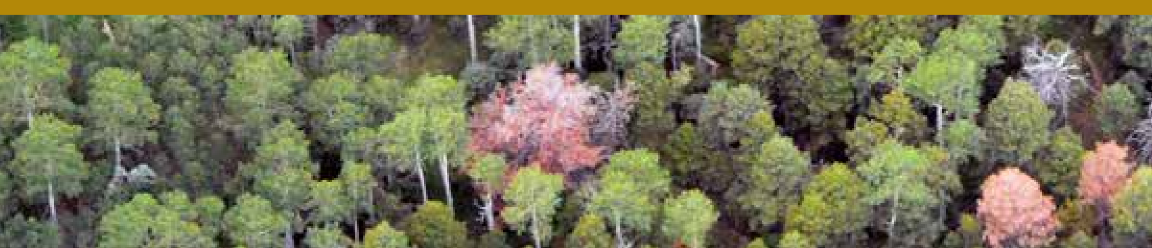
Aerial Signatures of Forest Damage in Colorado and Adjoining States

William M. Ciesla, S. Sky Stephens,
Brian E. Howell and Justin C. Backsen



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Preface

“Aerial Signatures of Forest Damage in Colorado and Adjoining States” is a revision and update of the USDA Forest Service, Forest Health Technology Enterprise Team (FHTET), publication FHTET-01-06 “Aerial Signatures of Forest Insect and Disease Damage in the Western United States” (Ciesla 2006).

This revision focuses on aerial signatures of forest damage in Colorado and other states that comprise the Rocky Mountain Region of the USDA Forest Service (R-2). However, since the basic principles of aerial identification of affected host trees and damage patterns addressed in this manual are more or less standard, it also should serve as a reference for aerial forest health survey teams working in portions of the Northern Region (R-1), Southwestern Region (R-3) and Intermountain Region (R-4), as well as portions of California (R-5) and eastern Oregon and Washington (R-6).

The material presented in this publication reflects the experiences of the team of authors since the original aerial signatures manual was published (2006-2014). The authors have more than 75 years of combined experience conducting aerial forest health surveys. Included are refined descriptions of many of the “classic” aerial signatures under both endemic and epidemic conditions, as well as descriptions of additional damage signatures encountered in the Rocky Mountain Region. A discussion of the history and future direction of aerial forest health detection surveys and their unique challenges also is included.

Acknowledgments

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We dedicate this manual to the pilots who fly aerial forest health surveys. They are highly skilled, precise and safe pilots. Aerial forest health observers could not do their job without the expertise and support of these pilots.

Photo Credits

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* (i) denotes insert

Cover photo: Douglas-fir beetle infestation near Ouray, Colo., ***W. M. Ciesla***

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Introduction

Colorado's forests, as well as those of neighboring states in the Rocky Mountain West, are subject to damage by a wide range of insects, diseases and other disturbances. Damage caused by many of these agents, especially those that kill trees or damage foliage, is visible from long distances and therefore can be detected and mapped via several remote-sensing technologies.

The most common technique for the mapping and assessment of forest damage that produces aerially visible symptoms is a technique known as aerial sketchmapping, or aerial forest health detection surveys. This relatively inexpensive procedure involves the use of skilled aerial observers, representing both state forestry agencies and the USDA Forest Service, flying over forested areas in small, high-wing aircraft. They record and classify damaged areas from an average flying height of approximately 1,000 feet above the terrain at airspeeds of 100-120 mph. Damaged areas are recorded as points or polygons and labeled by causal factor(s) responsible for the damage. In many cases, damaged areas also are classified according to the intensity of damage, or an estimate of the number of affected trees is made. Aerial sketchmapping allows for large areas of remote forestland to be monitored within a short time span. A single observer doing contour flights over rugged, mountainous terrain can classify an average of 17 acres per second. Two observers flying east-west or north-south flight lines at three-mile intervals in a grid pattern over relatively level terrain can cover approximately 30 acres per second per observer.

Resultant data are analyzed, displayed, stored and made available to forest managers and the public at large. A primary use of these data is to make decisions about management actions to reduce pest impacts. In addition, data acquired during aerial forest health surveys on the status of pest outbreaks are summarized annually in national, regional and statewide reports published by state forestry agencies and the USDA Forest Service. These surveys provide an overview of forest conditions, information for planning and execution of pest management activities, and a historical record of the status and trend of important forest pests (Ciesla 2000, McConnell et al. 2000).

Small aircraft have been used for many years to detect and assess forest damage. During the early 1920s, open cockpit aircraft were used in Canada to map defoliation caused by spruce budworm *(Choristoneura fumiferana),* (Swaine 1921). Several years later, bi-wing aircraft were used to map bark beetle damage in California (Furniss and Wickman 1998). There also are early records of aerial surveys being flown in the Black Hills (Heller et al. 1952) and Yellowstone National Park (Furniss and Renkin 2003). The passage of the Forest Pest Control Act of 1947 authorized the USDA to conduct surveys for forest insect and disease damage. This legislation, coupled with the availability of a large number of military-trained pilots, led to the development of systematic aerial surveys for mapping of forest damage. In the Pacific Northwest, aerial forest insect and disease surveys have been conducted annually since 1947, and guidelines for their conduct were published in 1955 (Johnson 1995, Wear and Buckhorn 1955). Research designed to develop mapping standards and observation limits for aerial sketchmapping was conducted by USDA Forest Service units based in Beltsville, Md., and Portland, Ore.

Initially, locations of damaged areas were “sketched” as points or polygons on paper maps, generally at a map scale of around 1:100,000. When the survey was completed, the location data were inked and area of damage was determined using such tools as planimeters or dot grids. The inked paper maps were archived for future reference. Recently, many of the archived maps were converted to digital format.

Data presently are recorded by aerial observers using touch-screen computers equipped with mapping software. The computers are interfaced with a Global Positioning System (GPS) receiver that displays the position of the survey aircraft on the computer screen. Resultant data are entered into a Geographic Information System (GIS) that computes area of damage by causal agent(s), stores the data and produces maps showing location of damaged areas. These maps can be available within a short time after a survey area is completed. Methods for collecting data on the status of forest insect and disease pests could change dramatically in the future as new technologies become available.

Certain characteristics of forest damage, when seen from survey aircraft, allow aerial observers to identify the insect, disease or other causal agent(s) responsible for the damage with reasonable accuracy. Ability to recognize these characteristics, or **signatures**, is critical to the success of aerial forest health surveys. The purpose of this publication is to describe aerial signatures of forest damage in Colorado and neighboring states in the Rocky Mountains, and is intended for use as a training and reference guide by both beginning and experienced aerial observers.

1. AERIAL SIGNATURES – AN OVERVIEW

What Are Signatures?

Signatures are signals that consist of one or more unique characteristics, which can be used to identify something such as an object, a person, etc. The classic “signature” is a person’s name, written in his or her own handwriting. Everyone’s handwriting is unique. Whether legible or illegible, people can be identified by their handwriting, and their signature on an agreement or contract is legally binding. Another example of a signature is the theme music played at the beginning of a television show. The tempo and melody of the music, typically composed especially for that show, allow it to be identified. In the context of forest entomology, galleries engraved by bark beetles in the cambium and inner bark of host trees often are referred to as signatures. The galleries, and the host tree attacked, usually are sufficient to permit identification of the bark beetle to at least genus level and sometimes to species.

Aerial signatures of forest damage caused by insects, disease and other factors generally are defined by two parameters: the crown characteristics of the trees affected and the appearance of the damage. This manual provides a two-step approach to aerial identification of forest damage signatures:

- Characteristics of host trees
- Characterization of the damage

Characteristics of Host Trees

Biotic agents that cause tree and forest damage, such as insects, fungi or parasitic plants, 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 the first step in recognizing forest damage signatures. The complex of potential damaging agents that could be present can be narrowed down by identification of tree species and forest types present over the areas flown. 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 vertical aerial photographs are a combination of **foliage color, crown form, crown margin, branch patterns** and **foliage texture** (Table 1, Fig. 1). These characteristics also can be readily seen by aerial observers who are looking at the forest from an oblique view. Several guides have been published on identification of tree species and forest cover types on large-scale vertical aerial photographs (Heller et al. 1959, Sayn-Wittgenstein 1978). At least two guides are available to aid in tree species identification using large-scale, full-color vertical aerial photos in Western forests (Ciesla and Hoppus 1990, Croft et al. 1982).

Foliage Color

Undoubtedly, the most notable characteristic of tree crowns when seen by aerial observers during aerial forest health surveys is foliage color. Most conifers have foliage in various hues of dark green. The foliage of subalpine fir (*Abies lasiocarpa*) and corkbark fir (*A. lasiocarpa* var. *arizonica*) is significantly darker green than other conifers. Douglas-fir (*Pseudotsuga menzeisii*) has medium to dark green foliage, while ponderosa pine (*Pinus ponderosa*) has a yellow-green foliage color. The foliage of several species or species groups of conifers have a blue-green or blue cast. Most white or soft pines (e.g., limber pine [*Pinus flexilis*]) indigenous to the Rocky Mountain West, for example, have foliage color in varying hues of blue-green. The foliage of blue spruce (*Picea pungens*), white fir (*Abies concolor*) and Rocky Mountain juniper (*Juniperus scopulorum*) also has a distinct blue cast. The foliage of most deciduous broadleaf trees is lighter in color than that of conifers.

Crown Shape

Overall crown form is another characteristic helpful for identification of tree species or species groups during aerial forest health surveys. Tree crowns can be acuminate or spire-like (subalpine fir), acute (Douglas-fir, grand fir, white fir, spruce), narrowly rounded (lodgepole pine), rounded (ponderosa pine) or broadly rounded (junipers, most broadleaf species). 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, Table 1, Fig. 2) and can be used to aid in tree identification during aerial forest health 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 apex tends to flatten, as is the case with mature Douglas-fir (Fig. 3).

Crown Margin

The outer margin of a tree crown, when seen vertically or from an oblique angle, may be sinuate, serrate or entire, as is the case with most of the yellow or hard pines, Douglas-fir, true fir or spruce. The crown margin of most white or soft pines, on the other hand, is deeply lobed (Fig. 3). Crown margins are most easily seen in open forests where trees of interest are not obscured by neighboring trees (Ciesla 1990).

Branch Pattern

Some conifers, such as blue spruce and Engelmann spruce (*Picea engelmannii*), have distinct branches when viewed from low-flying aircraft. Others, such as subalpine/corkbark fir and young Douglas-fir have less distinct branches. Branches of white fir (*Abies concolor*) and grand fir (*A. grandis*) tend to occur in distinct layers. Branching pattern can vary with tree age. Branches on large, old Douglas-fir, for example, tend to be more distinct than on younger trees of the same species (Fig. 3, Ciesla and Hoppus 1990).

