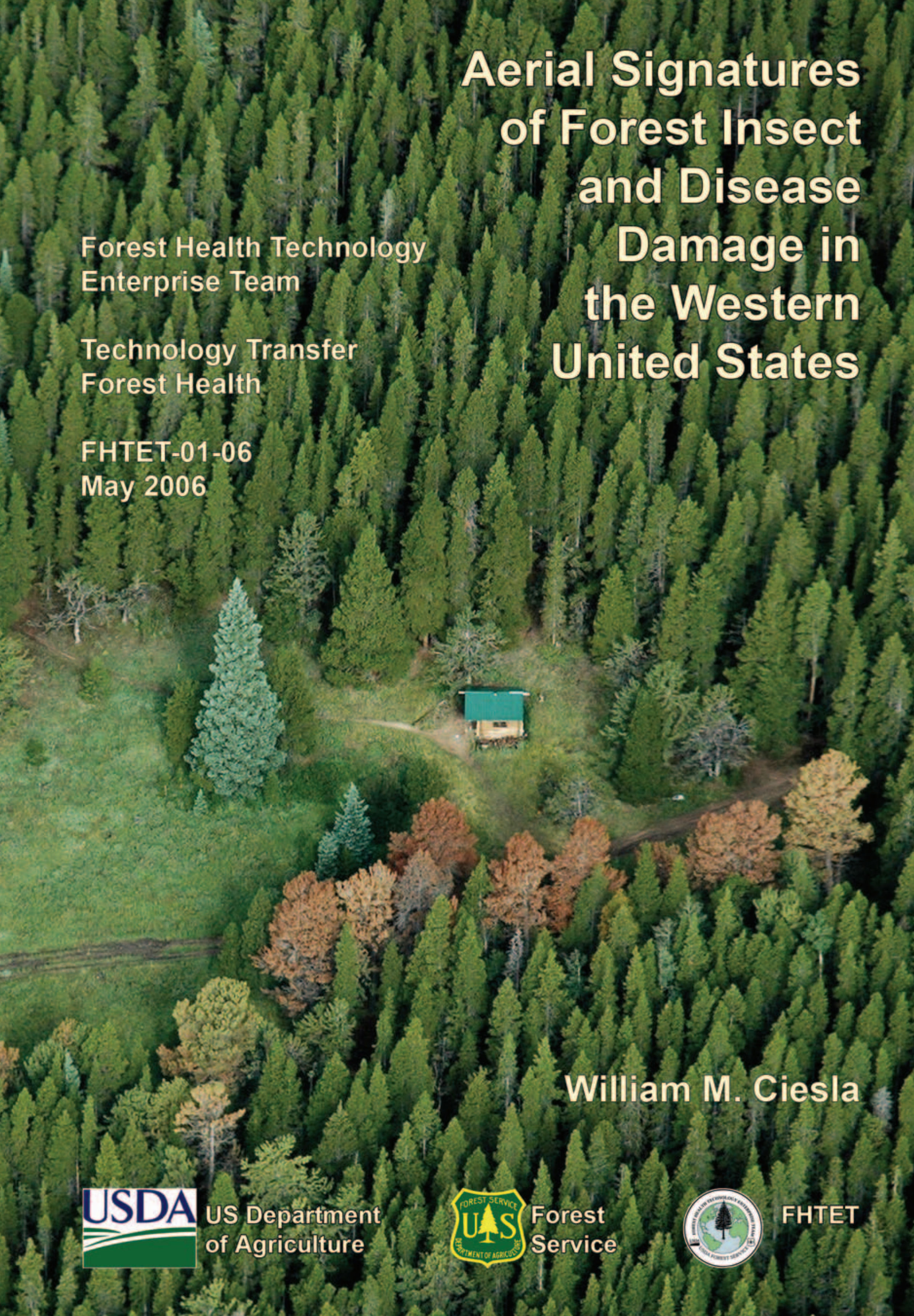

Aerial Signatures of Forest Insect and Disease Damage in the Western United States

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William M. Ciesla

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Cover photo by William M. Ciesla.

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The inspiration for the preparation of a guide to aerial signatures of forest insect and disease damage in the western U.S. came to me during the summer of 2004 while seated in a Cessna 206 buffeted by winds coming off of the steep eastern slopes of the Wet Mountains in southern Colorado. I was mapping lots of damage, training two Colorado State Forest Service aerial observers, **Dennis Will** and **Kelly Rogers**, and attempting to describe, over noise-canceling headphones, the differences between the damage signatures of Douglas-fir beetle and fir engraver beetle.

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Introduction

The forests of the western United States are subject to damage by many forces, chief among them being fire, insects, diseases, parasitic plants and storms. Damage caused by some of these agents, especially those that kill trees or damage the foliage, is often visible from long distances and, therefore, can be assessed via various remote sensing technologies. Damage caused by forest insects and diseases and visible from aircraft can be mapped using a technique known as aerial sketchmapping. This relatively simple and inexpensive procedure involves skilled aerial observers flying over forested areas in small, high-wing aircraft and recording the location of damaged areas either on paper maps or in digital map files displayed on computer-interfaced touch screens. In some areas of the West, aerial forest health surveys have been conducted annually since 1947, initially for detection of outbreaks of bark beetles and foliage feeding insects. Guidelines for conduct of these surveys have been available since 1955 (Wear and Buckhorn 1955). These surveys provide critical information for planning and implementing pest-management activities and provide 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 can enable aerial observers to identify with reasonable accuracy the insect, disease or other causal agent(s) responsible for the damage. Ability to recognize these characteristics, or "aerial signatures," is critical to the success of aerial forest health surveys. The purpose of this publication is to describe some of the aerial signatures of forest damage common in the western U.S. (exclusive of Alaska, Hawaii and the Pacific Island Territories), as seen from operational flying heights of 1,000 to 2,000 feet above ground level (AGL), and is intended for use as a reference guide and teaching aid for beginning and experienced aerial observers, alike.

1. Aerial Signatures - An Overview

What is a Signature?

A signature is a signal that consists of one or more unique characteristics that can be used to identify something - an object, a person, etc. A person's name, written in his or her own handwriting, is the classic example of a signature. Because everyone's handwriting is unique, every person can be identified by his or her signature.

Another example of a signature is the theme music played at the beginning of a radio or TV show. The tempo and melody of the music, often composed especially for that show, identify 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, in combination with the host tree attacked, usually are sufficient to permit identification of the bark beetle at least to genus and sometimes to species.

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

Characteristics of Host Trees

Forest insects and diseases tend to be host specific. Therefore, the ability to recognize tree species or at least species groups (e.g. true firs, white or soft pines) is essential to the recognition of forest damage signatures. By identifying from the air the tree species 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).

Several guides have been published to aid in the identification of tree species on large-scale vertical aerial photographs (Heller et al. 1964, Sayn-Wittgenstein 1978) and two guides are available to aid in tree species identification from large-scale color vertical aerial photos of western forests (Ciesla and Hoppus 1990, Croft et al. 1982). Although aerial observers engaged in forest health surveys typically view trees from an oblique rather than a vertical perspective, many of the characteristics discussed in these guides can be used by aerial observers to help identify tree species or species groups.

Foliage Color

Generally, foliage color is the first characteristic an aerial observer notices when attempting to identify tree species. Most healthy conifers have foliage in various hues of dark green. Trees such as western hemlock, *Tsuga heterophylla*, and subalpine fir, *Abies lasiocarpa*, can be significantly darker in color than associated species. Douglas-fir, *Pseudotsuga menzeisii*, has medium to dark green foliage. Ponderosa pine, *Pinus ponderosa*, and two pines indigenous to California, Jeffrey pine, *P. jeffreyi*, and Coulter pine, *Pinus coulteri*, have a yellow-green foliage. The foliage of several species or species groups of conifers has a blue-green or blue cast. For example, most white or soft pines indigenous to the West, blue spruce, *Picea pungens*, white fir, *Abies concolor,* and noble fir, *Abies procera*, have blue-green foliage. The new growth of subalpine fir also has a blue cast. The foliage of Engelmann spruce, *Picea engelmanni*, is gray-green, whereas the foliage of lodgepole pine, *Pinus contorta*, is olive-green. The cedars of the Pacific Northwest and northern California tend to have yellow-green foliage, wheras western and alpine larches, *Larix occidentalis* and *L. lyallii*, which are deciduous, have light-green foliage.

The foliage color of various species of junipers, *Juniperus* spp., indigenous to the West can vary from blue-green for Rocky Mountain juniper, *Juniperus scopulorum*, to gray-green for western juniper, *Juniperus occidentalis*, and to dark green for Utah juniper, *Juniperus osteosperma.* Typically, juniper cones are blue: heavy cone crops can give junipers a bluish cast regardless of the foliage color. The foliage color of most deciduous broadleaf trees is lighter than that of conifers. For example, the color of quaking aspen, *Populus tremuloides*, foliage can range from light yellow-green to light blue-green.

Crown Shape

The shape of the crown is another characteristic helpful for identifying tree species or species groups during aerial surveys. A tree crown can range from acuminate or spire like (subalpine fir), acute (Douglas-fir, grand fir, white fir, spruces), narrowly rounded (lodgepole pine) or broadly rounded (pines, junipers, most broadleaf species). The crown apex, as it appears on large-scale vertical aerial photos, has been defined for many of the conifers indigenous to the western U.S. (Croft et al. 1982, Ciesla and Hoppus 1990, Fig. 2, Table 1) and can help identify trees during aerial surveys. Crown shape within a tree species or species group is variable and can change with tree age, especially when height growth is reduced and the crown tends to flatten.

Crown Margin

Crown margins are easiest to see in open forests where they are not obscured by neighboring trees (Ciesla 1990). Whereas the outer margins of tree crowns for most of the yellow or hard pines, Douglas-fir, true fir and spruce, may be sinuate, serrate or entire, the crown margins of most white or soft pines are deeply lobed (Fig. 3).

Branch Pattern

Some conifers, such as spruces, *Picea* spp., and hemlocks, *Tsuga* spp., have distinct branches that can be seen from survey aircraft. Others, such as the true firs, *Abies* spp., and young Douglas-fir have less-distinct branches. The visibility of branching can vary with tree age. For example, heavy branches on large, old Douglas-fir trees tend to be more distinct than on younger trees of the same species (Fig. 3, Ciesla and Hoppus 1990).

Foliage Texture

Foliage textures can help identify species or species groups. Western larch and Port Orford cedar, *Chaemacyparis lawsoniana*, have fine, lacy, transparent foliage. The foliage of most yellow or hard pines, such as ponderosa, Jeffrey and Coulter pines, appears clumped (Fig. 3). Among broadleaf species, oaks, *Quercus* spp., have a coarse foliage texture. The foliage of quaking aspen is fine textured.

Landscape Features

Location relative to certain landscape features, especially elevation, aspect, and proximity to drainages, can help identify trees. In the West, the distribution of most trees is greatly influenced by elevation and aspect. For example, in the central Rocky Mountains and the Southwest, woodlands of piñon pine, juniper, *Juniperus* spp., and gambel oak, *Quercus gambelii*, occur at the lowest elevations. As elevation increases, these species are replaced by ponderosa pine and Douglas-fir. Lodgepole pine, subalpine fir and Engelmann spruce are the dominant species in high elevation forests.

Aspect can define the species present at any given elevation zone. Throughout the West, low- to mid-elevation, south facing slopes usually are occupied by open stands of ponderosa pine, whereas at the same elevation, north facing slopes, with their cooler more moist microclimates, may be dominated by denser stands of species such as Douglas-fir and true fir. In Washington state, the north facing slopes of high elevation forests often will have subalpine larch, whereas south facing slopes will be dominated by whitebark pine, *Pinus albicaulis*.

In the central Rocky Mountains, limber pine, *Pinus flexilis*, and bristlecone pine, *P. aristata*, often occur on exposed windy slopes. Trees with lobed crown margins and growing on exposed slopes are easily identified as white or soft pines.

Proximity to water is another factor that can be used to help identify tree species. Typically, blue spruce, cottonwoods and willows grow near streams. Both blue spruce and white fir have a blue cast to their foliage and acute crown shapes: however, blue spruce usually is found in stream bottoms, whereas white fir usually is found on adjacent upland slopes. Therefore, during aerial surveys trees with blue foliage seen in stream bottoms are likely to be blue spruce, and blue trees growing on slopes are likely to be white fir. There are exceptions, however. At its lower elevation limits, white fir also can be confined to cool, moist microclimates typical of riparian areas.

Characteristics of the Damage

Characteristics that can be helpful in making an aerial diagnosis of the causal agent responsible for the damage include:

- Color and texture of the affected crowns.
- Distribution of damage.
- Size of trees affected.
- Portion of the tree crown affected.

