# Chapter 3. Area and Percent of Forest Affected by Biotic Agents Beyond Reference Conditions

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## Introduction

Criterion 3, Indicator 15, of the Montréal Process identifies the impact that biotic processes and agents have on forests (Montréal Process Working Group 2007). Where change due to these agents and processes occurs beyond a critical threshold, forest ecosystem health and vitality may be significantly altered and a forest's ability to recover could be reduced or lost. Monitoring and measuring the effects of these processes provides information helpful in the formulation of management strategies to mitigate risk. A variety of detection and monitoring surveys are conducted annually by Forest Health Protection (FHP) Program of the Forest Service, U.S. Department of Agriculture, and FHP partners. Aerial detection survey (ADS) data are the primary focus of this chapter, though additional ground survey data are considered and reported.

Aerial surveys have been conducted in the United States since the early 1900s. During the early years, surveys were conducted intermittently by various Federal, State, and local governments and private individuals. Survey expertise grew as frequency of flights at regular intervals within a few geographic areas improved over time. The Forest Service began coordinating aerial surveys nationwide during the mid-1990s. Since 1997, FHP and its partners have consistently been using aerial surveys to collect forest injury data caused by a variety of biotic and abiotic agents. Standard methods and regular survey intervals have been established through the Forest Health Monitoring (FHM) Program of the Forest Service, and national efforts continue to improve the reliability and accuracy of data, as described at www.fs.fed.us/foresthealth/aviation/qualityassurance.shtml. These data have not only been important at the local level for decades but, in terms of trends and forecasting, the analysis of annually surveyed areas is becoming increasingly useful. The ADS program is also credited with new pest detections utilizing fixed or rotor wing aircraft and digital aerial sketchmapping techniques (DASM—a computerized data capture system). The ADS program is also credited with new pest detections. Some examples of new pest detections in either country, State, or county are: *Agrilis coxalis* in southern California 2008 (new introduction, native to Mexico),[1] *Phytophthora ramorum* confirmed in Lake County California 2004 (expanding list of regulated CA counties),[2] *Agrilis planipennis* in Michigan 2002 (discovered during field trip, followed with aerial and ground surveys to locate additional infestations and aid defining regulated area).[3]

To provide scientists, managers, and the public with information necessary to aid resource decisions, this chapter focuses on survey results

[1] Personal communication. 2009. Zachary Heath, U.S. Department of Agriculture Forest Service, Pacific Southwest Region, 1731 Research Park Drive, Davis, CA 95618.

[2] Personal survey experience and sample collection. 2004. Jeff Mai, U.S. Department of Agriculture Forest Service FHTET, 2150 Centre Ave., Bldg. A, Suite 331, Fort Collins, CO 80526.

[3] Personal communication. 2009. Roger Mech, Michigan Department of Natural Resources, P.O. Box 30452, Lansing, MI 48909.

as related to current forest condition, trends of biotic indicator impacts for the current period compared to a reference period, and highlighting areas, agents, and possible changes in host distribution and climate that appear to contribute to sustainability concerns.

## Objectives and Methods

To gain an understanding of what the future of our forests may be, it is necessary to examine historic processes impacting forest health. Biotic indicator impacts have been estimated using several methods at varying scales. Few, however, are as consistently gathered at a national scale as ADS. Aerial estimates of affected forested area, damage intensity, and associated biotic agents are the primary data for this chapter providing current information and trend data over broad areas. The objective of this information is to help guide resource decisions that improve forest health and provide for the future of the Nation's forests. These data may be combined with other forest-health related data and products to further refine and highlight resources at risk.

Insect and disease damage estimates were created using ADS data (primarily from aerial detection surveys). Areas of insect and disease impact either were sketched directly on maps using standard coding and reporting criteria, or were captured using DASM as an aide in the airplane. Some data were also captured through DASM on the ground; all have consistent reporting formats. Temporally, the data represent damage from 1997 to 2008. The selected agents and forest injury data were subsequently analyzed and mapped using ArcGIS. Additionally, for the purpose of highlighting county-level presence of select invasive species reported, county-level maps were created in ArcGIS 9.2 and ArcView 3.3.

Aerial survey protocol requires the annual mapping of new defoliation, mortality, and other damage that has occurred since the last observation (current damage). As a consequence, forested areas with chronic health issues may be repeatedly mapped as long as trees continue to die or otherwise show signs of decline. For example, a stand with 100 trees per acre and a mortality rate of 10 dead trees per acre per year could be mapped every year for 10 years (even longer with ingrowth followed by additional mortality). Damage must exhibit visible signatures in order to be mapped, and some of the most damaging biotic agents (such as root diseases and dwarf mistletoes) are rarely isolated during aerial survey. Aerial survey areas are largely predetermined as part of an annual program of work; however, some flexibility is desired to further prioritize based on pest reports (nonnative and endemic), specific areas of concern (for example, high value plantations, recreational areas, and forest host types of interest) and flight logistics. Surveys are conducted by resource experts with local forest health knowledge and highly trained to safely manage flights. Resource professionals conducting ADS include foresters, entomologists, and pathologists. For more information pertaining to objectives and methods, please see McConnell and others (2000) and Forest Health Monitoring (1999, 2005).

## Results and Products

Damage caused by select forest insect and disease indicators are presented to highlight changes and trends due to biotic impacts comparing two 6-year periods, the reference period from 1997 through 2002 to the current period from 2003 through 2008. Though surveys have been conducted for more than 60 years in some areas, complete national data are only available since 1997. Important nonnative invasive plant, insect, and disease establishment and spread are also detailed.

The 2008 aerial survey area by FHM region is shown in figure 3.1. Acres with mortality reported due to insects and diseases during 2008 are shown in figure 3.2 (note that the

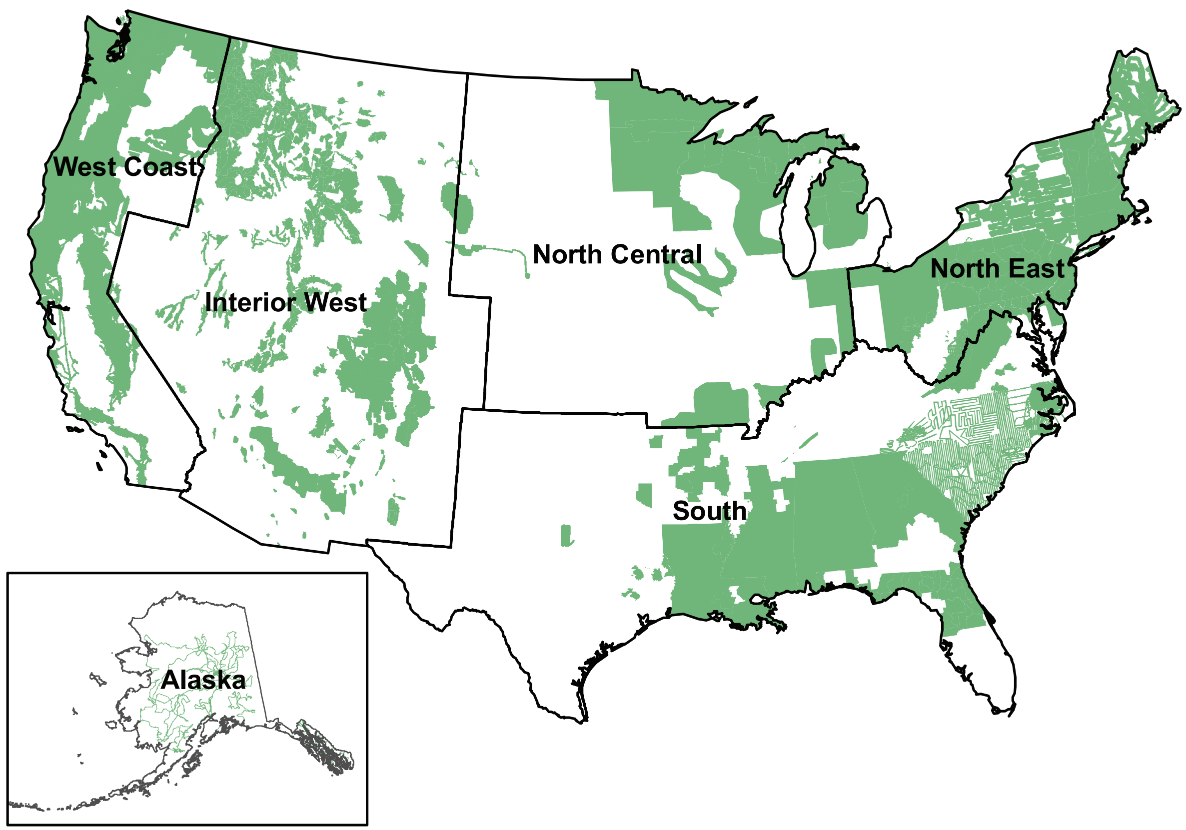



*Figure 3.1—Forest Health Monitoring regions and area flown during the 2008 insect and disease detection survey.*

