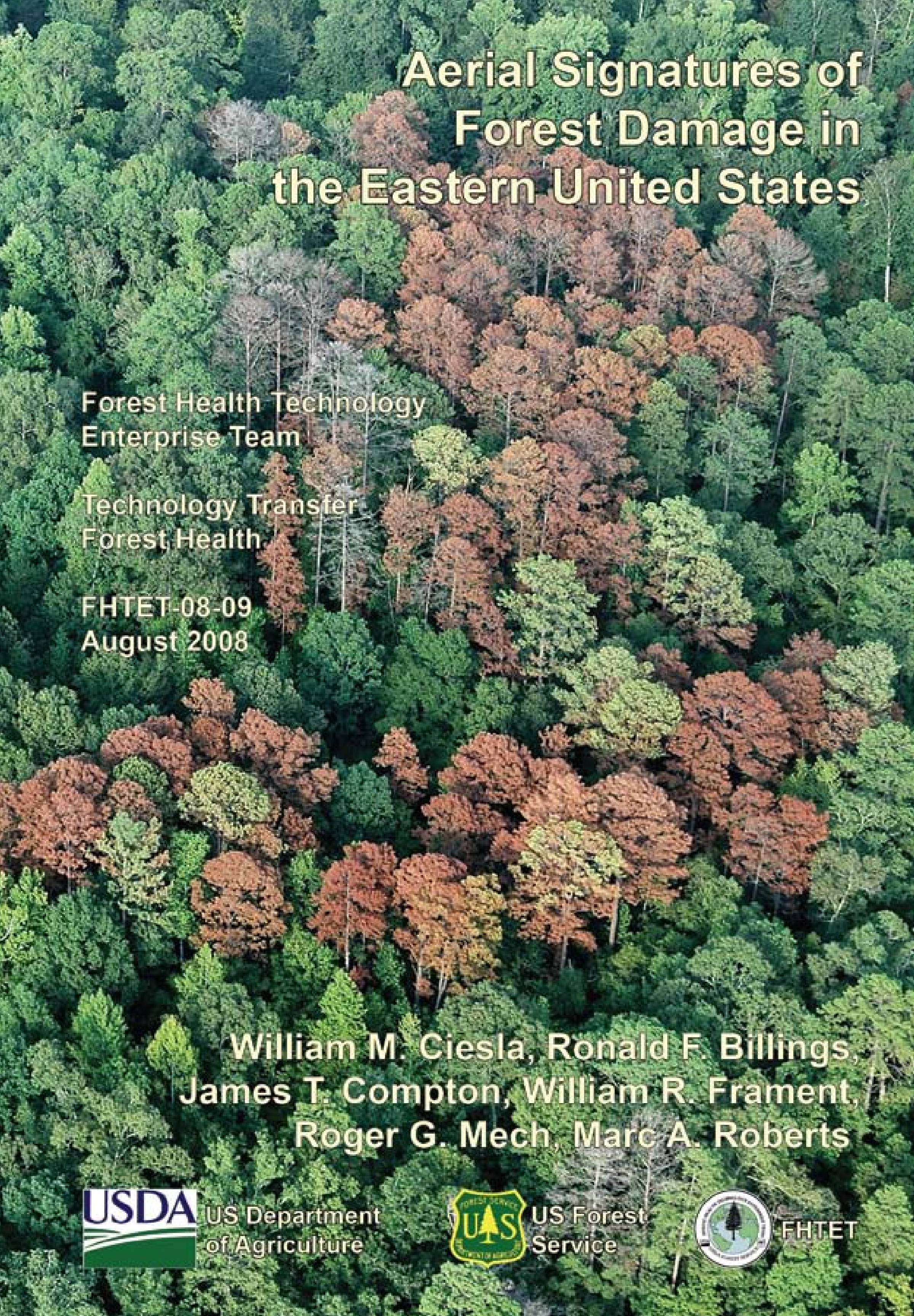

Aerial Signatures of Forest Damage in the Eastern United States

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Forest Health

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William M. Ciesla, Ronald F. Billings, James T. Compton, William R. Frament, Roger G. Mech, Marc A. Roberts

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William M. Ciesla is owner of Forest Health Management International (FHMI), Fort Collins, CO, and was an employee of Information Technology Experts (ITX), Fort Collins, when he wrote this manual.

Ronald F. Billings is an entomologist with the Texas Forest Service, College Station, TX.

James T. Compton is a forestry technician, USDA Forest Service, Southern Region, Forest Health Protection, Asheville, NC.

William R. Frament is a forester and remote-sensing specialist, USDA Forest Service, Northeastern Area, Forest Health Protection, Durham, NH.

Roger G. Mech is a forest-pest specialist, Michigan Department of Natural Resources, Lansing, MI.

Marc A. Roberts is a forester, USDA Forest Service, Northeastern Area, Forest Health Protection, St. Paul, MN.

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W.M. Ciesla, R.F. Billings, J.T. Compton
W.R. Frament, R. Mech and M.A. Roberts

For additional copies of this publication, contact:

Frank Sapio
USDA Forest Service
2150 Centre Ave., Bldg. A.
Fort Collins, CO 80526
970-295-5840
fsapio@fs.fed.us

Christine Mattingly
USDA Forest Service
2150 Centre Ave., Bldg. A.
Fort Collins, CO 80526
970-295-5839
cmattingly@fs.fed.us

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This manual is dedicated to the pilots who fly aerial forest-health surveys. There aren't many of them, but they number among the most highly skilled, precise, and safe pilots in the world, and they are essential to successful forest damage assessment.

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Introduction

The forests of the eastern United States are subject to damage by many agents, chief among them being fire, insects, diseases, and storms. Damage caused by some of these agents, especially those that damage foliage or kill trees, is often visible from long distances and, therefore, can be assessed via various remote sensing technologies. Damage caused by forest insects and diseases that produce symptoms visible from the air is most frequently recorded using a technique known as aerial sketchmapping. This relatively simple and inexpensive procedure involves skilled observers flying over forested areas in small, high-wing aircraft to survey and record the location of damaged areas either on paper maps or on digital map files displayed on computer-interfaced touch screens (digital aerial sketchmapping). These surveys provide critical information for both planning and implementing pest-management activities, and a historical record on the status and trend of important forest pests (Ciesla 2000, McConnell et al. 2000).

When seen from survey aircraft, certain characteristics of forest damage, known as "signatures," enable aerial observers to identify, with reasonable accuracy, the insect, disease or other causal agent(s) responsible for the damage. The ability to recognize these signatures is critical to the success of aerial forest-health surveys. The purpose of this publication is to describe and illustrate the common signatures of forest damage in the eastern U.S. as seen from operational flying heights of 1000 to 2000 feet above ground level (AGL). (This area is found within the jurisdictions of USDA Forest Service Regions 8 and 9 and the Northeastern Area and portions of the Great Plains states in Forest Service Regions 1 and 2.) Also, this publication is intended as a reference guide for beginning and experienced aerial observers alike, and is a companion guide to *Aerial Signatures of Forest Insect and Disease Damage in the Western United States.* (Ciesla 2006).

1. Aerial Signatures - An Overview

What is a Signature?

A signature is a signal or sign consisting of one or more unique characteristics that can be used to identify something, such as an object, a person, etc. A person's name, written in his or her own handwriting, is the classic example. Every person's handwriting is unique: therefore, written signatures are a legal means of identifying people. Another, less formal example of a signature is the theme music played at the beginning of a radio or TV show. Composed especially for that show, the tempo and melody of the music identifies the show to the listener. In the context of forest entomology, the galleries engraved by bark beetles in the cambium layer of host trees are referred to as signatures. These patterns, such as the characteristic S-shaped egg galleries of the southern pine beetle, *Dendroctonus frontalis*, in combination with the host tree attacked, usually are sufficient to identify the bark beetle involved.

Aerial signatures of forest damage caused by insects, diseases and other factors generally are defined by two parameters: the crown characteristics of the trees affected and the visual appearance of the damage.

Characteristics of Host Trees

Forest insects and diseases tend to be host specific, so the ability to recognize tree species or at least species groups (e.g. broadleaf trees, true firs, white or soft pines) is essential to the recognition of forest damage signatures. By identifying from the air the tree species or species groups and forest types present in the areas surveyed, the observer can narrow the complex of potentially damaging agents that could be present. Recognition of tree species or species groups, both healthy and damaged, should be second nature to experienced aerial observers. Crown characteristics used to identify healthy tree species or species groups on medium- or large-scale aerial photographs are a combination of foliage color, crown form, crown margin, branch patterns and foliage texture (Table 1, Fig. 1).

The aerial crown characteristics of conifers are more distinct than those of broadleaf trees and are more easily recognized by aerial observers.

Several guides featuring large-scale vertical aerial photographs are available to help identify tree species indigenous to eastern North America (Ciesla 1984, Heller et al. 1964, Sayn-Wittgenstein 1978). Although aerial observers typically view trees from an oblique rather than a vertical perspective, many of the characteristics discussed in these guides can help them identify tree species or species groups.

Foliage Color

Generally, foliage color is the first characteristic that an aerial observer notices when attempting to identify tree species. Most healthy deciduous (broadleaf) trees have foliage in various hues of medium green and conifers have foliage in hues of dark green (Fig. 4). The color contrast between conifers and broadleaf trees is most conspicuous in late spring/ early summer, after deciduous trees have leafed out fully, but the foliage has not yet hardened. Conifers, such as red pine, *Pinus resinosa*, balsam fir, *Abies balsamea*, Fraser fir, *Abies fraseri*, and red spruce, *Picea rubens*, are significantly darker than other conifers. The foliage of eastern white pine, *Pinus strobus*, has a distinct blue-green cast, which is visible from aerial survey flying heights. The foliage of Scotch pine, *P. sylvestris*, native to Eurasia but widely planted in the northeastern and north central states, also has a distinct blue-green cast but when viewed from a distance the foliage of this species tends to have a green-brown cast. The foliage of Northern white cedar, *Thuja occidentalis*, has a yellow-green cast. Tamarack, or eastern larch, *Larix decidua*, which is a deciduous conifer, has light green foliage.

Crown Shape

The shape of the crown is another characteristic helpful for identifying tree species or species groups during aerial surveys (Fig. 2). A tree crown can range from acuminate or spire-like (balsam fir at low elevations), acute (spruces), rounded (jack pine, *Pinus banksiana*, or red pine) or broadly rounded (southern pines, eastern red cedar, *Juniperus virginiana*, and most broadleaf species). Crown shape within a tree species or species group varies and can change with tree age or site. For example, balsam fir growing on or near the summits of high mountains does not have the acuminate, spire-like form characteristic of trees growing at lower elevations, making it difficult to distinguish from red spruce, another conifer with which it is often associated.

The nature of the apex or tip of a tree crown can be helpful in tree identification from the air. The crown apex of eastern hemlock, *Tsuga* *canadensis*, droops and is indistinct. Pines, which have rounded crowns, also do not have distinct crown apices. When viewed from low flying aircraft, the crown apices of spruces and true firs appear to be acute and quite distinct.

Crown Margin

Crown margins are most easily seen in open forests where they are not obscured by neighboring trees (Ciesla 1990). The outer margins of tree crowns for most of the yellow or hard pines, true firs, and spruce are sinuate, serrate, or entire, whereas the crown margins of eastern white pine are deeply lobed (Fig. 3).

Branch Pattern

Some conifers, such as pines and spruces, have distinct branches when viewed from survey aircraft. The branches of others, such as balsam fir, larch, and hemlock, are less distinct (Fig. 3).

Foliage Texture

Conifers, such as eastern larch and eastern hemlock have fine, lacy, sometimes transparent foliage. The foliage of most yellow or hard pines (e.g., red pine, pitch pine, *Pinus rigida*, or the southern yellow pines) has a clumped appearance. Two exceptions are jack pine, and Virginia pine, *P. virginiana*, which have shorter needles and give the foliage a fine-textured appearance. Among broadleaf species, oaks, *Quercus* spp., and hickories, *Carya* spp., tend to have a coarse foliage texture, whereas the foliage of bigtooth aspen, *Populus grandidentata*, quaking aspen, *P. tremuloides*, birches, *Betula* spp., and black locust, *Robinia pseudoacacia*, is fine-textured.

Landscape Features

The location of trees, relative to certain landscape features, especially elevation and proximity to drainages, also provides clues to their identity. In the Adirondack and northern Appalachian Mountains, mid–low elevations contain either northern hardwood forests of beech, *Fagus grandifolia*, yellow birch, *Betula allegheniensis*, and sugar maple, *Acer saccharum*, or mixed forests of broadleaf and coniferous species. The highest peaks have forests of red spruce and balsam fir.

In the Southern Appalachians, where there is a great diversity of tree species, the lowest elevations (ca 2000 feet) have a mixture of pines and broadleaf trees, usually oaks and hickories. These forests transition first to a mixed broadleaf forest that consists of a great variety of species and eventually to northern hardwoods (beech, yellow birch, and buckeye, *Aesculus* spp.). At elevations over 5,000 feet, red spruce and Fraser fir become the dominant species (Fig. 5).

Depending on location, broadleaf species, such as eastern cottonwood, *Populus deltoides*, willow, *Salix* spp., alder, *Alnus* spp., American elm, *Ulmus americana*, and sycamore, *Platanus occidentalis*, are typically found near or adjacent to streams. Eastern hemlock and baldcypress, *Taxodium distichum*, commonly grow in streamside forests (riparian areas).

Several tree species indigenous to the eastern U.S. are associated with bogs. In the northern states, black spruce, *Picea mariana*, northern white cedar, eastern larch and black ash, *Fraxinus nigra*, are common bog species. Baldcypress is common in the bays and along the stream banks in the South Atlantic or Gulf Coast regions. In some poorly drained areas of the South, water tupelo, *Nyssa aquatica*, occurs in both pure forests and mixed in with baldcypress.