Crown Color and Texture

Most tree damage caused by insects and disease first appears as a change in the crown color. The foliage of trees killed by bark beetles or other tree killing pests changes from green to yellow, orange, red or brown. This process is referred to as “fading” and dying trees, especially conifers, are called “faders.” The color of fading provides a clue to the identity of the affected trees. For example, the color difference in fading is striking between lodgepole and ponderosa pine species even when attacked by the same bark beetle (Fig. 4). The foliage color of ponderosa pines killed by bark beetles fades first from green to yellow-green, progresses to a straw yellow, and finally to dull red-brown before dropping from the trees. Lodgepole pine foliage fades first to yellow-green, progresses to red-orange, and finally to red-brown before needle fall.

Douglas-fir fades to a red hue and trees attacked during the same year can fade at different rates. Grand fir, *Abies grandis*, and white fir fade to a red-orange hue. Subalpine fir faders are red. The fading foliage of true firs can remain on trees for three to five years, gradually changing to red brown or even a purple hue. Spruces attacked by bark beetles are often difficult to detect because initially they fade to a pale yellow-green color, yet needles can drop from trees while they are still green. Regardless of species involved, all trees suffering foliar injury typically take on a red-brown to gray hue and their crowns often appear thin.

Distribution of Damage

Occurrence of large bark beetle spots (50 to >100 trees) is usually a good indicator that species of *Dendroctonus* (e.g. mountain pine beetle, western pine beetle, Douglas-fir beetle, spruce beetle) are involved, whereas smaller group kills (1 to 50 trees) tend to indicate damage by ips engraver beetles (*Ips* spp.). However, this rule may not hold true for *Dendroctonus* beetles during the early stages of outbreaks when smaller group kills may be present. Moreover, several species of ips engraver beetles can become aggressive and cause large group kills, especially during periods of prolonged drought. Some bark beetles, such as ips engraver beetles in pine, or fir engraver, *Scolytus ventralis*, in true fir typically cause a scattering of either single trees or small groups of 2 to 50 trees over an infested area.

Tree Size

In some cases the size of the tree affected can offer a clue to the identity of the damaging agent. Some species of bark beetles, such as western pine beetle and Douglas-fir beetle, typically attack large mature trees. Others, such as the Douglas-fir engraver beetles, *Scolytus* spp., and ips engraver beetles, *Ips* spp., in lodgepole pine, prefer to attack smaller, pole-sized trees. Subalpine firs of all sizes can be killed by either western balsam bark beetle, *Dryocoetes confusus*, or balsam woolly adelgid, *Adelges piceae*.

Portion of Crown Affected

The portion of the affected crown also can provide clues as to what caused the damage. Bark beetles of the genus *Dendroctonus* attack the mid and lower boles of their host trees. Consequently, when trees die the entire crown fades. Some species of ips engraver beetles prefer thin bark and initiate attacks in the upper quarter, third, or half of the crown, causing top kill (Fig. 5). A similar attack pattern can occur with Douglas-fir engraver beetles and fir engraver, *Scolytus ventralis*.

Top kill usually is most apparent on large trees growing in open stands, but is often difficult to see from operational aerial survey flying heights (1,000 to 2,000 feet AGL). However, unless a special survey is planned that takes into account the increased risks, flying lower than the recommended flying height to detect top kill is *not* recommended.

Foliage feeding insects often begin to feed in the upper crown and, during heavy infestations, progress downward until the entire crown is defoliated. However, the reverse holds for the larvae of at least one species of defoliator indigenous to the west, the western hemlock looper, *Lambdina fiscellaria lugubrosa*, which initially feeds in the lower crowns of host trees.

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 for those agents that damage foliage. 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 (Figs 6-7). In western forests, most of the important damaging agents can be mapped during July and August as part of an "aerial overview survey" (McConnell et al. 2000). There are exceptions, however. Damage caused by larch casebearer, *Coleophora laricella*, on western larch occurs early and peaks in late June. Foliar damage due to Swiss needle cast, caused by the fungus *Phaecryptopus gäumannii*, in coastal Douglas-fir forests is at its peak in May immediately prior to bud burst (Kanaskie et al. 2002). In order to map all of the trees killed by Douglas-fir beetle in a given area, two surveys may be required, one in mid summer and another in early fall.

Light and Shadow

Light and shadow can have significant effects on an aerial observer's ability to discern subtle differences in damage signatures. Weather permitting, mid-summer surveys (July and August) can be flown on most days from about 8:00 a.m. to 4:00 p.m. It is better to fly east-facing slopes during the early morning hours, while they are in direct sunlight, and west facing slopes during the afternoon.

Although clouds can reduce the amount of sunlight that strikes the survey area, less light is not always detrimental to the survey. High cirrus clouds can diffuse sunlight, reduce the sharp contrasts caused by full sunlight, and make it easier to classify damage signatures. On the other hand, cumulus clouds can intersperse dark shadows on brightly lit slopes, making some signatures less visible. Late afternoon thundershowers and atmospheric haze can significantly reduce visibility, thereby making it difficult to classify forest damage signatures (McConnell et al. 2000).

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 the fall (September and October) coloration of deciduous trees. Undoubtedly the most confounding are the brilliant yellow and gold hues associated with quaking aspen in the Rocky Mountains (Fig. 8), or western larch in the northern Rockies (Fig. 9). The bright red hues of the canyon maple, *Acer grandidentatum*, in portions of the Rockies, especially Utah, and vine maple, *Acer circinatum*, in the Pacific Northwest are more localized but can mask fading conifers. The gold and bronze hues associated with fall coloring of gambel oak can mask the occurrence of fading piñon pines in low elevation forests when the two species occur together.

Spring bud burst also produces myriad colors and could mask certain kinds of foliar injury. Late spring frosts, especially in broadleaf species, can cause a signature virtually identical to that of some defoliating insects. Heavy cone crops, especially on spruce, can cause the upper crowns to have a brown cast, which can mimic defoliation or fading due to bark beetle attacks. In the Pacific Northwest, the older foliage of western red cedar, *Thuja plicata*, turns a reddish brown or brown color in autumn and can resemble fading from bark beetles (Fig. 10).

Ground Checking

Ground checking should be an integral part of aerial forest health surveys to verify both the host(s) affected and the causal factor(s) responsible for the damage. 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 cannot always be done. Therefore, high priority should be given to ground checks of areas wherein (1) questionable or unfamiliar damage signatures have been observed, (2) potentially severe damage may occur in the future (e.g. localized areas of suspected defoliation by Douglas-fir tussock moth), and (3) where forest management actions are planned or underway. In addition, new and less-experienced aerial observers should plan for extra time to do more ground checking so they can become more familiar with the damage signatures characteristic of the areas over which they fly.

Pest Complexes

During aerial forest health surveys, most observers attribute forest damage to a single causal factor, even though existing protocols allow for classification of up to three causal factors for each damage occurrence mapped (USDA Forest Service 1999). While it may be expedient during an aerial survey to code only for a single causal factor, much of the observed damage could be 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 among insects, diseases and other factors that affect 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 such as western spruce budworm or Douglas-fir tussock moth, or damaged by fire and subsequently attacked by bark beetles, will have lost a large portion of their foliage. Hence, they will not fade to the bright red and yellow colors of non-defoliated trees. Trees with heavy root disease infections and subsequently attacked by bark beetles fade at faster rates than uninfected trees or trees with light infections. Root-disease occurrence causes random variation in foliage color and needle retention in groups of Douglas-fir trees killed by Douglas-fir beetle.

Because of the complex of factors that can cause trees to die or suffer foliar damage, and the relative difficulty of reliably attributing the damage to a specific causal factor, some aerial observers prefer to record only the host tree(s) affected. However, this alone may not satisfy the data requirements of the survey.

3. Descriptions of Pest Damage Signatures

The following sections provide detailed descriptions of the aerial signatures of damage caused by commonly occurring forest insects and diseases in western forests. They are organized into three major groups: bark beetles, foliage feeding insects, and other damage signatures. Information for bark beetles and foliage feeders is organized according to the tree species or species groups affected by these insects. Finally, information is provided on damage signatures that could mimic insect and disease signatures commonly observed during aerial forest health surveys.

Insects

Bark Beetles

Bark beetles (Family Scolytidae) are the most damaging insect pests of western conifer forests. Many species of bark beetles are tree killers and in some years kill hundreds of thousands of trees over large areas. Bark beetle adults attack *en masse* the boles of host trees and construct breeding galleries in the cambium layer where eggs are deposited and larvae and pupae eventually develop.

The classic aerial signature of bark beetle damage is the occurrence of trees with discolored or fading foliage, often in groups but sometimes as a scattering of faders throughout a forest. The host tree affected, the color of the fading foliage, the portion of the crown affected, and the number of fading trees in a group provides clues to the identities of the bark beetles causing the damage (Tables 2-3).

Ponderosa Pine

Ponderosa pine is one of the most widely distributed pines in the western U.S. and forms extensive pure or nearly pure stands at or near the lower elevation limits of forests. This pine is subject to attack by several species of bark beetles. When attacked, ponderosa pine initially fades to a yellow-green, gradually to straw yellow, and finally to dull red-brown. The timing of the fading varies according to the species of bark beetle involved, the length of the beetle's life cycle, soil moisture levels, and the location of the infestation (latitude and/or elevation).

Several bark beetles are important pests of ponderosa pine forests. The natural ranges of many these species overlap and in some cases two or more species cohabit the same tree. Therefore, during an aerial survey identifying the species responsible for tree mortality in a given area is often difficult and is based on a combination of the aerial signature, the observer's knowledge of bark beetle activity in the area, and/or supplemental ground checks.

Mountain Pine Beetle

Dendroctonus ponderosae occurs throughout the West and is considered the most damaging insect pest of western pine forests. It attacks ponderosa, lodgepole, and other western pines, and has been at epidemic levels somewhere in the West for as long as forest damage has been monitored (Furniss and Carolin 1977). In ponderosa pine, outbreaks typically develop in mature and/or young, overstocked forests.

Generally, ponderosa pines attacked by mountain pine beetle begin to fade in late June during the year following attack (Fig. 11). Initially, they fade to a yellow-green and gradually to straw yellow or yellow-orange by mid summer. During the following year the affected foliage turns red-brown before dropping to the ground. During aerial surveys conducted in July or August, the differences in foliage colors make it relatively easy to differentiate most of the one-year-old attacks from two-year-old attacks (Fig.12).

In mature ponderosa pine forests, especially those along the Colorado Front Range or the Black Hills of western South Dakota and eastern Wyoming, mountain pine beetle attacks typically occur as distinct groups of from 20 to several hundred trees. When infestations occur in younger ($\leq$ 60 years) overstocked stands, a scattering of dead trees appears throughout the affected area (Fig.13).

Western Pine Beetle

Dendroctonus brevicomis is an important tree killing pest of ponderosa pine in Arizona, California, Oregon, Washington and portions of Idaho and western Montana. (It also attacks Coulter pine in California.) Unlike the mountain pine beetle, which typically has one generation a year, western pine beetle has two to three generations a year. Trees killed by this insect fade just as they do when attacked by mountain pine beetle, i.e., from green to straw-yellow to red-brown.

Western pine beetle often attacks large, old growth ponderosa pines. Therefore, the identification of the insect responsible for the attack sometimes can be made on the basis of tree size and crown diameter. Western pine beetle attacks in small, second-growth ponderosa pine forests are virtually impossible to distinguish from mountain pine beetle attacks, based on aerial signatures alone. Ground checks are necessary. In addition, western pine beetles often attack trees after the upper crowns have been attacked by ips engraver beetles (Fig. 14).

Roundheaded Pine Beetle

Dendroctonus adjunctus, is a pest of ponderosa pine in the American Southwest including Arizona, Nevada, and New Mexico. Infestations consist of either single trees or small groups of up to 20 trees, and both large and small diameter trees may be attacked during outbreaks. This insect is often associated with western pine beetle and/or ips engraver beetles (Massey et al. 1977). Correct classification of roundheaded pine beetle infestations depends on the aerial observer's knowledge of the bark beetle outbreak history of the areas flown and/or ground checks.

Ips Engraver Beetles

Several species of engraver beetles, *Ips* spp., attack ponderosa pine. Common species include: the pine engraver, *Ips pini*, throughout much of the Rocky Mountains and Pacific Northwest; the Arizona five-spined engraver, *I. lecontei*, in Arizona; and the California five-spined ips, *I. paraconfusus*, in southern Oregon and California (Furniss and Carolin 1977).

