeric infestation levels using integers 1 through 5, using values provided in a numeric field called *NLevel*. Values 1 through 4 mirror the four-tier A, B, C, and D rankings used by the USDA Animal and Plant Health Inspection Service, Asian Longhorned Beetle Cooperative Eradication Program. Level 1 trees (APHIS level A) are those with oviposition pits and no exit holes. Level 2, 3, and 4 trees (APHIS levels B, C, and D) have 1 to 10 exit holes, 11 to 100 exit holes, and more than100 exit holes, respectively. The dataset should include one (and only one) level 5 tree. This tree is assumed by the model to be the first infested tree. In many cases, it is not known which tree was the first to be infested on a landscape. Preliminary analyses (Trotter and Hull-Sanders 2015) suggest that in these cases it is reasonable to simply select a highly infested tree in the stand that is most likely the epicenter of the infestation. All trees in the dataset should include an infestation value because missing values will generate an error when the tool is run. In cases where the level of infestation for a tree is not known, it is recommended users assign the value 1. Prior work (Trotter and Hull-Sanders 2015) suggests that if the trees with missing values make up a limited portion of the data and the dataset is large enough, the results may be robust to missing information.

Detection year: To calculate changes in risk as new infested trees are detected, the model requires that the year of detection be included for each tree in a numeric field called *year*. Values in *year* should use four digits and should be limited to integers. Records of tree detections and removals may be incomplete and the year of detection may not be known, an issue which can arise particularly in older or early eradication program records. In these cases, it is recommended that the last year of survey activity be used as a surrogate *year* value. This provides a conservative estimate of updated risk by assuming the trees were detected as recently as was feasible. All trees should include a value in the *year* field because missing values will generate an error.

Limits to the number of infested trees: The tool does not place an upper limit on the number of trees that can be included in the analysis, although using datasets with more than 50,000 trees may result in the tool running slowly. Similarly, the tool does not place a lower limit on the number of trees that must be included; however, it is important to note that as the number of trees decreases, the relative quality of the estimated kernels used to calculate the starting point for risk estimates may decrease.

2.2 Formatting the Ground Survey Data Layer

Records of ground surveys should be stored within a polygon layer in the geodatabase, and the layer should use the same projection and coordinate system used for the infested trees layer. Each polygon within the ground survey layer should include two numeric fields, one providing the year in which the polygon was surveyed (*year*), and a field called *inside*. Each polygon should represent a single discrete survey. A single location may be included in multiple overlapping polygons if the area has been surveyed multiple times and/or using multiple survey methods.

Naming the ground survey data layer: As noted for the infested trees layer (section 2.1), any name can be used to identify the ground survey data layer, although the user may find it convenient to use the default name *GroundSurvey* because doing so reduces the number of parameters the user will need to set when running the tool. It is also important that the label shown for the data layer in the Table of Contents in ArcMap match the name of the layer within the geodatabase.

Ground survey year: The data layer should include a numeric field called *year* which provides the year in which a ground survey was conducted using a four-digit integer value. In some cases, particularly in large survey areas, a survey may bridge two calendar years. In these situations, using the year in which the survey was completed may provide a more conservative approach to estimating survey efficacy and impact.

Field indicating inside: To calculate changes in risk on the landscape resulting from surveys, ALB Hazard Management and Monitoring will designate each part of the landscape as either inside or outside a survey area for each year of the analyses. To designate the areas that are inside, the data table should include a numeric field called *inside*, and the value for each polygon should be set to 1. When the tool runs, it will designate all areas that are not indicated with a 1 as being outside the survey area (i.e., not surveyed). If the data layer does not include an *inside* field, it can be added using the Add Field tool. Polygons with a value other than 1 will be ignored (treated as not surveyed) by ALB Hazard Management and Monitoring.

When no ground survey data are available: If ground surveys have not been carried out, or if no data from ground surveys are available, the geodatabase should still include a ground survey layer with the indicated fields, and the layer should be empty (no polygons).

2.3 Formatting the Climbing Survey Data Layer

The climbing survey data layer uses a format like the one described for the ground survey data (section 2.2). It should use the same projection and coordinate system used by the infested tree data, include two fields (called *year* and *inside*), and use individual polygons for individual surveys, so that a location surveyed twice is documented as two polygons (even if the polygons are geographically the same). The default name for the layer is *ClimbingSurvey*; using the default name will reduce the number of parameters the user needs to set when running ALB Hazard Management and Monitoring.

Other aerial survey methods: Eradication programs may use multiple methods to conduct aerial surveys, such as tree climbers, bucket trucks, or personnel lifts. In the absence of additional information on survey efficacy for these methods, these other survey methods can be included in the climbing survey dataset and will be assumed to have the same survey efficacy as tree climbers.