Another factor that can help identify at least one tree species indigenous to the South is the level of tree stocking. Among the southern yellow pines, longleaf pine, *Pinus palustris*, a fire dependent species, grows in open stands with grassy understories, characteristics readily identified from aerial survey flying heights.

Characteristics of Damage

The following categories are used to classify damage caused by forest insects, diseases and other agents (USDA Forest Service 1999a):

- defoliation
- mortality
- discoloration
- dieback
- top-kill
- branch breakage
- mainstem broken or uprooted
- branch flagging

The most frequently mapped damage categories are defoliation and mortality. Some damage signatures may contain more than one category.

Defoliation

Defoliation is damage that results in either partial or complete, physical or functional removal of foliage. Insects are the most common cause of defoliation but in a few cases (e.g., tatters) defoliation can be caused by climatic factors, such as high winds or hail. The aerial signature of defoliation consists of discoloration and thinning of affected tree crowns. Feeding damage by some insects, such as the spruce budworm and jack pine budworm, results in partially damaged foliage, which turns red-brown during the peak period of defoliation. After the insects stop feeding, the partially damaged foliage is washed away by rains and/or blown away by winds, leaving a gray cast to the defoliated trees. Broadleaf defoliating insects, such as the forest tent caterpillar or gypsy moth, can consume all of the foliage except the midribs and major veins, causing affected areas to have a light brown to gray cast. Refoliation of defoliated broadleaf trees can occur within 10 to 14 days. However, the new leaves are usually smaller and somewhat chlorotic.

Mortality

A number of pest agents, including insects, fungi, fire, drought, inundation and mammals, such as beavers, cause tree mortality. Bark beetle attacks on conifers is one of the more common causes of tree mortality observed by aerial sketchmappers. The foliage of pines attacked by bark beetles changes first from dark green to yellow green, then to red, and finally brown before dropping from the affected trees. This process is commonly referred to as "fading." Bark beetle-infested trees with yellow crowns are called "faders," and those with red or red-brown foliage are called "red tops."

Depending on the causal agent, tree mortality may occur in distinct groups or as a scattering of dead trees in the forest. The host trees affected, size of the group kills, size of the affected trees, and the color of the fading foliage all provide clues as to the cause of the damage. For example, in the pine forests of the South the occurrence of large groups of dead and dying pines indicates an outbreak of southern pine beetle is underway. In broadleaf forests, mortality and dieback are often difficult to distinguish at operational aerial survey flying heights.

Discoloration

Discoloration is defined as tree crowns with foliage that is any color (yellow, red or brown) but green. Agents that can alter foliage color include needle or leaf-mining insects, fungi that attack the foliage, late spring frost, hail, and herbicides or other chemicals. The foliage color and the location and pattern of damage can provide clues to the cause of the damage. In mountainous terrain, damage by late spring frosts can be found at high elevations or in low-lying areas or "frost pockets." Herbicide damage is often found adjacent to roads, utility rights-of-way and agricultural fields where weed or brush control has been done. Trees with yellow or yellow green (chlorotic) foliage is often an indicator of deficiencies in soil nutrients, such as iron (iron chlorosis) or magnesium or, in the case of American beech, beech bark disease.

Another factor that can cause tree crowns to appear discolored is the presence of cones or seeds This is especially true of spruce, fir and northern white cedar, which have cones concentrated in the upper crowns or on the outer branches, causing the tips of the trees to have a brownish or gray cast that can resemble defoliation or top kill.

Dieback

Dieback occurs when the upper crowns of trees exhibit dead or dying branches. Dieback may be the result of repeated defoliation by insects, drought, or a complex of interacting factors known as "declines and diebacks," and is often accompanied by tree mortality (Manion 1991).

Top Kill

Top kill is a condition in which the upper quarter, third or half of the tree's crown, including the terminal and all branches, dies and is most frequently the result of attack by some species of bark beetles. Generally, it is difficult to see from aerial survey flying heights.

Branch Breakage

This type of damage usually is caused by severe storms and is evidenced by branches with white or light-colored exposed wood at their breaks.

Main Stem Broken or Uprooted

Broken or uprooted trees over large areas are the result of severe storms, including tornadoes, ice storms, straight-line winds and hurricanes. When seen from the air, the pattern of damage can provide clues as to what caused it.

Branch Flagging

Branch flagging consists of individual branches with either dead or discolored (fading or red) foliage, and can be caused by several species of fungi, certain bark beetles, or porcupines or squirrels feeding on the bark.

2. Other Considerations

Peak Occurrence of Signatures

Aerial forest health surveys should be flown when the damage signatures of interest are at their peak, as defined by the seasonal history of the damaging agent. This is especially true when mapping defoliation or discoloration. Failure to identify the optimum survey window could result in flying too early, before all of the damage has occurred, or too late, when damaged foliage has been washed from trees by rains or is masked by new growth.

Light and Shadow

Light and shadow can have significant effects on an aerial observer's ability to discern subtle differences in damage signatures. During mid summer, surveys can be flown on most days from about 8:00 AM to 4:00 PM, provided that turbulence, thundershowers and cloud cover are not limiting factors. If contour flying is done in mountainous terrain, it is better to fly east-facing slopes during the morning, while they are in direct sunlight and, west-facing slopes during the afternoon.

Clouds will reduce the amount of sunlight that strikes the survey area, but less light is not always detrimental to the survey. Whereas high cirrus clouds can diffuse sunlight, reduce the sharp contrasts characteristic of full sunlight, and make damage signatures easier to see and classify, dark shadows from cumulus clouds can be interspersed with brightly lit areas, making signatures less visible (Fig. 6).

In the eastern U.S., atmospheric haze often reduces visibility and can affect an aerial observer's ability to detect damage. This is especially true in the central and southern Appalachian Mountains and the Ozark-Ouachita regions of Arkansas, southern Missouri and eastern Oklahoma, where some level of haze is almost always present (Fig. 7).

Background Noise

At certain times of the year phenomena may occur that mask or mimic signatures of insect and disease damage. The classic case is fall (September and October) coloration of deciduous broadleaf trees, which can mask most damage signatures (Fig. 8). This is especially true of diebacks and declines, because early fall coloring actually could be a symptom of the decline (Fig. 9).

Two deciduous conifers (eastern larch and baldcypress) occur in the eastern U.S., and their foliage turns brilliant colors in autumn. In the North, the foliage of eastern larch turns yellow (Fig. 10) and in the South the foliage of baldcypress turns red-orange, a color that resembles that of pines fading from bark beetle attack (Fig. 11).

Live oaks, *Quercus virginina* and *Q. fusiformis*, drop old foliage and put on new leaves in February and March. This time of year is not suitable for aerial detection of oak wilt in central Texas.

Spring bud burst also produces myriad colors and could mimic certain kinds of foliar damage. This is especially true at high elevations where bud burst is delayed (Fig. 12). Late spring frosts, especially in broadleaf species, can cause a signature similar to that caused by defoliating insects. Heavy cone crops, especially on balsam fir, spruce or northern white cedar, can cause the upper crowns to have a gray or brownish cast, which can mimic defoliation or trees fading due to bark beetle attacks (Fig. 13).

Ground Checking

Ground checking to verify the host(s) affected, the causal factor(s) responsible for the damage and the intensity of damage should be an integral part of aerial forest health surveys. Unfortunately, because of the large areas of remote forests that must be covered, a shortage of qualified aerial observers, and the short time period during which surveys can be made, thorough ground checks of all damaged areas mapped during aerial surveys is not always possible. Therefore, high priority should be given to ground checks of areas where questionable or unfamiliar damage signatures have been observed, potentially severe damage may occur in the future (e.g., southern pine beetle infestations), damage is thought to have been caused by an exotic pest outside of its known established range, or where forest management or pest suppression actions are planned or underway. In addition, new and less experienced aerial observers should plan for extra time to do ground checking so they can become more familiar with the damage signatures characteristic of the areas being surveyed.

Pest Complexes

During aerial surveys, most forest damage is attributed to a single causal factor, even though existing protocols allow for classification of up to three causal factors for each damage polygon (USDA Forest Service 1999a). While coding for a single causal factor may be expedient, much of the damage observed and mapped during aerial surveys is the result of multiple factors. Often, two or more species of bark beetles cohabit the same tree, with some species attacking the upper bole and others attacking the mid- and/or lower bole. Bark beetles often attack groups of trees stressed by root disease. Some bark beetles attack trees following wildfire or defoliator outbreaks. These complex interactions between insects, diseases and other factors affecting forest health can be confirmed only by ground checks.

The occurrence of more than one causal factor also can influence the appearance of the signature. For example, trees that have been defoliated by insects or severe storms, or damaged by fire and subsequently attacked by bark beetles, will not fade to the bright colors of non-defoliated trees, because a large portion of the foliage has already been removed.

3. Descriptions of Damage Signatures

The following sections provide descriptions of the aerial signatures of damage caused by commonly occurring forest insects, diseases and other damage agents in eastern forests. Characteristics described are considered "typical" signatures, but are subject to variation due to time of year, visibility, local conditions and other factors. The descriptions are organized according to damage types noted in the current "USDA Forest Service Aerial Survey Standards" (USDA Forest Service 1999a). Descriptions for defoliation and mortality are further subdivided into conifers and broadleaf trees. Damage signatures by forest and damage types are summarized in Tables 5 and 6.

Defoliation

Conifers

Budworms

Spruce Budworm

The spruce budworm, *Choristoneura fumiferana* (Lepidoptera: Tortricidae), is one of the most destructive native insects of spruce-fir forests in the eastern U.S. and Canada. Periodic and widespread outbreaks of this insect have been recorded since the early 1800s. Balsam fir is the species most severely damaged by spruce budworm and outbreaks in the eastern U.S. have occurred in Maine, New Hampshire, New York, Michigan, Minnesota, Vermont and Wisconsin. White, red, and black spruces are also damaged and during outbreaks some feeding may occur on eastern larch, pines, and eastern hemlock. Spruce mixed with balsam fir is more likely to suffer damage than spruce in pure stands (Orr and Kucera 1980).

In spring/early summer, the larvae leave their overwintering sites and feed inside the expanding buds of host trees. Later, they feed on the new growth. Branch tips containing partially damaged foliage turn red brown and are tied together with silken webbing. This is most conspicuous during July. During the first year or two of an outbreak, damaged trees have an outer "halo" of red-brown damaged foliage against a backdrop of green older foliage (Fig. 14). As outbreaks progress, and affected forests suffer from successive years of defoliation, top dieback and tree mortality, they develop a gray cast with thin crowns almost totally devoid of foliage. Damage often occurs over large areas (Figs. 15, 16).

Jack Pine Budworm

Closely related to the spruce budworm, jack pine budworm, *Choristoneura pinus pinus* (Lepidoptera: Tortricidae), occurs in Michigan, Minnesota and Wisconsin and portions of Canada. Hosts are jack pine and red pine. Feeding habits are similar to those of spruce budworm. Larvae feed on the needles but do not consume them entirely. Usually, they clip off the needles at their base and web them together (Drooz 1985). The partially damaged needles turn red-brown in late June/early July. During outbreaks, defoliated trees are bright red-brown, later changing to dull brown as the affected foliage drops from the trees (Fig. 17).

Baldcypress Leafroller

First detected in 1983 and initially reported as the fruit tree leafroller, *Archips argysophila* (Lepidoptera: Tortricidae), the baldcypress leafroller, *Archips goyerana*, is a recurrent defoliator of baldcypress in the southern Achafalaya River Basin in southern Louisiana (Goyer and Lenhard 1988). The aerial signature of defoliation is yellow-red foliage, often most severe on edges of waterways or where the basal area is low. The reddish cast is imparted by drying, partially consumed foliage in the lower crown. Since baldcypress does not occur in extensive, pure stands, defoliated trees are often interspersed amid broadleaf species with green crowns (Figs. 18, 19). Peak defoliation occurs in early May (R.A. Goyer, personal communication).

Loopers

Several species of loopers (Lepidoptera: Geometridae) feed on the foliage of conifers and can cause aerially visible defoliation.

Hemlock Looper

Hemlock looper, *Lambdina fiscellaria fiscellaria*, occurs from Newfoundland to Alberta and south to Georgia. The larvae prefer the foliage of balsam fir and hemlock and, during outbreaks, are known to feed on all species of conifers and some broadleaf species (Maier et al. 2004). The aerial signature is a light brown to gray discoloration and thinning of host trees (Fig. 20). Defoliation is most visible in July and August after the larvae have finished feeding. In the eastern U.S., outbreaks have occurred in Michigan, New England, New York, Ohio and Wisconsin.

A Baldcypress Looper

The larvae of the looper, *Anacamptodes perigracilis*, feed on the foliage of baldcypress. This insect is known from Florida, Georgia, Louisiana, Maryland, Mississippi, Texas and Virginia and outbreaks have occurred in Florida and Mississippi. This insect has multiple generations per year and defoliation is most visible in July and August. Defoliated trees often have a reddish color caused by dried, partially consumed needles (Dixon 1982).

A Gray Pine Looper

The larvae of a gray pine looper, *Iridospis (=Anacamptodes) vellivolata*, feed primarily on the foliage of pines but will also feed on balsam fir, eastern larch and spruce (Maier et al 2004). This insect ranges from eastern Canada south to Florida and eastern Texas (Wagner 2005). In southern locations it may have several generations per year. Mature larvae may be present from June to September (Maier et al. 2004).

This looper has reached outbreak levels, causing aerially visible defoliation of loblolly pine, on at least one occasion in eastern Texas (Personal communication, H.A. Pase III, Texas Forest Service, Lufkin, TX). The aerial signature of defoliation is thin, discolored foliage with feeding damage concentrated in the lower and mid-crowns (Fig. 21).