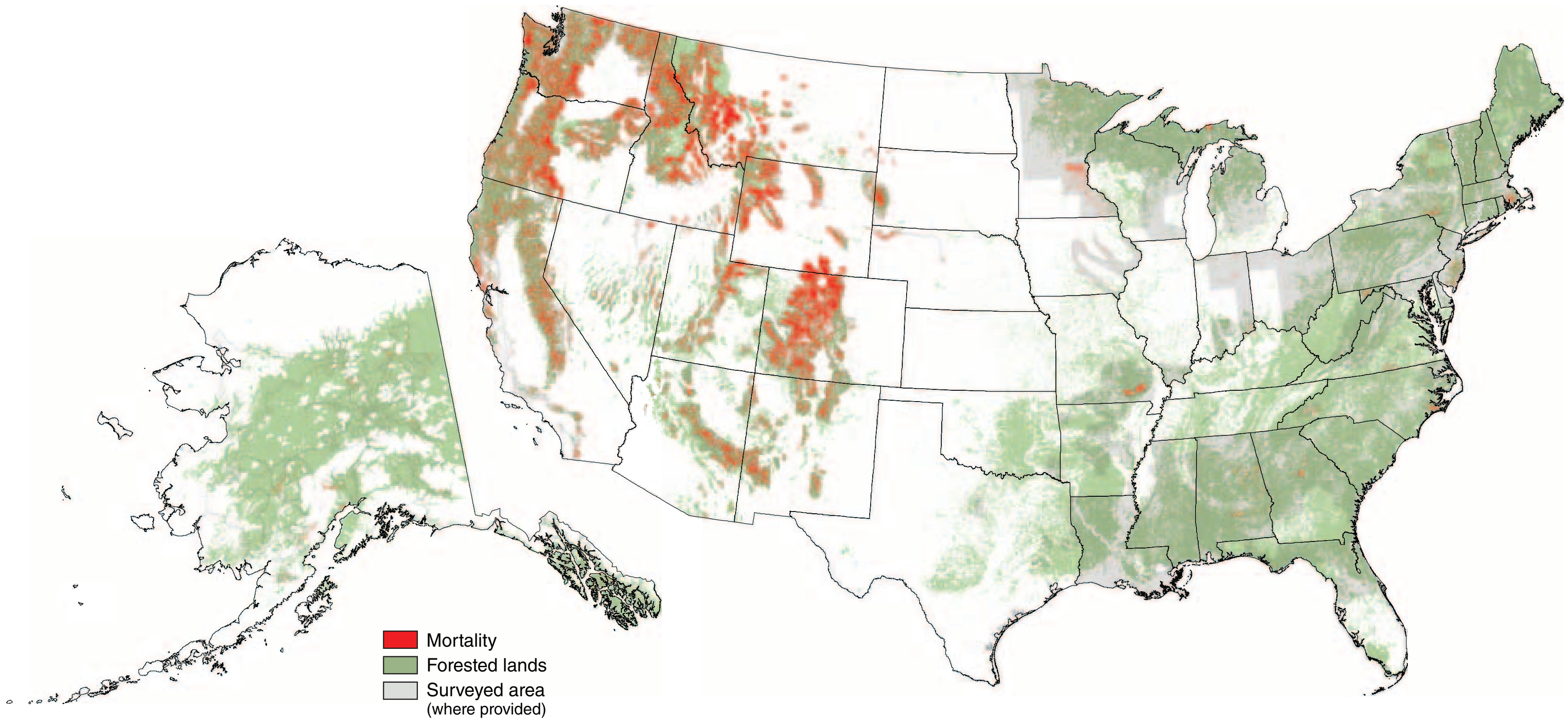



*Figure 3.2—Areas with mortality mapped during the 2008 detection survey; graphed acres exclude widely scattered mortality primarily from bronze birch borer, beech bark disease, and gypsy moth.*

figure includes only areas with some level of visible tree mortality; other damage types such as defoliation are described elsewhere in this chapter). Consistently surveyed and reported areas with mortality and defoliation make trend analysis possible and facilitate describing cumulative environmental effects. (Cumulative effects analyses are conducted to evaluate a variety of factors combining to cause negative environmental consequences and described for specific resource areas analyzed in Environmental Analyses or Environmental Impact Assessments, such as for fish and wildlife habitat, forest health, fire and fuels, cultural resources, recreation watersheds, etc.). The forested area with mortality mapped has quadrupled over that mapped during the reference period (fig. 3.3). These impacts should be considered cumulative where they occur repeatedly on the same acreage and expand into new areas. The impacts described are likely underestimated because understory pest impacts may be only partially observable during aerial survey and because not all of the forested area in the United States is surveyed.

Forest health issues occur regardless of ownership; consequently, aerial surveys are conducted regardless of ownership. The proportion of all damage types observed and mapped during the 2008 ADS on Forest Service, other Federal, and non-Federal lands is shown in figure 3.4. The most prevalent damage types mapped include forest injury classified as mortality, defoliation, dieback, and discoloration (table 3.1). Though not broken down further in this report, finer resolution for specific land classes or ownership is possible representing all resource interests, stakeholders, and the public. The genetic resources which may be threatened also transcend boundaries. Important genomes are possibly located among the smallest of land ownership classifications. However, the degree of collaborative intervention necessary to maintain genetic variability is beyond the scope of this chapter but appears to be a developing concern for forward-thinking resource managers.

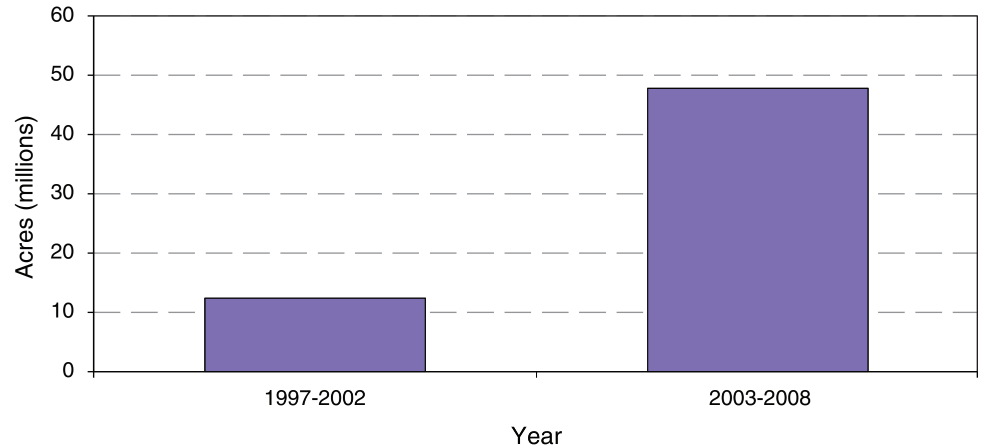



*Figure 3.3—Total forest insect and disease mortality in the conterminous United States for two periods; the area with mortality for select indicators (specific biotic indicators are listed elsewhere in this chapter) is summed for all years within the period. Cumulative impacts are occurring where mortality continues within previously mapped areas and expands into new areas.*

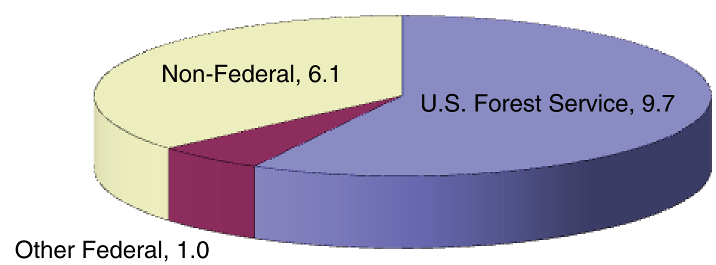



*Figure 3.4—2008 National Insect and Disease Detection Survey forest injury by ownership; the total is approximately 16.7 million acres, of which approximately 10.5 million acres are classified as "mortality" damage type.*

**Table 3.1—Area by damage type and ownership from the 2008 National Insect and Disease Detection Survey for Alaska and the conterminous 48 states**

| Damage type | U.S. Forest Service | Other Federal | Non-Federal | Total |
|---|---|---|---|---|
| | | *acres* | | |
| Branch breakage | 101 | 6 | 27,298 | 27,405 |
| Branch flagging | 177,899 | 20,807 | 10,239 | 208,945 |
| Defoliation | 2,085,390 | 290,605 | 2,802,881 | 5,178,876 |
| Dieback | 187,698 | 46,993 | 249,751 | 484,442 |
| Discoloration | 183,051 | 20,881 | 101,856 | 305,788 |
| Main stem broken/uproot | 8,897 | 2,908 | 120,510 | 132,316 |
| Mortality | 7,155,549 | 580,896 | 2,760,447 | 10,496,892 |
| Other damage | 6,274 | 1,973 | 9,979 | 18,227 |
| Topkill | 1,074 | 4,487 | 244 | 5,805 |
| Footprint total | 9,661,441 | 956,590 | 6,053,196 | 16,671,228 |
| ADS area flown | 142,340,283 | 30,234,211 | 284,569,122 | 457,143,616 |

Note: the "footprint total" omits overlapping damage types and thus does not double count acreage.

## Predictions and Effects

The 2006 National Insect and Disease Risk Map (NIDRM)[4] predicted the following mortality-causing or defoliating agents would have the greatest impacts on U.S. forests: mountain pine beetle, red oak decline, southern pine beetle, root diseases, gypsy moth, pine engravers, fir engraver, Douglas-fir beetle, spruce beetle, hardwood decline, and western pine beetle (fig. 3.5). The purpose of NIDRM is to provide a strategic assessment estimating risk of tree mortality due to major insects and diseases, specifically, highlighting areas where 25 percent of live tree volume loss is expected during the next 15 years.

All of those agents were observed as causal factors of forest injury during the 2008 surveys. The survey results reported are not all-inclusive in terms of agent or damage extents. Though specific agents are reported from these data, interpretation must consider the role of pest groups and a long list of individual agents (biotic and abiotic) that function as a complex on any given acre. The top five damage agents identified

[4] U.S. Department of Agriculture Forest Service. 2007. Mapping risk from forest insects and diseases 2006. On file with: The Forest Health Technology Enterprise Team, 2150 Centre Avenue, Building A, Suite 331, Fort Collins, CO 80526.