When no climbing survey data are available: If climbing surveys have not been carried out, or if no data from climbing surveys are available, the geodatabase should still include a climbing survey layer with the indicated fields, and the layer should be empty (no polygons).

2.4 Formatting the Full-Host Removal Data Layer

Eradication programs may elect to carry out the full removal of host trees from a given area to accelerate eradication progress. These areas of full host removal should be documented as polygons and use a data format like the one described for the ground survey data (section 2.2). The default name used for the layer is *HostRemoval*.

When no full host removal data are available: If no full host removals have been conducted or if data for full host removals are not available, the geodatabase should still include a full host removal layer with the indicated fields, and the layer should be empty (no polygons).

3 Loading the Input Data and ALB Tools into the Map

ALB Hazard Management and Monitoring 1.0 is provided as a tool that can be added to the ArcToolbox in ArcMap (ArcGIS Desktop or ArcGIS Online). Running the tool requires the user to open a map and load the layers used by the model. Follow these steps to set up the analysis map:

1. Open a new map in ArcMap and load the ALB Tools into ArcToolbox if needed (see the overview). If a map has already been set up, open the saved map and skip to section 4.

2. If the map is new, add each of the four data layers (e.g., the layers *InfestedTrees, GroundSurvey, ClimbSurvey,* and *HostRemoval*) to the map. The order in which the layers are loaded does not matter.

3. Confirm the projections for each of the four data layers in the geodatabase are in a UTM projected coordinate system and that each of the layers uses the same projection. To check each layer, right click on the name of the layer in the Table of Contents and select **Properties**. In the Layer Properties window, select the **Source** tab. Scroll down to **Projected Coordinate System** and ensure that the listed coordinate system is UTM. While the coordinate system should be UTM, the layers can use any projection (e.g., Transverse or Mercator.), but each layer must use the same projection

4. Confirm the data provided in the infested trees layer meet the requirements listed below. (See section 2.1 for how to format the data layers.)

    a. The infested tree layer must be a point layer.

    b. The data table for the infested tree layer must provide X coordinates, Y coordinates, a numeric value representing the level of infestation, and the year of detection. The fields should be called *Point_X, Point_Y, NLevel*, and *year*, respectively. The order of the fields within the table is not important.

    c. Each of the fields should include numeric data, be defined as a numeric field, and should not include NULL values.

    d. Confirm that the fields *year* and *NLevel* include only integer values using the Attribute Table.

    e. Confirm that the field *NLevel* includes values limited to 1, 2, 3, 4, and 5, and that the dataset includes one (and only one) level-5 tree.

    f. Confirm the values in the field *year* are limited to those years between 2004 and the present. Data for years prior to 2004 will be ignored by the model.

5. Confirm the data provided in the ground survey layer meet the requirements listed below. (See section 2.2 for how to format the layers.)

    a. The ground survey layer can use any name; however, using the default name *GroundSurvey* reduces the number of parameters the user will need to set when running the tool.

   b. The ground survey layer should be a polygon layer.

   c. The ground survey layer can include any number of polygons (including none, if no ground surveys have been conducted). If no ground surveys have been conducted, the datasets and map should still include an empty ground survey data layer.

   d. The layer should include two fields, one called *inside* and one called *year*. Both fields should be numeric.

   e. For each polygon, the value for *inside* should be set to 1.

   f. Confirm the values in the field *year* are limited to those years between 2004 and the present. If the analyses include data from years before 2004, please contact Talbot Trotter (Robert.T.Trotter@usda.gov) for a modified model that can include these data.

6. Confirm the data provided in the climb survey layer meet the following requirements:

   a. The climbing survey layer can use any name; however, using the default name *ClimbSurvey* reduces the number of parameters the user will need to set when running the tool.

   b. The climbing survey layer should be a polygon layer.

   c. The climbing survey layer can include any number of polygons (including none, if no climbing surveys have been conducted). If no climbing surveys have been conducted, the datasets and map should still include an empty climbing survey data layer.

   d. The climbing survey layer should include two fields, one called *inside* and one called *year*. Both fields should be numeric.

   e. For each polygon, the value for *inside* should be set to 1.