Sawflies

Sawflies are common defoliators of pines, spruce, hemlock, fir and larch in the forests of the eastern United States. Most species affect pines (Drooz 1985).

Pine sawflies

The redheaded pine sawfly, *Neodiprion lecontei* (Hymenoptera: Diprionidae) is the most widespread and commonly occurring pine sawfly. This species defoliates young trees but, unless large areas of young plantations are affected, the damage is not easily seen from aerial survey altitudes. Other species of *Neodirion* sawflies, such as the blackheaded pine sawfly, *N. exitans*, feed on the foliage of mature pines, causing damage that is visible from aerial survey altitudes. Regardless of the species involved, defoliated pines have thin, light brown or gray crowns, with gray indicating heavy defoliation (Fig. 22). Peak appearance of signatures varies with the life history and number of generations for each species (Table 2). Available historical data or ground checks are needed to verify the species involved.

Larch Sawfly

The larch sawfly, *Pristophora erichsonii* (Lepidoptera: Tenthredinidae) is an exotic species, first reported in North America in 1880, and now found throughout most of the natural and planted ranges of larches in North America. All life stages and defoliation can be found throughout the summer. The larvae seldom completely defoliate trees, because they prefer to feed on needle tufts found on short shoots rather than single needles on elongated shoots (Drooz 1985). Feeding damage occurs when larvae remove pieces of needles, causing the remaining portions to turn yellow or brown (Fig. 23).

Yellowheaded Spruce Sawfly

The yellowheaded spruce sawfly, *Pikonema alaskensis* (Hymenoptera: Tenthredinidae), is found across the northern tier of North America from Newfoundland to Alaska. The larvae feed on the foliage of spruce and can be a serious defoliator of both young spruce plantations and natural regeneration in open areas (Drooz 1985). The larvae are active in June and July. The signature is yellow to brown discoloration and crown thinning, and is most conspicuous in late July.

Broadleaf Trees

Insects are the primary cause of defoliation in broadleaf forests and many species, mostly of the order Lepidoptera (moths and butterflies), can cause widespread defoliation. The aerial signature of defoliation of broadleaf forests is thin foliage and light green, brown or gray crowns. Partial, light to moderate defoliation will cause some crown thinning and foliage discoloration (Fig. 24). Heavy feeding can result in complete defoliation, giving affected areas the appearance of broadleaf trees in winter (Fig. 25). The borders between damaged and undamaged forests often contain partially damaged trees, making the borders appear blurred when viewed from the air. In mountainous regions, heaviest damage often occurs on or near ridges.

Peak appearance for defoliation in broadleaf forests is relatively short because affected trees can refoliate within 10 days. However, the second crop of foliage is often sparse and the leaves tend to be smaller than normal and chlorotic. Therefore, some aerial evidence of defoliator outbreaks may be present throughout the remainder of the growing season.

Regardless of the insect species or host(s) affected, the aerial signatures of defoliation of broadleaf forests are similar in appearance. Historical data or ground checks are required to verify the causal agent(s) involved.

Spring–Early Summer Defoliators

Many species of insect defoliators are active in the spring, and damage trees shortly after the spring flush of foliage. This group of defoliators is considered most damaging because defoliation occurs during the period of greatest tree growth.

Gypsy Moth

Introduced into the northeastern United States in 1869, the gypsy moth, *Lymantria dispar* (Lepidoptera: Lymantriidae), is now considered one of the most damaging defoliating insects of eastern broadleaf forests (McManus et al. 1989). During some years, aerially visible defoliation can occur over millions of acres and has been reported from the Northeast south to Virginia and west to Michigan and Wisconsin (Figs. 26, 27). Gypsy moth defoliates a wide range of broadleaf trees and can also defoliate some conifers. Period of peak defoliation varies from mid June in southernmost areas to early July, in northern areas.

Tent Caterpillars

The forest tent caterpillar, *Malacosoma disstria* (Lepidoptera: Lasiocampidae), occurs throughout North America, wherever broadleaf forests occur. The larvae appear in spring just as the leaves unfold. Peak defoliation can occur as early as April and May in the Gulf Coast Region and in late June/early July in the northern states. During outbreaks, this insect can defoliate tens of thousand of acres of broadleaf forests. Hosts vary according to location. In the Northeast, sugar maple, northern red oak and ash are preferred (Fig. 28). In the Lake States, oaks, quaking aspen and sugar maple are damaged (Fig. 29). In the Appalachians and Central States, oaks are the preferred host (Fig. 30). In the Atlantic and Gulf Coast regions, low lying forests of water tupelo, sweetgum, *Liquidambar styraciflua*, and other species are defoliated almost every year (Figs. 31, 32). In the Mississippi Valley, cottonwood and elms are damaged and in eastern Texas, oak forests are defoliated (Batzer and Morris 1978).

The eastern tent caterpillar, *M. americanum*, feeds on the foliage of cherry, apple, *Malus pumila*, crabapple, *Malus* sp., hawthorn, *Crataegus* spp. and, occasionally, other broadleaf trees. The larvae construct large silken nests in branch crotches of host trees (Fig. 33). Heavy defoliation is a common occurrence, especially along fencerows, roadsides and in fruit orchards. In areas where a large component of cherry has invaded old fields, defoliation, which peaks in June, and tents can be visible to aerial observers.

Loopers

Several species of inchworms or loopers (Lepidoptera: Geometridae), all native species, periodically reach epidemic levels and can defoliate large areas of broadleaf forests. Most species have one generation per year. In some cases, more than one species may be involved in an outbreak. Most loopers feed on a variety of broadleaf trees (Table 3) and can cause areas of moderate to heavy defoliation. The exception is the cherry scallop moth, *Hydria prunivorata*, which feeds on black cherry, *Prunus serotina.* In mixed broadleaf forests with a component of black cherry, the signature of this insect consists of individual defoliated trees, tan to brown, amid an otherwise green forest. Peak period of damage by loopers is from mid June to early July.

Leafrollers and leaftiers

The larvae of leafrollers or leaftiers (Lepidoptera: Tortricidae) fold or roll individual leaves or parts of leaves or shoots to form a nest from which the larvae feed. Several species of leafrollers and leaftiers can cause aerially visible defoliation in broadleaf forests.

The oak leaf tier, *Croesia semipurpurana*, feeds on various species of oaks and is known from southeastern Canada and Massachusetts, west to Minnesota, and south to Texas (Drooz 1985). Outbreaks have occurred in Florida, Maine, Pennsylvania, Tennessee, Texas, Virginia and West Virginia. Defoliation is at its peak during June and July.

The large aspen tortix, *Choristoneura conflictana*, is a relative of the spruce budworm and jack pine budworm and occurs throughout much of the range of quaking aspen in North America. The larvae hatch in July–August, feed on the undersides of leaves, and later overwinter in rough bark or under moss. In spring, they feed on the swelling buds. Later, they roll leaves and feed within the enclosures. The favorite host is quaking aspen, but the larvae also feed on balsam poplar, bigtooth aspen, paper birch, *Betula papyrifera*, willow and alder (Drooz 1985). In the eastern U.S., outbreaks have been reported in Michigan, Minnesota, New England, New York, and Wisconsin. This insect can reach outbreak levels and cause complete defoliation of aspen forests. Defoliation is at its peak in June and the aerial signature is virtually identical to that of forest tent caterpillar outbreaks in aspen forests. Historical information or ground checks are needed to confirm which species is causing the damage.

Frost Damage

Late spring frost can produce an aerial signature that mimics insect defoliation, especially in broadleaf forests. Depending on severity, late spring frosts can kill the margins of newly emerged leaves, causing a brown discoloration, or kill entire leaves. In addition, when a second crop of foliage develops, it is often sparse and the leaves are smaller than normal, giving affected crowns a thin, open appearance that is present throughout the remainder of the growing season. In mountainous regions, frost damage is most common either at higher elevations or in frost pockets.

Tatters

This condition is evidenced by the occurrence of newly emerging leaves that are lacy or malformed when they should be fully developed. The cause is unknown. Tatters was first reported during the 1980s in Iowa, Indiana and Ohio, but has been observed in many other states including Minnesota, Michigan, Wisconsin, Illinois, and Missouri. Tree species affected include white oaks, a few red oaks, and hackberry.

Symptoms first appear at the time of leaf emergence, generally in mid- to late May. Newly emerging leaves have reduced interveinal tissues, which give them a lacy, skeletal, or tattered appearance. From a distance, trees may appear to be light in color or undeveloped in comparison to other trees. The damage is often evenly distributed throughout the entire crown, but sometimes may be greater in the lower crown. Within a few weeks, trees will begin to produce a second flush of leaves that are generally free of tatters symptoms. The new foliage may be smaller and lighter in color than normal leaves. Tatters may affect all sizes and ages of trees and whole stands of same species in woodlands or urban areas. However, adjacent trees of the same species may remain unaffected (Hayes 2003).

Late Summer Defoliators

Insects that feed on the foliage of broadleaf trees in late summer/early fall are generally considered less damaging than the spring/early summer defoliators, because feeding damage occurs just prior to leaf fall and after most of the tree's growth has taken place. A number of species are capable of causing damage over large areas.

Defoliating Caterpillars

A complex of defoliating caterpillars of the family Notodontidae feeds in late summer/early fall (usually August/September) (Table 4). Other than the time of peak defoliation, the aerial signature of damage caused by late summer/early fall defoliators is identical to that of the spring/early summer feeding species (Figs. 34, 35). However, mapping damage can be more challenging because some early fall coloration of broadleaf trees may already be present (Fig. 36).

Skeletonizers

Insects that feed on all of the leaf tissue except the veins are referred to as "skeletonizers." Damaged foliage turns from green to light, reddish brown or brown (Fig. 37). The aerial signature of damage by skeletonizers is foliage discoloration accompanied by some crown thinning.

The birch skeletonizer, *Buccalatrix canadensisella* (Lepidoptera: Lyonetiidae), occurs from southern Canada and Maine to Minnesota and North Carolina. The larvae feed on the foliage of white birch, other birches, and alder. Outbreaks occur at frequent intervals, often over large areas, and can last 2 to 3 years (Drooz 1985). The larvae feed from mid-July to September and peak defoliation occurs in August–September. Outbreaks have been reported from Maine, New Hampshire and Vermont.

The oak skeletonizer, *Buccalatrix ainsliella*, occurs from southern Canada and the Lake States south to North Carolina and Mississippi. The larvae feed on various oaks and chestnut (Drooz 1985). This insect has at least two generations per year with defoliation occurring in May–June and August–September (Fig. 38).

Nest-making Caterpillars

Several species of late summer tent-making caterpillars are common defoliators and occasionally cause aerially visible defoliation. The fall webworm, *Hyphantria cunea* (Lepidoptera: Arctiidae), occurs throughout the US and southern Canada and feeds on over 100 species of broadleaf shrubs and trees. After egg hatch, the larvae immediately enclose branches on which they feed with a brown silken nest, which they enlarge as the colony grows (Fig. 39). During heavy infestations, entire trees may be covered with nests (Fig. 40). This insect has from one to four generations per year but damage and nests are most conspicuous from August to September (Douce 1997). During some years, damage is heavy enough for both defoliation and tents to be visible from the air.

The larval colonies of the ugly nest caterpillar, *Archips cerasivorana* (Lepidoptera: Tortricidae), spin dense webs around feeding sites, which become filled with pieces of leaves and frass. Host plants include cherry, rose, *Rosa* spp. and hawthorn. Eggs hatch in May and June and the larvae feed until August. Tents and defoliation are most conspicuous in July and August (Minnesota DNR 1997).

Walkingsticks

Several species of walkingsticks, (Phasmatodea: Heteronemiidae), including *Diapheromera femorata* in the eastern US and *Megaphasma dentricus* in Texas, occasionally reach epidemic levels and cause aerially visible defoliation. These insects feed on a wide range of broadleaf species (northern red and black oaks, post oak, basswood, black locust, cherry and others). Both the nymphs and adults feed and the adults cause most of the damage, which usually peaks in late August/early September (Fig. 41).

Mortality

Conifers

Bark Beetles

Bark beetles (Coleoptera: Curculionidae: Scolytinae) are among the most damaging insect pests of conifer forests throughout North America. The adults attack the boles of host trees en masse, construct galleries in the cambium layer, deposit eggs, and in the process introduce blue-stain fungi. The larvae feed in the cambium and pupate. The adults emerge, migrate to, and attack other trees. Infested trees are killed.

Southern Pine Beetle

Pine forests in the South are subject to periodic outbreaks of the southern pine beetle, *Dendroctonus frontalis*. This insect is considered one of the most destructive pests of southern pine forests and, depending on location, can complete from three to seven generations per year. Southern pine beetle can attack all pines within its natural range but prefers loblolly, shortleaf, Virginia, pond and pitch pines (Thatcher and Barry 1982). Periodic aerial surveys are the principal means for detecting infestations and are a required first step in suppression operations for this pest (Billings and Ward 1984).

The classic aerial signature of damage by southern pine beetle is the occurrence of distinct groups of dead and dying trees, known as "spots." Multiple, overlapping generations of beetles commonly occur in a single, multiple-tree spot. Therefore, the color of fading trees in an active southern pine beetle spot ranges from pale green to yellow, yellow orange, red and red-brown (Fig. 42). The most recently attacked trees, and those likely to contain late brood stages, are pale green to yellow, except during winter months. There is also a high probability of additional infested green trees beyond the area wherein dead and dying trees are visible. Relatively small spots, those with <100 trees, typically have a single active "head" indicated by the presence of pale green and yellow crowns (Fig. 43) (Billings 1979).

Sometimes, southern pine beetle infestations become exceptionally large, with a large number of multiple-tree spots in both natural stands and plantations (Fig. 44). Large spots can have either single- or multiple-active heads (Figs. 45–48). Usually, spots with only red or red-brown trees are inactive and no longer contain trees with beetle broods. The pattern and color of tree fading does not vary by species of pine attacked.