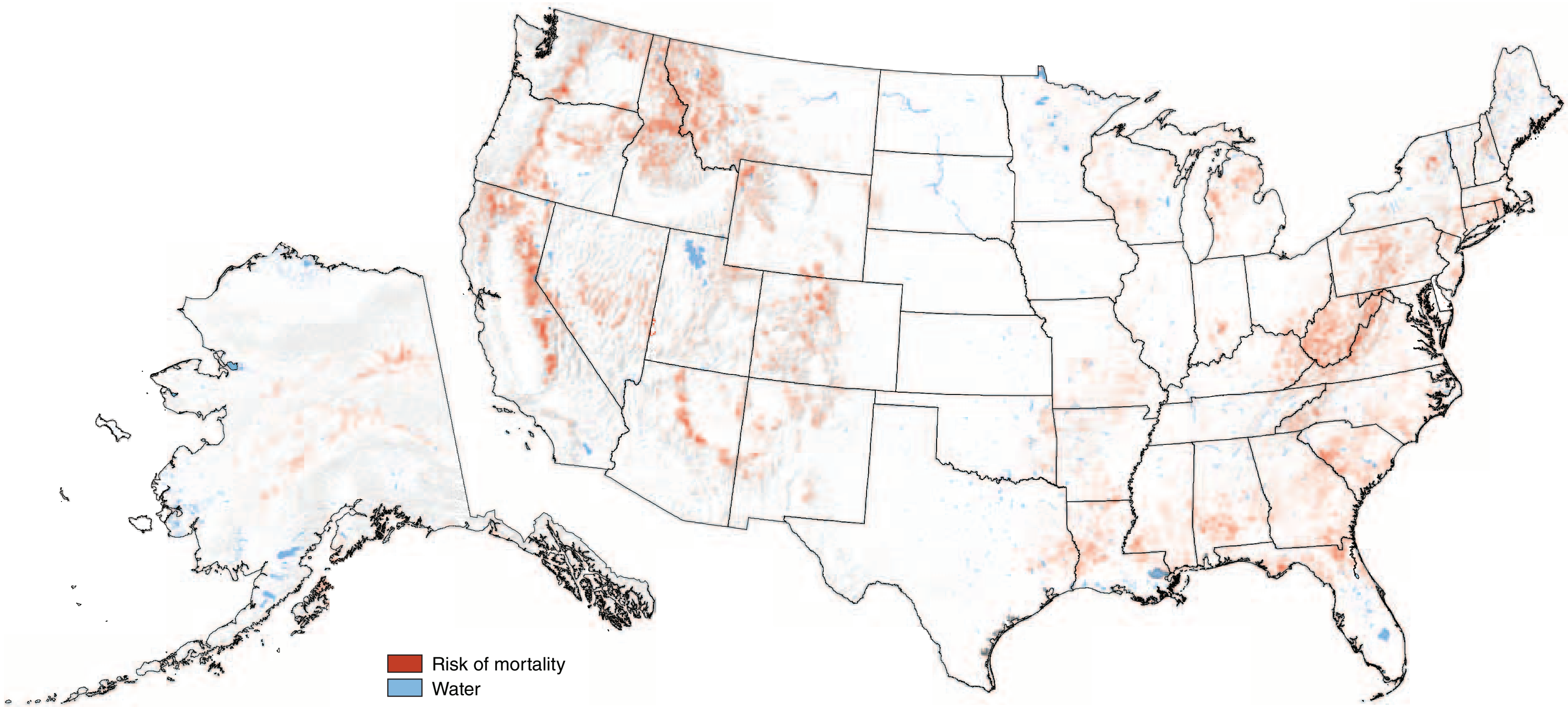



*Figure 3.5—An area of approximately 58 million acres is predicted to be at risk of disturbance by biotic factors; risk is defined as the predicted "loss of 25% standing volume over the next 15 years" (2006 National Insect and Disease Risk Map).*

during 2008 surveys are shown in figure 3.6 and are detailed further in this report, as are a few key nonnative pests. Based on the numbers of tabulated acres from surveys, nonnative pests appear to have lesser impacts than native pests. However, as displayed at the end of this chapter, nonnative pests increasingly present a serious threat to forest sustainability.

Of the top five mortality agents in 2008 ADS, mountain pine beetle tops the list with the affected area increasing over what was mapped during 2007 (table 3.2). Lodgepole pine stands are severely affected, as are whitebark and other five-needle pine species. In general, the sustainability of certain five-needle pine species

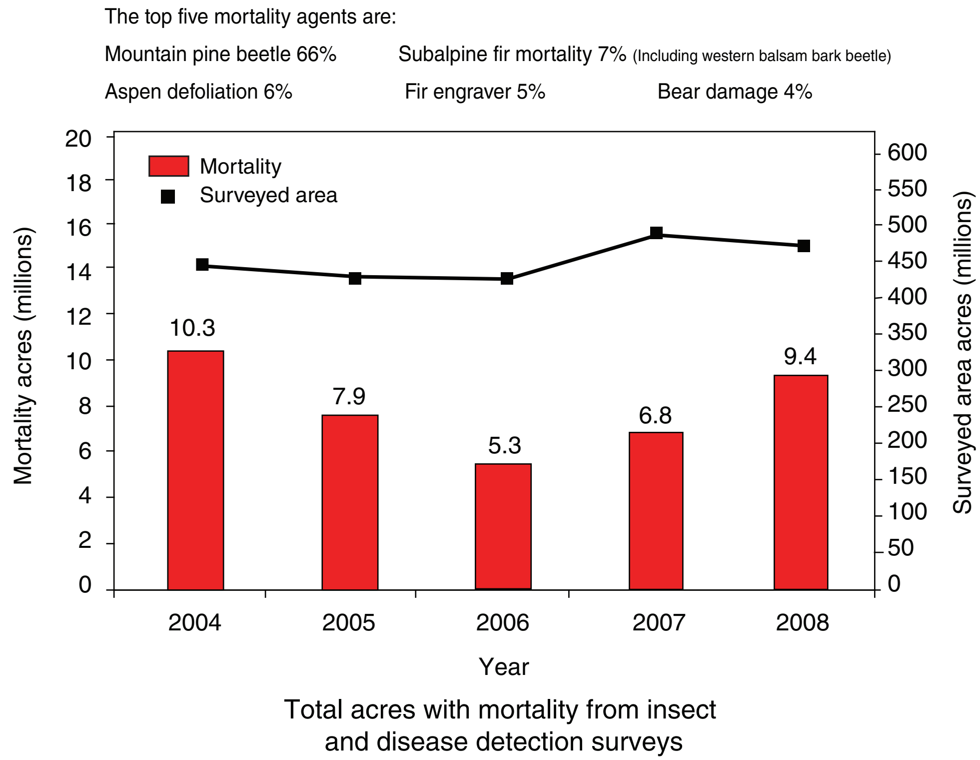



*Figure 3.6—The top five mortality agents mapped during 2008 are listed to provide current status; graphed are the acres with mortality from all damage agents and area flown during surveys conducted over the last 5 years.*

has long been a concern and, combined with the effects of white pine blister rust, mountain pine beetle activity may have permanent effects upon the range of five-needle pine. Additional information and important questions regarding impacts of various agents upon these pines are detailed in the FHP publication Mountain Pine Beetle Impacts in High Elevation Five-Needle Pines: Current Trends and Challenges (Gibson and others 2008). Subalpine fir mortality is once again second, followed closely by aspen defoliation. Aspen defoliation seems to be resulting in mortality and, though the phenomenon did not make the top five list in 2007, has been gaining importance as observers and scientists work to describe what

**Table 3.2—Select mortality and defoliating agent impact totals from surveys during two analysis periods**

| Indicator | Acres (1000s) with mortality reference period | | | | | | Total acres reference | Acres (1000s) with mortality current period | | | | | | Total acres current | Ratio of increase or decrease |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Conterminous States | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | | |
| Mountain Pine Beetle | 317 | 352 | 421 | 432 | 805 | 1,336 | 3,663 | 1,581 | 2,418 | 2,930 | 2,722 | 3,921 | 6,015 | 19,587 | 5.35 |
| Fir Engraver | 177 | 44 | 59 | 18 | 46 | 308 | 651 | 912 | 1,774 | 960 | 381 | 442 | 492 | 4,962 | 7.62 |
| Douglas-fir Beetle | 49 | 134 | 352 | 353 | 415 | 319 | 1,622 | 385 | 551 | 676 | 200 | 287 | 196 | 2,294 | 1.41 |
| Western Pine Beetle | 38 | 43 | 24 | 22 | 57 | 121 | 305 | 189 | 254 | 101 | 146 | 30 | 104 | 823 | 2.70 |
| Other Insects | 490 | 476 | 376 | 543 | 1,047 | 2,382 | 5,313 | 3,820 | 2,470 | 1,856 | 1,206 | 1,308 | 963 | 11,623 | 2.19 |
| Oak Mortality (SOD and decline) | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 1 | 4 | 24 | 65 | 34 | 129 | 59.37 |
| Port-Orford-cedar Root Disease | 4 | 2 | 3 | 5 | 6 | 6 | 27 | 9 | 10 | 9 | 11 | 12 | 6 | 58 | 2.18 |
| Annosus Root Disease | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 5 | 0 | 13 | 2516.14 |
| Armillaria Root Disease | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 31 | 0 | 18 | 0 | 52 | 85.16 |
| Other Root Diseases (mostly Black Stain) | 18 | 75 | 1 | 6 | 4 | 4 | 108 | 1 | 1 | 2 | 1 | 8 | 1 | 14 | 0.13 |
| Pinyon (multi) | 17 | 0 | 0 | 5 | 17 | 266 | 306 | 3,779 | 1,738 | 74 | 34 | 20 | 6 | 5,652 | 18.47 |
| Subtotal | 1,110 | 1,125 | 1,236 | 1,386 | 2,397 | 4,744 | 11,998 | 10,686 | 9,218 | 6,644 | 4,723 | 6,116 | 7,818 | 45,206 | 3.77 |
| Alaska | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | | |
| Insects | 573 | 335 | 288 | 121 | 104 | 59 | 1480 | 115 | 157 | 114 | 134 | 184 | 129 | 833 | 0.56 |
| Yellow Cedar Decline (multi) | 0 | 0 | 0 | 0 | 1 | 3 | 4 | 9 | 14 | 33 | 32 | 26 | 9 | 123 | 28.17 |
| Subtotal | 573 | 335 | 288 | 121 | 106 | 62 | 1,485 | 124 | 171 | 147 | 166 | 210 | 138 | 956 | 0.64 |
| Total mortality | 1,683 | 1,460 | 1,524 | 1,507 | 2,503 | 4,806 | 13,483 | 10,811 | 9,389 | 6,791 | 4,889 | 6,326 | 7,956 | 46,162 | 3.42 |