Foliage Texture

Another characteristic helpful in aerial identification of tree species or species groups is foliage texture. Foliage of most yellow or hard pines has a clumped appearance. Ponderosa pine, which has relatively long needles, has notably clumped foliage. Foliage of lodgepole pine, which has shorter needles, has less of a clumped texture (Fig. 3). Among broadleaf species, Gambel oak (*Quercus gambelii*) has a coarse foliage texture, whereas quaking aspen (*Populus tremuloides*) foliage is finely textured.

Landscape Features

Location of tree species and forest types relative to certain landscape features, especially elevation, aspect and proximity to drainages, also provides clues to their identity, which often are helpful in their identification during aerial forest health surveys.

Throughout the West, most trees are distributed according to elevation and aspect. In northern Colorado, for example, woodlands of Rocky Mountain juniper are the first trees encountered at an elevation of approximately 6,500 feet. Juniper woodlands transition into forests of ponderosa pine and Douglas-fir as elevation increases. At roughly 8,000 feet, lodgepole pine becomes the dominant tree, interspersed with small stands of limber pine; above approximately 9,500 feet, subalpine fir and Engelmann spruce become the dominant species (Fig. 4A). In southern Colorado, low elevations (around 7,000 feet) are dominated by woodlands of pinyon pine and juniper (Fig. 4B). These transition into forests of ponderosa pine at around 7,500 feet and then mixed conifer forests of ponderosa pine, white fir and Douglas-fir. Beginning at elevations of approximately 9,200 feet, subalpine/corkbark fir and Engelmann spruce are the dominant trees. In high-elevation spruce-fir forests throughout Colorado, the proportion of Engelmann spruce gradually increases with increased elevation. From around 10,500 to 11,000 feet, which is roughly timberline, the forest is comprised of nearly pure stands of this species interspersed with small stands of five-needle (limber and bristlecone) pines (Fig. 4A-B). In Idaho, Montana and Wyoming, limber pine tends to occur at lower elevations than in Colorado, and whitebark pine (*Pinus albicaulis*) becomes the dominant five-needle pine at high elevations. Quaking aspen, the region's most abundant broadleaf tree, is found in all but the highest elevation zones.

At any given elevation zone, aspect can define the species present. In Colorado, low- to mid-elevation, south-facing slopes usually are occupied by open stands of ponderosa pine, while north-facing slopes at the same elevation, with cooler, moister microclimates, may be dominated by denser stands of species, such as Douglas-fir and white fir.

Proximity to water is another factor that can aid in tree species identification. Trees, such as Colorado blue spruce, cottonwoods (*Populus* spp.) and willows (*Salix* spp.), typically are found in riparian areas. Both Colorado blue spruce and white fir have a blue cast to their foliage and acute crown shapes. In many areas, Colorado blue spruce is found in stream bottoms and white fir on adjacent upland slopes; however, there are exceptions. At the lower elevation limits of white fir, it also can be confined to cool, moist microclimates typical of riparian areas.

Characteristics of Forest Damage

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

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

Some damage signatures may consist of more than one damage class. For example, the larvae of some conifer-defoliating insects, such as western spruce budworm, partially feed on or clip the needles from branches, which are trapped in silken webbing produced by the larvae. Affected needles turn red-brown, which is aerially visible during outbreaks. The damage signature is a combination of **defoliation** and **discoloration** and would be classified by an experienced observer as defoliation. Similarly, tree mortality caused by bark beetles first appears as **fading** or **discolored** foliage. Because the objective of aerial forest health surveys, in this example, is to detect areas of active bark beetle infestation, the trees with fading foliage are mapped. Therefore, the distinctive foliage **discoloration** caused by bark beetle-induced mortality is the characteristic mapped in areas affected by bark beetle outbreaks. Some bark beetles, such as ips engraver beetles or fir engraver, can cause both **top-kill** and **mortality** during outbreaks.

Defoliation

Defoliation consists of either partial or complete removal of foliage. Insects are the most common cause, but defoliation also can be caused by foliage diseases, high winds, hail or late spring frost. Aerial signatures of tree defoliation typically consist of thinning tree crowns, which gives affected forests a gray cast. As mentioned in the preceding section, feeding by insects, especially some conifer defoliators, causes partially damaged foliage, which turns red-brown, and the characteristic signature is a combination of thin crowns and discolored foliage. Broadleaf defoliating insects, such as western tent caterpillar, large aspen tortrix or inchworms, can consume all of the foliage except the midribs and major veins, causing affected areas to have a light brown to gray cast. Refoliation of defoliated broadleaf trees can occur later in the growing season; however, the new leaves usually are smaller and may have a yellow (chlorotic) cast.

Mortality

Many damaging agents, including insects, fungi, fire, drought, flooding and mammals, can cause tree mortality. In western North America, bark beetle attacks in conifer forests are the most common cause of tree mortality mapped during aerial forest health surveys. Depending on tree species affected, foliage of conifers attacked by bark beetles changes from green to various hues of yellow, orange or red and finally brown before dropping from infested trees (Tables 2 and 3). This process is referred to as **fading**. Depending on the causal agent, tree mortality can occur in distinct groups or as a scattering of dying trees in the forest. The host trees affected, size of group kills, size of the affected trees and color of fading foliage all provide clues as to the cause of the damage.

Other causes of tree mortality mapped during aerial forest health surveys include root disease fungi, often in association with bark beetles, and climatic stresses, such as prolonged drought or inundation.

Discoloration

Discoloration is defined as tree crown foliage that is any color but the host tree's characteristic green when healthy. Agents that can alter foliage color include needle or leaf-mining insects, fungi that attack foliage, late spring frost, hail and herbicides or other chemicals. The foliage color and location and pattern of damage can provide clues to the cause of the damage. In mountainous terrain, damage by late spring frosts can be found at high elevations or in low-lying areas or "frost pockets." Herbicide damage often is found adjacent to roads, utility rights-of-way, agricultural fields where weed or brush control has been done, or in areas of low woody vegetation (e.g., Gambel oak) for range improvement. Trees with yellow or yellow-green (chlorotic) foliage often indicate deficiencies in soil nutrients, such as iron (iron chlorosis) or magnesium. Heavy cone crops in some conifers, especially spruce, can cause tree crowns to appear discolored.

Dieback

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

Top-Kill

Top-kill is a condition in which the upper quarter, third or half of a tree's crown, including the terminal and all associated branches, dies. Most frequently, this is the result of attack by certain species of bark beetles, especially ips engraver beetles in ponderosa pine and fir engraver in firs. Top-kill usually is difficult to see from flying heights at which aerial forest health surveys are conducted. However, top-kill may be visible on large trees, in open stands and along fire perimeters.

Branch Breakage

Branch breakage usually is caused by severe storms and is characterized by branches with white or light-colored exposed wood at their breaks. Branch breakage, by itself, usually is not detectable from aerial forest health survey flying heights, but often is associated with broken or uprooted trees.

Main Stem Broken or Uprooted

Broken or uprooted trees are the result of severe storms, such as straight-line winds (microbursts) or tornadoes. Intensity of damage may vary from areas where entire stands of trees have been windthrown, which is readily visible from aerial forest health survey flying heights, to a scattering of broken or uprooted trees within stands, which is considerably more difficult to detect.

Branch Flagging

Branch flagging consists of individual branches with either dead or discolored (fading or red) foliage, and can be caused by fungi, such as white pine blister rust (*Cronartium ribiciola*) and elytroderma needle disease (*Elytrodrema deformans*), or twig beetles or porcupines feeding on bark. This damage class often is difficult to detect from aerial forest health survey flying heights unless large numbers of dead or discolored branches occur. Branch flagging typically is overlooked in areas where a significant occurrence of other damage exists.

Classification of Intensity of Forest Damage

In addition to identification of the agent causing the damage, in some cases, aerial observers also estimate the degree or intensity of damage. Several approaches have been developed for classification of intensity of damage caused by bark beetles, diebacks and declines, and for agents that damage foliage. For most other damaging agents, drawing and coding of polygons that identify areas of "aerially visible damage" usually is sufficient.

Bark Beetles

Several methods have been used during aerial forest health surveys to classify the intensity of damage caused by bark beetles. In cases of relatively isolated infestations or where fading trees occur in fairly distinct groups, as is the case with bark beetles, such as the Douglas-fir beetle, the common protocol is to estimate the number of fading trees in the group or spot. Where a scattering of fading trees in the stand occurs, estimates have been made of numbers of fading trees per acre (TPA). It recently has been established, however, that aerial estimates of fading trees per acre in the central Rocky Mountains have been grossly conservative (Backsen and Howell 2013, Meddens et al. 2012).

In 2012 and 2013, a method used by the Canadian Forest Service to classify intensity of widespread bark beetle outbreaks

(British Columbia Ministry of Forests 2000) was slightly modified and evaluated for use by the Rocky Mountain and Southwestern regions of the USDA Forest Service. This method assigns a percent mortality class, based on the total number of stems (living and dead) in the overstory, to each infestation polygon, as follows:

Trace:	1-3% current year's faders
Light:	4-10% current year's faders
Moderate:	11-29% current year's faders
Severe:	30-50% current year's faders
Very Severe:	>50% current year's faders

This approach has several drawbacks and advantages: drawbacks – each percent class includes a range of the numbers of trees killed, and end users must adjust to the new assessment method; advantages – improved data representation, ease of use and greater consistency between aerial observers. Moreover, rough estimates of numbers of fading trees per acre can be made during the post-processing of data. A series of templates that depict the mid levels of each mortality class have been developed as a reference tool for aerial observers (Figs. 5 and 7).

Throughout the course of a bark beetle outbreak, it is possible to use both of the methods described as activity levels change. The "trace" class, for example, is helpful in mapping scattered tree mortality in declining outbreaks. Consensus among aerial survey observers and data end users regarding method of data collection, quantification and post-processing is important to ensure that national data collection standards are met.

Sudden Aspen Decline

Since approximately 2004, widespread decline and mortality of quaking aspen, referred to as sudden aspen decline (SAD), has been reported over large portions of the Rocky Mountains (see discussion on sudden aspen decline in Section 3 of this manual). The signature of SAD is easily seen during aerial forest health surveys. Intensity of damage can range from occurrence of trees with thin or discolored crowns to scattered tree mortality or nearly 100-percent tree mortality. The following three classes are used to describe intensity of damage (Fig. 8):

> **SAD with No Mortality** (R-2 code 75) – The first detectable SAD stage is characterized by trees with thin crowns or discolored foliage, but no tree mortality.
>
> **SAD with Light to Moderate Mortality** (R-2 code 75L) – Thin, discolored crowns are accompanied by individual trees devoid of foliage. More than 50% of trees have some foliage.
>
> **SAD with Heavy Mortality** (R-2 code 75H) – Crowns are thin and greater than 50% of the standing trees are devoid of foliage.

Defoliating Insects

In the central Rocky Mountains, damage by defoliating insects has simply been classified as "aerially visible defoliation." There have, however, been attempts to classify intensity of defoliation caused by western spruce budworm into three rather ill-defined classes – **light**, **moderate** and **heavy** – based on degree of foliage thinning and discoloration. Experience has shown that discoloration associated with defoliation changes relative to sun angle and becomes most conspicuous when the area being surveyed is backlit. Therefore, attempts to classify intensity of defoliation have been discontinued and all aerially visible defoliation by western spruce budworm is considered "heavy."