Engraver beetles often initiate attacks in the upper crown and kill only a portion of the total crown. Subsequent generations of ips engraver beetles or other species of bark beetles then attack the lower bole. For example, in California large ponderosa pines are top killed by *Ips paraconfusus* and subsequently attacked by western pine beetle. Occasionally, top kill can be seen from operational aerial survey flying heights (Fig. 15).

Another characteristic of engraver beetle attacks in ponderosa pine is that group kills tend to be smaller (1 to 20 trees) than those caused by *Dendroctonus* bark beetles (20 to several hundred trees) (Fig.16). There are exceptions to this rule, however. For example, during extended dry periods, ips engraver beetles can become more aggressive and kill large groups of trees. Moreover, in the early stages of mountain pine beetle or western pine beetle outbreaks, group kills caused by these bark beetles can be smaller. When in doubt, ground checks should be done.

Jeffrey Pine

Jeffrey pine is indigenous to California and adjoining portions of southern Oregon and western Nevada and is so similar in appearance to ponderosa pine it is difficult to distinguish between the two even on the ground. Jeffrey pine is the dominant yellow pine in forests on the eastern slopes of the Sierra Nevada and the Transverse and Peninsular Ranges south into Baja California, Mexico (Jenkinson 1990). When attacked by bark beetles, Jeffrey pine fades to the same straw yellow color characteristic of ponderosa pine and Coulter pine attacked by bark beetles. Unless *a priori* knowledge of the occurrence of Jeffrey pine is available, tree species and the identities of the causal agents responsible for their damage must be verified by ground checks.

Jeffrey Pine Beetle

The Jeffrey pine beetle, *Dendroctonus jeffreyi*, is the most destructive bark beetle pest of Jeffrey pine and is similar in appearance and habits to mountain pine beetle (Furniss and Carolin 1977). During outbreaks, tree killing by Jeffrey pine beetle consists of either scattered tree mortality or small group kills of up to 30 trees (Fig.17). Infestations occur most commonly in large diameter trees, generally greater than 8 inches dbh, but with a preference for material with a stem diameter greater than 12 inches (Smith 1971).

Ips Engraver Beetles

Several species of ips engraver beetles, *Ips* spp., including *I. emarginatus, I. latidens*, and *I. pini* also attack Jeffrey pine. These insects can kill small diameter trees on their own, but often do so in association with Jeffrey pine beetle. A high proportion of trees killed by Jeffrey pine beetle are attacked initially by *I. pini* and/or a flatheaded woodborer, *Melanophila californica* (Coleoptera: Buprestidae) (Furniss and Carolin 1977). Except for top kills or attacks in small diameter trees (Fig.18), which may be evident from the air, the damage signatures of this complex of insects are identical to those of Jeffrey pine beetle.

Lodgepole Pine

Lodgepole pine is a wide-ranging species found throughout most of the Rocky Mountains, the Pacific Northwest, and in the higher elevations of the Sierra Nevada Range. It grows in extensive, pure stands but also may occur in association with other trees. Forests dominated by lodgepole pine cover about 15-million acres in the western U.S. (Lotan and Critchfield 1990).

The mountain pine beetle and ips engraver beetle are important pests of lodgepole pine. When attacked by either, the foliage color of lodgepole pine fades initially to yellow green, progresses to red-orange, then to red-brown before needle fall.

Mountain Pine Beetle

The foliage color of lodgepole pines attacked by mountain pine beetle initially fades to yellow green, rapidly progresses to red-orange the year following attack (Fig.19), and finally to red-brown two years after attack. As with ponderosa pine, fading usually begins in late June. Typically, attacks occur either as a scattering of fading trees or as small group kills (5 to 50 trees) (Fig. 20), and outbreaks develop in forests 60 years of age or older. Trees with thick phloem and large diameters, the largest trees in the stand, are preferred (Amman et al. 1985). From the air, attacks appear as fading in trees with large crown diameters. During the early stages of an outbreak, the trees most often attacked first are growing at the lower elevations, near creek bottoms, or at the edges of stands, where often there is a concentration of large-diameter trees with thick phloem. As outbreaks progress, large areas of pure or nearly pure lodgepole pine forests can be affected (Fig.21).

Ips Engraver Beetles

Several species of ips engraver beetles, *Ips* spp., attack lodgepole pine. The signature of an ips engraver beetle attack in lodgepole pines is relatively easy to distinguish from a mountain pine beetle attack. Typically, ips attacks occur in trees much younger and smaller than those attacked by mountain pine beetle, and tend to occur in dense stands and in distinct groups of from 10 to 50 trees (Fig. 22). Because lodgepole pine is a thin-barked species, attacks occur in the mid and lower boles of trees and not in the crown. Thus, top kill is usually not associated with ips engraver beetle in lodgepole pine.

White Pines

Several species of white, soft, or five-needle pines are indigenous to the West, including: western white pine, *Pinus monticola*, in the Northern Rockies and Cascade Range; sugar pine, *P. lambertiana*, in southern Oregon and California; limber pine and whitebark pine in the Blue Mountains, Cascades and Rocky Mountains; bristlecone pine, *P. longaeva*, in California and the Great Basin; Colorado bristlecone pine, *P. aristata*, in Colorado and New Mexico; and southwestern white pine, *P. strobiformis*, and foxtail pine, *P. balfouriana*, in California. These pines are attacked and killed by mountain pine beetles and ips engraver beetles and are subject to infection by the introduced white pine blister rust caused by the fungus *Cronartium ribicola.* All of these agents can cause significant tree mortality (Fig. 23). During aerial surveys, these pines are easily distinguished from the "yellow" or "hard" pines by their broader, deeply lobed crowns. In addition, the foliage of most species of healthy white or soft pines is blue-green. When attacked by bark beetles and/or white pine blister rust, portions or entire crowns fade from yellow-green to red-orange and eventually to red-brown.

Mountain pine beetle outbreaks sometimes occur in mixed stands of lodgepole, limber, and whitebark pines. While the color of the fading crowns of these pines is similar, the affected hosts can be differentiated on the basis of the crown characteristics (see page 7). (Fig. 24).

Piñon Pines

Piñon-juniper woodlands are the dominant vegetation in the lower elevations of the Southwest. The most widespread species of piñon pines in these woodlands are New Mexico piñon, *Pinus edulis*, in Arizona, Colorado, New Mexico and Utah, and the singleleaf piñon, *Pinus monophylla*, in Nevada and on the eastern slopes of the Sierra Nevada Range in California. Several species with localized ranges also occur in California, the Southwest and Mexico (Lanner 1981).

Piñon Ips

The piñon ips, *Ips confusus*, can be an important pest of piñon pines, especially following prolonged drought. Assessment of piñon ips beetle outbreaks may require special aerial surveys over a vegetation type that is not normally included in annual aerial overview surveys.

When attacked by the piñon ips, piñon pines initially fade to pale orange, then gradually change to red-brown the following growing season. Small groups of 5 to 20 trees, or a scattering of affected trees, may be involved (Figs. 25, 26). Fading piñon pines are sometimes difficult to see from the air because of the open character of piñon–juniper woodlands and the amount of bare soil between trees, which often has a color similar to the fading piñons.

During severe droughts, piñon mortality caused by piñon ips also can be accompanied by mortality among junipers caused by bark beetles of the genus *Phloeosinus*. The color of fading junipers is identical to that of piñon pines and cannot be reliably distinguished during aerial surveys. Ground checks should be done.

Piñon Twig Beetles

Piñon pines also are subject to attack by several species of twig beetles of the genus *Pityophthorus*. Up to six species of *Pityophthorus* may be involved (Leatherman 2004). Light infestations result in the death and fading of a few scattered shoots, but this level of damage is not visible from the air. During prolonged droughts, twig beetles can become more abundant and can kill large numbers of shoots on individual trees. This causes much of the foliage in the outer crown to fade, while foliage in the interior of the crown remains green (Fig. 27). During aerial surveys this type of damage is difficult to distinguish from tree mortality caused by the piñon ips (described above). Ground checks should be done.

Douglas-fir

Douglas-fir is one of the world's most important and valuable trees. It has the greatest latitudinal range of any western North American conifer and is found from British Columbia, Canada, south into northern Mexico. Douglas-fir is a common component of low to mid elevation forests. In the interior West, it commonly occurs on cool, north facing slopes. When attacked by bark beetles, the foliage color of Douglas-fir initially fades to an off-green or yellow-green color and progresses to red.

Douglas-fir Beetle

The Douglas-fir beetle, *Dendroctonus pseudotsugae*, is the most destructive bark beetle of Douglas-fir. Outbreaks can develop in fresh windthrow with subsequent generations attacking standing trees, or following fire scorch, insect defoliation, or prolonged drought. Trees infected by root disease, usually caused by the fungus, *Phellinus weirii*, often serve as centers for Douglas-fir beetle attack.

The "classic" aerial signature of Douglas-fir beetle attack consists of distinct groups of trees (10 to more than 200) with fading foliage. Attacked trees are characteristically large and often occur on steep slopes. Some trees may fade as early as four months after attack between April and June, while others may remain green until the following June. Therefore, the pattern of fading of individual trees in the group is often random with some individuals being slightly off green in color, others red (sometimes referred to as "salmon red"), and others with varying degrees of foliage loss (Fig. 28), possibly the result of an interaction with root disease. The more severely infected trees fade at faster rates. Other factors that determine the time of fading include location, intensity of infestation, elevation, and seasonal weather (Furniss and Orr 1978). Because of the large size of the trees affected, the distinct groups, and the red color of the fading trees, Douglas-fir beetle infestations are among the more conspicuous of bark beetle attacks in the West and, under favorable weather conditions, can be detected over distances of up to 4 miles.

Douglas fir beetle attacks in trees weakened by defoliation by western spruce budworm, *Choristoneura occidentalis*, or Douglas fir tussock moth, *Orgyia pseudotsugata*, tend to be more scattered. Fresh faders often are scattered among trees killed either by defoliation during previous years, or by bark beetle attacks following defoliation (Fig. 29). These infestations also may be difficult to detect, because defoliation during previous years has reduced the foliage complement of the affected trees.

Douglas-fir Engraver Beetles

Collectively, several species of bark beetles are referred to as Douglas-fir engraver beetles and the species involved vary according to region. They include species of *Scolytus* and the Douglas-fir pole beetle, *Pseudohylesinus nebulosus* (Furniss and Carolyn 1977). The aerial signatures in this complex are identical for all of the species involved and cannot be distinguished during aerial surveys. The characteristic signature associated with Douglas-fir engraver beetles is the occurrence of groups (2 to 100 trees) of pole-sized faders. Top kill is occasionally visible on some trees. Trees attacked by Douglas-fir engraver beetles can usually be distinguished from Douglas-fir beetle attacks on the basis of tree size and the number of trees affected.

Spruce

Spruce trees attacked by bark beetles are difficult to detect during aerial surveys, because fading is inconspicuous. In some cases the needles on infested spruces drop from the trees before they change color. In other cases, they turn a pale yellow-green or dull red-brown color.

Spruce Beetle

The spruce beetle, *Dendroctonus rufipennis*, is a major pest of mature spruce forests throughout North America. Engelmann spruce is the favorite host of spruce beetles in the western U.S., excluding Alaska. Outbreaks have occurred in the Blue Mountains of eastern Oregon and Washington, the Cascades and the Rocky Mountains. Typically, infestations develop in fresh windthrow or logging residues with subsequent generations attacking standing trees.

As a rule, the needles of trees infested by spruce beetle do not fade until the second summer following attack, when they first turn a pale yellow-green color (Fig. 30), progressing to dull gray–brown as the needles drop (Fig. 31). The needles on different branches of the same tree can discolor at different times. Dry needles are washed from fading trees by rainstorms, leaving the upper crowns of exposed twigs with a yellow-orange or reddish hue (Holsten et al. 1989). Typically, large mature trees are attacked. During major outbreaks, the only surviving spruces are small-diameter, pole-sized, or smaller.

Blue Spruce Engraver Beetle

Blue spruce engraver beetle, *Ips hunteri*, is an occasional pest of blue spruce in the Rocky Mountains. Blue spruce is easily recognized from the air; typically it occurs in riparian areas and the foliage of most trees has a distinct blue cast. The distinct color of blue spruce foliage is especially conspicuous from the air during a low sun angle. Blue spruce engraver beetle infestations are characterized by the occurrence of single faders or groups of 2 to 40 dead trees. Top kill is a common characteristic of *Ips hunteri* attack but may not be easily seen from aerial survey flying heights. As with trees killed by spruce beetle, and with the exception of the occasional beige-colored fader, faders killed by blue spruce engraver beetles are not conspicuous (Fig. 32).

Because of their occurrence in riparian areas, blue spruces are subject to inundation following beaver dam construction. If standing water is visible among the dead trees, inundation should be considered as the probable cause of damage.