*continued*

**Table 3.2—Select mortality and defoliating agent impact totals from surveys during two analysis periods (continued)**

| Indicator | Acres (1000s) with defoliation reference period | | | | | | Total acres reference | Acres (1000s) with defoliation current period | | | | | | Total acres current | Ratio of increase or decrease |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Conterminous States | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | | |
| Tent Caterpillars | 11 | 98 | 569 | 3,325 | 21,007 | 12,475 | 37,485 | 3,622 | 1,122 | 1,776 | 2,899 | 614 | 402 | 10,435 | 0.28 |
| Leafminers | 4 | 603 | 41 | 22 | 0 | 8 | 678 | 15 | 17 | 26 | 16 | 0 | 1 | 76 | 0.11 |
| Budworms | 796 | 1,154 | 637 | 696 | 930 | 711 | 4,922 | 1,112 | 1,295 | 1,891 | 2,978 | 2,596 | 2,092 | 11,965 | 2.43 |
| Leafrollers | 0 | 537 | 308 | 179 | 63 | 199 | 1,286 | 0 | 310 | 66 | 102 | 7 | 19 | 505 | 0.39 |
| Gypsy Moth | 51 | 350 | 569 | 1,559 | 1,473 | 441 | 4,442 | 250 | 128 | 652 | 1,280 | 1,399 | 1,551 | 5,260 | 1.18 |
| Subtotal | 862 | 2,741 | 2,123 | 5,781 | 23,473 | 13,834 | 48,814 | 4,999 | 2,873 | 4,411 | 7,275 | 4,616 | 4,065 | 28,239 | 0.58 |
| Alaska | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | | |
| Leafminers | 4 | 123 | 181 | 44 | 11 | 330 | 692 | 467 | 834 | 734 | 512 | 848 | 287 | 3,684 | 5.32 |
| Sawflies | 274 | 466 | 160 | 70 | 19 | 2 | 991 | 1 | 15 | 17 | 3 | 0 | 0 | 35 | 0.04 |
| Budworms | 69 | 88 | 1 | 41 | 76 | 9 | 284 | 46 | 85 | 17 | 55 | 48 | 9 | 260 | 0.92 |
| Other | 39 | 76 | 29 | 60 | 44 | 83 | 329 | 237 | 58 | 161 | 129 | 67 | 16 | 667 | 2.03 |
| Subtotal | 386 | 752 | 370 | 215 | 150 | 423 | 2,296 | 751 | 993 | 930 | 698 | 963 | 312 | 4,646 | 2.02 |
| Total defoliation | 1,248 | 3,493 | 2,493 | 5,997 | 23,623 | 14,257 | 51,110 | 5,750 | 3,866 | 5,341 | 7,973 | 5,578 | 4,377 | 32,885 | 0.64 |

Note: The ratio is expressed as increase or decrease for each pest or pest grouping; all estimates are a subset of national totals, which consider other damage agents (not included). "Multi" indicates pest complex. Oak Mortality includes general decline and sudden oak death (SOD) aerially mapped as "likely to be infected" plus areas subsequently confirmed through official sampling, but does not include all SOD special surveys (many of which were reported separately during early 2000s).

some feel is a significant aspen-related event.[5] Fir engraver-caused mortality also makes the top five list again in 2008 but has slipped to fourth, edged out by aspen defoliation. Among the top five agents in 2007, spruce and Douglas-fir beetles do not make the list in 2008; bear-caused damage does. The increase in bear-caused damage is documented primarily in the Northwestern United States. The priority for ADS is to capture data relating to insect and disease activity; however, these surveys are useful to report on a variety of biotic and abiotic damage types. For a complete list of possible damage agents, see appendix E in Forest Health Monitoring (2005).

There are many factors which determine tree species distribution, overall stand composition, and the number and extent of live trees. Tree species composition, abundance, and other environmental conditions contribute to elevated levels of mortality and epidemics that, in some cases, result in forest type conversion. Mortality and other types of damage are important to characterize but the number and extent of live trees is an alternative and perhaps an improved expression of forest health. Additional conclusions regarding sustainability in a spatial and temporal context may be derived by considering areas with damage as inversely related to the approximate number and extent of live trees remaining. Areas with mapped mortality have yet to be fully developed as a proxy for the extent of live trees and in fact, the approach may not be entirely appropriate. Though methods to accurately describe the number and extent of live trees are not referenced within this chapter, areas mapped with mortality and other damage remain credible indicators of forest sustainability. Described elsewhere in this chapter are some examples of regional effects threatening sustainability such as invasive pests and plants in Hawaii, Douglas-fir/spruce beetles in the Northwest, and mountain pine beetle in the Rocky Mountains.

**Trends in Alaska and the conterminous United States—**The total area flown remains fairly consistent from year to year, particularly in the conterminous United States, which adds significance to the annual increase in area mapped with forest injury. Within the last decade, annual mortality estimates peaked in 2003 for the conterminous United States (fig. 3.7), and then declined somewhat during subsequent years. However, the area with mortality during the current period (the last 6 years) has never dropped below any year in the reference period. Alaska mortality levels appear to be slightly more stable statewide during the current period. However, less confidence should be associated with the notion that Alaska may be more stable since the flown area has been relatively more sporadic and there is a much smaller proportion of forested area surveyed.

[5] Various professional communication regarding Sudden Aspen Decline, including workshop discussion at the Cooperative U.S. Department of Agriculture, Forest Service and Colorado State Forest Service Aerial Survey Calibration and Conformity Fly-In. 2008. Fort Collins Loveland Airport, Loveland, CO 80538.

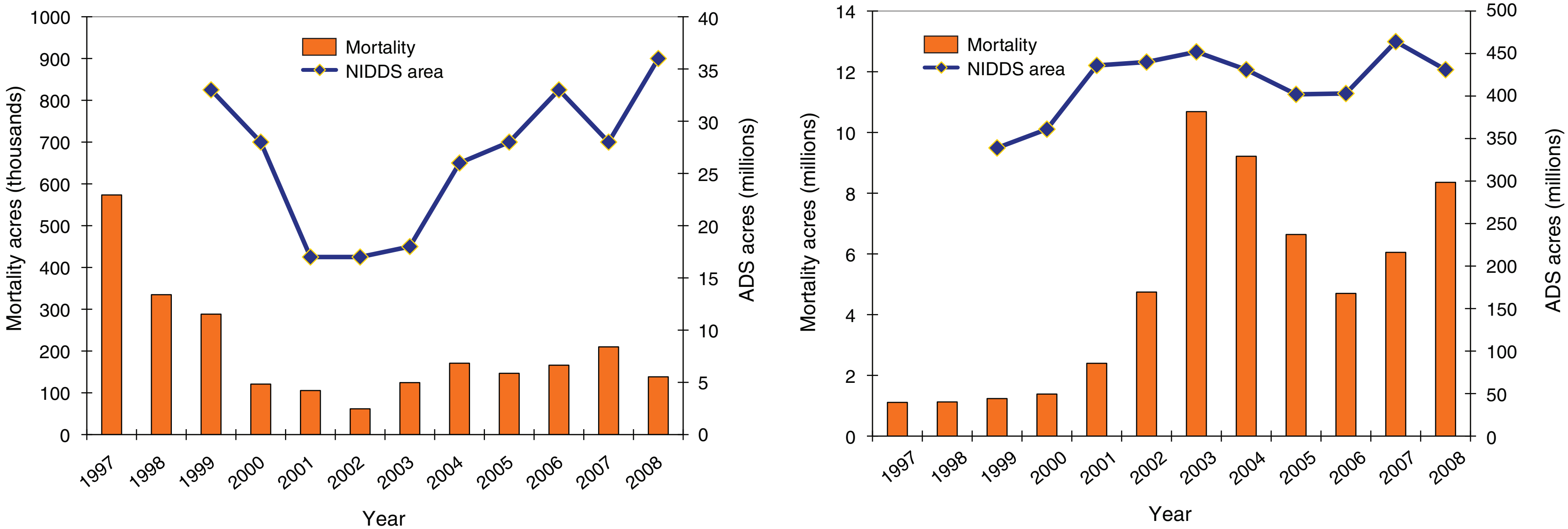
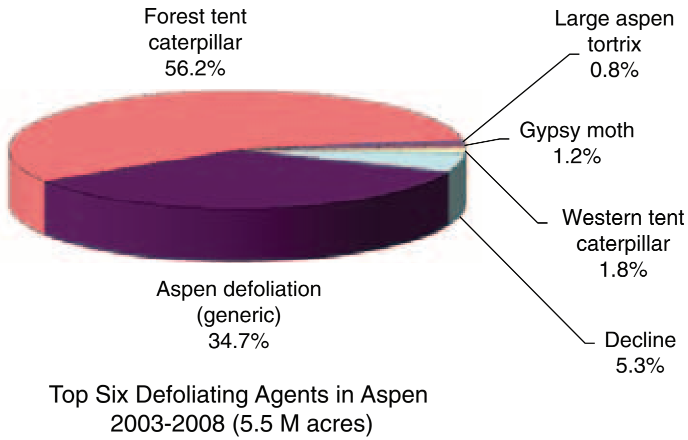



*Figure 3.7—Annual National Insect and Disease Detection Survey results for area with mortality and area flown for Alaska (left) and the conterminous United States (right); the area includes select insects, diseases, and complexes as listed in table 3.1. The large increase in the conterminous United States during 2003 reflects a spike in pinyon mortality extending into 2004; mortality during more recent years has increased in other softwood, oak, and aspen types due to a variety of agents. Regional reporting of area flown began in 1999.*

The following highlights trends for two tree species groupings, connectivity to climate and concludes with a more detailed description of effects within Alaska, the conterminous United States, and Hawaii.

**Recent trends highlighted for aspen and five-needle pines**—Using ADS data to examine trends in aspen damage indicates gradual decreases in defoliation accompanied by gradual increases in mortality. Large areas of defoliation caused by forest tent caterpillar were recorded in the late 1990s through the early 2000s, and the defoliation since has subsided. A varied range of aspen-defoliating agents has been mapped more recently. Large areas with prior defoliation are recently experiencing mortality. The top six defoliating and mortality-causing agents or complexes are shown in figure 3.8.