Other Factors that Influence Appearance of Forest Damage

Peak Occurrence of Signatures

Aerial forest health surveys should be conducted when damage signatures of interest are at their peak. This is defined by the seasonal history of the damaging agent. Failure to identify the optimum survey window could result in flying too early, before all of the damage is aerially visible (Fig. 9), or too late, when damaged foliage has been washed from trees by rains or is masked by new growth. In the Rocky Mountain West, aerial signatures of most agents that damage forests are at or near their peak during July and August and can be mapped as part of an aerial overview survey (McConnell et al. 2000).

Light and Shadow

Light and shadow can have significant effects on the ability of an aerial observer to discern subtle differences in damage signatures. During midsummer (July and August), surveys can be flown on most days from three to four hours before and after noon, weather permitting. It is best to fly east-facing slopes during the early morning hours, while they are in direct sunlight and, conversely, west-facing slopes during the afternoon. Cloud cover can reduce the amount of sunlight, but is not always detrimental. High cirrus clouds can diffuse sunlight, reducing the sharp contrasts characteristic of full sunlight and making damage signatures easier to classify. Cumulus clouds, on the other hand, can cause dark shadows interspersed with brightly lit slopes and reduce the visibility of signatures. Late afternoon thundershowers, atmospheric haze and smoke from wildfires can significantly reduce visibility and, consequently, the ability to see and classify signatures of forest damage (Fig. 10, McConnell et al. 2000).

Background Noise

At certain times of the year, phenomena may occur that mask or mimic signatures of forest damage. The classic example is fall coloration of deciduous trees in September and October. In the central and southern Rocky Mountains, the most confounding is the brilliant fall coloration associated with quaking aspen (Fig. 11) and/or Gambel oak. Spring bud burst on broadleaf trees also produces myriad colors and may mask attempts to map certain kinds of foliar injury. In addition, delayed foliage development on broadleaf trees at high elevations can be easily confused with defoliation. And heavy cone crops on some conifers, especially Engelmann spruce, can give upper crowns of trees a brown cast that resembles defoliation.

Pest Complexes

During aerial forest health surveys, most forest damage is attributed to a single causal factor, even though existing protocols allow for classification of up to three causal factors for each damage polygon (USDA Forest Service 1999). While coding for a single causal factor may be expedient, much of the damage mapped during aerial forest health surveys is the result of multiple factors. For example, two or more species of bark beetles often co-habit the same tree, with some species attacking the upper boles and others attacking the mid and/or lower boles. Bark beetles often attack groups of trees stressed by root disease. Some bark beetles also attack trees following wildfire or defoliator outbreaks.

The occurrence of more than one causal factor can influence the appearance of the damage signature. For example, conifers that have been defoliated by insects or damaged by fire and then are subsequently attacked by bark beetles will not fade to the bright colors characteristic of non-defoliated or fire-impacted trees. Trees with heavy root disease infection that are subsequently attacked by bark beetles tend to fade at faster rates than uninfected trees or trees with light infections. For example, root disease occurrence can cause a more or less random variation in foliage color and needle retention in groups of Douglas-fir killed by Douglas-fir beetle.

The complex interactions between insects, disease and other factors that affect forest health are a major challenge when attempting to identify the causal factor(s) responsible for forest damage during aerial forest health surveys. In some cases, they can only be accurately assessed by follow-up ground checks.

Ground Checking

Ground checking is an integral part of aerial forest health surveys to verify the host(s) affected and the causal factor(s) responsible for the damage. Unfortunately, due to the large amount of remote forest that must be covered in a relatively short time and a shortage of qualified aerial observers, aircraft and pilots, time is insufficient to conduct thorough ground checks of all areas of damage mapped from aerial surveys. Therefore, priority should be placed on ground checks of questionable or unfamiliar damage signatures, areas where potentially severe damage may occur in the future (e.g., localized areas of defoliation by Douglas-fir tussock moth), and areas where forest management actions are planned or underway. In addition, new aerial observers should take time to do more ground checking so they can become familiar with the damage signatures characteristic of the areas over which they are flying.

2. TREE SIGNATURES

This section describes the characteristics of commonly occurring tree species or species groups in the central Rocky Mountains, which are helpful in their identification during aerial forest health surveys (Table 1, Figs. 2 and 3).

CONIFERS

PONDEROSA PINE

Crown characteristics of ponderosa pine, when viewed aerially, include: yellow-green foliage, a rounded crown and a distinctly clumped foliage texture (Fig. 12). Ponderosa pine is one of the most widely distributed pines in western North America. In the central Rockies, it forms extensive pure or nearly pure stands at elevations of about 6,500-7,000 feet up to about 8,500 feet (Oliver and Ryker 1990).

LODGEPOLE PINE

Lodgepole pine is a wide-ranging species found throughout most of the central and northern Rocky Mountains, the Pacific Northwest, the higher elevations of the Sierra Nevada Range and north into western Canada. Forests dominated by lodgepole pine cover approximately 15 million acres in the western U.S. (Lotan and Critchfield 1990).

Crown characteristics helpful in identification of lodgepole pine during aerial forest health surveys include an olive-green foliage color, narrowly rounded crowns and a finely clumped foliage texture (Fig. 12). It typically grows in extensive, pure, even-aged stands, but may also occur in association with other trees. In the central Rocky Mountains, lodgepole pine occurs at elevations ranging from about 8,000 to 9,500 feet.

WHITE OR SOFT PINES

Several species of white, soft or five-needle pines are indigenous to the Rocky Mountains. These include limber pine, whitebark pine, Rocky Mountain bristlecone pine and southwestern white pine.

The aerial signatures of these pines are difficult to separate based on the signatures alone because their crown characteristics are similar. All have a medium to dark blue-green foliage color, broadly rounded crowns and lobed crown margins (Table 1, Figs. 2 and 3). The natural ranges of these pines may, however, offer some clues as to species involved. Limber pine is the most wide-ranging species of the group and is found throughout the Rocky Mountains as far south as northern New Mexico, where it is found in a wide range of elevations. Whitebark pine is a high-elevation species found from central British Columbia south to the southern Sierra Nevada Range in California, portions of Nevada and northwestern Wyoming. Rocky Mountain bristlecone pine occurs in southern Colorado and portions of Arizona and New Mexico. Southwestern white pine occurs from southern Colorado into portions of Arizona, New Mexico, western Texas and portions of northern Mexico (Critchfield and Little 1966). Both limber and Rocky Mountain bristlecone pines tend to occur on exposed slopes. Western white pine (*Pinus monticola*) occurs in portions of western Montana and northern Idaho.

Pinyon Pines

Covering a total land area of more than 48 million acres, the pinyon-juniper woodlands of the Southwest represent the most extensive forest cover type in the western U.S. Colorado, for example, has approximately 5.2 million acres of pinyon-juniper woodlands, which comprise roughly 21 percent of the state's forested area (Colorado State Forest Service n.d.). The most widespread species of pinyon pines in these woodlands are pinyon pine (*Pinus edulis*) in Arizona, Colorado, New Mexico and Utah, and singleleaf pinyon (*Pinus monophylla*) in Nevada and the eastern slopes of the Sierra Nevada Range in California (Lanner 1981). Pinyon pines are relatively small trees and can be identified during aerial forest health surveys by their dark green foliage color, broadly rounded crowns and open growth character.

Douglas-Fir

Douglas-fir is one of the West'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 (Hermann and Lavender 1990). Crown characteristics helpful in the aerial identification of this tree include a medium green to blue-green foliage color and an acute crown form. Branch pattern is variable and tends to be indistinct on small trees and distinct on large "old growth" trees (Fig. 3). Douglas-fir is an important component of low- to mid-elevation forests, and in the central Rocky Mountains often occurs on north-facing slopes.

Spruce

Two species of spruce are indigenous to the central Rockies: Colorado blue spruce (*Picea pungens*) and Engelmann spruce (*P. engelmannii)*. A third species, white spruce (*P. glauca),* is found in the Black Hills of South Dakota and Wyoming, and in isolated stands in northwestern Montana (Nienstaedt and Zasada 1990).

Aerial forest health survey teams can recognize Colorado blue spruce by the distinct blue or blue-gray cast of its foliage (Fig. 12). The distinct color of its foliage is especially conspicuous from the air during early mornings on east-facing slopes when the sun angle is low (Fig. 13). This spruce occupies a variety of habitats, but prefers moist sites and often is found in riparian zones (Figs. 12 and 13) over a wide range of elevations (±6,000-10,000 feet) (Fechner 1990).

Engelmann spruce foliage, on the other hand, is light gray-green in color and its crown form is acute to acuminate. In the central Rocky Mountains, Engelmann spruce generally is found at elevations ranging from 9,000-11,000 feet, where it occurs in association with subalpine fir (Alexander and Shepperd 1990). In the central Rockies, Engelmann spruce occurs in extensive pure or nearly pure stands at elevations above approximately 10,500 feet, continuing up to timberline.

Crown characteristics of white spruce are similar to Engelmann spruce. It is a wide-ranging species found across the boreal forests from eastern Canada to Alaska. In the Black Hills, it occurs primarily in riparian areas and on north-facing slopes.

True Fir

Species of true fir (*Abies* spp.) indigenous to the Rocky Mountains include white fir (*A. concolor*), grand fir (*A. grandis*), subalpine fir (*A. lasiocarpa)* and corkbark fir (*A. lasiocarpa* var. *arizonica)*.

White fir is relatively easy to recognize during aerial forest health surveys because of its blue-green foliage color and distinctly layered branch pattern. The natural range of this species extends from the mountains of southern Oregon and California east to central Colorado. In the central and southern Rocky Mountains, it occurs from Colorado Springs south and west into mountainous portions of Arizona, the southeastern corner of Idaho, New Mexico and Utah (Laacke 1990). In central and southern Colorado and northern New Mexico, it is found in mixed stands with Douglas-fir and ponderosa pine.

Grand fir, found from western Montana and central Idaho west to the Pacific Coast, is similar in appearance to white fir, but has a rich green foliage color. The two species readily hybridize (Foiles et al. 1990) and there are populations that have characteristics of both species. In portions of the Wasatch Range in Utah, for example, white fir has darker green foliage than populations in Colorado and northern New Mexico.

From the air, subalpine fir is readily identified by its acuminate or spire-like crown and dark green foliage color. Subalpine fir is widely distributed in western North America and occurs throughout the Rocky Mountains. It generally is found at high elevations in association with Engelmann spruce. A variety of subalpine fir, known as corkbark fir (*A. lasiocarpa* var. *arizonica)* occurs from southern Colorado south into Arizona and New Mexico and is recognized by its white, cork-like bark (Alexander et al. 1990). However, the two subspecies are indistinguishable from the vantage point of aerial forest health observers.