True Fir

When attacked by bark beetles, fir (*Abies* spp.) fade to conspicuous hues of red or red orange. Some aerial observers refer to this color as brick red. True firs can retain these colors for more than one growing season. Therefore, it is difficult to determine which year the trees were attacked.

Fir Engraver

The fir engraver beetle, *Scolytus ventralis*, is the most damaging bark beetle of true firs in the West. Hosts are grand fir, California red fir, *Abies magnifica*, and white fir (Ferrell 1986). The general crown shape of these species of fir is acute and somewhat similar to Douglas-fir, a tree with which they are often associated. Of the three, white fir is easiest to recognize from the air because of its blue cast.

Typically, the foliage color of grand fir attacked by fir engraver beetles fades to a red-orange color, whereas the foliage of white fir tends to fade to a hue that is more orange than red (Figs. 33, 34). Infestation patterns are variable, ranging from a scattering of dead trees in a stand to group kills of from 5 to 100 trees. The infestation pattern of fir engravers on individual trees also is highly variable and can consist of top kill, individual branch attacks, or attacks along the entire bole. Top kill caused by fir engraver beetle attacks sometimes can be seen from operational aerial survey flying heights (Fig. 35).

Trees killed by fir engraver often occur in association with Douglas-fir killed by Douglas-fir beetle. Under poor lighting conditions the two may be difficult to distinguish, because the color differences between fading Douglas-fir and fading true fir are less distinct. Douglas-fir beetle usually attacks groups of trees, whereas fir engraver attacks can be more scattered. Also, Douglas-fir beetle does not cause top kill, which is a fairly common characteristic of fir engraver.

Western Balsam Bark Beetle

Subalpine-fir is widely distributed throughout the West and is a component of high elevation forests, where it occurs in pure stands or in association with Engelmann spruce and lodegpole pine. The crown has a characteristic long, narrow, acuminate form terminating in a conspicuous spike-like point (Alexander et al. 1990). This makes the tree easy to recognize during aerial surveys. Western balsam bark beetle, *Dryocoetes confusus*, is a pest of subalpine fir throughout its range. This bark beetle is sometimes associated with root disease caused by *Armillaria* spp. and other fungi. The interaction between western balsam bark beetle and root disease has been referred to as subalpine fir decline. When attacked by western balsam bark beetle, subalpine fir fades to a deep red color. Typically, distinct groups of from 2 to100 trees are killed (Fig. 36).

Silver Fir Beetle

Pacific silver fir, *Abies amabilis*, is a high-elevation species found on the western slopes of the Cascades from southeastern Alaska to northern California. This tree has a spire-like crown similar to that of subalpine fir, with lateral branches perpendicular to the stem (Crawford and Oliver 1990).

The silver fir beetle, *Pseudohylesinus sericeus*, attacks Pacific silver fir as well as other species of true fir, western hemlock, and Douglas-fir. As with the western balsam bark beetle (discussed above), this insect often is associated with root-rot fungi (Furniss and Carolin 1977). When viewed from the air, the signature of a silver fir beetle attack in Pacific silver fir is virtually identical to that of western balsam bark beetle in subalpine fir.

Foliage Feeding Insects

The forests of the West are also subject to damage by a number of foliage feeding insects, several of which can reach epidemic levels and cause extensive damage. Like the damage caused by bark beetles, damage caused by foliage-feeding insects is highly visible and easy to assess and map during aerial forest health surveys. Damage signatures of foliar injury include foliage discoloration and thin or bare crowns.

Douglas-fir, True Fir and Spruce

Several insects feed on the foliage of Douglas-fir, true firs, and spruces. Some species are capable of causing defoliation, which can be seen from aircraft to spread over hundreds of thousands of acres.

Western Spruce Budworm

Western spruce budworm, *Choristoneura occidentalis* (Lepidoptera: Tortricidae), is the most widely distributed and destructive defoliator of conifer forests in western North America. This insect occurs in the Rocky Mountains and Pacific Northwest from Arizona and New Mexico north into Colorado, Utah, Wyoming, Montana, Idaho, northern California, Oregon, Washington and British Columbia, Canada. Outbreaks occur somewhere in the West every year. This insect has a wide host range; its favorite hosts are Douglas-fir and various true firs, and it is known to feed on spruce, hemlock, western larch, and several species of pines (Fellin and Dewey 1982).

Larvae of the western spruce budworm feed first in the expanding buds of host trees and later on the new growth. Branch tips containing partially damaged foliage turn red-brown and are tied together with silken webbing (Fig. 37). 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. 38). As outbreaks progress, and affected forests suffer from successive years of defoliation, top dieback and tree mortality, trees take on a gray cast and exhibit thin crowns almost totally devoid of foliage. Damage typically occurs over large areas (Figs. 39, 40).

Other “Spruce” Budworms

Several other species of *Choristoneura* feed on the foliage of Douglas-fir, true fir, and spruce in western forests. These insects occasionally reach outbreak levels and cause defoliation that is visible from the air. The aerial signature of damage caused by these insects is virtually identical to that described for western spruce budworm (directly above). Therefore, determining precisely which budworm species is responsible for the damage must be based on the aerial observer’s knowledge of the area flown, including its insect outbreak history, and/or ground checks.

Modoc or “green” budworm, *Choristoneura retiniana*, is found from northern California and southern Oregon east to the Great Basin and Wasatch Range of Utah. Its primary host is white fir but larvae feed also on Douglas-fir and grand fir. Outbreaks have occurred in the Warner

Mountains and nearby ranges of northeastern California and adjacent areas of southern Oregon (Harvey 1985).

Choristoneura carana occurs in the Sierra Nevada, Coast Ranges and southern mountains of California and occasionally reaches outbreak levels. It feeds primarily on Douglas-fir (Harvey 1985) except in southern California where it feeds on bigcone Douglas-fir, *Pseudotsuga macrocarpa.*

Douglas-fir Tussock Moth

Outbreaks of Douglas-fir tussock moth, *Orgyia pseudotsugata* (Lepidoptera: Lymantriidae), are cyclic and occur at intervals of 7 to 10 years. Typically, they cause severe defoliation for 2 to 3 years, then suddenly collapse, usually due to an epizootic of a virus. The larvae of the Douglas-fir tussock moth begin to feed on the new foliage of host trees that appears from late May to early June. When they reach the third instar, larvae are capable of feeding on older foliage and, during outbreaks, can strip a tree of all of its foliage in a single growing season.

The aerial signature of Douglas fir tussock defoliation consists of red-brown or gray discoloration in the crowns of Douglas-fir or true fir. Affected portions of the crown also appear thin. The heaviest damage occurs in the upper crown, where there is a high proportion of the current year's foliage. During severe outbreaks, the entire crown is affected.

Typically, in mixed forests of Douglas-fir and true fir defoliation occurs over large areas, and during the first year of an outbreak only the upper quarter or third of the crown is affected. This pattern of damage is typical of outbreaks in California, the Pacific Northwest and northern Idaho (Fig. 41). When outbreaks occur in pure Douglas-fir forests (e.g. western Montana and portions of Colorado), damage on individual trees tends to be more severe, with entire tree crowns stripped of their foliage during the first year. Tussock moth outbreaks in pure Douglas-fir forests tend to occur in relatively small patches ranging in size from about 40 to 200 acres (Fig. 42).

Western False Hemlock Looper

The western false hemlock looper, *Neptyia freemani* (Lepidoptera: Geometridae), is primarily a defoliator of Douglas-fir but also is known to feed on the foliage of Engelmann spruce, western larch, subalpine and white fir and ponderosa pine. Outbreaks have been reported in Idaho, Montana, Washington and Utah. The young larvae feed on the underside of new foliage first, causing the needles to shrivel and die, and on older needles later in the season. The larvae of this insect are wasteful feeders and often consume only parts of the needles, giving damaged trees a red-brown "scorched" appearance. During outbreaks, defoliation begins in the upper crown and eventually spreads to the entire tree. They are usually localized and occur in pole- and sapling-sized Douglas-fir. Overall, the damage caused by this insect is similar in appearance to western spruce budworm, western hemlock looper, and Douglas-fir tussock moth, and must be confirmed by ground checks (Furniss and Carolin 1977, Hagle et al. 2003).

Western Larch

Western larch is an important deciduous component of forests in portions of the northern Rockies (western Montana and northern Idaho), the Pacific Northwest (eastern Oregon and Washington) and adjoining portions of British Columbia, Canada (Schmidt and Shearer 1990). Typically, it occurs in mixed coniferous forests of Douglas-fir, ponderosa pine, and others, on low and mid-elevation slopes. The tree is easily recognized during aerial surveys because of its light green foliage and conical form. During fall, late September to early October, foliage turns a brilliant yellow before dropping from trees.

Larch Casebearer

The most damaging foliage feeding insect of western larch is the larch casebearer, *Coleophora laricella* (Lepidoptera: Coleophoridae). Native to Europe, this insect was first detected in the northern Rockies in 1957, and has since spread throughout the natural range of western larch (Schmidt and Shearer 1990).

Larch casebearer overwinters as a half-grown larvae enclosed in hollowed out larch needles still attached to branches. Feeding begins as soon as the new foliage appears in spring. From the air, damage caused by larch casebearer appears first as a yellow discoloration of the crown, gradually changes to yellow-orange, and to orange-brown later in the summer (Fig. 43). Damage is at its peak in late June, several weeks before the regular aerial survey season. So, it may be necessary to schedule a special survey in order to map defoliation by larch casebearer.

Western Hemlock

Western hemlock is an important commercial species and occurs in humid climates of the Pacific Northwest and Northern Rockies (northern Idaho) (Packee 1990). Its dark green foliage and distinct branching make it easy to recognize on aerial photographs or during aerial surveys (Ciesla and

Hoppus 1990). Western hemlock forests are subject to outbreaks of several defoliating insects.

Western Hemlock Looper

The western hemlock looper, *Lambdina fiscellaria lugubrosa* (Lepidoptera: Geometridae), is a periodically destructive defoliator of coastal forests of western hemlock and associated species (Furniss and Carolin 1977). Unlike many forest defoliators, the larvae of western hemlock looper begin feeding on branches in the lower crown of host trees and work their way upward. The larvae are wasteful feeders and often take only a bite or two out of each needle. Most injured needles fall without fading. Those that remain fade and give infested areas a thin yellow to red- brown color. Defoliation occurs most commonly in valley bottoms that contain a major western hemlock component and often occurs in distinctive elevation bands. Light infestations are difficult to detect during aerial surveys because conspicuous damage appears in the lower crown first (Wear and Buckhorn 1955).

Other Defoliators of Hemlock Forests

Other defoliating insects of coastal forests dominated by western hemlock include the black-headed budworm, *Acleris gloverana* (Lepidoptera: Torticidae), the hemlock sawfly, *Neodiprion tsugae* (Hymenoptera: Diprionidae) and the phantom hemlock looper, *Nepytia phantasmaria* (Lepidoptera: Geometridae). Sometimes several species can be involved in a single outbreak. With the exception of feeding damage first appearing in the lower crown, all of these pests produce a damage signature somewhat similar to the western hemlock looper. Thus, ground checks are required to determine which insects are responsible for the damage.

Pines

The larvae of several insects either feed on the foliage of pines or mine the insides of needles. A number of species can reach outbreak levels and cause damage severe enough to be visible from the air (Table 4). Defoliating insects remove the foliage from infested trees. Their aerial damage signatures consist of trees with thin red-brown, dull-brown or gray crowns (Figs. 44, 45). In contrast, needle miners feed inside the needles of host trees and do not physically remove the foliage while feeding. The aerial signature of pine needle miners during the peak period of defoliation is a red-brown discoloration of the tree crown (Fig. 46). Because the aerial signatures are similar for pine defoliators and needle miners, unless some *a priori* data are available, ground checks must be made to identify the insect(s) responsible for the damage.

Most foliage feeding insects of pine have one generation per year. An exception is the Pandora moth, *Coloradia pandora* (Lepidoptera: Saturniidae), a defoliator of ponderosa, Jeffrey and lodgepole pines. This moth requires two years to complete a generation, and defoliation occurs in alternating years. Pandora moth spends its first winter in the larval stage and feeds during warm winter days. Because defoliation peaks early, in mid to late June, in alternate years, a special survey must be scheduled to map the damage (Fig. 47).