Southern pine beetle spots are visible throughout the year. Due to hardwood foliage discoloration, aerial detection in mixed pine-hardwood stands is more difficult in the early spring and the fall. Also, during the winter infested trees tend to drop green needles and seldom exhibit the yellow foliage characteristic of trees infested in warm months. (A detailed guide to the recognition of aerial signatures of southern pine beetle infestations under a variety of conditions and times of year is available [Billings and Doggett 1980]).

Ips *Engraver Beetles*

Another group of bark beetles that attack and kill pines in the eastern U.S is the *Ips* engraver beetles. Three species, *Ips avulsus, I. grandicollis* and *I. calligraphus,* can cause small- to medium-sized group kills or spots in southern yellow pine forests. These insects are often associated with southern pine beetle, but can by themselves attack and kill trees. The pine engraver beetle, *Ips pini*, attacks both pine and spruce in the northern states.

Usually, infestations of *Ips* engraver beetles are in the range of 10 to 50 trees (Fig. 49). However, and especially during periods of dry weather, they can become larger and appear similar to southern pine beetle spots. Under these conditions, ground checks are required to determine the cause of tree death (Fig. 50). A scattering of single tree faders infested by *Ips* engraver beetles also can occur, especially in young pine stands (Figs. 51, 52).

Typically, *Ips* engraver beetles make their initial attacks in fresh down material, such as logging slash, freshly cut logs, pulpwood or windthrow, and later attack standing trees. Therefore, the occurrence of dead or dying pines near pulpwood decks at railroad sidings, or in the immediate vicinity of wood processing plants, is a clue that tree mortality may have been caused by *Ips* rather than southern pine beetle (Fig. 53).

Both *Ips avulsus* and *I. pini* can limit their attacks to the upper crown (see Top Kill, page 22).

Spruce Beetle

Spruce beetle, *Dendroctonus rufipennis*, is the most destructive bark-beetle pest of spruce forests in North America. This insect occurs throughout the range of spruce in North America. In the northeastern and north central states, red, white and black spruce can be attacked.

The aerial signature of spruce beetle attack is the most difficult to detect of the conifer-infesting bark beetles. As a rule, the needles of trees infested by spruce beetle do not fade until the second summer following attack, at which time they turn to a pale yellow-green or straw color, progressing to dull gray-brown as the needles drop. The needles on different branches of the same tree can discolor at different times. Dry needles are washed from fading trees by rains, leaving the upper crowns of exposed twigs with a yellow-orange or reddish hue (Holsten et al. 1989). Typically, damage occurs on large mature trees; during major outbreaks, the only surviving spruces are small-diameter, trees.

Eastern Larch Beetle

Eastern larch is subject to attack by eastern larch beetle, *Dendroctonus simplex*. Major outbreaks of this insect can kill thousands of larches. It has one generation per year. Adults emerge between April and June from trees infested the previous year and attack new trees. As with the southern pine beetle, adult eastern larch beetles are able to attack and produce brood in more than one tree (Seybold et al. 2002). In the eastern US, outbreaks have occurred in Maine, Michigan, Minnesota and Vermont.

The aerial signature of eastern larch beetle infestation is groups of dying larch with foliage fading initially to yellow and then light red-brown. Almost always, there are trees in several stages of fading present in the same stand; some with yellow foliage, some with red-brown foliage intermixed with older dead trees (Figs. 54, 55). Fading usually begins one year after attack.

Sucking Insects

Balsam Woolly Adelgid

Balsam woolly adelgid, *Adelges piceae* (Homoptera: Adelgidae), is an exotic species that infests both the main stem and branches of true firs (Fig. 56) and is established in fir forests in both the eastern and western US (Ragenovich and Mitchell 2006).

Attacks on the main stem cause tree mortality, which is aerially visible as a scattering of dead and dying trees. Dying firs fade to a bright, red-orange throughout the year and there is no peak period of tree fading. This was the predominant pattern of damage during the 1950s–1970s, when the insect first appeared in high elevation forests of Fraser fir in the Southern Appalachian Mountains and caused extensive tree mortality (Fig. 57). New stands of Fraser fir have developed in the aftermath of the heavy tree mortality (Fig. 58). In the Southern Appalachian Mountains, infested Fraser fir trees sometimes fade upward from the lower crown (Lambert and Ciesla 1966) (Fig. 59L).

Attacks on the branches cause a swelling and deformity called "gout." This type of attack is more common on younger trees and can result in a slow decline, characterized by a drooping of branches, and eventual tree death (Fig. 59R). Fir mortality caused by balsam woolly adelgid may be a factor that triggers wave-like areas of mortality in the Southern Appalachian Mountains (see Fir Waves, page 26).

Hemlock Woolly Adelgid

Native to Asia, hemlock woolly adelgid, *Adelges tsugae* (Homoptera: Adelgidae), has become established over much of the range of both eastern and Carolina hemlocks, *Tsuga caroliniensis*. This insect infests branches at the base of the needles (Fig. 60L). Feeding retards tree growth and causes the needles to turn from dark green to gray or brown and drop prematurely (Fig. 60R). Loss of new shoots and needles eventually leads to tree death (USDA Forest Service 2005b). The aerial signature of hemlock woolly adelgid infestation is thin crowns that are light green, brown or grey (Figs. 61–63). This signature is visible throughout the year but is most conspicuous when broadleaf trees are in full leaf, providing a green contrast to the dead and dying hemlocks.

Red Pine Scale

Red pine scale, *Matsucoccus resinosae* (Homoptera: Margarodidae), is considered the most destructive insect pest of red pine in the Northeast. Infestations are known to occur in Connecticut, Massachusetts, southeastern New York, New Jersey, Rhode Island and Pennsylvania. The scales occur on the branches and feeding damage, in combination with fungi and drought, ultimately causes tree death (Drooz 1985, USDA Forest Service 2000).

The aerial signature of infestation by red pine scale is trees with foliage turning from green to olive green, then to yellow and red. Mortality usually occurs in groups of trees (Fig. 64).

Woodwasp

The woodwasp, *Sirex noctilio* (Hymenoptera: Siricidae), is native to Eurasia and northern Africa. It is established in portions of New Zealand, Australia, South America and South Africa, where it has caused extensive tree mortality in exotic pine plantations (Ciesla 2003). A single adult was collected in a trap in Oswego Co, NY in 2004 (Hoebeke et al. 2005) and follow-up surveys indicate that this insect is now established in western New York and adjoining portions of Canada.

The aerial signature of *S. noctilio* infestations is scattered dead and dying trees in pine forests or plantations. The dead or dying trees do not occur in distinct groups or spots, as is the case with most bark beetle attacks (Fig. 65). This signature is visible throughout the year.

Fir Waves

Fir waves are alternating bands of dead balsam fir, found in high elevation forests of Maine, New Hampshire, New York, and Vermont. (Similar bands of mortality have been observed in Fraser fir forests in the Black Mountains of North Carolina.) They develop following high winds. When a tree dies and falls, a gap is formed in the canopy. This exposes trees at the leeward edge of the gap to greater wind. These trees are likely to die from damage and desiccation, gradually expanding the gap. At the same time, yougn fir trees become established in the leeward edge of the windward portion of the gap, protected from the high winds by the surviving trees. The combination of dying trees at the leeward edge and regenerating trees at the windward edge results in the occurrence of "waves" in the direction of predominant, prevailing wind (Sprugel 1976). The aerial signature of fir waves is distinct bands or waves of mortality in pure or nearly pure, high-elevation fir forests (Figs. 66, 67).

Root Diseases

Root diseases, such as that caused by the fungus *Heterobasidium annosum*, infect and kill pines in distinct centers much in the way that bark beetles kill trees. However, the action of root disease is much slower, so the aerial signature of root disease is more complex, comprised of small groups of dead trees, openings in a stand, and an occasional fader (Fig. 68). This signature is most apparent in even-aged pine plantations. While root disease centers sometimes can be seen on large-scale aerial photographs, they are difficult to detect and not normally mapped from low flying aircraft (Ciesla 2000).

Red Pine Pocket Mortality

This condition is reported from 30 to 40 year old red pine plantations in southern and west central Wisconsin and from the lower peninsula of Michigan. One tree or a small group of trees die followed by mortality of adjacent trees. The pockets of tree mortality are typically circular and can expand up to 0.3 acre per year. Sometimes, bark beetles and root collar weevils are associated with the mortality, but the actual cause(s) is still unknown. Affected trees have reduced leader and branch-tip growth, loss of older needles, and fading foliage (Cummings 1985).

The aerial signature of red pine pocket mortality is distinct groups of dead trees, some with fading foliage, and an advancing edge of trees with light green foliage. Broadleaf trees and shrubs often fill in the centers of the pockets of dead red pines (Figs. 69, 70).

Broadleaf Trees

Oak Wilt

Oak wilt, caused by the fungus *Ceratocystis fagacearum*, is a vascular disease that kills oaks, and has been found in 21 states from Pennsylvania south to North Carolina and west to Minnesota and central Texas.

Oaks of the red oak group are most often affected and symptoms can occur as early as May. The leaves turn dull green or bronze, appear water-soaked, wilt, and then turn yellow or brown. Damage occurs from the tip and outer edges toward the midrib and base. Wilting leaves typically curl around the midrib. These symptoms quickly appear throughout the crown, often within a few weeks, and leaves at the ends of branches are shed. Heavy defoliation accompanies leaf wilting and discoloration. Leaves fall in all stages of discoloration. Even entirely green leaves may fall from affected branches. Some affected branches hold green leaves longer than others, sometimes until autumn. Therefore, the crowns of trees with oak wilt are seldom as uniformly brown as those of non-diseased trees that have been poisoned, girdled, or killed by lightning. In dry years, the appearance of trees with oak wilt may be confused with that of trees with drought symptoms. The disease progresses rapidly in red oaks. All trees die within a year, and most trees die within 1 or 2 months after the onset of symptoms. Symptom progression on white oaks is slower (Rexrode and Brown 1983).

The aerial signature of oak wilt is groups of oaks with various stages of discoloration, defoliation, and trees with bare crowns. In the eastern states (North Carolina, Pennsylvania, Tennessee, Virginia and West Virginia), oak wilt generally occurs in single trees or groups of 2 to 3 trees. In the Midwest, groups of 100 or more infected trees are common (Figs. 71, 72).

In central Texas, oak wilt is at epidemic proportions and thousands of trees are killed each year. A variety of oak species are affected but the live oaks, *Quercus virginiana* and *Q. fusiformis*, are most seriously affected, because they grow from root sprouts and form vast interconnected root systems, thus facilitating the spread of the fungus (Appel et al 2005). The aerial signature of oak wilt in central Texas is small to large groups of dead and dying oaks. In some cases, entire stands of live oaks are affected (Figs. 73–75). Infected red oaks tend to be scattered, individual trees, visible during mid- to late summer as trees with fading or red crowns, particularly on ridges and slopes of the central Texas Hill Country. In central Texas, detection surveys for oak-wilt are generally flown in June, July or August.

Laurel Wilt Disease

Large numbers of red bay, *Persea borbonia*, a tree indigenous to the coastal regions from Virginia to Texas, are dying due to a combination of an ambrosia beetle, *Xyleborus glabratus* (Coleoptera: Curculioidae: Scolytinae) and a vascular fungus, *Raffaela* sp. Both the insect and the fungus are native to Asia. The beetle was first discovered in 2002 near Savannah, GA. By late 2003, the beetle was being found in the dying trees in coastal Georgia and South Carolina, and is now known in northeastern Florida (Johnson et al. 2007). Sassafras, *Sassafras albidum*, and several other plants in the family Lauraceae are also affected.

The signature of laurel wilt disease is understory vegetation (trees and shrubs) with deep red to red-brown foliage. The signature is most evident during the growing season, when the foliage should be green (Fig. 76). The red foliage tends to remain on infected trees after leaf fall. Since the host trees are in the understory, they may be difficult to see from aerial flying heights, during summer. Aerial surveys for this condition may be most effective during the leaf-off months, because the affected trees tend to retain their red-brown foliage; however, it may be difficult to distinguish the dying red bay from oaks, because they tend to retain their dry foliage well into the winter.

Agents affecting both Conifers and Broadleaf Trees

Wildfire

Damage caused by large catastrophic wildfires is easy to identify and consists of extensive areas of dead trees with scorched foliage, blackened stems and blackened ground vegetation. Damage caused by low intensity ground fires or prescribed fires in pine forests sometimes resembles damage caused by bark beetles. A good indication that fire has caused the damage is the occurrence of trees with fading foliage in the lower crowns and the presence of green foliage in the upper crowns. Black scorch marks are sometimes visible on the lower bole, or in open patches of ground vegetation or soil (Figs. 77–83).

Drought

Prolonged drought during the growing season can cause a variety of symptoms in trees, some of which are aerially visible. In deciduous trees, curling, bending, rolling, mottling, marginal browning (scorching), chlorosis, shedding, and early autumn coloration of leaves are well-known responses to drought. In conifers, drought may cause needle tips to turn yellow or brown. As drought intensifies, its effects may be expressed in dieback of twigs and branches in tree crowns and tree mortality.

The first symptom of drought stress is wilting leaves. Precipitation will relieve the symptoms in the early stages of wilting. However if the drought persists, wilting becomes permanent, followed by drying and browning (Fig. 84). Some broadleaf trees, such as black cherry, dogwood, birch and basswood, wilt more readily than other species. Another symptom of drought stress is leaf shedding. Typically, yellow poplar, *Liriodendron tulipifera,* sycamore and buckeye shed leaves during prolonged drought, resulting in thin or bare crowns (Coder 1999).