Juniper

Several species of juniper (*Juniperus* spp.) occur in the central Rocky Mountains. These include Rocky Mountain juniper (*J. scopulorum)*, one-seeded juniper (*J. monosperma)*, Utah juniper (*J. osteosperma)*, alligator juniper (*J. deppeana*) and common juniper (*J. communis)*. Rocky Mountain juniper can be found throughout the central Rockies. In the northern part of its range, it forms scattered, open stands at low elevations. Farther south, it is associated with pinyon pine. One-seeded, alligator and Utah juniper also are components of pinyon-juniper forests. One-seeded juniper ranges from near Denver, Colo. south into Arizona and New Mexico; alligator juniper is found from Arizona and New Mexico into central Mexico; and Utah juniper is found on Colorado's Western Slope, portions of Wyoming, southeastern Idaho and across much of Arizona, Nevada and Utah.

With the exception of common juniper, which is a small prostrate shrub not generally visible from aerial survey altitudes, junipers have broadly rounded crowns and a fine foliage texture. Like pinyon pine, they tend to be relatively small trees. Foliage color varies by species. Foliage color of Rocky Mountain and one-seeded juniper is gray to blue-green, and foliage color of Utah juniper is dark green. Juniper cones or berries are light blue in color and can give seed-bearing trees a distinct blue cast, regardless of their foliage color.

Broadleaf Trees

While conifers clearly are the dominant trees of the central Rocky Mountains and the primary trees of concern during aerial forest health surveys, several species of broadleaf trees occur over extensive areas and are subject to damage by a variety of agents. As a rule, broadleaf trees tend to have a lighter green foliage color than conifers and have broadly rounded crowns. Branch patterns are indistinct and foliage texture is variable. The following sections describe crown characteristics of several broadleaf species or species groups that can be used to identify them during aerial forest health surveys.

Quaking Aspen

Quaking aspen (*Populus tremuloides*) is the most widely distributed tree in North America and the most commonly occurring broadleaf tree in the forests of the Rocky Mountains. In Colorado and southern Wyoming, quaking aspen grows at an elevation zone of approximately 6,900 to 11,000 feet and occurs in association with all of the conifer forests in those zones. Foliage color ranges from light yellow-green to medium blue-green, crowns are broadly rounded and foliage texture is fine and indistinct (Fig. 12). In the Rocky Mountains, quaking aspen commonly regenerates by large trees producing runners, and most stands are of clonal origin, pure and even-aged (Perala 1990). In areas of extensive aspen forests, individual aspen clones are detectable by differences in foliage color, especially during autumn fall coloring.

Cottonwoods

Several cottonwood species are found in the central Rocky Mountains. Plains cottonwood (*Populus deltoides* ssp. *monilifera* (= *P. sargenti*)) occurs across the Great Plains and narrowleaf cottonwood (*P. angustifolia)* is found in the mountainous regions. Fremont cottonwood (*P. fremontii*) is found from Colorado's Western Slope south and west into portions of Arizona, California, New Mexico, Nevada and Utah. Foliage color of all species is medium green, crowns are broadly rounded and foliage texture is medium. Cottonwoods are commonly found along river banks.

Gambel Oak

Gambel oak (*Quercus gambelii*) occurs at low elevations, often in association with pinyon-juniper forests. It is a small tree with yellow-green foliage, broadly rounded crowns and a coarse foliage texture. The tree typically occurs in dense, pure, clonal stands, the product of vegetative reproduction.

3. DAMAGE SIGNATURES

This section provides descriptions of aerial signatures caused by a wide range of agents that damage forests. They are organized into the following categories:

- Bark Beetles
- Foliage-Feeding Insects
- Sucking Insects
- Diseases
- Animal Damage
- Abiotic Agents
- Other Signatures

Bark Beetles

Bark beetles are, without a doubt, the most damaging insect pests of Western conifer forests. Several bark beetles indigenous to western North America are tree killers and during outbreaks can kill hundreds of thousands of trees over large areas. Bark beetle adults attack boles of host trees en masse and construct breeding galleries in the inner bark and cambium where eggs are deposited and larvae and pupae eventually develop.

The aerial signature of bark beetle damage consists of trees with discolored or “fading” foliage, often in groups, but sometimes as a scattering of faders throughout the stand. The host tree, color of the fading foliage, portion of the crown affected and the number of fading trees in a group can all provide clues to the identity of the bark beetle causing the damage (Tables 2 and 3, Fig. 14).

Ponderosa Pine

Ponderosa pine is subject to attack by several bark beetles. When attacked, ponderosa pine foliage initially fades to yellow-green and gradually progresses to straw-yellow, yellow-orange 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).

The natural ranges of bark beetles that infest ponderosa pine overlap and, in some cases, two or more species can co-habit the same tree or be present in the same stand. Therefore, aerial diagnosis of the species responsible for tree mortality in a given area can be challenging 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

Mountain pine beetle (*Dendroctonus ponderosae*) is considered the most damaging insect pest of Western pine forests. This insect occurs throughout most of western North America and attacks ponderosa, lodgepole and other Western pines. This species has been at epidemic levels somewhere in the West ever since forest damage has been monitored (Furniss and Carolin 1977). In ponderosa pine, outbreaks typically develop in overstocked forests.

Ponderosa pines attacked by mountain pine beetle begin to fade in late June during the year following attack. Foliage color initially changes from green to yellow-green and then to straw-yellow or yellow-orange by midsummer (Figs. 15 and 16). During the following year, the affected foliage turns a red-brown hue before dropping to the ground. During aerial surveys conducted in July or August, it is relatively easy to separate most of the 1-year-old attacks from 2-year-old attacks by the difference in foliage color.

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 in distinct groups ranging from 10 to several hundred trees. When infestations occur in younger (± 60 years) overstocked stands, a scattering of dead trees typically appears throughout the affected area.

Western Pine Beetle

Western pine beetle (*Dendroctonus brevicomis*) is an important tree-killing pest of ponderosa pine. In the central and southern Rocky Mountains, it occurs from southern Colorado into Arizona and New Mexico (Wood 1982). In Colorado, outbreaks tend to occur in the Culebra Range and the southern slopes of the San Juan Mountains. Unlike mountain pine beetle, which typically produces 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, from yellow-green to straw-yellow to red-brown (Fig. 17). This insect often attacks large, old-growth ponderosa pines. When western pine beetle attacks occur in small, second-growth ponderosa pine forests, it is virtually impossible to distinguish between mountain pine beetle, western pine beetle or ips engraver beetle attacks based on aerial signatures alone. Ground checks or knowledge of the bark beetle history of an area are necessary for positive identification of causal agent(s).

Roundheaded Pine Beetle

Roundheaded pine beetle (*Dendroctonus adjunctus*) ranges from the southwestern U.S. south into Mexico and Guatemala. In the western U.S., it infests ponderosa pine in portions of Arizona, Colorado, Nevada, New Mexico and Utah (Wood 1982). Infestations consist of either single trees or small groups of 20-50 trees, and both large- and small-diameter trees may be attacked during outbreaks. It often is associated with western pine beetle and/or ips engraver beetles (Massey et al. 1977). Correct classification of roundheaded pine beetle infestations during aerial forest health surveys 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. The most common species in the central Rocky Mountains is the pine engraver (*Ips pini)* (Furniss and Carolin 1977).

Ips pini often initiates attacks in the upper crowns of large ponderosa pines and kills only a portion of the upper crown. Generations of ips engraver beetles or other bark beetles often subsequently attack the lower bole and ultimately kill the tree. Top-kill caused by ips engraver beetles in ponderosa pine occasionally can be seen from operational aerial survey flying heights (Fig. 18). In smaller, younger trees, the entire bole may be attacked. Infestations often occur as a scattering of single trees or small groups of fading ponderosa pines in and around the edges of recent wildfires (Fig. 19).

Group kills in ponderosa pine forests caused by ips engraver beetles tend to be smaller than those caused by *Dendroctonus* bark beetles, generally in the range of 1-20 trees. However, in some locations, ips engraver beetles may be associated with western pine beetle or other bark beetles that attack ponderosa pine and cause large group kills (Fig. 18). During the early stages of outbreaks by mountain pine beetle and/or western pine beetle, group kills also tend to be small, however, and it is difficult to determine which insect is causing the damage without some *a priori* knowledge or ground checks.

Lodgepole Pine

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

Mountain Pine Beetle

Foliage color of lodgepole pines attacked by mountain pine beetle initially fades to yellow-green in May or June during the year following successful attack, then progresses to red-orange in July (Fig. 20). The current year's faders can turn red-brown by late August/September, especially during dry years, which makes it difficult to separate 1-year-old attacks from 2-year-old attacks. Typically, attacks occur either as a scattering of fading trees or as small- to medium-sized group kills (5-50 trees). Outbreaks typically develop in even-age stands, 60 years or older in age. Trees with thick phloem and large diameters, usually the largest trees in the stand, are preferred (Amman et al. 1985). From the air, this appears as fading in trees with large crown diameters. During the early stages of an outbreak, the trees most often attacked occur at lower elevations, near creek bottoms or at the edges of stands, where there is a concentration of large-diameter trees with thick phloem (Fig. 21). As outbreaks progress, extensive areas of pure or nearly pure lodgepole pine forests will be damaged, with little preference given to tree diameter or phloem thickness as the preferred host becomes exhausted (Fig. 22).

Ips Engraver Beetles

The pine engraver beetle (*Ips pini)* is another pest of lodgepole pine. This beetle commonly attacks small groups (5-15 trees) of pole-sized trees. Because lodgepole pine is a thin-barked species, attacks occur in the mid and lower boles of trees and not in the upper crown, as is the case in ponderosa pine. Thus, top-kill usually is not associated with pine engraver beetle in lodgepole pine. Attacks in lodgepole pine can be distinguished from mountain pine beetle attacks because the infested trees tend to be of smaller size. Pine engraver beetle infestations can be identified with relative ease, provided that both species are not present in the same stands. It is not unusual, however, for pine engraver beetles to also be present in trees attacked and killed by mountain pine beetle, and/or for pine engraver to attack and kill small-diameter trees in the same stands in which mountain pine beetle is attacking large-diameter trees. In these cases, damage by the two species is virtually impossible to separate during aerial forest health surveys. If aerial observers suspect both beetles to be active in an area, the most logical approach is to assign multiple attributes to the infestation polygons.

White or Soft Pines

Mountain Pine Beetle

Mountain pine beetle is an important pest of all white or soft pines. When attacked by mountain pine beetle, the foliage of the white or soft pines fades to virtually the same colors as lodgepole pine; from pale yellow-green to red-orange and finally to red-brown. Limber pine often occurs in association with lodgepole pine and both are subject to attack by mountain pine beetle. In mixed stands, limber and whitebark pines are easily distinguished from lodgepole pine on the basis of their broadly rounded crowns and lobed margins (Figs. 23 and 24).