7. Confirm the data provided in the host removal layer meet the following requirements:

   a. The host removal layer can use any name; however, using the default name *HostRemoval* reduces the number of parameters the user will need to set when running the tool.

   b. The host removal layer should be a polygon layer.

   c. The host removal layer can include any number of polygons (including none, if no host removal has been conducted). If no host removals have been conducted, the datasets and map should still include an empty host removal data layer.

   d. The layer should include two fields, one called *inside* and one called *year*. Both fields should be numeric.

   e. For each polygon, the value for the field *inside* should be set to 1.

   f. Polygons included in the host removal layer should be limited to those areas where all host material has been removed from the area. Areas in which only portions of the host have been removed should not be included or should be integrated using a separate data structure in which risk can be identified specific to the partial removals.

8. Confirm that hardscapes and noncanopy areas, such as parking lots, buildings, and lakes, have been removed, if possible. The simplest method for including these hardscapes is to add hardscape polygons to the host removal layer and assign the first year of the analyses to the polygons.

4 Opening and Running the Tool: Setting Parameters

Once the data have been formatted and loaded into the map, the user can open the tool and set the required parameters. The tool can be opened by opening ArcToolbox, then expanding the **ALB Tools** toolbox, and selecting **ALB Hazard Management and Monitoring 1.0**.

When the tool opens, the user will be presented with a parameter window (Fig. 14). The window provides opportunities for the user to identify the data layers, set locations where output data will be stored, and change model parameters such as survey efficacy. The following pages summarize the parameters and provide recommendations.

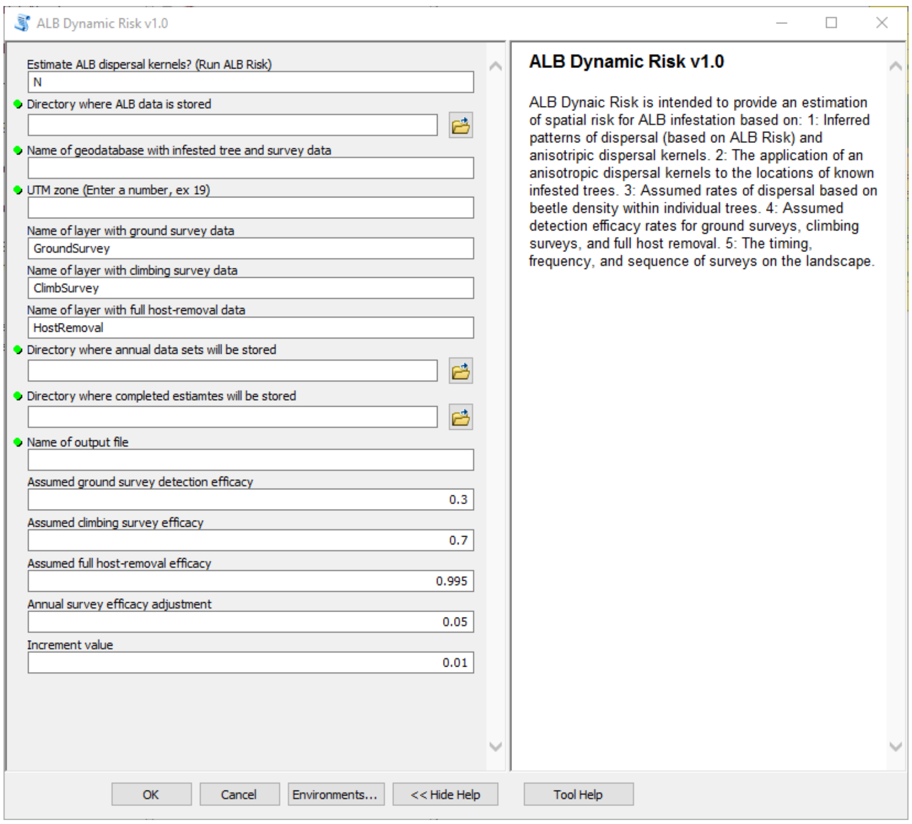

Figure 14.—ALB Dynamic Risk parameter window.

4.1 `Estimate ALB dispersal kernels?(Run ALB Risk)`

Enter **Y** or **N** in the field. If the user enters **Y**, a new DOS-style window will open to provide access to the tool ALB Risk (Fig. 15). ALB Risk is used to calculate a dispersal risk map to define the starting risk for the landscape. The model uses the locations and levels of infestation for each tree to reconstruct two-dimensional dispersal kernels and applies those kernels to the landscape to estimate the risk of beetle dispersal and presence on a hectare-by-hectare basis. The user guide for ALB Risk and the latest version of the tool are available at https://doi.org/10.2737/NRS-GTR-201. If the user enters **N**, ALB Risk will not be initiated, and ALB Hazard Management and Monitoring will assume that the map describing the starting risk on the landscape has already been calculated and is available in the directory *C:/ALB_Risk/application*, and that the file is called *risk.txt*. If multiple ALB Hazard Management and Monitoring runs, are being made using the same starting risk value, using an already available *risk.txt* file can speed processing.