The larvae of the pine tussock moth, *Paraorgyia grisefacta* (Lepidoptera: Lymantriidae) overwinter under the bark scales of their pine hosts and resume feeding in early spring (Furniss and Carolin 1977). Defoliation signatures peak in early summer; consequently, new growth may mask the signatures by the time aerial surveys are flown in July and August

Broadleaf Trees

As is the case with pines, a number of insects can defoliate broadleaf forests in the western U.S. and may require mapping through aerial forest health surveys (Table 5). The aerial signatures of foliar injury caused by insects in western broadleaf forests are similar, regardless of the species involved, characterized by brown or gray discoloration and a thin or bare appearance to the crowns (Fig. 48). The larvae of some species feed in spring and early summer with peak damage occurring in June or July. Other species are mid- to late-summer defoliators with damage not becoming visible until late August or September (Fig. 49).

Several common broadleaf defoliators of western forests produce tents within which the larvae live and feed. Examples are most of the tent caterpillars, *Malacosoma* spp. (Lepidoptera: Lasiocampidae) and the fall webworm, *Hyphantria cunea* (Lepidoptera: Arctiidae) (Table 5, Figs. 50, 51). During heavy infestations, tents may be visible from the air, especially during early mornings and late evenings when sunlight to reflects off the tents at low angles. Areas of broadleaf foliar injury require ground checks to determine the causal agent responsible for the damage.

Other Damage Signatures

In addition to tree killing bark beetles and foliage feeding insects, many other agents produce damage signatures visible from the air.

Insects

Balsam Woolly Adelgid

Balsam woolly adelgid, *Adelges piceae* (Homoptera: Adelgidae), is a small, inconspicuous sucking insect native to Europe. It first appeared in eastern North America around 1900, and in the Pacific Northwest around 1930 (Mitchell and Buffam 2001). Infestations were discovered in north central

Idaho in 1983 (Gast et al. 1990, Livingston et al. 2000). Its hosts include all species of true fir, *Abies* spp.

Infestations can occur on the boles, branches, twigs, and bases of the buds. Crown infestations can stunt terminal growth and cause branch tips to swell, a condition known as "gouting," which leads to crown thinning, dieback, and eventual tree death. However, tree death is more commonly associated with infestations on the mainstem than with gouting. In the West, the main hosts of balsam woolly adelgid are grand fir, subalpine fir, and Pacific silver fir. Grand fir is most resistant and can tolerate infestations for as long as 15 years. Subalpine fir is most susceptible; infested trees can die within 3 to 5 years following the development of stem infestations. Pacific silver fir is intermediate in susceptibility.

Balsam woolly adelgid infestations can be recognized by the presence of dying trees with fading foliage (Fig. 52), branch flagging, and declining trees that sometimes display flattened tops caused by reduced height growth. Fir trees of all sizes may be affected, and all of the symptoms are visible during aerial surveys. Studies conducted in the Pacific Northwest indicate that trees fading from balsam woolly adelgid infestations are at their peak from mid August to mid September (Buckhorn and Lauterbach 1957). Dying trees fade to the same color to which they would fade had they been attacked by bark beetles. In the case of subalpine fir, attacks by western balsam bark beetle could occur in association with attacks from balsam woolly adelgid. The occurrence in a stand of both pest species would be virtually impossible to determine through aerial surveys alone.

At least three years are required for trees to fade and die after they become infested with balsam woolly adelgid. Therefore, aerial surveys that map only fading trees are ineffective for detecting new infestations (Mitchell 1966). Recent work in Oregon indicates that the crowns of live trees with low-level infestations of balsam woolly adelgid, accompanied by crown deterioration and thinning foliage, tend to have a black cast. The black coloration is due to heavy populations of black lichens of the genus *Bryoria* in the crowns of trees (Fig. 53). Even healthy trees harbor populations of *Bryoria*; however, as tree crowns decline these lichens become more conspicuous, giving the crowns their black cast (Fig. 54). This signature makes it possible to detect balsam wooly adelgid infestations if there is little or no tree mortality.[1]

Spruce Aphid

The spruce aphid or green spruce aphid, *Elatobium abietinum* (Homoptera: Aphididae), is native to Europe and feeds on the foliage of spruce. It was introduced into North America during the early 1900s and by 1927 was distributed throughout the coastal Sitka spruce, *Picea sitchensis*, forests of the Pacific Northwest and Alaska (Furniss and Carolin 1977). In 1988, this insect appeared in New Mexico and several years later outbreaks were detected in high elevation spruce forests in Arizona. In the Southwest, spruce aphid feeds primarily on Engelmann spruce and to a lesser degree blue spruce (Wilson and Lynch 2004).

Spruce aphid infestations cause premature loss of older needles. As a result, infested trees develop a thin crown with a red-brown cast, which is visible during aerial surveys. Large Sitka spruce in the Pacific Northwest can suffer severe infestations of spruce aphid, and some branches or entire trees may die after successive years of heavy defoliation. Defoliation by spruce aphid on Sitka spruce is concentrated in the mid and lower crown of older open grown trees and on trees growing along the perimeter of a stand (Fig. 55). Sapling-sized trees and trees in the interior of dense stands are rarely affected.[2] In the Southwest, the damage signature consists of small groups or a scattering of trees with thin or discolored foliage.

Spruce aphids are most abundant during late winter and early spring before bud burst. In both the Pacific Northwest and the Southwest, needles turn yellow and fall from heavily infested trees during April and May. In cases of severe defoliation, infested trees may appear dead immediately before spring (Overhulser 1999, Wilson and Lynch 2004).

Pathogens

Needle Diseases of Western Larch

Western larch is affected by two needle diseases: larch needle blight, caused by the fungus *Hypodermella laricis*, and larch needle cast, caused by *Meria laricis*. *H. laricis* causes a yellow discoloration similar in appearance to defoliation by larch casebearer (see page 28 and Fig. 43) (Fig. 56). *M. laricis* tends to cause a reddish foliage discoloration and is often heavier in the lower crown. Ground checking is necessary to determine which of the two agents is causing the damage (Garbutt 1995, Hagle et al. 2003).

Root Disease

Several root diseases, such as those caused by the fungi *Heterobasidium annosum*, *Phellinus weirii* and *Armillaria* spp., infect and kill trees in distinct centers much in the way bark beetles kill trees. However, the action of root disease is much slower. The aerial signatures of root disease are often characterized by the presence of a scattering of dead trees and an occasional fader. While root disease centers sometimes can be seen on large-scale aerial photographs (1:4,000 – 1:8,000), they are usually difficult to detect from low flying aircraft (Ciesla 2000). Two exceptions are large centers caused by laminated root rot and Port Orford cedar root disease.

In the northern Rockies and the Pacific Northwest, laminated root rot, caused by the fungus *Phellinus weirii*, is a major pest of Douglas-fir, several species of true fir, and mountain hemlock, *Tsuga mertensiana*. Susceptible host trees are infected and killed regardless of vigor (Hansen and Goheen 2000, Nelson et al. 1981). In Douglas-fir forests on the western slopes of the Cascades, laminated root rot can cause large, slowly expanding centers, some of which can be seen from low flying aircraft. From the air, these centers appear as distinct, roughly circular open areas, with a scattering of live trees of species less susceptible to infection. Trees on the edges of these openings are in a state of decline or have recently been killed. Toward the center of these openings, windthrown and scattered standing dead trees, some with broken tops, may be seen. The number of trees surviving in these openings depends on the proportion (ratio) of less-susceptible species to susceptible species in the stand (Nelson et al. 1981) (Fig. 57). Centers of infection by *Phellinus weirii* are less conspicuous in other parts of the West.

Port Orford cedar root disease is caused by *Phytophthora lateralis*, a water mold of unknown origin that was first detected in 1952. This organism attacks the root systems of both Port Orford cedar, a tree of exceptionally high value found only in southwestern Oregon and adjacent portions of California, and to a lesser degree, Pacific yew, *Taxus brevifolia*. Infected Port Orford cedars die rapidly and can be detected through aerial surveys.

Healthy Port Orford cedar can be distinguished from other conifers by their yellow-green foliage color, lack of distinct branches, and lacey foliage texture (Ciesla and Hoppus 1990). The color of trees infected by *Phytophthora lateralis* initially fades to a pale orange hue, and gradually progresses to orange and red-brown before needle fall. In areas where this pathogen has been present for some time, it is common to see faders in a range of colors mixed in with older, dead, trees with no needles. Since the spores of this organism are spread by water, trees growing near streams are more likely to become infected and die. The presence of dead and dying Port Orford cedar adjacent to streams is a common signature of Port Orford cedar root disease in the more mountainous areas of its natural range (Fig. 58).

Swiss Needle Cast

Swiss needle cast is a foliage disease of Douglas-fir caused by the fungus *Phaecryptopus gäumannii*. Since the early 1990s, it has damaged several hundreds of thousands of acres of Douglas-fir forests in coastal Oregon and Washington in an area known as the "fog belt". The disease causes infected needles to drop from trees. Prior to needle cast, the needles turn yellow and later become mottled or entirely brown. Symptoms appear in spring, prior to bud burst. Special aerial surveys to map the damage caused by this disease have been flown since 1996. Generally, they are flown between mid April and late May (Kanaske et al. 2002, Omdal et al. 2002, Worrell 2004)

The Swiss needle cast aerial signature consists of patches of Douglas-fir with yellow, sometimes brown, foliage discoloration (Fig. 59). Symptoms are most severe on south facing slopes and exposed ridges and are most conspicuous in May immediately prior to bud burst. The upper crowns of trees are most severely affected. Symptoms generally occur within 18 miles of the Pacific coast although damage has been detected as far as 30 miles inland (Kanaske et al. 2002).

Sudden Oak Death

Sudden oak death is caused by *Phytopthora ramorum*, a newly described species of water mold. First discovered in California in 1995, this disease affects a number of trees but the most severe damage has occurred on tanoak, *Lithocarpus densiflora*, and several species of red oaks, *Quercus* spp., indigenous to the Pacific Coast. Symptoms of this disease include a rapid wilting of foliage on individual branches, dieback, and tree death.

Special aerial surveys to detect sudden oak death have been conducted in California and Oregon since 2001. These surveys are flown between late May, after flowering of host trees, and early July. Sudden oak death is characterized by the occurrence of host trees, especially tanoak, with red-orange to brown wilted foliage and/or trees that have lost their foliage (Fig. 60). Damage can be seen on single trees and/or groups of dead and dying trees (Fisher 2004, Goheen 2004).

Damage signatures of at least two other agents in California are known to be confused with the signature of sudden oak death: California oakworm, *Phryganidia californica* (Lepidoptera: Dioptidae) and late summer drought. California oakworm defoliates Coast live oak, *Quercus agrifolia*, and to a lesser degree California white oak or valley oak, *Q. lobata*, primarily in the Coast Range. Late summer drought causes premature fall coloration and loss of foliage (Fig. 61) among certain deciduous broadleaf species, especially California buckeye, *Aesculus californica* . Coast live oak and California buckeye are known hosts of sudden oak death. Sudden oak death can be confirmed only through ground checks and laboratory tests to detect the presence of *Phytopthora ramorum*. Confusion between sudden oak death and late summer drought damage to deciduous broadleaf trees can be avoided by conducting aerial surveys during late spring or early summer.[3]

Other Damaging Agents

Bears

In the Pacific Northwest, black bears, *Ursus americanus*, damage trees during the spring by peeling the bark and eating the cambium. An aerial survey conducted in 2000 over 6.4 million acres in western Oregon detected 29,500 acres of tree mortality of which 19,370 acres was attributed to bears peeling the bark from trees. If the bear girdles the tree, peels a strip around the entire circumference of the bole, the tree will die. Partial bark peeling can reduce growth and vitality, introduce decay and may eventually result in tree mortality. Douglas-fir is most frequently damaged, followed by western hemlock and western red cedar (Kanaskie et al. 2001). Bears also are known to damage other species. For example, in northern Idaho young plantations of western larch may be damaged.[4]

The aerial signature of bear damage consists of groups or scattered trees with fading yellow, red, or brown foliage (Figs. 62, 63). Damage is most conspicuous during June and early July. Damaged trees on warm, dry sites may fade earlier than those on cool, wet sites. In areas where bear damage is an important problem, it may be necessary to conduct a special aerial survey, before the regular July-August overview surveys (Kanaskie et al. 2001).

Signatures that mimic damage caused by insects and disease

Several factors, including chemicals, low intensity ground fires, heavy cone crops, and late spring frost, can cause signatures that mimic damage caused by insects and disease.

Chemical Injury

Various chemicals can cause foliar injury and/or tree death, some of which will be visible from the air. In recent years, such injuries and tree deaths have been observed on a number of tree species (e.g. ponderosa pine, lodgepole pine, Douglas-fir, and quaking aspen) growing immediately adjacent to roads in Colorado. The exact cause(s) of the damage is yet to be determined. However, the pattern of damage suggests it is being caused by deicing chemicals used on roads and highways. Such damage is visible from the air and consists of one or two strips of fading and/or dead trees on one or both sides of a road. When ponderosa pines or lodgepole pines are affected, they fade to the same color as when attacked by bark beetles (see above). In fact, secondary bark beetle attacks may occur in some trees thought to be injured by chemicals (Fig. 64).