Twig Beetles

The white or soft pines occasionally are subject to attack by twig beetles of the genus *Pityophthorus*. These beetles confine their breeding attacks to shoots and branches, which are subsequently killed (Fig. 25). Foliage of infested branches fades to red-orange as the branches die. Heavy infestations, such as those with 70- to 80-percent branch infestation, can cause a red-brown discoloration that is aerially visible and may resemble defoliation or bark beetle attack (Fig. 26). In 2009, an outbreak of the twig beetle *Pityophthorus boycei* occurred in forests of Rocky Mountain bristlecone pine on the summit of Thirtynine Mile Mountain in southeastern Park County, Colo., causing aerially visible discoloration (Colorado State Forest Service 2010).

Pinyon Pines

Pinyon Ips

Pinyon ips (*Ips confusus*) is an important pest of pinyon pines, especially during and after periods of prolonged drought. Assessment of pinyon ips outbreaks may require special aerial surveys over a forest cover type that normally is not included in annual aerial forest health surveys. When attacked by pinyon ips, pinyon pine foliage initially fades to pale orange and then gradually to red-brown. Infestations typically occur in distinct groups ranging in size from 5-10 trees to well over 100 trees during outbreaks (Fig. 27). Fading pinyon pines sometimes are difficult to see from the air because of the open character of pinyon-juniper woodlands and the amount of bare soil between trees, which often has a color similar to that of the fading pines.

Pinyon Twig Beetles

Pinyon pines also are subject to attack by several species of twig beetles of the genus *Pityophthorus*. Up to 12 species of *Pityophthorus* are known to attack pinyon twigs (Ciesla 2011, Wood 1982). Light infestations result in the death and fading of a few scattered shoots. This level of damage is not visible from the air. During prolonged droughts, however, these insects 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, but foliage in the interior of the crown remains green (Fig. 28). During aerial forest health surveys, heavy pinyon twig beetle damage is virtually impossible to distinguish from tree mortality caused by pinyon ips. Moreover, twig beetles, pinyon ips and shoot-boring caterpillars (*Dioryctria* spp.) could be collectively involved in the damage signature (Fig. 29).

Douglas-fir

Bark beetle pests of Douglas-fir include Douglas-fir beetle (*Dendroctonus pseudotsugae*) and a complex of engraver beetles referred to collectively as Douglas-fir engraver beetles. When attacked by bark beetles, the foliage of Douglas-fir initially fades to an off-green or yellow-green and progresses to bright red.

Douglas-fir Beetle

Douglas-fir beetle is the most destructive bark beetle pest of Douglas-fir. Outbreaks can develop in fresh windthrow with subsequent generations attacking standing trees, or following fire scorch, insect defoliation, prolonged drought or root disease (Furniss and Carolin 1977, Schmitz and Gibson 1996).

The classic aerial signature of Douglas-fir beetle attack consists of distinct groups of trees (10 to > 200) with fading foliage (Fig. 30). Attacked trees are characteristically mature, large-crowned and often occur on steep slopes. Some trees may fade as early as four months after attack (April-June) while others may remain green until the following June. Therefore, the fading pattern of individual trees in a group often is 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. 31). This possibly is the result of an interaction with root disease. The more severely infected trees fade at faster rates. Other factors that determine when fading occurs include location, intensity of infestation, elevation and seasonal weather. Due to 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 seen over distances of up to four miles.

Attacks in trees weakened by defoliation by western spruce budworm (*Choristoneura freemani* [=*occidentalis*]), or Douglas-fir tussock moth *(Orgyia pseudotsugata)*, tend to be more scattered and are difficult to detect because the previous year's defoliation has reduced the foliage complement of the affected trees and fading is not conspicuous. Fresh faders, however, often are found around the edges of defoliated stands, especially near areas defoliated by Douglas-fir tussock moth.

Douglas-fir Engraver Beetles

Several species of bark beetles are referred to collectively as Douglas-fir engraver beetles. They include species of *Scolytus* and the Douglas-fir pole beetle (*Pseudohylesinus nebulosus)* (Furniss and Carolyn 1977). The aerial signatures of all of the species involved in this complex are identical and cannot be distinguished during aerial surveys. The characteristic signature associated with Douglas-fir engraver beetles is the occurrence of single trees, small groups (5-20 trees) or a scattering of pole-sized faders. Occasionally, top-kill is visible on some trees. Trees attacked by Douglas-fir engraver beetles usually can be distinguished from Douglas-fir beetle attacks on the basis of tree size and the number of trees affected.

Spruce

Spruce Beetle

Spruce beetle (*Dendroctonus rufipennis*) is the major bark beetle pest of mature spruce forests throughout North America. In the western U.S., exclusive of Alaska, Engelmann spruce is the favorite host, and massive outbreaks have occurred throughout the range of this species. Infestations typically develop in fresh windthrow or logging residues, with subsequent generations attacking standing trees (Holsten et al. 1999).

Engelmann spruce attacked by spruce beetle represent the most difficult bark beetle signature to detect during aerial forest health surveys because fading is subtle and inconspicuous. In some cases, needles on infested trees drop before they change color. As a rule, needles of bark beetle-infested Engelmann spruce do not fade until the second summer following attack, when they turn pale yellow-green, progressing to dull gray–brown as the needles drop (Figs. 33 and 34). The needles on different branches of the same tree can discolor at different times. Infestations begin as a scattering of fading trees in stands and progress to extensive areas of nearly 100-percent tree mortality. Typically, damage occurs on large, mature trees, but during major outbreaks, the stunted, elfin trees at the edge of timberline, known as krummholz, also can be attacked and killed (Fig. 35).

Blue Spruce Engraver

Ips hunteri, the blue spruce engraver, infests Colorado blue spruce and is a pest of both native forests and urban trees. The foliage of blue spruce typically fades to a beige color when attacked by these bark beetles. Infestations may occur as single trees or small group kills of up to 40 trees (Fig. 32). Top-kill is a common characteristic of blue spruce engraver attack, but is not easily seen from aerial survey altitudes.

Because of their occurrence in riparian areas, blue spruce are especially subject to flooding from beaver dam construction. This can also cause the death of groups of trees that appears identical to bark beetle attack and could, in fact, contain bark beetle infestations. If standing water is visible among the dead trees, flooding should be considered as a probable cause of damage (Figs. 64 and 65, see section "Animal Damage").

True Firs

When attacked by bark beetles, species of *Abies* fade to conspicuous hues of red or red-orange. They can retain these relatively bright colors for more than one growing season. Therefore, it is difficult to separate current year's faders from two- or even 3-year-old faders.

Fir Engraver

Fir engraver beetle (*Scolytus ventralis*) attacks most species of true fir in the West and is the most damaging bark beetle of both white and grand fir (Ferrell 1986). Typically, foliage color of white fir tends to fade to orange or pale orange, whereas foliage of grand fir fades to bright red-orange. Infestation patterns can be variable and range from a scattering of dead trees in a stand to group kills of 5-100 trees (Figs. 36 and 37). The infestation pattern of fir engraver 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 attacks on large trees sometimes is visible during aerial forest health surveys (Fig. 38).

Trees killed by fir engraver often occur in association with Douglas-fir killed by Douglas-fir beetle, especially following periods of prolonged drought. Under poor light conditions, the two may be difficult to distinguish because the color differences between fading Douglas-fir and true fir are less distinct. Douglas-fir beetle infestations occur in more distinct groups or pockets of mortality than fir engraver infestations. Also, Douglas-fir beetle doesn't cause top-kill, which is a fairly common phenomenon associated with fir engraver.

Western Balsam Bark Beetle

Western balsam bark beetle (*Dryocoetes confusus*) is a pest of subalpine and corkbark fir throughout their ranges. Trees selected for attack by this beetle often are infected by one of several species of root decay fungi, including *Armillaria* spp. and *Heterobasidum parviporum* (= *H. annosum*). Tree mortality caused by the interaction of western balsam bark beetle and root disease fungi is referred to as subalpine fir decline. When attacked by western balsam bark beetle, subalpine fir foliage fades to a bright red color. Infestation patterns vary from a scattering of fading trees in a stand or distinct groups of from 2-200 trees (Figs. 39 and 40).

Foliage-feeding Insects

Forests of the central Rocky Mountains are subject to damage by a number of foliage-feeding insects, which can reach epidemic levels and cause extensive, aerially visible damage. Damage signatures of defoliation consist of thin or bare crowns with an overall gray cast, red-brown discoloration due to clipping of needles by feeding larvae, or a combination of the two. Needle-mining insects also cause discoloration, but the needles remain on the trees, so the crowns do not thin immediately. Aerial signatures of many foliage-feeding insects are similar in appearance and ground checks may be needed to provide positive identification of the causal agent(s) involved.

Pines

A number of insects feed on the foliage of pines in the central Rocky Mountains. Defoliating insects, such as pine sawflies, pine butterfly and Pandora moth, all produce a similar aerial signature during outbreaks, which consists of thin crowns. Some foliage discoloration also may be present (Table 4).

Pine Sawflies

Several pine sawflies are known to defoliate pines in the central Rocky Mountains. These include a complex of *Neodiprion* species, which feed on ponderosa and lodgepole pines. The most commonly occurring and widespread species is *Neodiprion autumnalis*. Two sawflies are known to feed on pinyon pine; the pinyon sawfly (*Neodiprion edulicolis)* and Rohwer's pinyon sawfly (*Zadiprion rohweri)*. Aerial signature of defoliation by sawflies is a thinning and sometimes gray-brown discoloration of the crowns of affected trees (Figs. 41 and 42).

Pine Butterfly

Pine butterfly (*Neophasia menapia*) feeds on foliage of ponderosa pine and occurs throughout the range of its host. It is considered one of the most damaging defoliators of ponderosa pine in the West. Outbreaks tend to be more common in the northern Rockies and portions of eastern Oregon and Washington, but the insect also is known to occur in the central Rocky Mountains (Furniss and Carolin 1977). The aerial signature of defoliation is crown thinning, resulting in a gray cast to infested stands. During outbreaks, large areas may suffer defoliation.

Pandora Moth

Pandora moth (*Coloradia pandora*) larvae feed on several species of pines, including ponderosa and lodgepole pines. Recent outbreaks have been reported in portions of Arizona, California and Oregon. However, there is record of an outbreak in lodgepole pine forests on the Arapaho National Forest, Colo., during 1937-1940 (Furniss and Carolin 1977). Outbreak populations of Pandora moth can cause complete defoliation of host trees over large areas, which appears as crown thinning and a gray cast to infested stands, similar to that of pine butterfly or pine sawflies (Fig. 43). Unlike most foliage-feeding insects, which produce one generation per year, Pandora moth has a 2-year life cycle and, during outbreaks, defoliation occurs every other year. Moreover, since this insect spends its first winter in the larval stage and feeds during warm winter days, defoliation is at its peak during mid- to late-June and may require a special survey to effectively capture the damage.