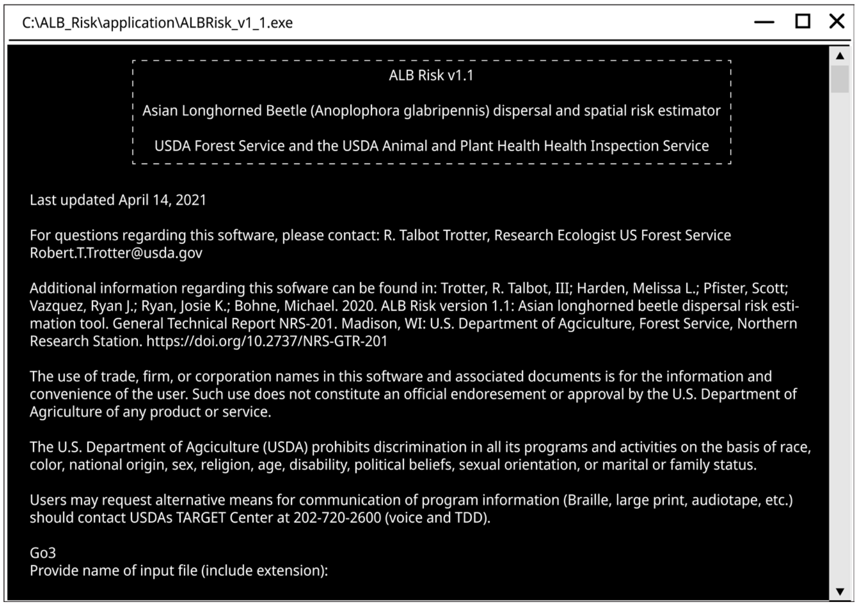

Figure 15.—The DOS-style window that opens when the option to run ALB Risk is set to Y or Yes.

4.2 `Directory where ALB data are stored`
Identify the folder or directory that contains the geodatabase used in the map. This can be done by either typing the directory pathfile or using the folder icon to search for the directory.

4.3 `Name of geodatabase with infested tree and survey data`
Enter the name of the geodatabase that contains the data layers. It is not necessary to include the *.gdb* suffix in the name.

4.4 `UTM zone (Enter a number, ex 19)`
Enter a number to identify the UTM zone in which the analyses will be carried out. For infestations in the United States, the infestation in Worcester is in zone 19, Long Island is in zone 18, South Carolina is in zone 17, and Ohio is in zone 16.

4.5 `Name of layer with ground survey data`
Enter the name of the layer that provides the ground survey data. The name *GroundSurvey* is provided as the default layer name.

4.6 `Name of layer with climbing survey data`
Enter the name of the layer that provides the climbing survey data. The name *ClimbSurvey* is provided as the default layer name.

4.7 `Name of layer with full host-removal data`
Enter the name of the layer that provides the full host removal data. The name *HostRemoval* is provided as the default layer name.

4.8 `Directory where annual datasets will be stored`
As the model runs, it will generate up to nine intermediate data layers for each year included in the analysis. The user may select a location where these annual layers will be stored. If a location or directory that already contains copies of annual layers from previous analyses is selected, the old data layers will be overwritten when new layers are generated.

4.9 `Directory where completed datasets will be stored`

Running the model will produce a series of raster files that provide the starting estimate of risk, annual changes in risk, and the most recent/current estimate of risk for each hectare within the area of analysis. If the user is running multiple scenarios, it may be helpful to create a directory for each scenario to organize results.

4.10 `Name of output file`

Enter the name to be used to identify the file that will store the final estimate of current risk (or risk through the dates for which data are available). If running multiple scenarios, using a file name that identifies the scenario can help organize results.

4.11 `Assumed ground survey detection efficacy`

The model assumes that the probability that a ground survey crew will detect an infested tree within a given hectare (assuming at least one infested tree is present) is 30 percent. The user may select a different value based on local estimates. (See the introduction and overview sections of this document for more information on this parameter.)

4.12 `Assumed climbing survey efficacy`

The model assumes tree climbers have a 70 percent probability of detecting an infested tree within a hectare in which infested trees are present. The user may modify this value based on available information. (See the introduction and overview sections of this document for more information on this parameter.)

4.13 `Assumed full host-removal efficacy`

The default probability that full host removal will eliminate infestation risk is set to 99.9 percent. Using this value allows the user to assume that host removal has mitigated but not eliminated the potential for beetle infestation. The user may opt to use 100 percent if they are confident that all host material has been removed from a given area. In situations in which high risk host or partial host-removal actions are taken, the value may be adjusted to reflect the relevant proportion of material or risk removed.