Historical records indicate aspen was affected primarily by the following (in decreasing order of area impacted): defoliation agents—forest tent caterpillar, large aspen tortrix, Marssonina blight,



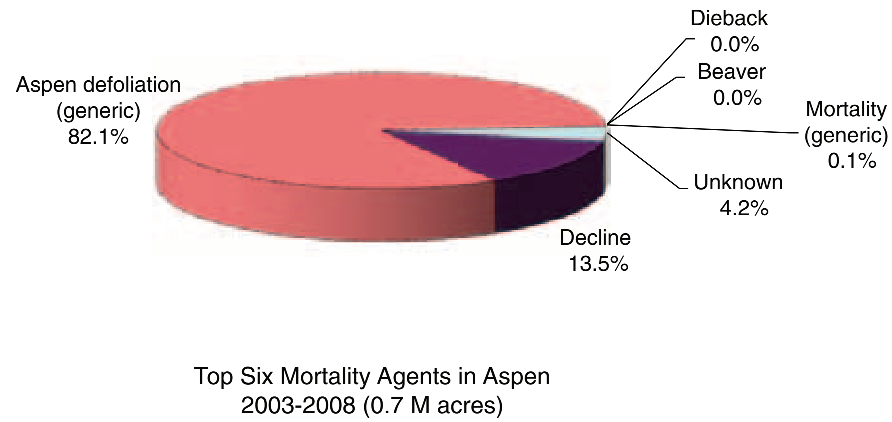




*Figure 3.8—The top six biotic defoliating (left) and mortality (right) agents in aspen mapped during the last 6 years of National Insect and Disease Detection Surveys; total acres with defoliation and mortality are approximately 5.5 million and 0.7 million acres respectively; dieback and beavers are among the top six mortality agents, but amount to only trace acreages.*

Melampsora rusts; and mortality agents—the leading causes of mortality in aspen are due to defoliation from the specific agents listed above and from a general "decline" damage agent. Decline is one option among damage agents available to attribute mapped polygons, and is often used when symptoms do not indicate anything more specific. Early in the 2000s, some large areas of forest tent caterpillar outbreaks were mapped in Minnesota and Wisconsin and, to a lesser extent, in the southern and northeastern areas of the conterminous United States. More recently, mortality is occurring from defoliation and from decline, mostly mapped in the FHM Interior West Region. Many aspen stands are relatively old (80–100 years) and in declining health, but the stands continue to regenerate from healthy, long-lived root systems. Where these stands of mature trees are dying rapidly without successful regeneration, and where the causal agents are not readily identifiable, there is cause for concern. Drought and high temperatures are implicated as inciting factors. The term "sudden aspen decline" has been used to describe this phenomenon (Worrall and others 2008).

Trends in five-needle pine injury mapped within western FHM regions are shown in figure 3.9. The total for the 12-year period is 4.4 million acres, with injury compared to 24,000 acres for eastern white pine (sum of annual totals including mortality, defoliation, and other damage). Surveys indicate a steady increase in acres affected throughout the analysis period. The most damaging biotic agents mapped in the West (in descending order of area impacted) are mountain pine beetle,

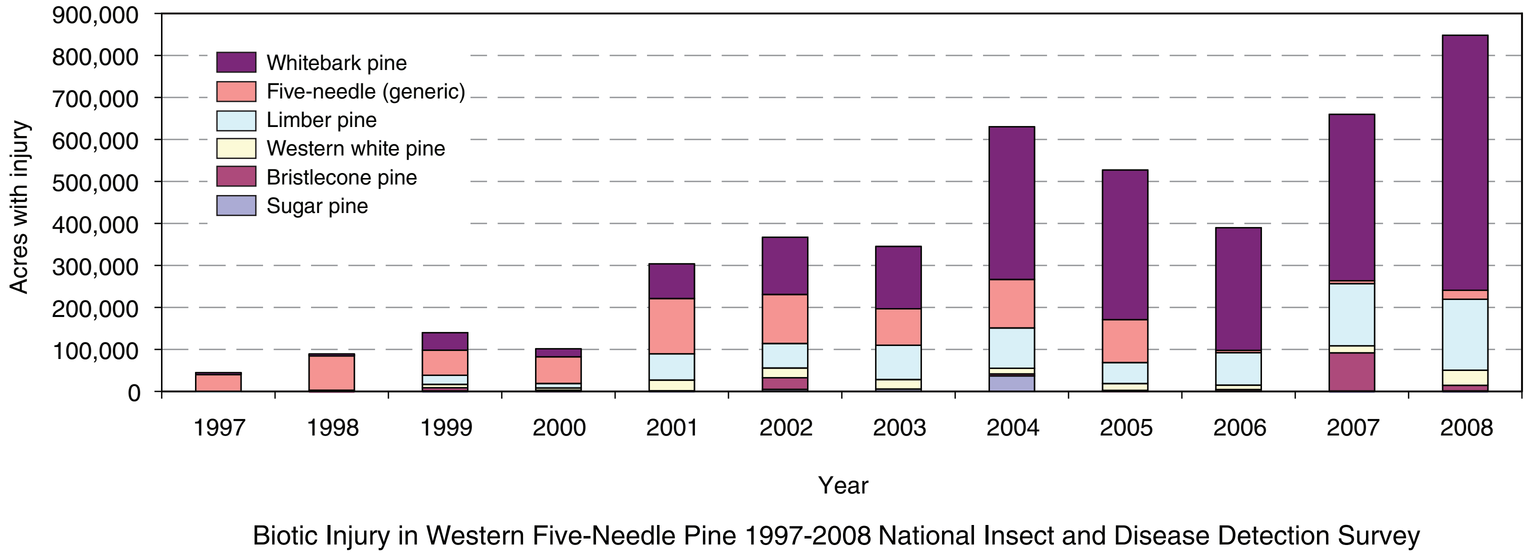



*Figure 3.9—Annual acres with biotic injury in western five-needle pines; the biotic agents included are primarily mortality-causing agents. "Five-needle pine (generic)" includes white pine blister rust injury where a host is not specified; National Insect and Disease Detection Survey forest or host type codes "mixed conifer" and "pine" are not included, possibly not reporting some five-needle pine injury.*

five-needle pine decline, white pine blister rust, bark beetles (general), and multi-damage (fig. 3.10). Trend data and research indicate a proactive approach to reducing impacts to five-needle pine is prudent. These stands are likely to continue to decline without some form of intervention to enhance and regenerate them.

**Influence of climate upon succession and host/pest relationships—**Much research is being done to evaluate the effects of climate upon terrestrial resources and systems, including forest types. Tree growth, species composition, and distribution are certain to be impacted by climate change. Current examination of biotic indicator data suggests tree hosts and pests are responding to climactic effects now. Temperature time trend and geographic extent were queried (using NASA's online query builder at http://data.giss.nasa.gov/) to illustrate that global changes may currently be contributing to the observed increases in forest area with damage and reduced productivity. Are we beginning to see a shift in where certain species are able to grow well? Survey data indicate biotic impacts are increasing at worrisome rates, and desired natural regeneration may be compromised

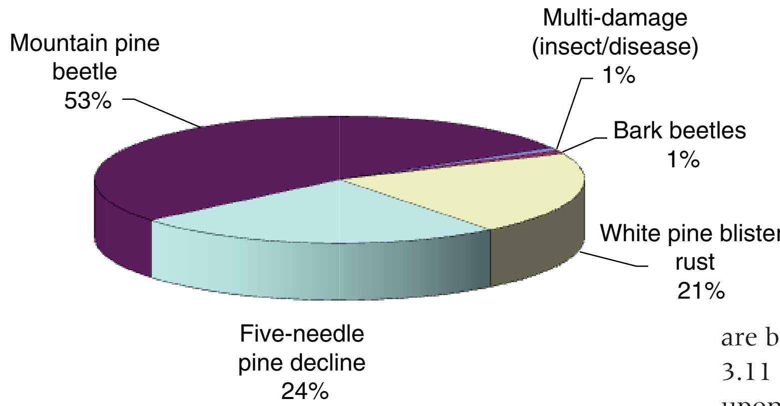



*Figure 3.10—Proportion of 4.4 million acres affected by the top five-needle pine damage agents mapped during aerial surveys conducted from 1997 to 2008. Most but not all charted are mortality-causing agents; in reality, complexes play a more significant role than this chart indicates.*

during a changing climate. The trend for warmer global temperatures and reduced precipitation in certain areas is expected to continue. Generally, climate models suggest that a warmer earth will be wetter on average, but the rain might not be where it is needed to maintain existing ecosystems.

Some questions relating climate to host and pest distribution remain, such as: are climate changes affecting host species distribution and/or historical pest range? Is warming also associated with lower precipitation and changes in generational times or numbers of annual generations for pests? If climate is connected to changes we are seeing in North American forests and their long-term resource implications, what will be the social and biological effects and possible mitigations? Answers to these questions are beyond the scope of this chapter, but figure 3.11 hints at the effects climate may be having upon mountain pine beetle movement in Colorado. Based on aerial survey data, there is an apparent shift upward in elevation for mapped pine mortality due to mountain pine beetle. The proportion of beetle occurrence charted can be interpreted to have climbed 300-400 m during recent years, moving from lodgepole pine into upper elevation pine species within the confined, localized area of analysis in Colorado. This could be due to climate, sheer numbers of insects and/or availability of host.

Regardless of real or perceived climatic influences, the total forest area with defoliation and mortality mapped from 1997 to 2002 compared to 2003 to 2008 has changed (see select biotic indicators and damage types, table 3.2). Note that “footprint” of forest damage is reconciled within individual years, i.e., the subtotal for any given year represents footprint area with damage and does not count overlapping impacts within that year; a simple summation of annual impacts across years shows total increase or decrease in area mapped for the two time periods indicated. In general, increasing amounts of area with mortality have been mapped annually in the conterminous

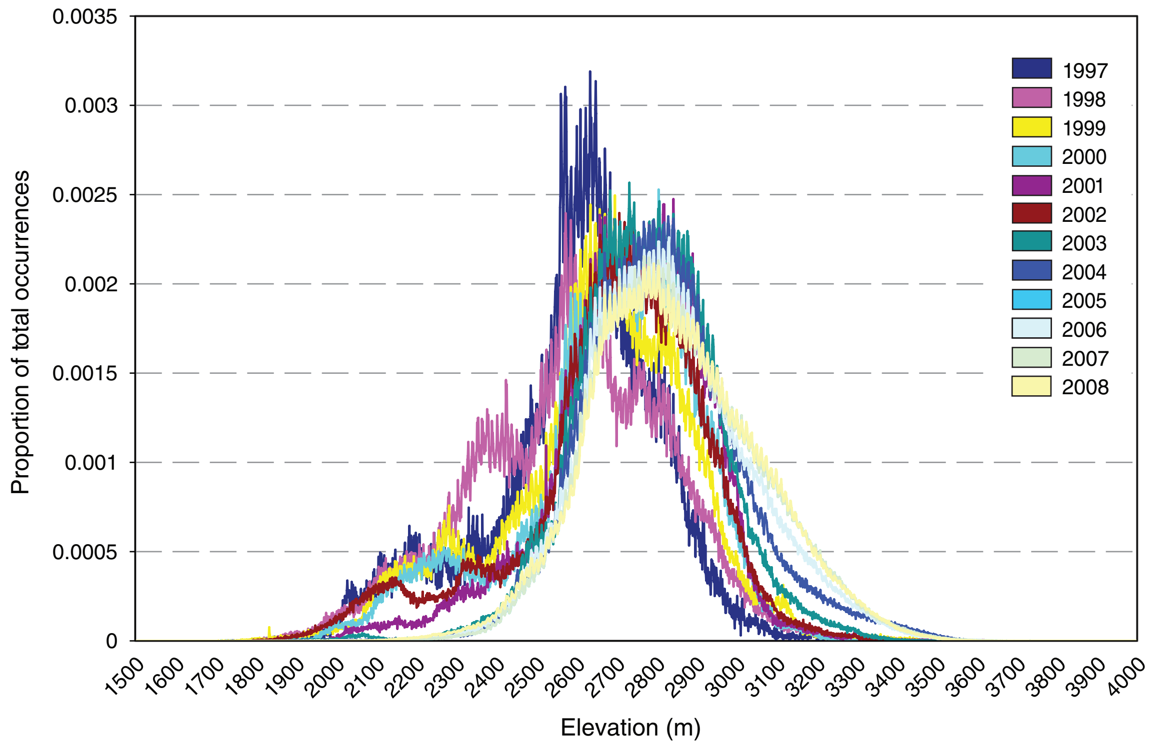



*Figure 3.11—Pine injury mapped during 12 years of National Insect and Disease Detection Survey on 30-m elevation pixels, within map zone 28 in Colorado; the histograms for each year are proportioned to display normalized injury occurrence to pine species, primarily caused by mountain pine beetle. Damage is at its maximum at an elevation of approximately 2600 m in 1997, gradually moving uphill to peak at approximately 2900 m in 2008.*