Western Pine Tussock Moth

Western pine tussock moth (*Dasyschira grisefacta*) feeds on a wide range of conifers, including ponderosa pine, Douglas-fir, western hemlock, Engelmann spruce, white spruce and ponderosa pine. Minor hosts include subalpine fir, grand fir, western larch, western white pine and lodgepole pine. This tussock moth has reached epidemic levels in ponderosa pine forests on the eastern slopes of the Rocky Mountains and the Great Plains, including portions of eastern Montana, the Black Hills of South Dakota and Wyoming and western Nebraska (Duncan 2007, Gannon and Sontag 2008, USDA Forest Service 2005, 2006).

The signature of defoliation by western pine tussock moth consists of a combination of crown thinning and yellow-brown foliage discoloration (Fig. 44). Larvae overwinter under the bark scales of pines and resume feeding in early spring (Furniss and Carolin 1977). Therefore, the defoliation signatures peak in early summer and new growth may mask defoliation by the time aerial surveys are conducted during July and August.

Rusty Tussock Moth

Rusty tussock moth (*Orgyia antiqua*) is a wide-ranging species found in North America and Eurasia. It feeds on a variety of host plants, including broadleaf trees, woody shrubs and conifers (Ciesla 2011).

During 2011-2012, an outbreak of this species developed in portions of the Bighorn Range, Wyo., primarily on lodgepole pine (Backsen et al. 2013). The aerial signature of damage in lodgepole pine forests consists of red-brown discoloration of crowns accompanied by some crown thinning (Fig. 45).

Ponderosa Pine Needle Miner

Discoloration of ponderosa pine, caused by outbreaks of ponderosa pine needle miner (*Coleotechnites ponderosae*) can be seen during aerial forest health surveys. This usually appears as areas of yellow discolored foliage. Damage typically is localized and confined to areas of less than 50 acres (Fig. 46).

Douglas-fir, True Fir and Spruce

Western Spruce Budworm

Western spruce budworm (*Choristoneura freemani* [=*occidentalis*]), is the most widely distributed and destructive defoliator of conifer forests in western North America. This insect occurs from Arizona and New Mexico north into Colorado, Utah, Wyoming, Montana, Idaho, northern California, Oregon, Washington and British Columbia, Canada. Since the 1920s, outbreaks have occurred somewhere in the West almost every year. This insect has a wide host range; in addition to its favorite hosts, Douglas-fir and various species of true fir, during outbreaks, it also feeds on spruce, hemlock, western larch and several pines (Fellin and Dewey 1986).

Larvae first feed in expanding buds of host trees and later on new shoots. Branch tips containing partially damaged foliage turn reddish-brown and are tied together with silken webbing (Fig. 47). During the first year or two of an outbreak, damaged trees have an outer “halo” of reddish-brown, discolored foliage against a backdrop of green foliage (Fig. 48). As outbreaks progress and affected forests suffer from successive years of defoliation, defoliated forests tend to have a gray cast. After several years of successive defoliation, top dieback and tree mortality develop and it often is difficult to separate defoliated areas from older areas of infestation where trees have been killed. Damage typically occurs over large areas (Figs. 48 and 49).

Douglas-Fir Tussock Moth

Outbreaks of Douglas-fir tussock moth (*Orgyia pseudotsugata*) are cyclical and occur at intervals of approximately 7 to 10 years. They typically cause severe defoliation for 2 to 3 years then suddenly collapse, usually due to an epizootic of a nucleopolyhedrosis virus. Larvae begin to feed on new foliage of Douglas-fir and true firs from late May to early June. When they reach the third instar, they 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 moth defoliation consists of reddish-brown or gray discoloration in the crowns of Douglas-fir or true firs. Affected portions of the crown appear thin. The heaviest damage occurs in the upper crown, where a high proportion of the current year's foliage occurs. During severe outbreaks, the entire crown is affected (Figs. 50 and 51).

In mixed forests of Douglas-fir and true fir, defoliation typically 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 typically is found in outbreaks in California, the Pacific Northwest and northern Idaho. However, in the Southwest (Arizona and New Mexico), mixed stands of Douglas-fir and true fir tend to suffer complete defoliation (Fig. 50). When outbreaks occur in pure Douglas-fir forests (e.g., in western Montana and portions of Colorado), damage on individual trees tends to be severe, with entire tree crowns stripped of their foliage during the first year of an outbreak. The area affected by outbreaks in pure Douglas-fir forests often tends to be localized (Fig. 52).

White Fir Needle Miner

White fir needle miner (*Epinota meritana*) is found over most of the western U.S. and portions of southwestern Canada. Larvae mine inside needles of white fir in the central and southern Rockies, and red fir (*Abies magnifica*) in central California. This insect has occasionally reached epidemic levels in portions of Arizona, California, Colorado and Utah. During the mid-1970s, white fir needle miner and western spruce budworm were at epidemic levels in the vicinity of Pass Creek Pass in the Sangre de Cristo Range, Huerfano County, Colo. (Yarger and Leatherman 1975).

On white fir, feeding by white fir needle miner produces bleached-yellow needles from late spring to early autumn. Abandoned mined needles often detach from twigs and are caught in webbing produced by the larvae. Larvae prefer 1-year-old needles, but also will mine older needles during outbreaks (Washburn and McGregor 1974).

The aerial signature of white fir needle miner damage in the central Rocky Mountains consists of white fir stands with light yellow foliage discoloration.

Broadleaf Trees

Defoliating Insects

Several insects can cause aerially visible defoliation of broadleaf trees in the central Rocky Mountains. Quaking aspen is subject to periodic outbreaks of two species of defoliating insects: western tent caterpillar (*Malacosoma californicum*) and large aspen tortrix (*Choristoneura conflictana*), a leaf roller. Western tent caterpillar also defoliates a wide range of woody shrubs and other broadleaf trees. Further north, in portions of Idaho, Montana and North Dakota, forest tent caterpillar (*Malacosoma disstria)* defoliates broadleaf trees and shrubs. Gambel oak is subject to defoliation by several inchworms or loopers, including fall cankerworm (*Alsophila pometaria)*, linden looper (*Erannis tiliara)* and oak looper (*Lambdina punctata)* (Colorado

State University 2004). New Mexico locust (*Robinia neomexicana*) is subject to skeletonizing and defoliation by a species of *Agonopterix* (Lepidoptera: Oecophoridae), a family of moths sometimes referred to as concealer moths.

The aerial signature of insect defoliation in Western broadleaf forests is similar, regardless of species involved, and consists of brown or gray discoloration and a thin or bare appearance to the affected crowns (Figs. 53 and 54). Defoliation by leaf fungi (e.g., Marssonina blight) and abiotic agents such as hail, high winds or late spring frosts produce a similar signature. Boundaries of defoliated areas typically transition from complete stripping of the foliage to a narrow band of partial defoliation to undamaged trees. This gives the edges of defoliated areas a “fuzzy” or out-of-focus appearance (Fig. 55). Larvae of most defoliating insects, including those listed above, feed in spring and early summer, and peak damage occurs in late June to early July. However, a few species feed during late summer. Areas of broadleaf defoliation require ground checks to establish the causal agent(s) responsible for the damage.

Diorhabda Beetle on Tamarisk

Biological control of tamarisk or salt cedar (*Tamarix* spp.), an invasive tree that has displaced native species in many riparian areas of the Southwest, is underway via the release of leaf beetles of the genus *Diorhabda*. These beetles are native to the Near East, Central Asia and China. Both larvae and adults feed on tamarisk foliage and green stems. This causes the foliage to dry and turn bright yellow beginning in mid- to late-June (Fig. 56). Tamarisk foliage normally turns brilliant yellow in autumn (Colorado State Forest Service 2012). While defoliation of tamarisk typically is not mapped during the course of aerial forest health surveys unless specifically requested, it is important for aerial observers to recognize this damage signature in order to avoid misclassification.

Leaf-Mining Insects

Infestations of leaf-mining insects cause foliage discoloration, but damaged foliage does not necessarily drop from infested trees. At least one species of leaf miner, the poplar blackmine beetle (*Zeugophora scutellaris)*, can cause aerially visible damage on cottonwoods. This insect is native to Eurasia and has been introduced into North America. During heavy infestations, aerially visible damage consists of areas of yellow-brown discoloration in riparian cottonwood stands. The discoloration superficially resembles early fall coloring (Fig. 57).

Sucking Insects

Insects with specialized mouthparts equipped for piercing plant tissue and sucking juices are included in the order Hemiptera. This is a large order of insects and includes aphids, psyllids, plant hoppers and scales (Ciesla 2011). Heavy infestations can cause stems and foliage to dry and, in extreme cases, cause tree death.

Pinyon Pine

Pinyon Needle Scale

Nymphs of the pinyon needle scale (*Matsucoccus acalytpus*) infest needles of pinyon pines throughout the Southwest. Feeding damage causes the needles to dry out and turn brown, resulting in foliage loss on large trees and death of young trees.

The aerial signature of heavy pinyon needle scale infestations consists of a mix of trees with brown discolored foliage and trees that have been killed. Discolored foliage may be difficult to see because bare soils associated with pinyon-juniper forests often are a reddish-brown color (Fig. 58).

Spruce

Green Spruce Aphid

Green spruce aphid (*Elatobium abietinum*) is native to continental Europe and has been accidentally introduced into several parts of the world, including portions of North America. It feeds on foliage of spruce. Initial introduction into North America occurred during the early 1900s, and by 1927, it was distributed throughout the coastal Sitka spruce (*Picea sitchensis)* forests of the Pacific Northwest and Alaska (Furniss and Carolin 1977). In 1976, infestations were detected in Santa Fe, N.M., and in the White Mountains of Arizona in 1987-1988. As of 2002, infestations were known to occur in five mountain ranges in Arizona and New Mexico. In the Southwest, spruce aphid feeds primarily on Engelmann spruce and, to a lesser degree, on blue spruce (Lynch 2002). This insect is not yet known to occur in Colorado or other states in the central Rocky Mountains, but potential exists for infestations to spread into this region.

Spruce aphid infestations cause premature loss of older needles. As a result, infested trees develop thin crowns with a reddish-brown cast, which is visible during aerial surveys. Life stages of this insect are most abundant during late winter and early spring, before bud burst. Needles turn yellow and fall from heavily infested trees during April and May. In cases of severe defoliation, infested trees may appear dead (Lynch 2002).

Heavy infestations of spruce spider mite (*Oligonychus ununquis*) cause similar damage and a similar aerial damage signature.

Diseases

Symptoms of forest damage caused by fungi, viruses, parasitic plants and other disease agents typically are more subtle than those caused by insects, and are considerably more difficult to detect and assess during aerial forest health surveys. Moreover, some disease-causing agents only predispose trees to attack by bark beetles, and tree mortality due to bark beetle attack is what produces an aerially visible signature. However, several forest disease agents by themselves produce aerially visible signatures.

Conifers

Root Disease

Several fungi cause root decay and associated tree decline and mortality of conifers in the central Rocky Mountains. These include *Armillaria mellea* and *Heterobasium* (=*Fomes*) *annosum* in several conifers, *Heterobasidum parviporum* in subalpine fir and *Leptographium wagneri* in pinyon pine (Francis et al. 1999, James and Goheen 1981).