Drought stress can incite dieback and decline or promote outbreaks of bark beetles in conifer forests. Typically, drought affects trees of all ages and sizes on a site and is commonly observed on the western fringe of the southern pine zone in Texas and Oklahoma (Figs. 85, 86). In mountainous or hilly terrain, drought symptoms are often most severe on ridge-tops and around exposed rocks.

Inundation

The damage signature of inundation, dead and dying trees in standing water, is one of the easiest to recognize from aerial surveys. A frequently encountered form of inundation is stream water backed up on the upstream side of a road or highway, caused by plugged or an insufficient number of culverts. The water builds up behind the culverts, creates a small pond, and floods the standing trees (Fig. 87).

Saltwater inundation occurs near coastal areas and can be the result of storm surges associated with heavy storms or hurricanes. Tree damage and mortality are the result of a combination of inundation by rising sea levels and salt spray produced by high winds. During severe events several thousands of acres of coastal forests may be affected.

Beavers, *Castor canadensis*, kill trees in riparian areas by girdling them and constructing dams, thereby inundating trees adjacent to streams. The aerial signature of beaver damage is the presence of dead trees standing in a recently constructed beaver pond. In open areas, the beaver dam may be visible from aerial survey flying heights (Fig. 88).

Discoloration

Several additional damage types, other than defoliation or tree mortality, can be recognized during aerial surveys. While not all of these secondary signatures may be recorded (mapped) during aerial forest health surveys, it is important that observers be able to recognize and distinguish them from the signatures of insect and disease damage.

Needle and Leaf Miners

Defoliating insects mine the interior of the foliage but do not remove the foliage. The damaged foliage remains on the tree and becomes discolored, changing from green to yellow, red-brown or brown (Fig. 89). Several species of needle and leaf miners are capable of causing extensive damage visible during aerial surveys.

The larch case bearer, *Coleophora laricella* (Lepidoptera: Coleophoridae), is native to Europe, and was first detected in Massachusetts in 1886. It now occurs throughout the range of eastern larch in North America (Drooz 1985). This insect overwinters as a half-grown larva enclosed in a hollowed-out larch needle still attached to a branch. Mining begins as soon as the new needles appear in spring. From the air, damage caused by larch casebearer first appears in spring in the crown, where the foliage first changes from green to yellow, then to tan, yellow-orange or orange-brown later in the summer. Peak damage usually occurs in June.

The larvae of an arborvitae leaf miner, *Agryresthia thuiella* (Lepidoptera: Yponomeutidae), feed within the scale-like leaves of northern white cedar. The mined foliage turns from green to yellow and brown. Heavy infestations are visible during aerial surveys and appear as areas of brown discoloration, especially in the upper crowns of trees. This insect has one generation per year and peak damage occurs in late summer.

A locust leaf miner, *Odontota dorsalis* (Coleoptera: Chrysomelidae), occurs throughout the eastern US. Its favorite host is black locust but also it is known to feed on other broadleaf species. The larvae mine inside the leaves and the adults are skeletonizers (Fig. 90). Outbreaks occur almost every year and the aerial signature of damage is a brown or red-brown discoloration of the foliage (Figs. 91, 92). Peak damage appears from late July until leaf fall.

Several introduced species of leaf-mining sawflies, including *Fenusa pusilla* (Hymenoptera: Tenthredinidae) and *Mesa nana* (Hymenoptera Tiphiidae), feed on various species of birches. Leaves damaged by the leaf-mining larvae wrinkle and turn brown. Outbreaks can occur over large areas of gray and paper birch forests in the Northeast and cause browning over large areas. *Fenusa pusilla* has 3 to 4 generations per year (Drooz 1985).

Needle Cast Fungi

Needle casts caused by fungi of the genera *Lophodermium* and *Hypoderma* produce a yellow to red-brown discoloration of loblolly, longleaf, shortleaf, slash, Virginia and eastern white pines (Enebak and Flynn 1997). Under the right conditions, infections can be widespread, resulting in a scattering of pines with red-brown discolored foliage. The aerial signature of needle cast infection sometimes mimics faders caused by bark beetle attack; however, pines infected by needle cast fungi will have some green foliage, mostly in the upper crown. Pine needle cast can be seen from operational flying heights. In the south Atlantic and Gulf Coast regions, symptoms of pine needle cast can be seen as early as February.

Chlorosis

Chlorosis is a condition in which the foliage produces insufficient chlorphyll, causing it to turn from green to pale green, yellow, or yellow-white. Soil nutrient deficiencies of iron, magnesium or nitrogen, often aggravated by high soil pH and/or drought, are the usual causes of chlorosis. Occasionally, entire stands are affected and can be seen from aerial flying heights (Fig. 93).

Hail Damage

Hail storms, especially those that produce large hailstones, can tear and kill foliage and wound or break branches of both conifers and broadleaf trees. From the air, hail damage usually appears as a brown discoloration of the foliage, which can mimic the damage signatures of defoliating insects or foliar fungi.

Herbicide/Chemical Injury

Various types of chemical injury can cause foliar discoloration and/or tree death, some of which is visible from the air. One of the most common aerial signatures of chemical injury is the presence of discolored trees of a variety of species immediately adjacent to roads, pipelines, or utility rights-of-way. This may be due to herbicides or de-icing chemicals (salts) used during the winter.

Heavy Cone and Seed Crops

Heavy cone crops, especially in spruce and fir,, can cause the crowns to have a brown (spruce) or grey (fir) discoloration and some thinning of the foliage. Heavy cone crops on northern white cedar or in some broadleaf species can cause a brownish cast over the entire crown (Fig. 10). Discoloration associated with heavy cone and seed crops can mimic defoliation or leaf mining by insects.

Dieback

“Dieback,” or “decline,” is a collective term that refers to a group of diseases caused by several interacting factors (Manion 1991), resulting in the presence of dead and dying branches in the crown of a tree. The symptoms are progressive and include branch dieback, foliage thinning, chlorosis, smaller than normal foliage, premature fall coloring on broadleaf trees, occasional heavy seed crops and tree mortality (Fig. 94). Regardless of species involved, the aerial signatures of dieback are similar and require ground checking to determine the specific causes.

Oak Decline

Oak decline is one of the most common declines and diebacks found in the eastern U.S., and is present throughout the range of oaks in both forests and urban situations. Symptoms include a progressive dieback from the branch tips back, production of dwarfed and sparse foliage, sprouts, and premature autumn leaf color and leaf drop. Many affected trees ultimately die. Trees are often predisposed to oak decline by a root fungus of the genus *Armillaria* that weakens trees. Drought and outbreaks of defoliating insects can incite the decline. Attacks by secondary insects, such as the two-lined chestnut borer, *Agrilus bilineatus* (Coleoptera: Bupresitdae), or the red oak borer, *Elaphalodes rufulus* (Coleoptera: Cerambycidae), kill weakened trees (Wargo et al 1983).

The aerial signature of oak decline ranges from small groups to entire stands of trees with discolored foliage, dead branches and/or dead trees (Figs. 95–97).

Emerald Ash Borer

Emerald ash borer, *Agrilus planipennis* (Coleoptera: Buprestidae), is an exotic beetle that was discovered in southeastern Michigan near Detroit in the summer of 2002. This insect has killed millions of ash trees and is now established in portions of Illinois, Indiana, Michigan, Ohio, western Pennsylvania and portions of Canada. The adult beetles nibble on ash foliage but cause little damage. The larvae feed on the cambium layer of ash, disrupting the tree's ability to transport water and nutrients.

Dieback is the initial symptom of emerald ash borer infestation, and usually begins in the upper third of the crown and progresses until the tree dies. Infested trees often produce copious epicormic sprouts before they die (Wilson and Rebek 2005). In mixed broadleaf forests, this will appear as a scattering of trees with symptoms. The aerial signature of emerald ash borer infestation is identical to that of ash dieback (see Ash Dieback, below) and the two can only be distinguished through ground checks.

Ash Dieback

This progressive dieback of ash in the Northeast and north central states is caused by a number of factors, including drought. Ash yellows, a specific form of ash dieback, is caused by a mycoplasma-like organism (MLO). Symptoms of ash dieback include chlorotic foliage, crown dieback, epicormic sprouts, and witches brooms (Solomon et al. 1993). The aerial signature consists of dieback and dead trees and is similar to that of the emerald ash borer.

Beech Bark Disease

Caused by a combination of an exotic scale insect, *Cryptococcus fagisuga*, (Hemiptera: Eriococcidae), (Fig. 98L) and a fungus, *Nectria coccinea* var. *faginata* or *Nectria galligena*, beech bark disease is a major cause of decline, dieback and mortality of American beech (Houston and O'Brien 1983). This disease is widespread in the Northeast and infestations also occur in Michigan, North Carolina, Tennessee, Virginia and West Virginia.

In the early stages of an infestation the aerial signature of beech bark disease is a scattering of trees with bright or lemon-yellow foliage, thin crowns, dieback and tree mortality (Fig. 98R, Fig. 99). As the infestation progresses, dieback and tree mortality become the dominant components of the signature.

Other Diebacks

Several other diebacks or declines can produce similar symptoms and aerial signatures. Birch dieback emerged as a major problem between 1930 and 1950 and affected yellow and paper birches in eastern Canada and the northeastern United States and is still a potential problem. Maple decline affects sugar maple and may be the result of a number of factors including drought, insect defoliation, weak pathogens and secondary insects (Manion 1991).

Top Kill

Top kill is a term used when the upper quarter, third or half the tree has been killed and the affected portion of the tree's foliage fades or turns red. This damage type is most commonly associated with two species of *Ips* engraver beetles: the pine engraver beetle, *Ips pini*, that attacks pines in the North, and the four-spined engraver *I. avulsus,* in the South (Fig. 100). Top kill is difficult to see at operational flying heights. Moreover, top kill often occurs in trees at the edges of larger bark beetle spots where entire trees have been killed.

In eastern white pine forests, top kill could be the result of either attacks by *Ips* engraver beetle, or infection by white pine blister rust, caused by the fungus *Cronartium ribicola.*

Branch Breakage/Main Stem Broken or Uprooted

Mechanical breakage of trees is usually the result of catastrophic climatic events such as ice storms, hurricanes, straight-line winds (microbursts) or tornadoes. Areas where forest are flattened are highly visible. Another eye-catching symptom is exposed white wood from broken main stems and branches. Where blowdown has occurred, tipped-up root balls may be visible from the air, especially in wet areas (Fig. 101). However, broken foliated branches may be difficult to detect in hardwood stands and forests. High winds can defoliate broadleaf trees, thereby making the signature more visible. The foliage of uprooted and broken conifers fades within several days, making that signature more visible, too (Fig. 102). Remote sensing techniques for rapid assessment of forest damage caused by windstorms and other catastrophic climatic events have been developed (Ciesla et al. 2001).

Snow and Ice Storms

Wet snow and ice deposited on tree branches and stems can cause crown breakage and bending and broken stems. Snow damage can be especially damaging in early fall, when deciduous broadleaf trees are still leafed out. Ice storms, such as the event that occurred in the Northeast in January 1998, can damage millions of acres of forests. Birches are particularly vulnerable to bending, which is easily seen from the air (USDA Forest Service 1998).

Cyclonic Winds

Cyclonic winds such as those associated with hurricanes, typhoons, tropical storms, and tornadoes cause a twisting action, which can break crowns and stems in mature trees, and uproot, bend or break young trees. Within a given stand, trees generally fall in a single direction. However, over the landscape, a cyclonic pattern of windthrow is apparent. Hurricanes, such as Camille in 1969, Hugo in 1989 and Katrina and Rita in 2005, caused extensive damage to forests in the Atlantic and Gulf Coastal states (Fig. 102). Tornado damage tends to be more localized and trees may be laid down in several directions along a relatively narrow path (Fig. 103).

Straight-line Winds

Straight-line winds, or "microbursts," associated with low-pressure cells can cause widespread damage to forests. The storm of July 1999, which blew down over 500,000 acres in the Superior National Forest in northern Minnesota, is an example of a straight-line wind event (Fig. 104). Windthrow and bent trees caused by straight-line winds are generally deposited in a single direction (Figs. 105, 106).

Branch Flagging

Several agents damage individual branches on trees and cause branch flagging. This signature is often difficult to see from aerial survey flying heights, especially in closed forests and when the flagging occurs in mid or lower crown. Agents that cause branch flagging also can cause top-kill and tree mortality.

Diplodia Blight of Pines

This disease, caused by the fungus *Diplodia pinea*, kills current-year shoots and major branches of pines. It has a worldwide distribution and in the Northeast and north central states, it damages pines growing as ornamentals or in windbreak plantations. Initial infection usually begins in the lower crown (Peterson 1981). The aerial signature is branches with red-brown foliage.

White Pine Blister Rust

Caused by *Cronartium ribicola*, a fungus of Asian origin, white pine blister rust infects all species of five-needled (white) pines. Damage caused by white pine blister rust includes branch flagging, top kill, and total tree mortality in eastern white pines. Mortality generally occurs only on scattered trees in a stand (Fig. 107).

Porcupine Damage

Porcupines, *Erethizon dorsatum,* feed on the bark of many species of conifers. Feeding injury can girdle branches, resulting in branch flagging. Porcupines tend to select individual trees on which to feed, causing multiple branch flagging and sometimes the death of young trees. Damage is more prevalent during dry years.

Periodical Cicada

The periodical cicada, *Magicicada septendecum* (Hemiptera: Cicadidae), has a 17-year life cycle except in the South, where it has a 13-year cycle. The females create wounds in the branches of more than 70 broadleaf trees and other woody plants and lay eggs inside the wound. These branches die in mid-summer during brood years, resulting in widespread, aerially visible branch flagging.