United States, and increasing amounts of area with defoliation have been mapped annually in Alaska. The sum total of this change within the two periods is as follows:

- Mortality in the conterminous United States has increased by approximately 33.2 million acres
- Mortality in Alaska has decreased by approximately 0.5 million acres
- Defoliation in the conterminous United States has decreased by approximately 20.6 million acres
- Defoliation in Alaska has increased by approximately 2.3 million acres

Aerial and ground survey results presented in this chapter include a large proportion, but not all, of the total forested area in the United States. Annual aerial surveys cover up to 70 percent and 23 percent of forested area in the conterminous United States and Alaska, respectively. Though surveys are prioritized within areas where impacts are most likely to occur, the area surveyed remains considerably less than the total forested for both Alaska and the conterminous United States (fig. 3.12). Therefore, interpreters of these data should consider insect and disease impacts underestimated. Underestimates are further compounded by impacts within the understory

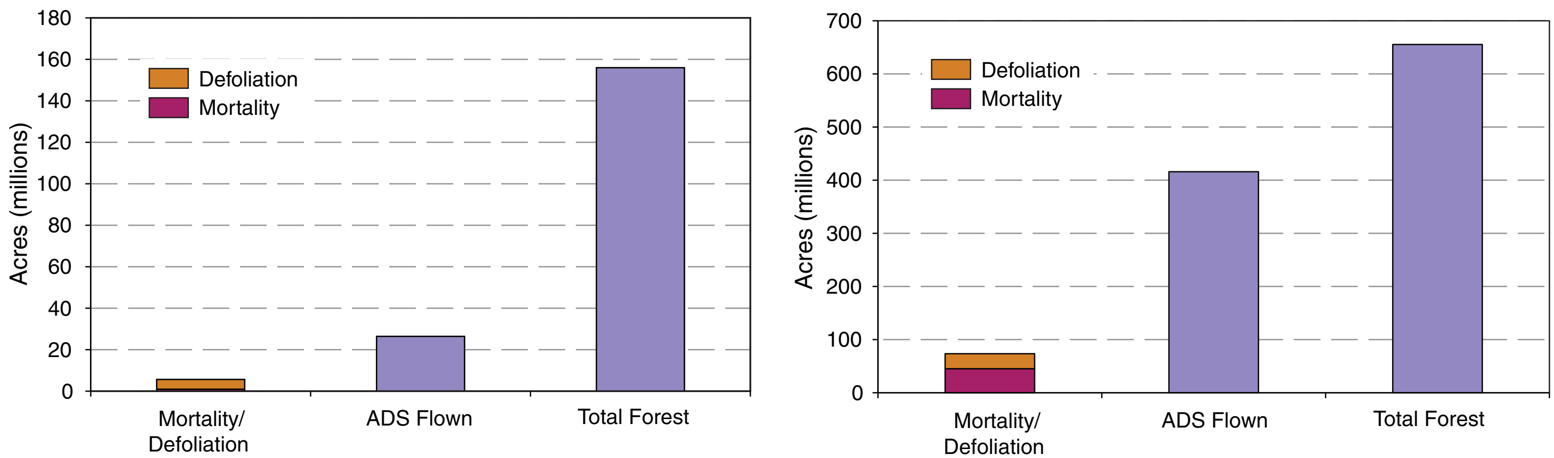



*Figure 3.12—2003–08 total mortality and defoliation acres for Alaska (left) and the conterminous United States (right) as compared to average annual National Insect and Disease Detection Survey flown area and total forest; Alaska surveys are confined to major river drainages with flights based out of Fairbanks, Anchorage, Juneau, and Wrangell; sources of total forest cover estimated for Alaska and conterminous United States are varied, 1991–2003 data were used (see Krist and others 2007).*

that are not readily visible during aerial survey. Due to accessibility, only a fraction of the forested area in Alaska is surveyed and priority is given to surveying major river drainages. Aerial surveys are not reported for Hawaii; however, there are serious forest sustainability issues on the islands (see below).

Aerial detection surveys in Alaska show that yellow-cedar decline, spruce beetle, larch beetle, and engraver beetles are the leading contributors to current mortality. Unique to Alaska is the issue of yellow-cedar decline, believed to be directly related to climate (Hennon and others 2006). As shown in table 3.2, there is a 31-fold increase in yellow-cedar decline over reference condition. Though many biotic indicators are present in these yellow-cedar stands, current evidence points to poorly drained soils as perhaps one of the inciting factors and freeze injury to roots due to low snow pack as being the most likely cause.[6] Overall, a comparison of current condition to reference conditions indicates defoliation is increasing and mortality is decreasing. Current mortality and defoliation for Alaska should be considered grossly underestimated since, owing to remoteness and logistical constraints, surveys currently cover only a fraction of the total forested lands in the State. The total area with mortality and defoliation since 2003 is approximately 6 million acres.

Aerial detection surveys in the conterminous United States show total area with mortality has increased from 12 million acres (1997–2002) to 45 million acres (2003–2008) (table 3.2). Bark beetle, engraver beetle, gypsy moth-caused mortality, and mortality in the pinyon-juniper type are leading contributors to this increase. Areas impacted by root disease are documented as decreasing; however, it should be noted that root diseases are rarely mapped using ADS. Currently reported insect-caused mortality often includes complexes of both insects and diseases, so disease acreage is much higher than recorded. The total area with defoliation has decreased by approximately 40 percent compared to reference conditions. This decrease is likely attributable to effective gypsy moth suppression and eradication efforts and, in some cases, to repeated defoliation events that move some areas into the mortality category. The total area with both mortality and defoliation since 2003 is approximately 73 million acres.

While the percentage of affected forest land in the United States may appear relatively low, the rate at which acreage is being impacted is alarming. As predicted by risk modeling, and confirmed by site-specific observations, actual impacts at local or regional levels are often extreme.[7] Overall, the indicator shows a continuing trend in forest decline. Arguably, and considering the potential for certain

[6] U.S. Department of Agriculture, Forest Service. Uncovering the cause of yellow-cedar decline. www.fs.fed.us/r10/spf/fhp/cedar/causes.html.

[7] U.S. Department of Agriculture, Forest Service. National Insect and Disease Detection Survey interactive map. http://svinetfc8.fs.fed.us/aerialsurvey.

outbreak events to be cyclical in nature (e.g., mountain pine beetle in pure, unmanaged lodgepole pine stands), many affected areas will likely regenerate; however, the resulting single-species/single-age-class regeneration will not provide a sustainable forest. Spikes in mortality during the reporting period are largely due to a combination of high stand density in unmanaged forests and drought. Cumulative impacts are occurring within previously surveyed areas and expanding into new areas. The total area with mortality and defoliation has quadrupled over recent years for select indicators (table 3.2). Regardless of whether the cause of impacts is overstocking, climate, invasive pests, or a combination of all three, intervention may be necessary to restore ecosystems to health, vigor, and productivity.

**Other important local or regional impacts—** Finally, this chapter highlights a few of the important invasive pests managers have been wrestling during recent years. Cumulative impacts from both native and nonnative pests are particularly evident at regional and local scales where insect, pathogen, and invasive plant impacts are often considered to be of epidemic proportions or chronic in nature. Combined with other environmental factors, invasives are often responsible for affecting the number and extent of live trees, causing large fuel accumulations, and altering successional processes.

Whether flora or fauna, native or nonnative, invasive pests have a history of causing serious resource problems not only in terms of public nuisance and safety, but also problems for industry, wildlife habitat, air, and water quality. Examples include gypsy moth frass in recreational use areas, reduced mast production in tanoak forests affected by *P. ramorum*, reduced stocking leading to increased runoff, fuel accumulations from mortality, and nonnative grass invasion leading to increased burn intensity. The focus of this chapter is on insect and diseases but it must also acknowledge invasive plants. Aerial surveys have been done for invasive plant species, for example scotch broom and buffelgrass. Though not reported in great detail, aerial detection surveys for plants, combined with other detection methods, are critical to increased understanding of current forest dynamics. Other important invasive plant species such as cheat grass, salt-cedar, tree-of-heaven, spotted knapweed, miconia, and many more are contributing to localized sustainability issues.

Invasive species often become established and readily spread within forested regions currently out of the range of natural variability. For example in the West, stands that become dominated by shade tolerant tanoak due to a variety of factors (e.g., fire exclusion, absence of harvest practices that increase age and species diversity) provide optimum conditions for the presumed nonnative pathogen *P. ramorum* causing sudden oak death to become established and spread (e.g., Moritz and Odion 2005).