In some parts of western North America, such as the northern Rockies and Pacific Northwest, root disease-causing organisms, such as *Phellinus weirii* in Douglas-fir and *Phytophthora lateralis* in Port Orford cedar (*Chamaecyparis lawsonii*), readily produce aerially visible signatures (Ciesla 2006). In the central Rocky Mountains, however, root disease centers are not easily seen during aerial forest health surveys. They become most apparent when trees weakened by root decay fungi are subsequently attacked by bark beetles. Subalpine firs attacked and killed by western balsam bark beetle often are predisposed to attack by root disease fungi. This complex interaction is referred to as “subalpine fir decline” (Figs. 39 and 40). Similarly, pinyon pines infected by the fungus *Leptographium wagneri*, which causes black stain root disease, are susceptible to attack by pinyon ips (Fig. 27).

Rust Diseases

Several rust diseases can damage pines in the Rocky Mountains. These include two native species: Comandra blister rust of lodgepole pine, caused by the fungus *Cronartium comandre,* and stalactiform blister rust of ponderosa pine, caused by *C. coleoporiodes*. White pine blister rust, caused by the fungus *Cronartium ribicola*, native to Asia, is now widely distributed over western North America and infects all species of white or soft pines. These fungi infect branches and cause cankers, resulting in branch flagging. In the case of white pine blister rust, heavy infections ultimately cause tree death (Allen et al. 2010).

The aerial signature of rust infection consists of branches with fading or reddish-brown foliage and dying trees. Scattered branch flagging is difficult to detect during aerial forest health surveys, and trees killed by the white pine blister rust fungus resemble those that have been killed by bark beetles. Areas suspected of being infected by white pine blister rust detected during aerial forest health surveys require supplemental ground checks.

Broadleaf Trees

Marssonina Blight

Marssonina blight, caused by the fungi *Marssonina brunnea* and *M. populi*, infects foliage of aspen and, to a lesser degree, other poplars. It is the most common leaf disease of aspen in the Rocky Mountain region. The fungi produce dark brown flecks, often with yellow margins, on leaf surfaces. The spots may merge to form blotches. Heavy infections can cause premature leaf drop. Incidence of this disease is highest following periods of warm temperatures and relatively high rainfall (Allen et al. 2010, Colorado State University 2004).

The aerial signature of aspen forests damaged by Marssonina blight is a combination of yellow-orange discoloration accompanied by defoliation. In large clonal stands of aspen, where different clones may have varying susceptibilities to the fungi, the signature may be a mosaic of defoliated areas interspersed with discolored patches and stands, with no aerially visible damage (Fig. 59). The signature of Marssonina blight is difficult to reliably separate from insect, hail or frost damage without supplemental ground checks.

Sudden Aspen Decline

In approximately 2004, widespread decline and mortality of quaking aspen forests began to appear across large areas of Colorado and other states in the central and southern Rocky Mountains. The condition has been subsequently termed "sudden aspen decline" (SAD). SAD is an example of a complex disease caused by the interaction of several biotic and abiotic factors, including occurrence of mature and overmature aspen stands growing at the lower elevational limits of tree growth, moisture stress and secondary attacks by fungi and insects (Worrall et al. 2010, USDA Forest Service 2009).

The aerial signature of SAD is progressive and consists of stands with thin crowns and pale yellow foliage, scattered tree mortality and, ultimately, patches of dead and fallen trees (Figs. 60 and 61). The condition is most frequently encountered at the lower elevational limits of tree growth, on southern or western aspects or on poor sites where conditions tend to be driest. The signature of patches of dead trees superficially resembles that of defoliation. The two may be separated, however, by examining the edges of areas where mortality occurred. Defoliation generally is characterized by a transition from heavy defoliation to partial defoliation to no aerially visible defoliation, leaving an unclear boundary. Conversely, the edges of areas where aspen mortality associated with SAD occurred are more clearly defined (Figs. 8, 60 and 61).

Cottonwood Decline

Dieback and mortality of cottonwoods, likely due to moisture stress in mature and overmature trees, can be prevalent in riparian areas. The signature consists of stands of mature cottonwoods with dead upper crowns and/or dead trees (Figs. 62 and 63).

Animal Damage

Mammals and birds can cause tree damage, which, on occasion, may be aerially visible. While these damage types may not be of sufficient concern to map during aerial forest health surveys, it is important for aerial observers to recognize the characteristic signatures of animal damage to avoid misclassification.

Beavers

Beavers (*Castor canadensis)* construct dams across streams, resulting in localized inundation, which can kill trees. Conifers killed by inundation have fading foliage and resemble trees killed by bark beetle attacks. Evidence that beavers may be responsible include standing water, presence of beaver dams, more than one tree species affected and progressive damage (Figs. 64 and 65).

Porcupines

Damage by porcupines (*Erethizon dorsatum*) consists of stripped bark from branches of conifers. The resulting aerial damage signature is branch flagging and top-kill. While individual dying branches usually are not aerially visible, heavy damage on individual trees or groups of trees can occur and is aerially visible (Fig. 66).

Herons

Great blue herons (*Ardea herodias*) breed in colonies called heronrys. They build large nests in trees located near open water. Some trees (e.g., ponderosa pine) are intolerant of increases in soil nitrates, nitrites and phosphates (guanotropy) associated with concentrations of bird droppings, and die after a few years of nesting activity. An indication that trees have died as a result of heron nesting is the presence of nests near the tops of trees, which from aerial forest health survey altitudes appear as distinct white clumps (Fig. 67). Affected trees tend to be within a short distance of open water.

Abiotic Agents

Abiotic agents that cause forest damage include chemicals; weather-related factors, such as late spring frosts and high winds; and wildfire. One indication that an abiotic rather than a biotic causal agent is involved is that more than one species of tree shows similar damage signatures. Local knowledge of forest and range management, road maintenance practices and local weather events are helpful to correctly classify damage from abiotic agents.

Chemical Injury

Deicing and Dust Abatement Chemicals

Foliar injury and tree death can occur on a number of tree species (e.g., ponderosa pine, lodgepole pine, Douglas-fir and quaking aspen) growing immediately adjacent to roads. The pattern of damage suggests that it is caused by deicing and dust abatement chemicals used on roads and highways. The aerial signature of this damage 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. Secondary bark beetle attacks may occur in some trees (Fig. 68).

Herbicides

Application of herbicides to remove unwanted vegetation, including small trees and woody shrubs, can produce an aerial signature similar to that caused by defoliating insects, leaf fungi, frost or high winds. The aerial signature of herbicide damage consists of areas of yellow to brown discolored foliage and/or defoliation. Gambel oak often is the target of herbicide applications in efforts to improve forage for cattle or sheep (Figs. 69 and 70). Herbicides used to control roadside weeds also may adversely affect trees within the sprayed areas and cause a signature similar to that of deicing or dust abatement chemicals.

Weather and Climate-related Damage

Several weather-related factors, including drought, frost, hail and wind, can damage trees and forests, and result in aerially visible symptoms over large areas.

Frost

Foliage damage caused by late spring frost produces an aerial signature that mimics insect defoliation in broadleaf forests. Depending on severity, frost can kill margins of newly emerged leaves, causing a brown discoloration similar to "leaf scorch," or kill buds and/or newly emerging leaves, giving affected stands a gray appearance. In addition, when the second crop of foliage develops, it often is sparse and leaves are larger than normal, giving affected crowns a thin, open appearance that is present throughout the remainder of the growing season (Fig. 71). Frost damage on the current year's ponderosa pine foliage can appear as a yellow discoloration.

Hail

Hail storms, especially those that produce large hail stones, can cause tearing and bruising of foliage and wounding or breaking of branches. Both conifers and broadleaf trees are affected. From the air, hail-damaged broadleaf trees appear as though they have been defoliated (Fig. 72). Conifers typically suffer from bruised foliage following hail storms, which appears as gray or reddish-brown discoloration (Fig. 73). The latter signature may take several weeks to appear, whereas foliage shredding and loss on broadleaf trees appears immediately after the hail event.

Wind

High winds associated with microbursts or straight-line winds and tornadoes can cause extensive breakage and uproot trees. Shallow-rooted trees, such as lodgepole pine and Engelmann spruce, are especially susceptible to high wind events. The aerial signature of damage associated with microbursts consists of patches of broken or uprooted trees ranging in size from 5 to more than 200 acres (Figs. 74 and 75). Most or all of the downed material is facing the same direction. Tornadoes, on the other hand, produce a relatively narrow swath of broken or uprooted trees, which lie in a more or less circular pattern (Fig. 76).

Areas of heavy windthrow typically are interspersed with stands suffering partial damage, which usually are not aerially visible. Wind breakage in Engelmann spruce forests creates conditions favorable for buildup of spruce beetle populations, which can lead to outbreaks in standing trees within 2-3 years of the wind event. High winds also can cause defoliation of broadleaf trees, which presents a signature virtually identical to that of defoliation by insects, frost or hail (Fig. 77).

Avalanches

Avalanches can cause stem breakage if the avalanche path is in an area of established forest. Forest damage by avalanches usually appears as a narrow band of breakage on steep slopes (Fig. 78).

Drought and Leaf Scorch

Extreme drought accompanied by desiccating winds can cause a condition known as leaf scorch on broadleaf trees and shrubs. This causes leaves to have brown or reddish-brown edges. The aerial signature of this damage consists of reddish-brown to gray discoloration of affected trees and shrubs (Fig. 79).

Drought also may cause discoloration of ponderosa pine foliage. In 2013, for example, areas of yellow to brown discoloration of ponderosa pine needles were detected in several areas west of Walsenburg and Trinidad in Huerfano County, Colo., and in the vicinity of Wetmore, Beulah and Colorado City on the eastern edge of the Wet Mountains. The discoloration was confined to pine needles 2 years and older, and affected needles contained reddish-brown bands. Symptoms resembled those caused by a needle fungus, but no evidence of fungus infection (e.g., fruiting bodies) could be found (Fig. 80).

Winter Drying or Red Belt

Winter desiccation and rapid temperature fluctuations can damage or kill conifer foliage. Foliage damaged or killed by these factors often remains green as long as temperatures are cold. Damaged needles then turn brown as temperatures increase in late winter or early spring. New foliage usually emerges later in spring or early summer. The condition, known as "red belt," is a form of winter injury that can affect distinct patches or elevation bands of all conifers. Lodgepole pine tends to be most susceptible to red belt. South- and west-facing slopes are more susceptible to red belt than north- and east-facing slopes (Jackson 2004).

The classic aerial signature of red belt is a distinct band of red to reddish-brown, desiccated foliage on steep mountain slopes, usually at certain elevational zones. In other cases, winter drying appears as groups of trees with discolored or fading foliage, which can easily be confused with bark beetle attack. In the case of winter drying, however, some portions of the affected tree crowns generally will have some green foliage (Fig. 81). This usually is not the case with trees fading due to bark beetle attack. Affected trees tend to occur on exposed slopes (Fig. 82). In addition, only foliage on the exposed side of the tree may be affected (Fig. 83).