4. Conclusions

Many types of damage caused by forest insects, diseases and other damaging agents are highly visible to aerial observers and can be mapped using various remote sensing technologies. The most commonly used technique for detection and assessment of damage caused by forest insects and diseases is aerial sketchmapping. The characteristics or signatures of the damage mapped during aerial surveys can help identify causal agent(s) responsible for the damage. These signatures are a combination of the characteristics of the host trees affected and the pattern of damage.

The information presented in this guide is intended to assist aerial observers in the identification of the more common causal agents responsible for forest damage mapped during aerial sketchmap surveys in the eastern U.S. While some aerial signatures of damage are sufficiently unique to permit reliable identification of causal agents, others are more difficult to diagnose. In some cases data from previous surveys and historical records of the damaging agents in a given area can be used in combination with the aerial signatures to help identify the causal agents. In other cases, positive identification of the causal agent(s) can only be accomplished through supplemental ground checks. Factors such as available time and limited access to remote forest areas often constrain the amount of ground checking done during aerial forest health surveys. Ultimately, some ground checking, especially if new or unfamiliar damage signatures are detected, should be an integral part of these surveys.

Table 1. Crown characteristics of commonly occurring conifers in the northeastern and north-central United States as seen from low flying aircraft or on large-scale color vertical aerial photos.*

Species or species group	Foliage color	Crown form	Crown margin	Branch pattern	Foliage texture
Eastern white pine	Blue green	Broadly rounded	Lobed	Distinct	Fine
Red pine	Dark green	Narrowly rounded	Finely serrate	Indistinct	Clumped
Jack pine	Medium green	Rounded to broadly rounded	Slightly lobed -serrate	Distinct	Fine
Pitch pine	Medium–dark green	Rounded	Serrate	Distinct	Clumped
Red Spruce	Dark green	Acute	Slightly lobed -serrate	Layered	Fine–medium
White spruce	Gray green	Acute	Slightly lobed -serrate	Layered	Fine–medium

* Based on data from Ciesla 1984, Heller et al. 1964 and Sayn Wittgenstein 1978.

Table 1, *continued*. Crown characteristics of commonly occurring conifers in the northeastern and north-central United States as seen from low flying aircraft or on large-scale color vertical aerial photos.*

Species or species group	Foliage color	Crown form	Crown margin	Branch pattern	Foliage texture
Black spruce	Dark gray-green	Acute	Slightly lobed-serrate	Layered	Fine–medium
Balsam fir	Dark green	Acuminate**	Finely serrate	Indistinct	Fine
Hemlock	Dark green	Acute	Sinnuate	Indistinct	Fine
Eastern larch	Light green	Acute to narrowly rounded	Finely serrate	Indistinct	Fine
Northern white cedar	Yellow green	Rounded	Finely serrate	Indistinct	Fine
Eastern red cedar	Dark green	Rounded	Finely serrate	Indistinct	Fine

*On level terrain only, crown form is acute in high elevation forests subject to high winds.

Table 2. Examples of pine sawflies that can cause aerially visible damage in the eastern United States*

Common name	Scientific name	Pine hosts	Number of generations	Occurrence of peak damage	States outbreaks
Introduced pine sawfly	*Diprion similis*	Eastern white, Scotch, jack, red	2-3	May–September	NC, TN, VA
Blackheaded pine sawfly	*N. exitans*	Loblolly, shortleaf	3-4	Late summer/fall	FL, NC, MS, TX
Redheaded pine sawfly	*N. lecontei*	Jack, loblolly, pitch, red, short-leaf	1-3	Variable	Throughout the eastern US
Loblolly pine sawfly (Arkansas pine sawfly)	*N. taedae linearis*	Loblolly, shortleaf	1	May–early June	AR, LA, TN
Virginia pine sawfly	*N. pratti pratti*	Shortleaf, Virginia	1	May	MD, VA, NC
Hetrick's sawfly	*N. hetricki*	Loblolly, longleaf, Ponderosa	1	May–July	FL, GA, SC, VA

*Includes outbreaks reported in USDA Forest Service, *Insect Conditions in the United States – 1998-2004*. Other sources of information include Drooz 1885 and USDA Forest Service 1998.

Table 3. Loopers and inchworms (Lepidoptera: Geometridae) that can cause aerially visible damage of broadleaf forests in the eastern United States.*

Common name	Scientific name	Hosts	States where outbreaks have occurred
Bruce spanworm	*Operophtera bruceata*	Beech, sugar maple	ME, NH, NY, PA, VT
Cherry scallop moth	*Hydria prunivorata*	Black cherry, beech	GA, MI, NH, NY, OH, PA, VT, WV
Fall cankerworm	*Alsophila pometaria*	Maples, oaks, other broadleaf trees	KY, MA, MD, ME, NC, PA, TN. TX, VA, WV
Elm spanworm	*Ennomus subsignarius*	Hickory, oak, red maple and other broadleaf trees	GA, KY, MA, NC, NY, PA, SC, TN,
Half-winged geometer	*Phigalia titea*	Oaks, hickories, red maple	IN, OH, VA, WV
Linden looper	*Erranis tiliaria*	Basswood, elm, hickory, maple, oak, birch	NC, VA
Spring cankerworm	*Paleacrita vernata*	Apple, elm, other broadleaf trees	Usually associated with fall cankerworm and other loopers.

*Includes outbreaks reported in USDA Forest Service *Insect Conditions in the United States – 1998–2004*. Other sources of information include Ciesla (1964), Drooz (1985) and USDA Forest Service (1998).

Table 4. Some late summer/early fall defoliators that can cause aerially visible damage of broadleaf forests in the eastern United States.*

Common name	Scientific name	Hosts	States where outbreaks have occurred
Orange-stripped oakworm	*Anisota senatoria*	Oaks	CT, MD, NC, NJ, NY, PA, RI, TN, TX, WV
Pink-stripped oakworm	*Anisota virginiensis*	Oaks	CT, MD, NC, NJ, NY, PA, RI, TN, TX, WV
Saddled prominent	*Heterocampa guttivita*	Beech, sugar maple, yellow birch, paper birch	MA, ME, NH, NY, PA, VT, WI
Spiny oakworm	*Anisota stigma*	Oaks	CT, MD, NC, NJ, NY, PA, RI, TN, TX, WV

*Includes outbreaks reported in USDA Forest Service *Insect Conditions in the United States – 1998–2004*. Other sources of information include Drooz (1985), Rush and Allen (1987) and USDA Forest Service (1989).

Table 4, *continued*. Some late summer/early fall defoliators that can cause aerially visible damage of broadleaf forests in the eastern United States.*

Common name	Scientific name	Hosts	States where outbreaks have occurred
Yellow-necked caterpillar	*Datana ministria*	Oaks	CT, MD, NC, NJ, NY, PA, RI, TN, TX, WV
Variable oak leaf caterpillar	*Lochmeaus manteo*	Beech, Oaks	FL, MD, NJ, PA
Orange-humped mapleworm	*Symmerista leucitys*	Sugar maple	MI
Walkingstick	*Diapheromera femorata*	Red oak, black oak, basswood, black locust, cherry	AR, OK

*Includes outbreaks reported in USDA Forest Service, *Insect Conditions in the United States – 1998–2004*. Other sources of information include Drooz (1985), Rush and Allen (1987) and USDA Forest Service (1989).

Table 5. Commonly encountered, aerially visible forest-insect and disease damage by host type (conifers) and damage class in the eastern United States.

Host Type	Damage Class*					
	Defoliation	Mortality	Discoloration	Dieback	Top kill	Branch flagging
White pine	Introduced pine sawfly	White pine blister rust	Needle cast fungi	White pine blister rust	White pine blister rust	White pine blister rust
Red pine, jack pine	Jack pine budworm	Pine engraver beetle, red pine scale, root diseases, red pine pocket mortality			Pine engraver beetle	Diplodia blight of pines
Spruce, fir	Spruce budworm, hemlock looper, yellow-headed spruce sawfly	Spruce beetle, balsam woolly adelgid				
Northern white cedar			Arborvitae leaf miner			

*Damage classes, such as "branch breakage" and "mainstem broken or uprooted," caused by storm events can occur in all host types.

Table 5, *continued*. Commonly encountered aerially visible forest-insect and disease damage by host type (conifers) and damage class in the eastern United States.

Host Type	Damage Class*					
	Defoliation	Mortality	Discoloration	Dieback	Top kill	Branch flagging
Hemlock	Hemlock looper	Hemlock woolly adelgid				
Longleaf pine, slash pine	Pine sawflies (several species)	Southern pine beetle, *Ips* engraver beetles, root diseases, Laurel wilt disease				
Loblolly pine, shortleaf pine	Pine sawfilies (several species)	Southern pine beetle, *Ips* engraver beetles (generally <50) tree spots, root diseases	Needle cast fungi		*Ips* engraver beetle, *Ips avulsus*	

* Damage classes, such as "branch breakage" and "mainstem broken or uprooted," caused by storm events can occur in all host types.

Table 6. Commonly encountered aerially visible forest-insect and disease damage by host type (broadleef species and baldcypress) and damage class in the eastern United States.

Host Type	Damage Class*					
	Defoliation (spring/early summer)	Defoliation (mid/late summer)	Mortality	Discoloration	Dieback	Branch flagging
Oak, hickory	Gypsy moth, forest tent caterpillar, oak leaf tier, loopers	Oak skeletonizer, oak worms (several species), walkingsticks	Oak wilt		Oak decline	Periodical cicada
Oak, gum, baldcypress	Tatters, a baldcypress leaf roller, a baldcypress looper, forest tent caterpillar		Laurel wilt disease			
Elm, ash, cottonwood	Forest tent caterpillar	Emerald ash borer			Ash dieback, emerald ash borer	

* Damage classes, such as "branch breakage" and "mainstem broken or uprooted," caused by storm events can occur in all host types.

Table 6, *continued*. Commonly encountered aerially visible forest-insect and disease damage by host type (broadleef species and baldcypress) and damage class in the eastern United States.

Host Type	Damage Class*					
	Defoliation (sprint/early summer)	Defoliation (mid/late summer)	Mortality	Discoloration	Dieback	Branch flagging
Maple, beech, birch	Forest tent caterpillar, Gypsy moth, loopers (se-veral species)	Saddled prominent, orange -humped mapleworm	Beech bark disease	Beech bark disease	Beech bark disease, birch dieback, maple decline	
Aspen, birch	Forest tent caterpillar, Gypsy moth, large aspen tortrix	Birch skel-etonizer		Birch leaf minters		
Black locust				Locust leaf miner		

* Damage classes, such as "branch breakage" and "mainstem broken or uprooted," caused by storm events can occur in all host types.

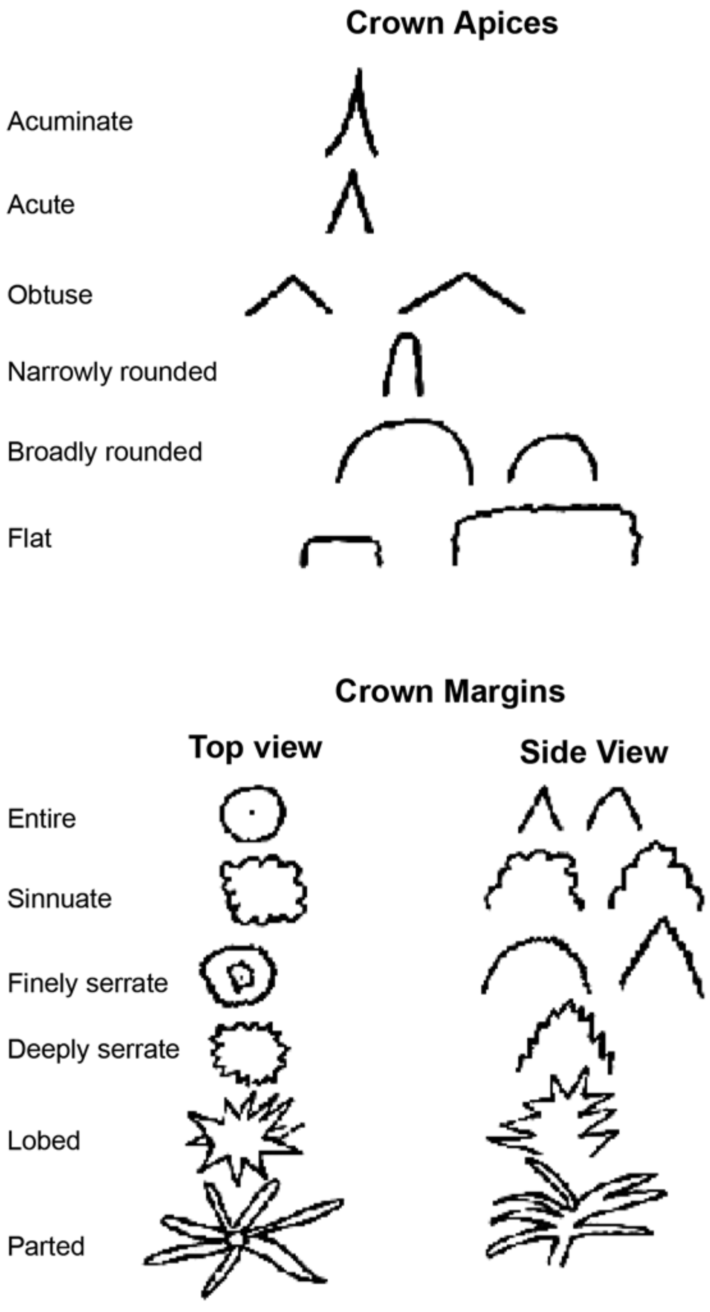

Figure 1. Descriptors of tree crowns used to help identify tree species and species groups on large-scale vertical aerial photos (Source: Heller et al. 1964).