4.14 `Annual survey efficacy adjustment`

It is possible that an infested hectare will be surveyed and that the infestation will not be detected. For example, in a densely wooded hectare, the difficulty of detecting a single exit hole or oviposition pit is extremely high. However, populations of the beetle would be expected to increase as the beetle goes through multiple generations, leading to a larger, denser infestation that is easier to detect. Thus, the more time that passes between surveys and the more time an infestation has had to grow, the higher the probability it will be detected. The value selected here is the annual adjustment made to the survey efficacy based on the number of years that have passed between the most recent and the current survey. Selecting a value of 0 assumes infestations do not become easier to detect as they age and removes this assumption from the model.

4.15 `Increment value`

The model includes functionality to conduct some sensitivity analyses when run under a set of related conditions. For example, users may wish to produce model outputs under varying assumptions of survey efficacy. The increment value sets the change in a modified parameter for iterations of the model. If the user is not running sensitivity analyses, this parameter can be ignored.

5 Output Data

The output files generated by ALB Hazard Management and Monitoring can be placed into two categories: Working Files and Output Files. As described above, the tool uses an iterative process to generate individual layers for each year and survey method used, layers to track the number of years between successive surveys, and incremental changes in risk associated with partial combinations of survey methods for each year of the analysis. These working files represent steps in the analysis, and while they can be useful for identifying where in the process a pattern may be generated, they may not be of interest for most users. For this reason, the files are stored by default in a directory called Annual Datasets or in a directory selected by the user (section 4.8). Additional output datasets are stored in the default directory Output Datasets or in the directory selected by the user (section 4.9) and should include one raster dataset for each year included in the analysis; a raster dataset providing the estimated risk based on the output generated by ALB Risk, which represents the starting point from which annual risk estimates are calculated in ALB Hazard Management and Monitoring; and a raster that represents the final estimate of risk based on all available survey data. The name used to identify this final output risk raster is provided by the user (section 4.10).

6 Suggestions, Tips, and Known Issues

Flickering polygons on displayed maps: As the tool runs, it will sequentially extract and compile data from each of the data layers for each of the years analyzed. If the layers being analyzed are currently visible on the map in ArcMap, the user may notice that polygons and points may be temporarily highlighted, and the map may be repeatedly redrawn. Although this is not a problem for the tool (and may be of some use to the user because it can help track the model's progress), redrawing the map can slow the tool down. To avoid this, the user can simply uncheck (but should not remove) each of the layers in the map so that the layers are not rendered.

Errors generated while running: ALB Hazard Management and Monitoring will provide status updates within the tool window as portions of the tool are executed. If the tool fails to run (i.e., stops and generates an error with red text), it is likely that one of the required conditions for data format and structure has not been met. If the data are in the correct format but an error is generated, the user should copy the model run messages (a screen capture using ctrl + prt sc works well), and contact Talbot Trotter (Robert.T.Trotter@usda.gov) to find a solution.

Layer names: The names of the layers in the Table of Contents shown in ArcMap should match the names of the layers as they are stored on the computer. Although ArcMap allows the user to load layers into a map and then rename layers in the map (which changes only how they are labeled in the map; it does not change the layer names themselves), doing so may cause an error when running ALB Hazard Management and Monitoring. For example, if the tool uses an input layer called *GroundSurvey*, and the data *GroundSurvey* are loaded into the map but renamed (only in the map) as *Ground Survey Data*, the tool may fail to find the layer (despite the fact that the tool will search using the pathfile for the layer and true layer name). Although the reasons why this occurs are not known, the error can be avoided by simply keeping the default layer names used in the map document when the layers are first loaded.

Unique layer names: Although ArcMap allows users to add multiple layers with the same name to the same map (for example, adding *GroundSurvey* for a New York dataset and *GroundSurvey* for an Ohio dataset), and although the tool specifies which geodatabase and directory contain the data that will be used, having multiple layers open in the map that use the same name can result in errors. To avoid this, ensure layers have unique names.

Requirement for initial risk estimate raster: When the tool runs, it uses the ASCII raster data generated by the dispersal model ALB Risk. Although the model can be run without re-running ALB Risk, the tool will look in the ALB Risk directories for the output of either a current or previous run. Because of this, it is necessary to have either the ALB Risk tool loaded onto the computer or at a minimum an ALB Risk directory that provides the expected location for the output. It is recommended that the tool be loaded to provide full functionality.

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