Not all damage observed along roads or highways can be attributed to deicing chemicals. Ground checks should be done, and because a roadway is involved, the damaged areas are readily accessible so there's little reason not to do them. In one instance, near Winthrop, Washington, damage to roadside ponderosa pines was traced to an incorrect formulation of a commonly applied herbicide used to control roadside weeds. This was discovered because the aerial observers conducted follow-up ground checks to investigate an unusual signature, a "line of dead trees."[5]

Fire Damage

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 (Fig. 65). However, localized damage caused by low intensity ground fires or prescribed fires sometimes can resemble damage caused by bark beetles (see above). 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 often visible on the lower bole (Fig. 66).

Hail Damage

Hail storms, especially those that produce large hailstones, can tear and kill foliage and wound or break branches. Both conifers and broadleaf trees can be affected. From the air, hail damage usually appears as a brown discoloration of the foliage, which can mimic the signature of foliar injury by insects or pathogenic fungi (Ciesla et al. 2001). During severe hail events, forests can take on a thin appearance similar to insect defoliation (Fig. 67).

Heavy Cone Crops

Heavy cone crops can cause the crowns to have a brown cast, especially in spruce forests where cones are produced in the very upper part of the crown (Fig. 68). This phenomenon is most common in high elevation Engelmann spruce forests (Fig. 69) but can also occur on other species such as the true firs and blue spruce. The brown cast can be mistaken for the early stages of defoliation or fading due to spruce-beetle kill.

Late Spring Frost

Late spring frost can produce an aerial signature that mimics insect defoliation, especially in broadleaf forests. Depending on severity, late spring frosts can kill entire leaves, or the margins of newly emerged leaves, causing a brown discoloration. 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 remains throughout the remainder of the growing season (Fig. 70).

Red Belt

This condition is the result of warm winds (Chinooks) buffeting the southern and western slopes of mountains during winter. The warm winds may cause the foliage to dry out, either because the frozen root systems cannot supply water (moisture), or cause the trees to loose winter hardiness (Manion 1991). Red belt often occurs in lodgepole pine forests but is known to affect other conifers.

Red belt appears on mountain slopes as distinct bands of red to red-brown, desiccated foliage. It usually occurs at distinct elevation zones (Fig. 71). Symptoms can appear in winter and continue into the early summer. Red belt is usually not mapped during annual forest health surveys, but the discoloration and resultant foliage loss could mask the presence of bark beetle damage.

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[1] Personal communication, Dave Overhulser, Oregon State Department of Forestry, Salem, OR.

[2] Personal communication, Dave Overhulser, Oregon State Department of Forestry, Salem, OR.

[3] Personal communication, Jeffrey Mai, USDA Forest Service, Forest Health Protection, McClellan, CA.

[4] Personal communication, R.Ladd Livingston, Idaho Department of Lands, Coeur d'Alene, ID.

[5] Personal communication, Keith Sprengel, USDA Forest Service, Pacific Northwest Region, Sandy, OR.

4. Conclusions

Tree mortality and damage to foliage caused by forest insects and diseases is highly visible and can be mapped using some remote sensing technologies, the most common being aerial sketchmapping, which is done annually over most forested areas in the western United States. The characteristics, or aerial signatures, of much of the damage observed can provide clues to the causal agent(s) responsible for the damage. Using aerial signatures to identify these causal agents requires the observer to have both a working knowledge of both the characteristics of the affected host trees and the pattern of damage.

The information presented in this guide can help aerial sketchmappers identify the more common causal agents responsible for forest damage in the western U.S. Some causal agents, such as mountain pine beetle in lodgepole pine, or Douglas-fir beetle, have aerial signatures which allow for reasonably reliable identification. Other aerial signatures, such as those of bark beetles in ponderosa pine and certain forest defoliators, are more difficult to diagnose. In some cases, in order to identify the causal agent(s), an observer must consider not only the aerial signatures, but also data from previous surveys and historical records. In other cases, reliable identification can be done only through supplemental ground checks. Time and accessibility to remote forest areas can limit both the amount and the quality of the ground checks; however, to the extent possible ground checks should supplement aerial surveys, especially if new or unfamiliar damage signatures are observed.

Tables

Table 1. Crown characteristics of commonly occurring conifers in western forests 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
Ponderosa pine, Jeffrey pine, Coulter pine	Yellow-green	Broadly rounded	Sinuate	Indistinct	Small clumps
Lodgepole pine	Olive-green	Narrowly rounded	Sinuate	Indistinct	Very small clumps
Western white and sugar pines	Blue-green	Broadly rounded	Lobed	Indistinct	Fine
Limber pine and whitebark pine	Blue-green to gray-green	Broadly rounded	Lobed	Indistinct	Fine
Colorado bristlecone pine	Olive green	Broadly rounded	Lobed	Indistinct	Fine
Piñon pine	Dark green	Broadly rounded	Serrate	Indistinct	Small clumps
Douglas-fir	Gray-green to medium green	Acute	Sinuate to lobed	Indistinct (young trees) Distinct (old trees)	Variable
Blue spruce	Blue-green	Acute	Serrate	Layered	Fine-medium

* Based on data from Ciesla and Hoppas (1990), Croft et al. (1982) and author's experience.

Table 1, *continued*. Crown characteristics of commonly occurring conifers in western forests 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
Engelmann spruce	Gray-green	Acuminate –acute	Serrate	Layered	Fine-medium
Grand fir	Green	Acute	Serrate	Layered	Fine
White fir	Blue-green	Acute	Serrate	Layered	Fine
Subalpine fir	Dark green to dark blue-green	Acuminate	Finely serrate	Layered	Fine
Western larch	Light green	Acute to narrowly rounded	Lobed	Distinct scraggly branches	Fine
Western hemlock	Dark green	Acute	Lobed-parted	Distinct "wheelspoke"	Fine
Port Orford cedar	Yellow-green	Broadly rounded	Sinuate	Indistinct	Lacey, transparent
Junipers	Gray-green, blue-green or dark green**	Broadly rounded	Entire to sinuate	Indistinct	Fine

* Based on data from Ciesla and Hoppas (1990), Croft et al. (1982) and author's experience

** Juniper cones are typically blue: Heavy cone crops can give trees a blue cast regardless of folia color.

Table 2. Characteristics of aerial signatures of tree mortality caused by bark beetles in western pines.

Host tree	Foliage color of current year's faders	Bark beetle	Mortality pattern	Other characteristics	Areas where insect is an important pest
Ponderosa pine	Yellow-green to straw yellow	Mountain pine beetle	Scattered in young stands (± 60 years), group kills in older stands.		CO, ID, MT, OR, SD, UT, WA, WY
		Western pine beetle*	Scattered in young stands, group kills in older stands.		AZ, CA, CO, OR, WA
		Roundheaded pine beetle	Scattered or small group kills.		AZ, NM, UT
		Ips engraver beetles	Scattered or small group kills (<50 trees).	Top kill may be evident in large trees.	West-wide

* Also attacks Coulter pine in California

Table 2 , *continued*. Characteristics of aerial signatures of tree mortality caused by bark beetles in western pines.

Host tree	Foliage color of current year's faders	Bark beetle	Mortality pattern	Other characteristics	Areas where insect is an important pest
Jeffrey pine	Yellow-green to straw yellow	Jeffrey pine beetle and/or ips engraver beetles	Scattered or small group kills.	Top kill by ips engraver beetles may be evident in large trees.	CA, western NV
Lodgepole pine	Red-orange	Mountain pine beetle	Small group kills and or scattered mortality over large areas.	Trees with large crown diameters attacked.	West-wide throughout range of host.
		Ips engraver beetles	Distinct groups of 10-50 trees.	Attacks occur in pole sized stands.	West-wide throughout range of host.
White or soft pines	Red-orange	Mountain pine beetle and/or Ips engraver beetles*	Small group kills and/or scattered mortality.		West-wide throughout range of host.
Piñon pine	Orange-brown	Piñon ips	Small group kills and/or scattered mortality.		AZ, CA, CO, NM, NV, UT

* White pine blister rust, caused by the fungus *Cronartium ribicola*, can also cause partial to complete tree mortality.

Table 3. Characteristics of aerial signatures of tree mortality caused by bark beetles in Douglas-fir, spruce and true fir.

Host tree	Foliage color of current year's faders	Bark beetle	Mortality pattern	Other characteristics	Areas where insect is an important pest
Douglas-fir	Pale green to red. Crown color of individual trees can vary more or less randomly within a spot.	Douglas-fir beetle	Group kills of 10 to 200 trees	Attacks occur in large trees, often on steep slopes. Rates of fading between trees in a spot may vary due to level of root disease infection.	West-wide throughout range of host.
	Red	Douglas-fir engraver beetles	Single trees or small groups of up to 10 trees.	Attacks occur in pole-sized trees. Top kill may be evident.	West-wide throughout range of host.
Spruce	Yellow-green progressing to dark brown. Some needles may drop from trees while still green.	Spruce beetle	Extensive mortality over large areas.	Large, mature trees are attacked.	West-wide throughout range of host.
	Yellow-brown	Blue spruce engraver	Single trees or group kills of 2-40 trees.	Attacks occur in riparian areas.	CO, UT, WY

Table 3, *continued*. Characteristics of aerial signatures of tree mortality caused by bark beetles in Douglas-fir, spruce and true fir.

Host tree	Foliage color of current year's faders	Bark beetle	Mortality pattern	Other characteristics	Areas where insect is an important pest
Grand, red and white fir	Orange to red-orange	Fir engraver	Scattered trees or groups of 5 to 100 trees.	Top kill may be evident.	West wide throughout range of hosts.
Subalpine fir	Red	Western balsam bark beetle	Scattered trees or groups of up to 200 trees.	Attacks occur in high elevation forests Spire-like crown form of host is easily identified.	West-wide throughout range of host.
Pacific silver fir	Red	Silver fir beetle	Scattered trees or groups of up to 200 trees.	Spire-like crown form of host is easily identified.	Western slope of Cascades in OR and WA

Table 4. Common foliage feeding insects in the western United States that can cause damage to pines visible from aircraft.

Common name	Scientific name	Primary hosts affected	States where outbreaks have occurred*
Jack pine budworm	*Choristoneura pinus*	Jack pine (plantations)	NE
Lodgepole needle miner	*Coleotechnites milleri*	Lodgepole pine	CA (Yosemite National Park)
Pandora moth**	*Coloradia pandora*	Ponderosa pine, Jeffrey pine, lodgepole pine	AZ, CA, CO, OR, UT, WY
Pine butterfly	*Neophasia menapia*	Ponderosa pine, lodgepole pine	CO, ID, MT, OR, WA
Pine looper	*Phaeoura mexicanaria*	Ponderosa pine	MT
Pine sawflies	*Neodiprion* spp.	Ponderosa pine, lodgepole pine, piñon pine (Also true fir, western hemlock)	Westwide
	Zaodiprion spp.	Piñon pine, ponderosa pine	Southwest and central Rockies
Pine tussock moth	*Paraorgyia grisefacta*	Ponderosa pine	MT, NE, WY***
Western pine budworm	*Choristoneura lambertiana*	Lodgepole pine, sugar pine	CA, ID, MT

*Sources: Dewey et al. (1972), Furniss and Carolin (1977)

** Pandora moth has only one generation every two years: Therefore, new defoliation within a given population or outbreak is visible from the air only every other year.

*** Personal communication, Bill Schaupp, USDA Forest Service, Rocky Mountain Region, Rapid City, SD.

Table 5. Examples of common foliage feeding insects of broadleaf forests that can cause defoliation in the western United States visible from aircraft.

Common name	Scientific name	Hosts affected	Occurrence of peak damage	Occurrence of tents	Regions where outbreaks have occurred*
California oakworm	*Phryganidia californica*	California live oak, California white oak, golden chinkapin	Mid-late summer.*	No	CA, southern OR
Fall webworm	*Hyphantria cunea*	Various species	Mid-late summer	Yes	Westwide
Fruit tree leaf roller	*Archips argyrospilus*	Oaks, fruit trees	Early summer	No	CA
Forest tent caterpillar	*Malacosoma disstria*	Alder, birch, aspen, willow, other species	Early summer	No	West-wide
Large aspen tortrix	*Choristoneura conflictana*	Aspen	Early summer	No	West-wide
Satin Moth**	*Leucoma salicis*	Poplar, willow	Early summer	No	CA, OR, WA, WY

*This insect has 2-3 generations/year. Therefore, occurrence of defoliation can vary with location.
**Introduced species. Source: Furniss and Carolin (1977)

Table 5, *continued*. Examples of common foliage feeding insects of broadleaf forests that can cause defoliation in the western United States visible from aircraft.