Hawaii is also negatively affected by invasive pathogen, plant, and insect pests. Impacts of invasive species, including animals, have been profound in Hawaii and are at the root of Hawaii's biodiversity crisis (fig. 3.13). Guava rust is currently defoliating nonnative forests at low elevation; there is a potential threat to native ohia, which dominates 80 percent of Hawaii's native forests. The erythrina gall wasp threatens widespread mortality of native wili trees, a component of much of Hawaii's remaining dry forests, and has almost eliminated the introduced coral tree. Nonnative invasive plant species impacting ecosystems in Hawaii include strawberry guava, velvet tree, peacock plume, and hundreds of other plants; there are nearly as many naturalized alien plant species as native species. Hawaii is particularly vulnerable to invasive species because its native species evolved in the absence of ungulates, rodents and predators, which have since been introduced. Nonnative mosquitoes carry avian malaria, decimating native birds. Invasive grasses provide fuel for fire.[8]

Additional nonnative invasive insects and diseases which threaten the mainland include sudden oak death and Port-Orford-cedar root disease in the West; gypsy moth (fig. 3.14), hemlock woolly adelgid (fig. 3.15), sirex woodwasp (fig. 3.16), and emerald ash borer (fig. 3.17) in the Northeast; chestnut blight and butternut canker in the East; white pine blister rust, Dutch elm disease, and more.

Monitoring regional indicator impacts is critical to early detection in order to apply management strategies for prevention and control in infested areas, areas currently in a condition predisposed to pest attack, and areas that are approaching a condition in which sustainability is at risk without management.

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[8] Personal communication. 2009. Katie Friday and Anne Marie LaRosa. U.S. Department of Agriculture, Forest Service Pacific Southwest Region, Institute of Pacific Islands Forestry, 60 Nowelo Street, Hilo, HI 96720.

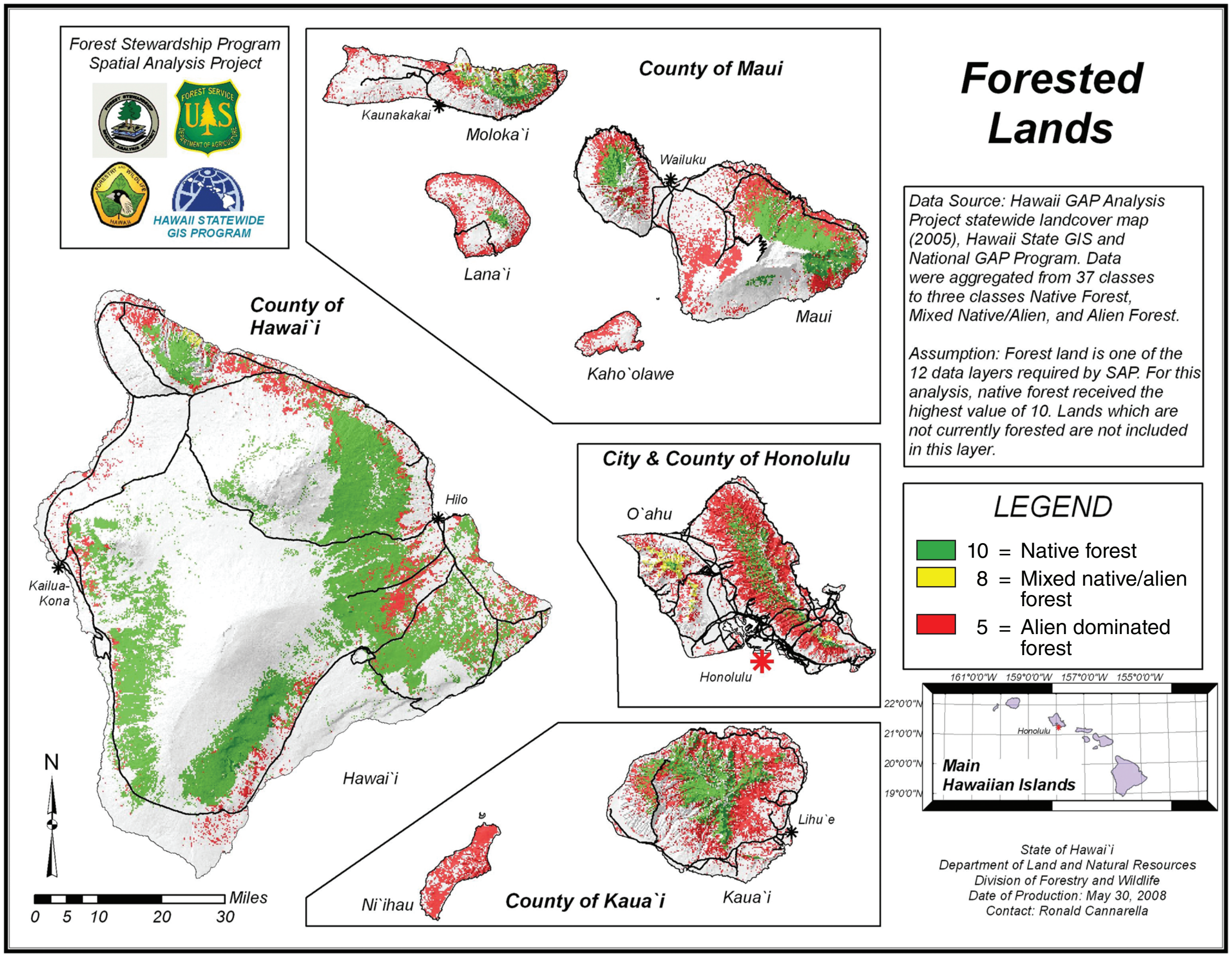


*Figure 3.13—Hawaii forests are dominated by overstory native, mixed, and alien species; approximately half of Hawaii's remaining forest has been transformed from reference conditions by alien plants.*