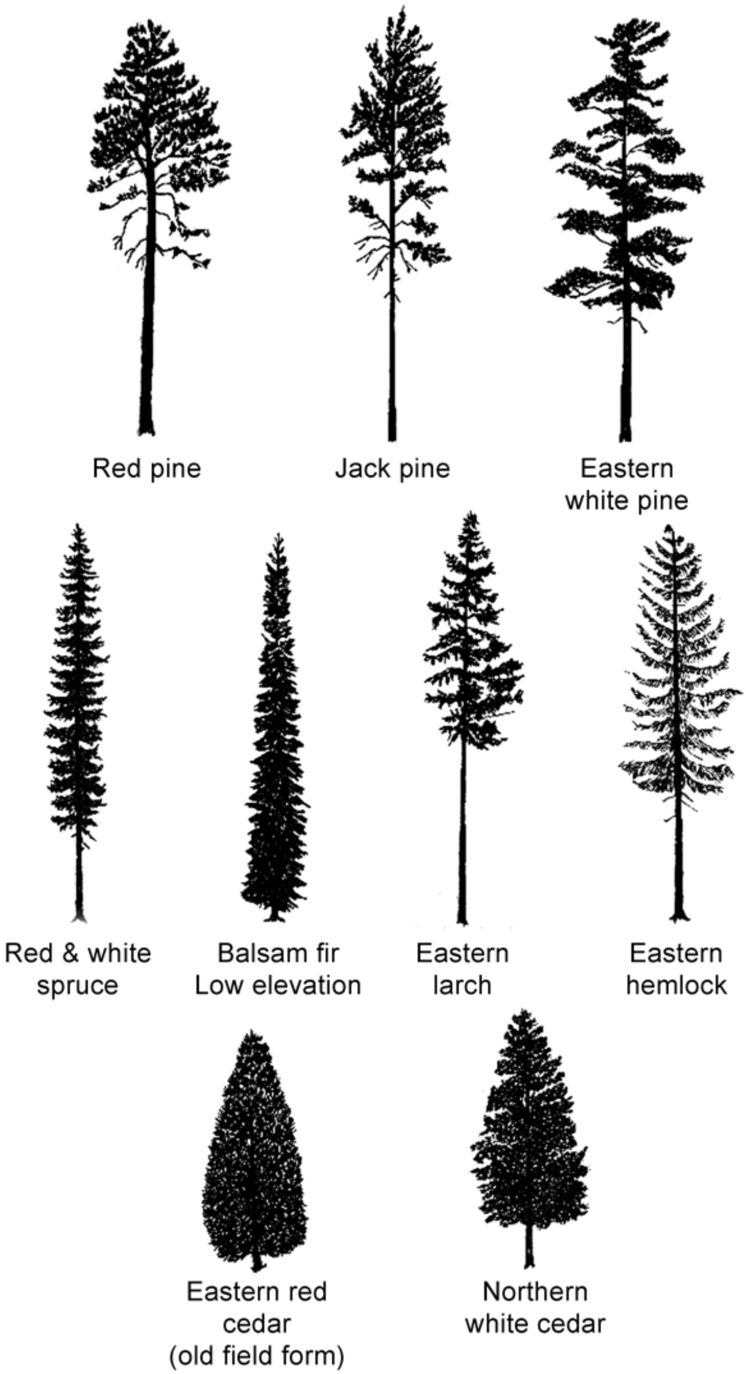

Figure 2. Crown shapes of some conifers indigenous to the northeastern and north central U.S. (Sources: Ciesla 1984, Heller et al. 1964 and Sayn Wittgenstein 1978).

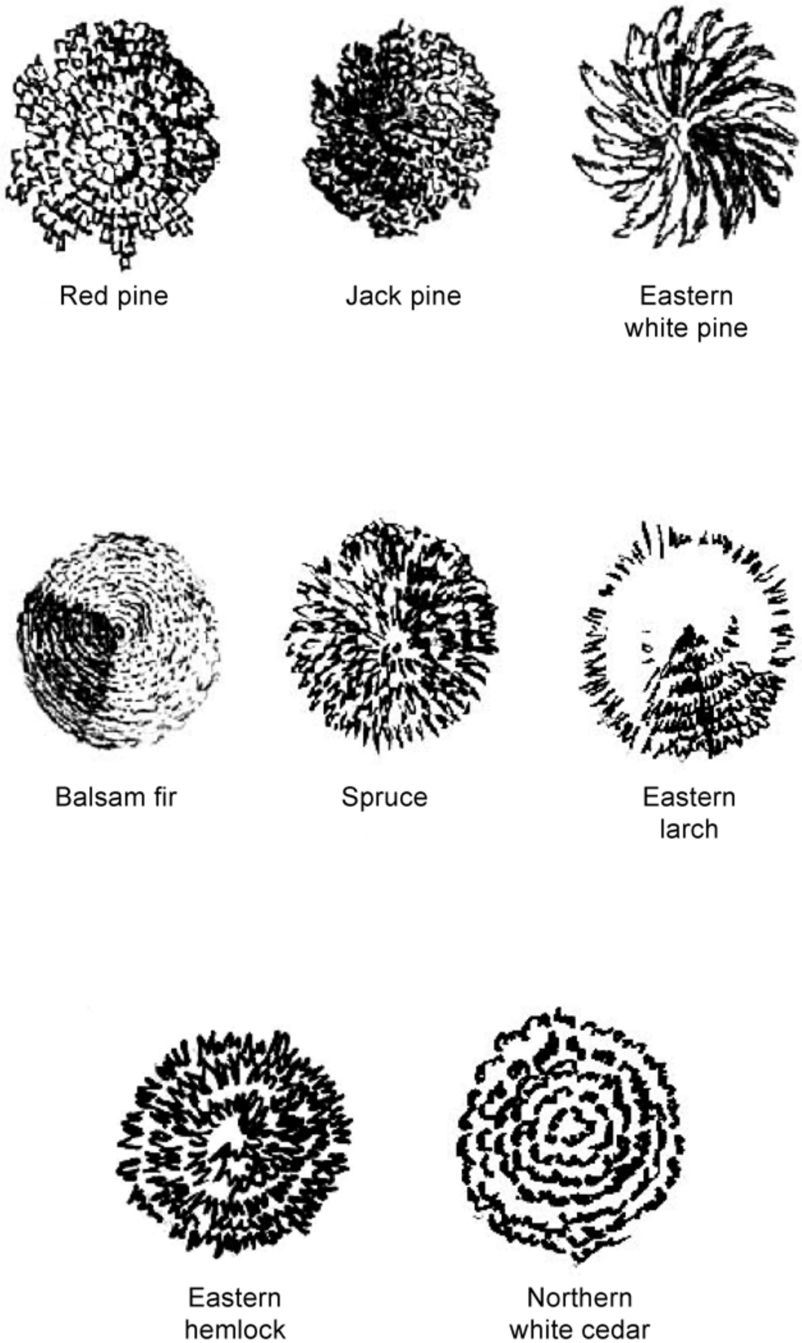

Figure 3. Vertical views of crown margins, branch patterns, and foliage textures of conifers indigenous to the northeastern and north central U.S. (Sources: Ciesla 1984, Heller et al. 1964 and Sayn-Wittgenstein 1978).

Figure 4. Aerial view of spruce-fir and mixed aspen/birch forests typical of the northern Great Lakes region. Dark green areas are conifers, light–medium green areas are broadleaf forests. Superior National Forest, MN.

Figure 5. Red spruce and Fraser fir are the dominant species above elevations of 5,000 feet in the Black Mountains, NC, and other sites in the southern Appalachian Mountains.

Figure 6. Shadows caused by cumulus clouds can reduce the visibility of damage signatures. Shawnee National Forest, IL.

Figure 7. Haze in mountainous regions can reduce visibility and an aerial observer's ability to detect damage. Looking Glass Rock, Pisgah N.F., NC.

Figure 8. Brilliant fall coloring of broadleaf species can mask symptoms of forest-pest damage. Graveyard Fields, Blue Ridge Parkway and Pisgah National Forest, NC.

Figure 9. Fall coloring on broadleaf trees masks an area of beech bark disease. Balsam Mountains, Blue Ridge Parkway, NC.

Figure 10. Eastern larch at peak of fall color will mask most damage signatures. North of St. Paul, MN.

Figure 11. Brilliant fall coloring of baldcypress resembles fading and red-topped pines killed by bark beetles. Big Thicket National Preserve, TX.

Figure 12. Delayed spring bud burst at high elevations can mimic defoliation. Newfound Gap, Great Smoky Mountains National Park, NC and TN.

Figure 13. Heavy cone crop on northern white cedar produces a brownish cast on tree crowns and can resemble damage caused by insect feeding. Koochiching County, MN.

Figure 14. Small stand of balsam fir with a slight reddish-brown cast to the foliage, indicative of light defoliation by spruce budworm. Superior National Forest, MN.

Figure 15. Extensive area of balsam fir defoliated by spruce budworm. Superior National Forest, MN.

Figure 16. Defoliation by spruce budworm adjacent to a lakeshore. Superior National Forest, MN.

Figure 17. Defoliation of jack pine by the jack pine budworm along the north shore of Lake Superior. Superior National Forest, MN.

Figure 18. Extensive, heavy defoliation by baldcypress leafroller. Atchafalaya River Basin, LA.

Figure 19. Stand of baldcypress defoliated by baldcypress leafroller. Atchafalaya River Basin, LA.

Figure 20. Heavy defoliation of eastern hemlock and other conifers by hemlock looper. Upper Peninsula, MI.

Figure 21. Defoliation of loblolly pine caused by a gray pine looper. East Texas.

Figure 22. Defoliation of loblolly pine by the loblolly or Arkansas pine sawfly near Hammond, LA.

Figure 23. Defoliation of eastern larch by the larch sawfly. Near the confluence of the Nowitna and Yukon Rivers, west of Fairbanks, AK.

Figure 24. Light to moderate defoliation of red oaks by gypsy moth. Shenandoah National Park, VA.

Figure 25. Complete stripping of foliage from oaks and other broadleaf species by gypsy moth. South Mountain, PA.

Figure 26. Defoliation of a mixed broadleaf forest by gypsy moth. Bear Brook State Park, NH.

Figure 27. Heavy defoliation of a mixed broadleaf forest by gypsy moth. Little North Mountain, George Washington National Forest, VA.

Figure 28. Defoliation of northern hardwood forests by forest tent caterpillar. Near Woodstock, VT

Figure 29. Defoliation of northern hardwoods by forest tent caterpillar. Near Kingsley, MI.

Figure 30. Heavy defoliation of bottomland hardwoods by forest tent caterpillar. Shawnee National Forest, IL.

Figure 31. Defoliation of water tupelo and other bottomland hardwood by forest tent caterpillar. Mobile River Basin, AL.

Figure 32. Bands of heavily defoliated water tupelo amid un-defoliated mixed bottomland broadleaf forests. Mobile River Basin, AL.

Figure 33. Tents made by larvae of the eastern tent caterpillar in cherry. Near Pineville, KY.

Figure 34. Defoliation of sugar maple and beech by the saddled prominent. Outer Island, Apostle Islands National Lakeshore, WI.

Figure 35. Defoliation of sugar maple and beech by the saddled prominent. Outer Island, Apostle Islands National Lakeshore, WI.

Figure 36. Defoliation of sugar maple by the orange-humped mapleworm. Note early fall coloration of red maples. Near McNearney Lake, Chippewa County, Upper Peninsula, MI.

Figure 37. Examples of leaf skeltonizing by insects: Right, American chestnut, left, sassafras. Causal agent is unknown. Shendandoah National Park, VA.

Figure 38. Defoliation of oaks by oak leaf skeletonizer. Northern Georgia.

Figure 39. Fall webworm nest. Shenandoah National Park, VA.

Figure 40. Heavy infestation of fall webworm resulting in nests on all branches. East Texas.

Figure 41. Defoliation of oaks and other broadleaf trees by the walkingstick, *Diapheromera femorata*. Note individual trees with early fall coloring. Windingstair Mountain, Ouachita National Forest, OK

Figure 42. Two southern pine beetle spots in loblolly pine. The upper spot has an active head as indicated by light green and yellow foliage. The lower spot contains only trees with red-brown foliage and is considered inactive. Angelina National Forest, TX.

Figure 43. Small southern pine beetle spots with single active heads. Openings at the heads of the spots occurred when freshly attacked trees were felled in combination with an experimental application of verbenone. Houston County, TX.

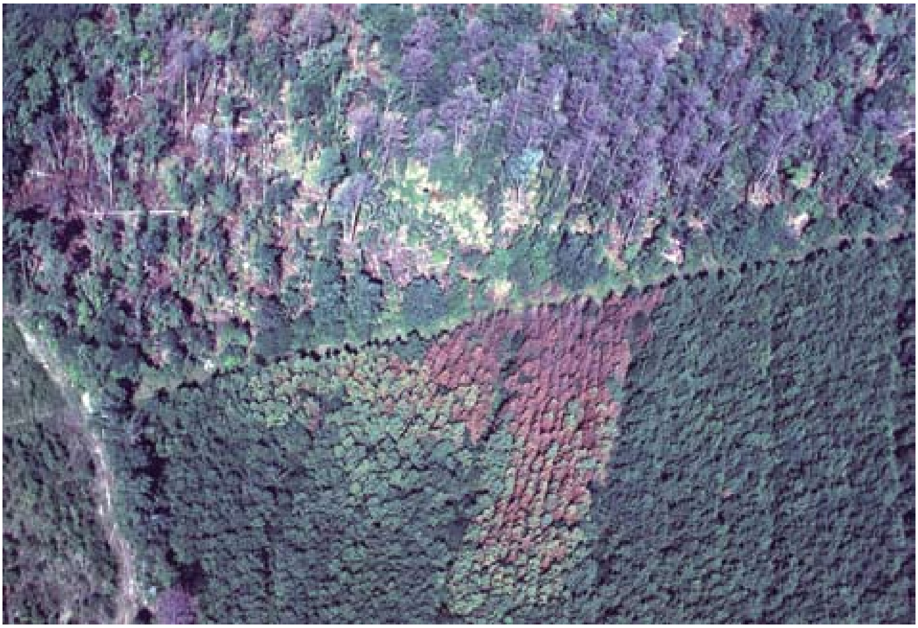

Figure 44. Southern pine beetle spot in a young plantation. Note old kill in adjacent stand. East Texas.