Common name	Scientific name	Hosts affected	Occurrence of peak damage	Occurrence of tents	Regions where outbreaks have occurred*
Western tent caterpillar	*Malacosoma californicum*	Alder, aspen, birch, *Ceanothus*, cherry, oaks, poplar, willow	Early summer	Yes	West-wide (six subspecies recognized)
Southwestern tent caterpillar	*Malacosoma incurvarum*	Poplar, willow	Early summer	Yes	Southwest
Variable oak leaf caterpillar	*Lochmaeus manteo*	Oaks, other species	Late summer	No	Northern Great Plains

* Introduced species. Source: Furniss and Carolin (1977)

Figures

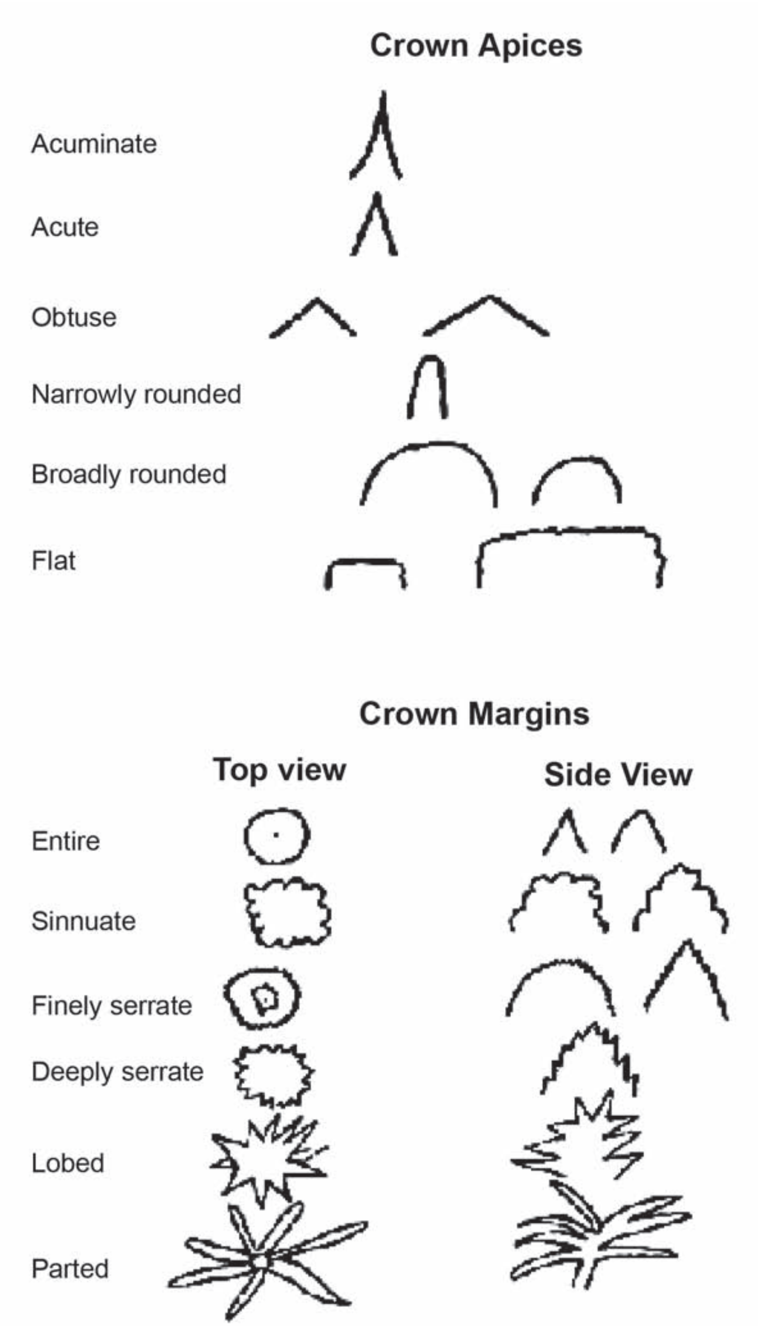

Figure 1. Descriptors of tree crowns used to aid identificaton of tree species and species groups on large-scale vertical aerial photos (Source: Heller et al. 1964).

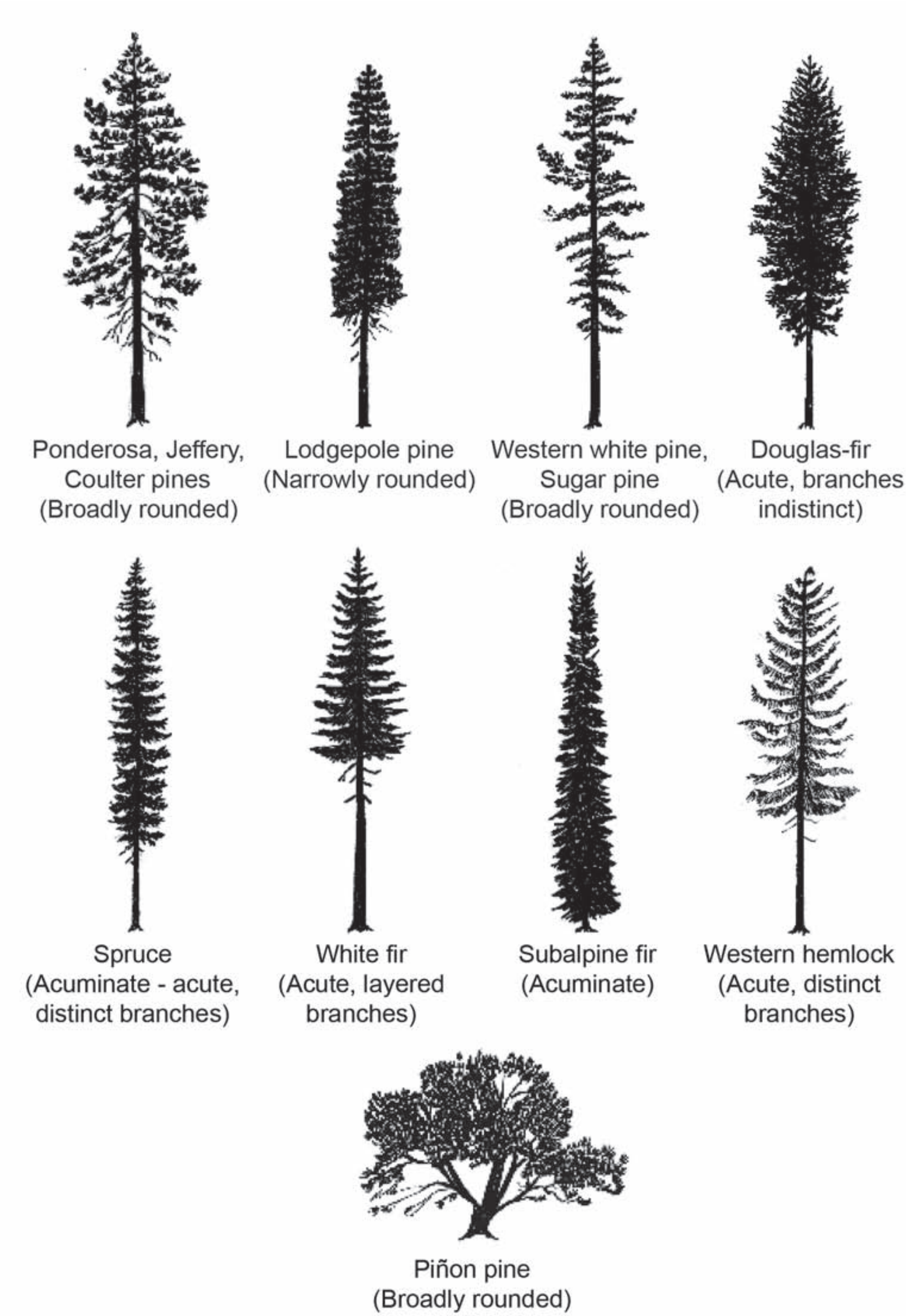

Figure 2. Typical crown shapes of common western conifers.

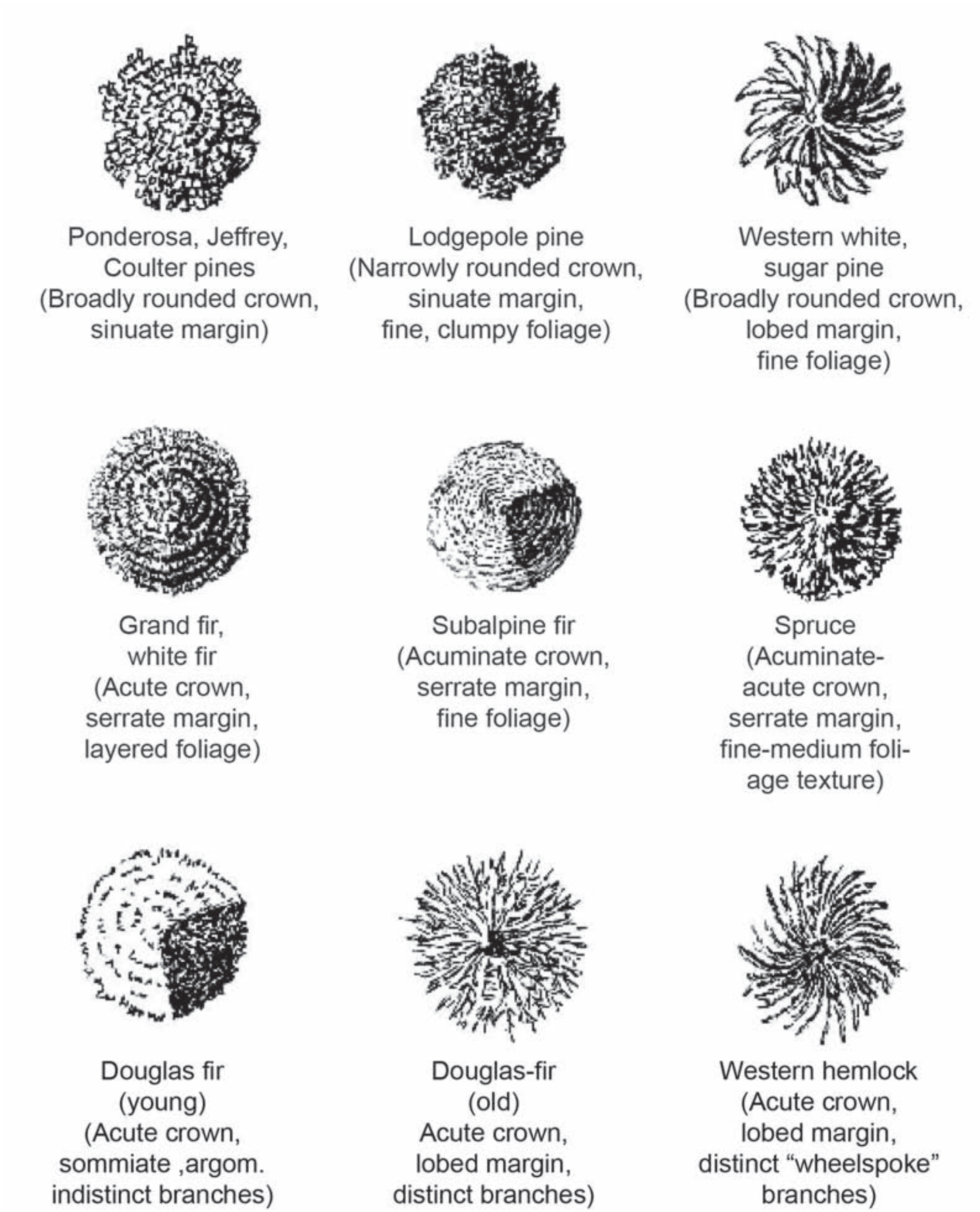

Figure 3. Vertical view of crown margins, branch patterns and foliage textures of several western conifers.

Figure 4. Mixed lodgepole pine and ponderosa pine forest attacked by mountain pine beetle. Red-orange faders with narrow crowns are lodgepole pines and yellow-green to yellow-orange faders with broader crowns are ponderosa pines. Glacier National Park, MT.

Figure 5. Top kill in ponderosa pine caused by pine engraver beetle attack. Warm Springs Indian Reservation, OR.

Figure 6. Douglas-fir tussock moth infestation mid July 2004. Feeding is still underway and only the upper crowns are defoliated. Doublehead Mountain near Aspen Park, CO.