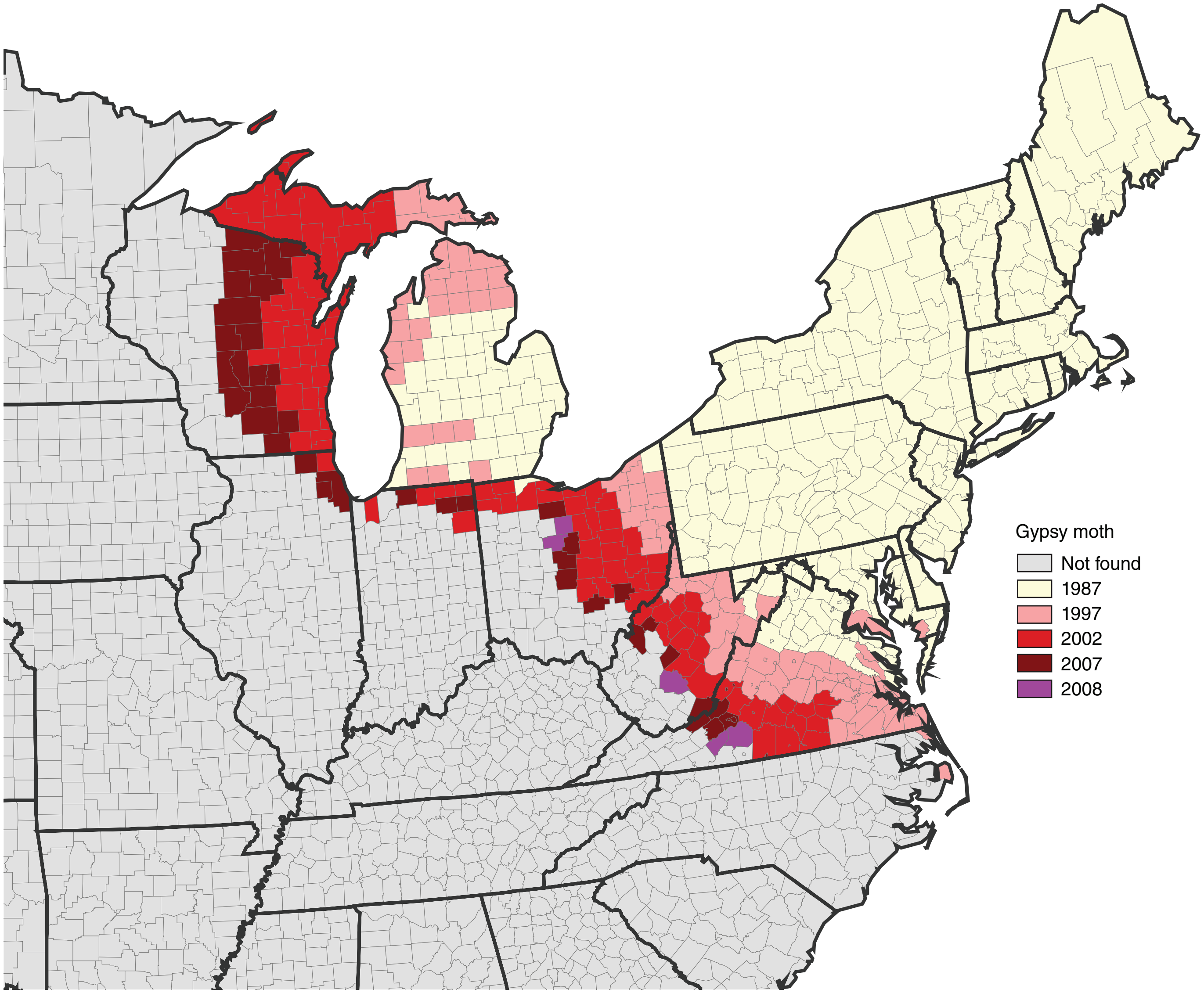


*Figure 3.14—Gypsy moth counties impacted/progression of quarantine, 1987–2008.*

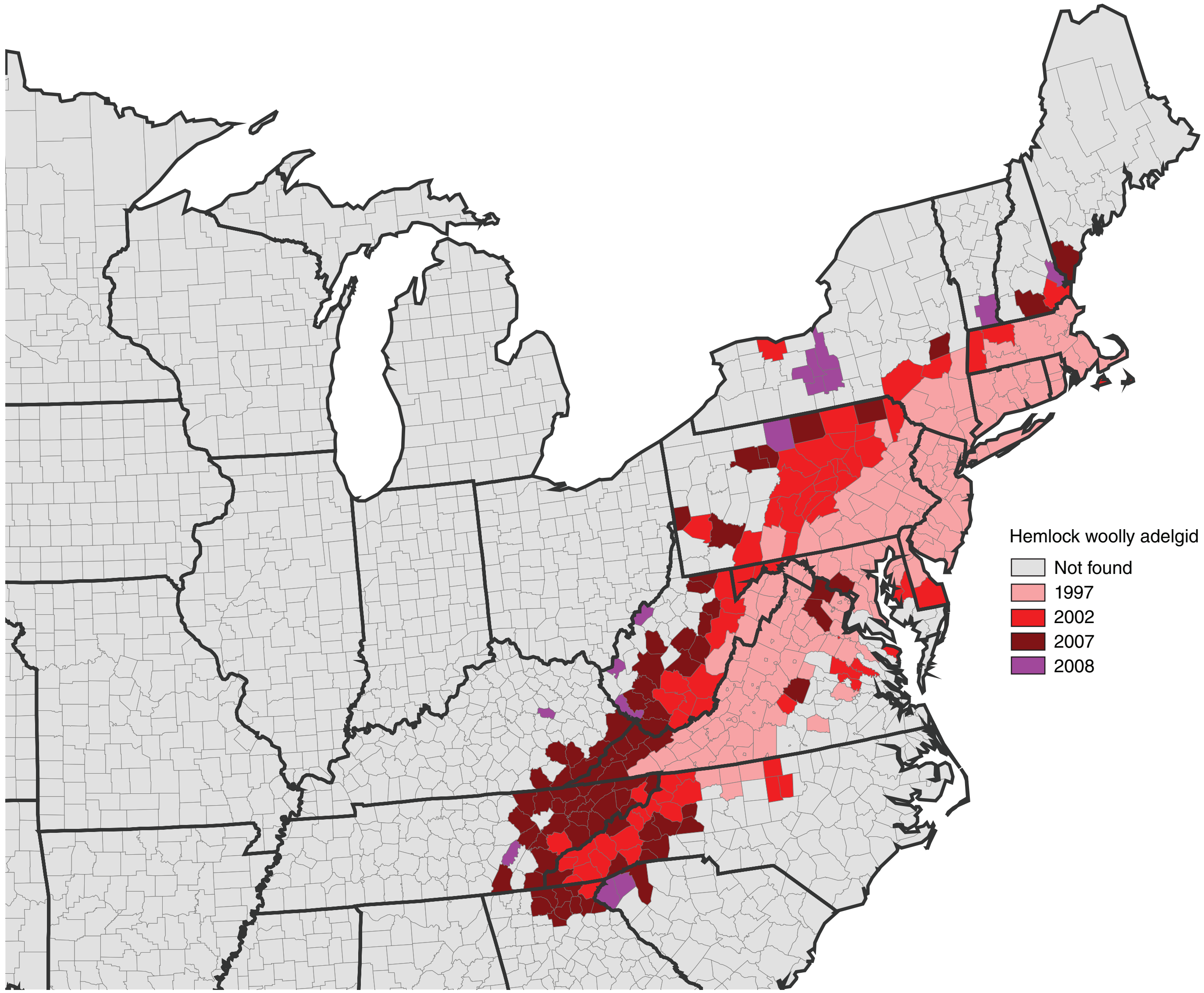


*Figure 3.15—Hemlock woolly adelgid spread by county.*

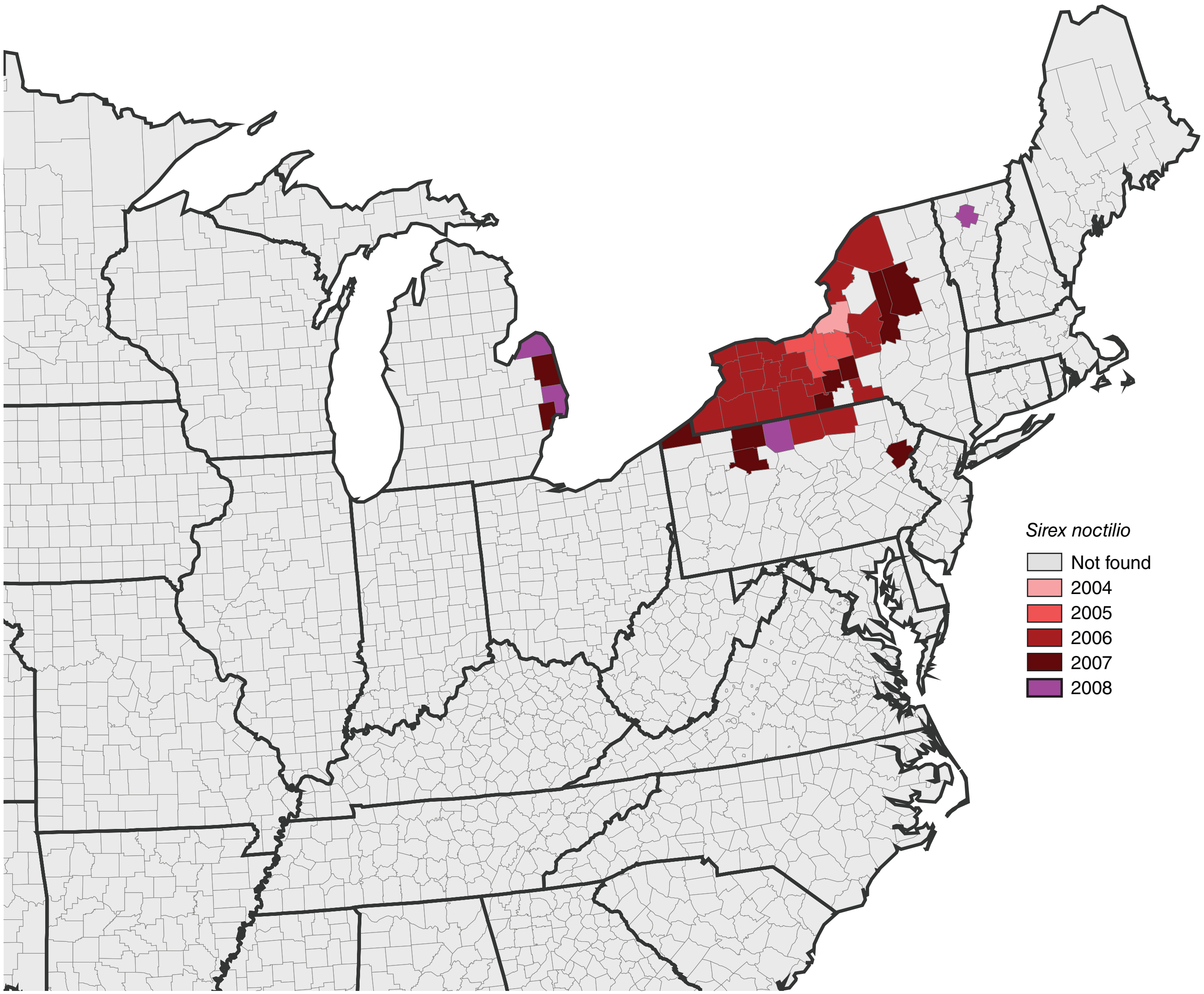


*Figure 3.16*—Sirex noctilio *spread by county.*

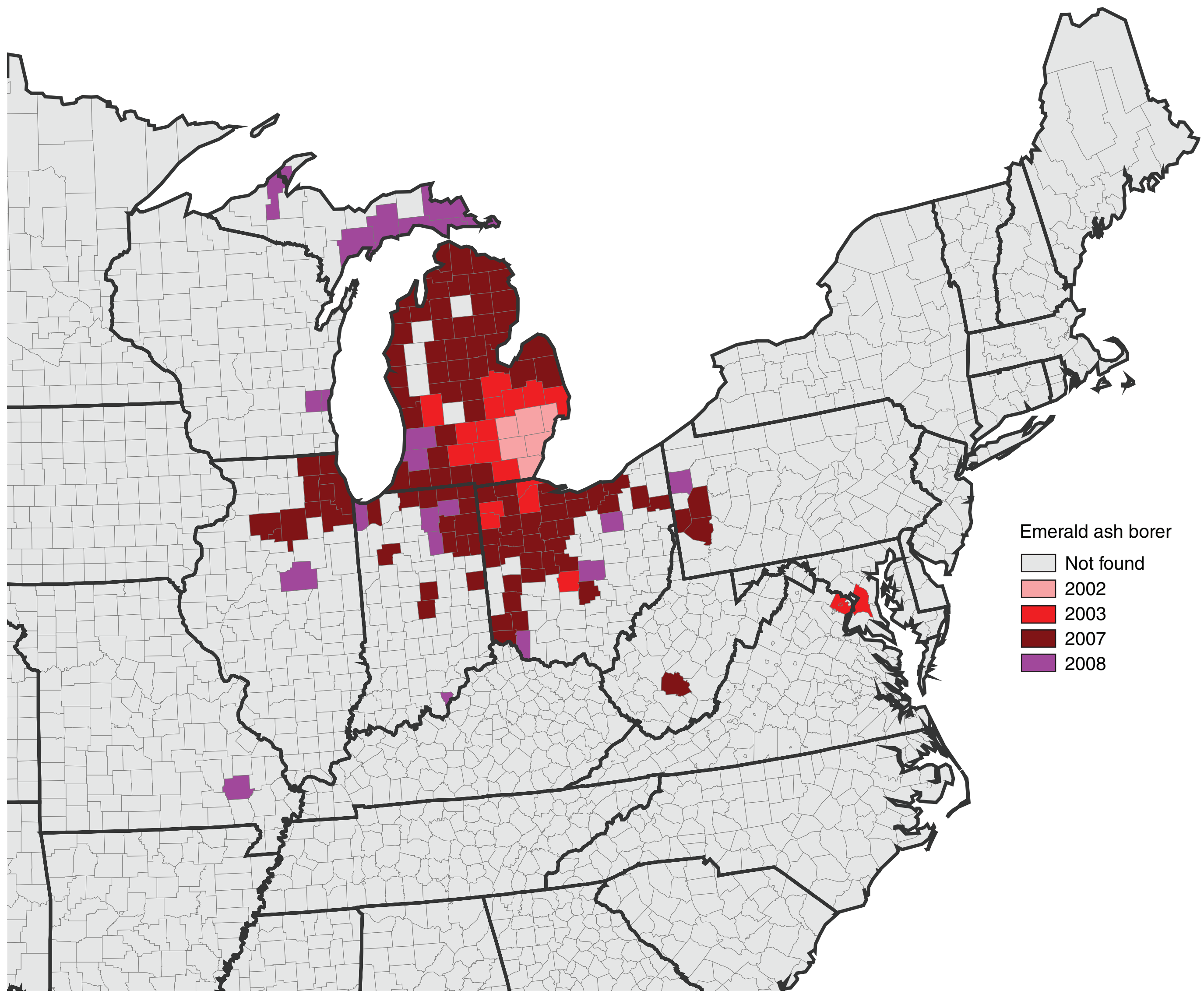


*Figure 3.17—Emerald ash borer spread by county.*

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