Figure 45. Southern pine beetle spot with several active heads. Walker County, TX.

Figure 46. Extremely large southern pine beetle spot located in the. Note small group of dead trees in foreground indicating an inactive spot. Upland Island Wilderness, Angelina National Forest, TX.

Figure 47. Large southern pine beetle spot in mountainous terrain. Northern Georgia.

Figure 48. Multiple southern pine beetle spots in mountainous terrain. Northern Georgia.

Figure 49. Mortality in a red pine plantation caused by the pine engraver beetle. North of Grand Rapids, MN.

Figure 50. Tree mortality in a mature loblolly pine forest caused by *ips* engraver beetles and drought stress. East Texas.

Figure 51. Scattered tree mortality in a red pine plantation caused by the pine engraver beetle. Chippewa National Forest, MN.

Figure 52. Scattered tree mortality in a young loblolly pine plantation caused by *ips* engraver beetles. Kisatchie National Forest, LA.

Figure 53. Large spots caused by *ips* engraver beetles near a paper mill. De-Ridder, LA.

Figure 54. Mortality of eastern larch caused by the eastern larch beetle. South of Big Falls, Koochiching County, MN.

Figure 55. Large area of larch mortality caused by the eastern larch beetle. South of Big Falls, Koochiching County, MN.

Figure 56. Balsam woolly adelgid infestation types on Fraser fir. Left, stem attack. Right, branch attack resulting in gouting. Mt. Mitchell State Park, Black Mountains, NC.

Figure 57. Heavy mortality of Fraser fir due to stem attack by balsam woolly adelgid as it appeared in 1964. Balsam Gap, Black Mountains, NC.

Figure 58. Red spruce–Fraser fir forest. The dead snags are Fraser fir killed by balsam woolly adelgid and the understory trees are Fraser fir regeneration. Summit of Clingman's Dome, Great Smoky Mountains National Park, NC and TN, as it appeared in 2007.

Figure 59. Left, Fraser fir dying from lower crown upward due to balsam woolly adelgid infestation. Right, Fraser fir with drooping branches indicative of decline due to balsam woolly adlegid attack. Balsam Mountains, NC.

Figure 60. Left, infestation of hemlock woolly adelgid on branches of eastern hemlock. Right, decline and mortality of eastern hemlock caused by hemlock woolly adelgid. Nantahala National Forest, NC.

Figure 61. Eastern hemlock damaged by hemlock woolly adelgid. Lake Singletary, Sutton, MA.

Figure 62. Extensive mortality of eastern hemlock caused by the hemlock woolly adlegid. Great Smoky Mountains National Park, NC.

Figure 63. Mortality of eastern hemlock caused by the hemlock woolly adelgid. Note concentrations of hemlocks in creek bottoms. Linville Gorge, Pisgah National Forest, NC.

Figure 64. Mortality in a red pine plantation caused by red pine scale. Tighe Carmody Reservoir, MA.

Figure 65. Loblolly pine plantation with scattered tree mortality caused by the woodwasp, *Sirex noctilio*. Paraná State, Brazil.

Figure 66. Fir or regeneration waves in pure balsam fir forest. Lookout Mountain, NY.

Figure 67. Wave-like mortality of Fraser fir, possibly triggered by tree mortality caused by balsam woolly adelgid. Entrance to Mt. Mitchell State Park, NC.

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REFERENCES

Appel, D.L., R.S. Cameron, A.D. Wilson, and J.D. Johnson. 2005. How to identify and manage oak wilt in Texas. USDA Forest Service, Southern Research Station, How-To SR-1, 2 pp.

Batzer, H.O. and R.C. Morris 1978. Forest tent caterpillar. USDA Forest Service, Forest Insect and Disease Leaflet 9, 8 pp.

Billings, R. F. 1979. Detecting and evaluating southern pine beetle outbreaks – operational guides. Southern Journal of Applied Forestry 3: 350–354.

Billings, R.F. and C. Doggett 1980. An aerial observer's guide to recognizing and reporting southern pine beetle spots. USDA, Combined Forest Pest Research and Development Program, Agriculture Handbook 560, 19 pp.

Billings, R.F., and J.D. Ward. 1984. How to conduct a southern pine beetle aerial detection survey. Texas Forest Service Circular 267, 19 pp.

Ciesla, W.M. 1964. Life history and habits of the elm spanworm, *Ennonmos subsignarius* in the southern Appalachian Mountains. Annals of the Entomological Society of America 57(5): 591–596.

Ciesla, W.M. 1984. Cooperative survey of red spruce and balsam fir decline and mortality in New Hampshire, New York and Vermont – 1984, photo interpretation guidelines. USDA Forest Pest Management, Methods Application Group, Fort Collins, CO, 14 pp + appendices.

Ciesla, W.M. 1990. Tree species identification on aerial photos: Expectations and realities. In: Protecting Natural Resources with Remote Sensing, Proceedings of the Third Forest Service Remote Sensing Applications Conference – April 9–13, 1990, Tucson, AZ. American Society for Photogrammetry and Remote Sensing, pp 308–319.

Ciesla, W.M. 2000. Remote sensing in forest health protection. USDA Forest Service, Forest Health Technology Enterprise Team and Remote Sensing Applications Center, Report FHTET 00-03, 266 pp.

Ciesla, W.M. 2003. European woodwasp: A potential threat to North America's conifer forests. Journal of Forestry 101 (2): 18–23.

Ciesla, W.M. 2006. Aerial signatures of forest insect and disease damage in the western United States. USDA Forest Service, Forest Health Technology Enterprise Team, Fort Collins, CO, Report FHTET-01-06, 94 pp.

Ciesla, W.M., W.R. Frament, and M. Miller-Weeks. 2001. Remote sensing techniques for rapid assessment of forest damage caused by catastrophic climatic events. USDA Forest Service, Northeastern Area, State and Private Forestry, NA-&TP-0101, 71 pp.

Coder, K.D. 1999. Drought damage to trees. University of Georgia, Daniel B. Warell School of Forest Resources, Extension Publication FOR 99-010, 5 pp.

Cummings, J. 1985. Red pine pocket mortality – Unknown cause. USDA Forest Service, Northeastern Area, Pest Alert NA-FB/P-30, 1 pp.

Dixon, W.N. 1982. *Anacamptodea perigracilis* (Hulst), a cypress looper (Lepidoptera: Geometridae). Florida Department of Agriculture and Consumer Services, Division of Plant Industry, Entomological Circular 244, 2 pp.

Douce, C.K. 1997. Fall webworm, *Hyphantria cunea* (Drury). University of Georgia, The Bugwood Network, http://www.bugwood.org/factsheets/webworm/html.

Drooz, A.T. 1985. Insects of eastern forests. USDA Forest Service, Miscellaneous Publication 1426, 608 pp.

Goyer, R.A., and G.J. Lenhard 1988. A new insect pest threatens baldcypress. Louisiana Agriculture 31(4):16–17.

Hayes, E. 2003. Tatters, oak tatters, hackberry tatters or something else? Minnesota Department of Natural Resources. http://www.dnr.mn.gov/fid/jul03/features.html.

Heller, R.C., G.E. Doverspike and R.C. Aldrich 1964. Identification of tree species on large-scale panchromatic and color aerial photographs. USDA Forest Service, Agriculture Handbook 261, 17 pp.

Hoebeke, R.E., D. Haugen and R.A. Haack 2005. *Sirex noctilio:* Discovery of a palearctic siricid woodwasp in New York. Newsletter of the Michigan Entomological Society 50 (1&2): 24–25.

Holsten, E.H., R.W. Thier and J.M. Schmid, 1989. The spruce beetle. USDA Forest Service, Forest Insect and Disease Leaflet 127, 12 pp.

Houston, D.R., and J. T. O'Brien 1983. Beech bark disease. USDA Forest Service, Forest Insect and Disease Leaflet 75, 8 pp.

Kucera, D.R., and P.W. Orr, 1981. Spruce budworm in the eastern United States, USDA Forest Service, Forest Insect and Disease Leaflet 160.

Johnson, J., L. Reid, B. Mayfield, D. Duerr and S. Fraederich, 2007. New disease epidemic threatens redbay and other related species. The Southern Perspective, April 2007. pp. 3–4.

Lambert, H.L. and W.M. Ciesla 1966.. Status of the balsam woolly aphid in North Carolina and Tennessee. USDA Forest Service, Southern Region, Division of State and Private Forestry, Zone 1, Forest Insect and Disease Control, Asheville, NC. Report 66-1-1, 12 pp.

Maier, C.T., C.R. Lemmon, J.M. Fengler, D.F. Schweitzer, and R.C. Reardon. 2004. Caterpillars on the Foliage of Conifers in the Northeastern United States. USDA Forest Service, Forest Health Technology Enterprise Team, FHTET-2004-1, 151 pp.

Manion, P.D. 1991. Tree disease concepts (Second edition). Prentice Hall Inc, Engelwood Cliffs, NJ, 402 pp.

McConnell, T.J., E.W. Johnson and B. Burns 2000. A guide to conducting aerial sketchmapping surveys. USDA Forest Service, Forest Health Technology Enterprise Team, Fort Collins, CO. Report FHTET 00-01, 88 pp.

McManus, M., N. Schneeberger, R. Reardon and G. Mason 1989. Gypsy moth. Forest Insect and Disease Leaflet 162, 13 pp.

Minnesota Department of Natural Resources 1997. Webworms, tent caterpillars and other web-making insects. http://www.dnr.state.mn.us.fid/june97/06209720.html.

Peterson, G. W. 1981. Diplodia blight of pines. USDA Forest Service, Forest Insect and Disease Leaflet 161.

Ragenovich, I.R. and R.G. Mitchell, 2006. Balsam woolly adelgid. USDA Forest Service, Forest Insect and Disease Leaflet 118, 11 pp.

Rexrode, C.O., and H. D. Brown, 1983. Oak wilt. USDA Forest Service, Forest Insect and Disease Leaflet 29, 6 pp.

Rush, P.A. and D. C. Allen, 1987. Saddled prominent. USDA Forest Service, Forest Insect and Disease Leaflet 167.

Sayn-Wittgenstein, L. 1978. Recognition of tree species on aerial photographs. Canadian Forestry Service, Forest Management Institute, Ottawa, Ontario, Canada, Information Report FMR-X-118, 97 pp.

Solomon, J.D., T.D. Leininger, A.D. Wilson, R.L. Anderson, L.C. Thompson and F.I. McCracken, 1993. Ash pests: A guide to major insects, diseases, air pollution injury and chemical injury. New Orleans, LA: USDA, Forest Service, Southern Forest Experiment Station, General Technical Report SO-96, 45 pp.

Seybold, S.J., M.A. Albers and S.A. Katovich 2002. Eastern larch beetle. USDA Forest Service, Forest Insect and Disease Leaflet 175.

Sprugel, D.G. 1976. Dynamic structure of wave-regenerated *Abies balsamea* forests in the north-eastern United States. Journal of Ecology 64: 889–911.

Thatcher, R.C., and P.J. Barry 1982. Southern pine beetle. USDA Forest Service, Forest Insect and Disease Leaflet 49.

USDA Forest Service. 1989. Insects and Diseases of Trees in the South. Forest Health Protection. Atlanta, GA R8-PR16, 98 pp. html://fhpr8.srs.fs.fed.us/forstpst.html

USDA Forest Service. 1998. Status report–ice storm 1998: cooperating for forest recovery, Northeastern Area State and Private Forestry, 36 pp.

USDA Forest Service. 1999a. Aerial Survey Standards. Forest Health Monitoring Program, State and Private Forestry, Forest Health Protection, 8 pp.

USDA Forest Service. 1999b. Forest insect and disease conditions in the United States – 1998. USDA Forest Service, Forest Health Protection, 80 pp.

USDA Forest Service. 2000. Forest insect and disease conditions in the United States – 1999. USDA Forest Service, Forest Health Protection, 94 pp.

USDA Forest Service. 2001. Forest insect and disease conditions in the United States – 2000. USDA Forest Service, Forest Health Protection, 101 pp.

USDA Forest Service. 2003. Forest insect and disease conditions in the United States – 2001. USDA Forest Service, Forest Health Protection, 112 pp.

USDA Forest Service. 2003b. Forest insect and disease conditions in the United States – 2002. USDA Forest Service, Forest Health Protection, 136 pp.

USDA Forest Service. 2004. Forest insect and disease conditions in the United States – 2003. USDA Forest Service, Forest Health Protection, 142 pp.

USDA Forest Service. 2005a. Forest insect and disease conditions in the United States – 2004. USDA Forest Service, Forest Health Protection, 141 pp.

USDA Forest Service. 2005b. Hemlock woolly adelgid. Pest Alert. Northeastern Area, State and Private Forestry, NA-PR-09-05, 1 p.

Wagner, D.L. 2005. Caterpillars of eastern North America: A guide to identification and natural history. Princeton University Press, 496 pp.

Wargo, P.M., D.R. Houston and L.A. LaMadeline. 1983. Oak decline. USDA Forest Service, Forest Insect and Disease Leaflet 165, 8 pp.

Wilson, M., and E. Rebek 2005. Signs and symptoms of the emerald ash borer. Michigan State University Extension, The Ohio State University Extension, Extension Bulletin E-2938, 2 pp.

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