Figure 7. Same Douglas fir tussock moth infestation as shown in Figure 7, but in mid September 2004, after feeding is completed. Most of the affected trees are completely defoliated as indicated by the thin gray-brown colored crowns.

Figure 8. Fall coloring of quaking aspen can mask ponderosa pines faders due to mountain pine beetle attack. Pike National Forest, CO.

Figure 9. Fall coloring of western larch. Kootenai National Forest, MT.

Figure 10. Fall needle cast of western red cedar can resemble foliage fading from bark beetle attack. Kaniksu National Forest, ID.

Figure 11. Ponderosa pines in the early stages of fading due to mountain pine beetle attack. Roosevelt National Forest, CO.

Figure 12. Tree mortality by mountain pine beetle in ponderosa pine. Yellow-green to yellow-orange faders were attacked during the previous growing season. Trees with red-brown foliage are two–year-old attacks. Black Hills National Forest, SD.

Figure 13. Scattered tree mortality and small group kills by mountain pine beetle in ± 60 year old ponderosa pine stand. Lolo National Forest, MT.

Figure 14. Large ponderosa pines killed by a combination of western pine beetle and the ips engraver beetle, *Ips paraconfusus*. Rubicon River Basin, CA.

Figure 15. Top kill in ponderosa pine caused by the ips engraver beetle, *Ips paraconfusus*. Eldorado National Forest, CA.

Figure 16. Scattered tree mortality in ponderosa pine forest, indicative of ips engraver beetle attacks. Rio Grande National Forest, CO.

Figure 17. Groups of tree mortality in pine forests. The trees are probably Jeffrey pine attacked by Jeffrey pine beetle with ips engraver beetles in the upper crown. Near Arrowhead Lake, San Bernardino National Forest, CA. (Photo: Jeffrey Mai, USDA Forest Service, Pacific Southwest Region, Sacramento, CA.)

Figure 18. Faders in a Jeffrey pine plantation. The small tree size suggests damage by ips engraver beetles. Sequoia National Forest, CA. (Photo by Jeffrey Mai, USDA Forest Service, Pacific Southwest Region, Sacramento, CA.)

Figure 19. Lodgepole pines attacked by mountain pine beetle in the early stages of fading. Roosevelt National Forest, CO.

Figure 20. Small groups of dead and dying lodgepole pines due to mountain pine beetle. Near Willow Creek Pass, Routt National Forest, CO.

Figure 21. Extensive mortality of lodgepole pine caused by mountain pine beetle. Glacier National Park, MT.

Figure 22. Groups of pole-sized lodgepole pines killed by ips engraver beetle. Near Conifer, CO.

Figure 23. Limber pines probably killed by ips engraver beetles, mountain pine beetle and white pine blister rust. Ferris Mountains, WY.

Figure 24 . Mountain pine beetle attacks in limber pines and lodgepole pines. Faders with broadly rounded crowns near photo center are limber pines. Faders with narrowly rounded crowns in upper and far right of photo are lodgepole pines. Near Nederland, CO.

Figure 25. Small group kill in piñon pine caused by the piñon ips, *Ips confusus*. Rio Grande National Forest, CO.

Figure 26. Scattered tree mortality in piñon pine caused by the piñon ips, *Ips confusus*. La Garita Creek, BLM lands, CO.

Figure 27. Heavy damage to twigs of piñon pine by twig beetles of the genus *Pityophthorus*. Note green foliage in the interior crown. Near Durango, CO.

Figure 28. Douglas-fir beetle spot. Note variation in foliage color and needle retention among adjacent trees. Nezperce National Forest, ID.

Figure 29. Scattered Douglas-fir faders attacked by Douglas-fir beetle following defoliation by western spruce budworm. Rio Grande National Forest, CO.

Figure 30. Engelmann spruce in various stages of fading due to spruce beetle attack. Red Mountain, Rio Grande National Forest, CO.

Figure 31. Tree mortality in Engelmann spruce caused by spruce beetle. Weminuchee Wilderness, San Juan National Forest, CO.

Figure 32. Blue spruce growing in a riparian zone killed by the blue spruce engraver beetle, *Ips hunteri*. Near Bailey, CO.

Figure 33. Tree mortality in grand fir caused by fir engraver beetle. Nezperce National Forest, ID.

Figure 34. Tree mortality in white fir caused by fir engraver beetle. San Juan National Forest, CO.

Figure 35. Top kill in white fir caused by fir engraver beetle on the eastern slope. Wet Mountains, CO.

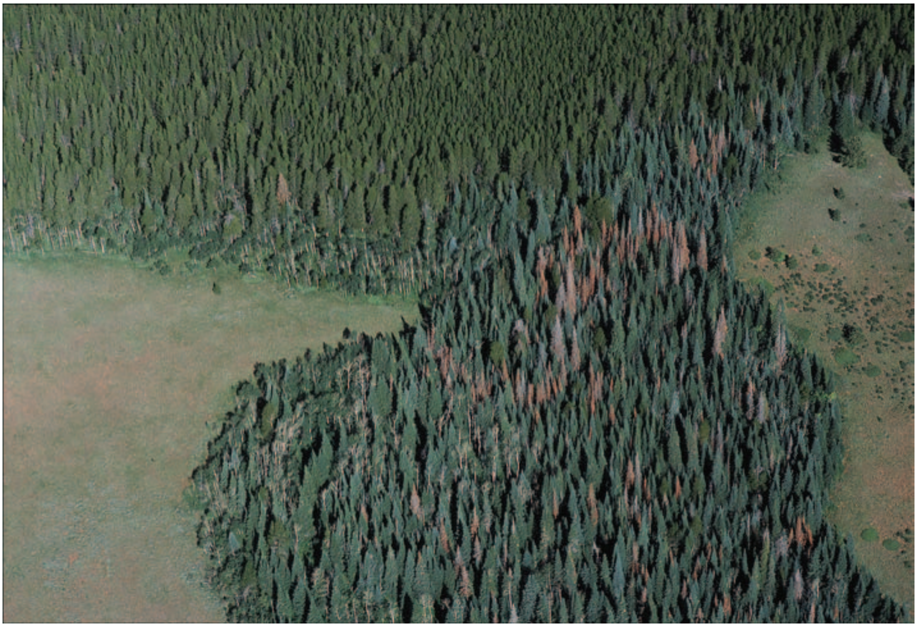

Figure 36. Mortality of subalpine fir probably caused by root disease and western balsam bark beetle (subalpine fir decline). BLM lands, Bull Mountain, northern CO.

Figure 37. Feeding damage on new growth of grand fir by western spruce budworm. Mount Hood National Forest, OR.

Figure 38. Subalpine fir defoliated by western spruce budworm during the early stages of an outbreak. Note red brown "halo" of defoliation of new foliage against green backdrop of undamaged foliage. Near Lolo Pass, Clearwater National Forest, ID.

Figure 39. Extensive defoliation of a mixed Douglas-fir/true fir forest by western spruce budworm. Santiam Pass, Deschutes National Forest, OR.

Figure 40. Defoliation by western spruce budworm during the later stages of an outbreak. High Rocks area, Mt. Hood National Forest, OR.

Figure 41. Mixed Douglas-fir/grand fir forest defoliated by the Douglas-fir tussock moth. Near Potlatch, ID.

Figure 42. Intense, localized patch of defoliation by Douglas-fir tussock moth in a pure Douglas-fir forest. Flathead Indian Reservation, MT.

Figure 43. Defoliation of western larch by larch casebearer. Near Moscow Mountain, ID.

Figure 44. Open ponderosa pine forest with patches of defoliation caused by pine butterfly. Bitterroot National Forest, MT.

Figure 45. Defoliation of ponderosa pine by a pine looper, *Phaeoura mexicanaria*. Northern Cheyenne Indian Reservation, MT.

Figure 46. Damage to lodgepole pine by lodgepole needle miner. Tuolomne Meadows, Yosemite National Park, CA.

Figure 47. Defoliation of ponderosa pine by Pandora moth. Deschutes National Forest, OR.

Figure 48. Quaking aspen with heavy defoliation caused by large aspen tortrix. Near Willow, AK.

Figure 49. Late summer defoliation of basswood and other broadleaf trees by variable oak leaf caterpillar. Devils Lake, ND.

Figure 50. Tents and defoliation of cottonwood caused by the southwestern tent caterpillar. Grand Staircase-Escalante National Monument, UT.

Figure 51. Conspicuous tents and defoliation of cottonwoods by the fall webworm. Near Westcliff, CO.

Figure 52. Subalpine fir killed by balsam woolly adelgid. Lewis County, ID. (Photo by David Beckman, Idaho Department of Lands, Coeur d'Alene, ID).

Figure 53. Black colored lichens of the genus *Bryoria* growing on branches of a grand fir. Malheur National Forest, OR.

Figure 54. Declining subalpine fir with a black cast due to heavy populations of lichens of the genus *Bryoria*. This signature is indicative of the occurrence of balsam woolly adelgid infestations. Oregon. (Photo by Michael McWilliams, Oregon State Department of Forestry, Salem, OR.)

Figure 55. Sitka spruce damaged by spruce aphid. Western Oregon (Photo by Michael McWilliams, Oregon State Department of Forestry, Salem, OR.

Figure 56. Foliage discoloration of western larch due to infection by a needle fungus. Wallowa Whitman National Forest, OR.

Figure 57. Roughly circular openings in the canopy are caused by the root fungus, *Phellinus weirii*. Susceptible species, (i.e., Douglas-fir) have been killed. Live trees in centers are less-susceptible species. Western Oregon. (Photo by Michael McWilliams, Oregon State Dept. of Forestry, Salem, OR.)

Figure 58. Port Orford cedar faders intermixed with trees killed by Port Orford cedar root disease. Southwestern Oregon. (Photo by Michael McWilliams, Oregon State Department of Forestry, Salem, OR

Figure 59. Foliage discoloration of Douglas-fir caused by Swiss needle cast disease. Near Tillamook, OR. (Photo by Michael McWilliams, Oregon State Department of Forestry, Salem, OR)

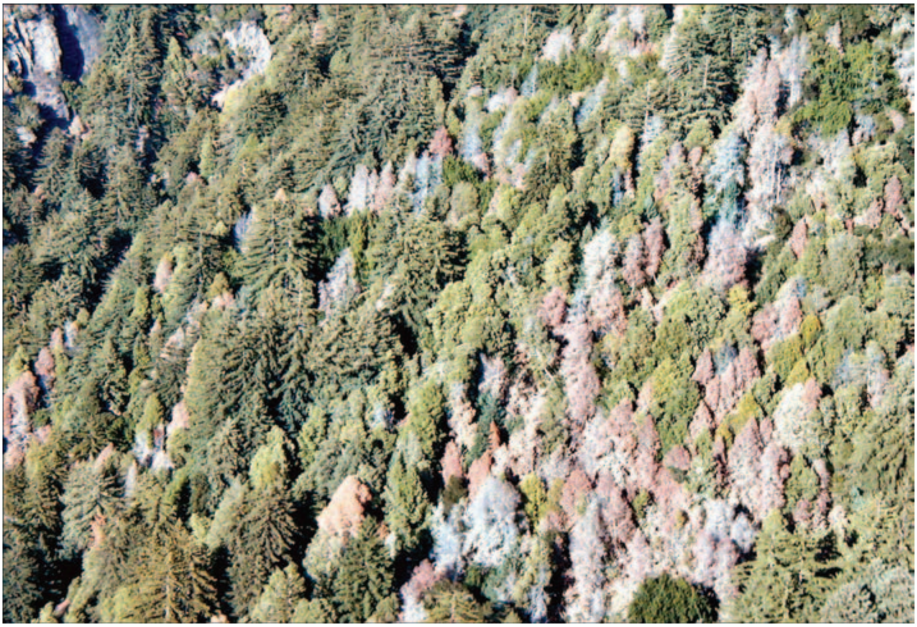

Figure 60. Mortality of tanoak and other broadleaf species indicative of sudden oak death. Los Padres National Forest, CA. (Photo by Susan J. Frankell, USDA Forest Service, Pacific Southwest Region, Vallejo, CA).

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Figure 62. Fading of scattered Douglas-fir, suggestive of bear damage. Near Tillamook, OR (Photos by Michael McWilliams and Alan Kanaskie, Oregon State Department of Forestry, Salem, OR).

Figure 63. Fading of scattered Douglas-fir, suggestive of bear damage. Near Tillamook, OR (Photos by Michael McWilliams and Alan Kanaskie, Oregon State Department of Forestry, Salem, OR).

Figure 64. Row of dying ponderosa pines adjacent to a road, probably due to the application of deicing chemicals. Near Boulder, CO.

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