Wildfire and Prescribed Burns

Damage caused by wildfires is easy to identify. Large wildfires tend to be a mosaic of dead trees with scorched foliage, blackened stems and blackened ground vegetation (Figs. 84 and 85). Low-intensity fires will cause foliage of affected conifers to fade, but only in the lower crowns (Fig. 85). Fires can burn through areas of ongoing bark beetle outbreaks. When this occurs, fading conifers caused by bark beetle attacks can persist in areas that escaped the fire and may be difficult to differentiate from fire damage (Fig. 86).

Other Signatures

Some phenomena produce aerial signatures that resemble forest damage and are potential sources of error during aerial forest health surveys. The following sections describe several signatures that have been observed in the central Rocky Mountains and have the potential of being confused with forest damage.

Flowering Trees

Crowns of trees that produce conspicuous clusters of flowers can have a mottled appearance. This can sometimes be mistaken for foliar damage. A classic example is New Mexico locust (*Robinia neomexicana*), a small- to medium-sized tree indigenous to portions of Arizona, Colorado, New Mexico and Utah (Little 1976). This tree produces clusters of purple flowers that tend to turn beige or light-brown after peak bloom (Fig. 87).

Forest Management Activities

Several forest management and protection activities can produce signatures that could be mistaken for forest damage caused by insects, disease or abiotic agents.

Tree Girdling

Tree girdling is designed to alter species composition and eliminate undesirable trees. As girdled conifers die, the crowns fade in the same manner as trees killed by bark beetles. In a few cases, localized areas of fading lodgepole pines in stands where aspen was the dominant species were initially believed by aerial observers to be early stages of a mountain pine beetle outbreak. Ground checks, however, established that the pines had been girdled in an attempt to maintain the aspen component of the stand (Fig. 88).

Thinning

Thinning, especially pre-commercial thinning, results in large volumes of slash, which is piled for burning at a later date. The slash piles tend to be cone-shaped, and branches with foliage turn red to red-brown. They can mimic bark beetle attacks, especially when surrounding stands have active bark beetle infestations. However, slash piles from thinning operations are spaced more or less regularly throughout the stand, and tend to have broader shapes than the crowns of residual trees (Fig. 89).

Fire Retardant Drops

Retardant drops during wildfire suppression operations cause a deep red discoloration of the affected vegetation. In most cases, fire retardant drops are located at the edges of fire scars and are easily recognized. However, there are occasions when retardant drops are made on smaller spot fires, which may be some distance from the main body of the wildfire. From a distance, these can resemble foliage discoloration associated with defoliator outbreaks. Residual fire retardant on other surfaces, including soil and rock outcrops, may or may not be readily visible during aerial surveying (Figs. 90 and 91).

Heavy Cone Crops

Heavy cone crops, especially in spruce forests where cones are concentrated in the upper crown, can cause trees to have a brown cast. This can sometimes be mistaken for the early stages of defoliation or fading of trees killed by bark beetles. Occurrence of heavy cone crops is most common in spruce forests (Fig. 92), but also can occur in other conifers.

4. CONCLUSIONS

Many types of forest damage are highly visible and can be mapped using a variety of remote-sensing technologies. The most commonly used technique for detection and assessment of damage caused by forest insects, diseases and numerous other agents is aerial sketchmapping. In the western U.S., aerial forest health overview or aerial sketchmap surveys are conducted annually over most forested areas. The characteristics or signatures of much of the damage observed during aerial surveys can provide clues to the causal agent(s) responsible for the damage. Aerial signatures of forest damage used to identify these causal agents are a combination of the characteristics of host trees affected, and colors and patterns associated with the damage.

The information presented in this guide is intended to assist aerial observers in the identification of the more commonly occurring agents responsible for forest damage mapped during aerial forest health surveys in the central Rocky Mountains. A number of signatures also are described that are not normally mapped during aerial forest health surveys, but could serve as sources of error or confusion. In addition, damage signatures not described in this manual will undoubtedly be encountered during future aerial forest health surveys.

While some aerial signatures are sufficiently unique to permit reliable identification of causal agents, others, such as agents that defoliate broadleaf forests, are more difficult to diagnose. In some cases, data from previous surveys and historical records of the damaging agents in a given area can be used in combination with the aerial signatures to help identify the causal agents. In other cases, positive identification of the causal agent(s) responsible for the damage can only be accomplished through supplemental ground checks. Available time and limited access to remote forest areas constrain the amount of ground checking that can realistically be done during aerial forest health surveys. However, some ground checking, especially if new, unusual or unfamiliar damage signatures are detected, should be an integral part of aerial forest health surveys.

Tables

Table 1. Crown characteristics of commonly occurring trees in the central and southern Rocky Mountains, as seen from low-flying aircraft.*

Species or Species Group	Foliage Color	Crown Form	Crown Margin	Branch Pattern	Foliage Texture
Ponderosa pine	Yellow-green	Rounded	Sinuate	Indistinct	Distinct clumps
Lodgepole pine	Olive green	Narrowly rounded	Sinuate	Indistinct	Small clumps
Limber, Southwestern white and whitebark pines	Dark blue-green	Broadly rounded	Lobed	Indistinct	Fine
Rocky Mountain bristlecone pine	Olive green	Broadly rounded	Serrate	Indistinct	Fine
Pinyon pine	Dark green	Broadly rounded	Lobed	Indistinct	Small clumps
Douglas-fir	Medium green	Acute	Sinuate to lobed	Indistinct (young trees); distinct (older trees)	Variable

* Based on data from Ciesla and Hoppas (1990), Croft et al. (1982) and experience of the authors.

Table 1 (cont). Crown characteristics of commonly occurring trees in the central and southern Rocky Mountains, as seen from low-flying aircraft.*

Species or Species Group	Foliage Color	Crown Form	Crown Margin	Branch Pattern	Foliage Texture
Blue spruce	Blue-green	Acute	Serrate	Layered	Fine-medium
Engelmann spruce	Gray-green	Acuminate-acute	Serrate	Layered	Fine
White fir	Blue-green	Acute	Serrate	Layered	Fine
Subalpine fir/ corkbark fir	Dark green to dark blue-green	Acuminate	Finely serrate	Indistinct	Fine
Junipers	Gray-green, blue-green or dark green**	Broadly rounded	Sinuate	Indistinct	Fine
Quaking aspen	Yellow-green to medium green	Broadly rounded	Sinuate	Indistinct	Fine
Cottonwoods	Medium green	Broadly rounded	Sinuate	Indistinct	Fine-medium
Gambel oak	Yellow-green	Broadly rounded	Sinuate	Indistinct	Clumpy

* Based on data from Ciesla and Hoppas (1990), Croft et al. (1982) and experience of the authors.

** Juniper cones typically are blue in color, and heavy cone crops can give trees a blue cast, regardless of foliage color.

Table 2. Characteristics of aerial signatures of tree mortality caused by tree-killing bark beetles in pines indigenous to the central Rocky Mountains.

Host Tree	Foliage Color of Current Year's Faders	Bark Beetle	Mortality Pattern	Other Characteristics	Remarks
Ponderosa pine	Yellow-green to pale yellow-orange	Mountain pine beetle	A scattering of trees in young stands (age < 60), group kills of 10-250 trees in older stands		
		Western pine beetle	Group kills of 10-250 trees		In the central and southern Rockies, found in southern Colorado, Arizona, New Mexico and southern Utah
		Roundheaded pine beetle	Scattered trees or small group kills		
		Ips engraver beetles	Scattered trees or small group kills (± 10 trees)		

Table 2 (cont). Characteristics of aerial signatures of tree mortality caused by tree-killing bark beetles in pines indigenous to the central Rocky Mountains.

Host Tree	Foliage Color of Current Year's Faders	Bark Beetle	Mortality Pattern	Other Characteristics	Remarks
Lodgepole pine	Red-orange	Mountain pine beetle	Small group kills and/or scattered tree mortality	Trees with large crown diameters are preferred, especially during the early stages of an outbreak	During outbreak, extensive stand level mortality may be observed
		Ips engraver beetle	Small group kills and/or scattered tree mortality		
Limber, Southwestern white and whitebark pines	Red-orange	Mountain pine beetle	Small group kills and/or scattered tree morality		
Pinyon pine	Orange to orange-brown	Pinyon ips	Group kills of 10-100 trees		

Table 3. Characteristics of aerial signatures of tree mortality caused by bark beetles in Douglas-fir, spruce and true firs indigenous to the central Rocky Mountains.

Host Tree	Foliage Color of Current Year's Faders	Bark Beetle	Mortality Pattern	Other Characteristics	Remarks
Douglas-fir	Yellow-green to bright red*	Douglas-fir beetle	Distinct groups of 10->200 mature trees	Infestations often occur on steep slopes	
	Bright red	Douglas-fir engraver beetles	Single trees, small groups of scattered pole-sized trees	Top-kill may be present	
Blue spruce	Beige	Blue spruce engraver	Single trees or small group kills of up to 40 trees	Top-kill may be present	
Engelmann spruce	Yellow-green to gray-brown	Spruce beetle	Infestations begin as a scattering of fading trees and progress to extensive tree mortality	Mature trees generally are affected, but during outbreaks, small trees also may be killed	

* Trees attacked following defoliation by western spruce budworm or Douglas-fir tussock moth are not conspicuous.

Table 3 (cont). Characteristics of aerial signatures of tree mortality caused by bark beetles in Douglas-fir, spruce and true firs indigenous to the central Rocky Mountains.

Host Tree	Foliage Color of Current Year's Faders	Bark Beetle	Mortality Pattern	Other Characteristics	Remarks
White fir	Orange	Fir engraver	Scattered trees or group kills of up to several hundred trees	Top-kill may be present	
Grand fir	Red-orange	Fir engraver	Scattered trees or group kills of up to several hundred trees	Top-kill may be present	
Subalpine fir	Red	Western balsam bark beetle	Scattered trees or group kills of up to 200 trees		

Table 4. Foliage-feeding insects of pine forests that can cause aerially visible defoliation in the central Rocky Mountains.

Insect	Host Trees Affected	Aerial Signature	Remarks
Pine sawflies	Lodgepole, pinyon and ponderosa pines	Crown thinning, gray cast; brown discoloration during severe outbreaks	
Pine butterfly	Ponderosa pine	Crown thinning, gray cast	Defoliation can occur over extensive areas
Pandora moth	Lodgepole and ponderosa pine	Crown thinning, gray cast	Defoliation can occur over extensive areas
Western pine tussock moth	Ponderosa pine and other conifers	Crown thinning and yellow-brown discoloration	
Rusty tussock moth	Wide range of conifers and broadleaf trees	Crown thinning and red-brown discoloration	
Ponderosa pine needle miner	Ponderosa pine	Yellow discoloration of foliage	Outbreaks and aerially visible discoloration tends to be localized

Figures

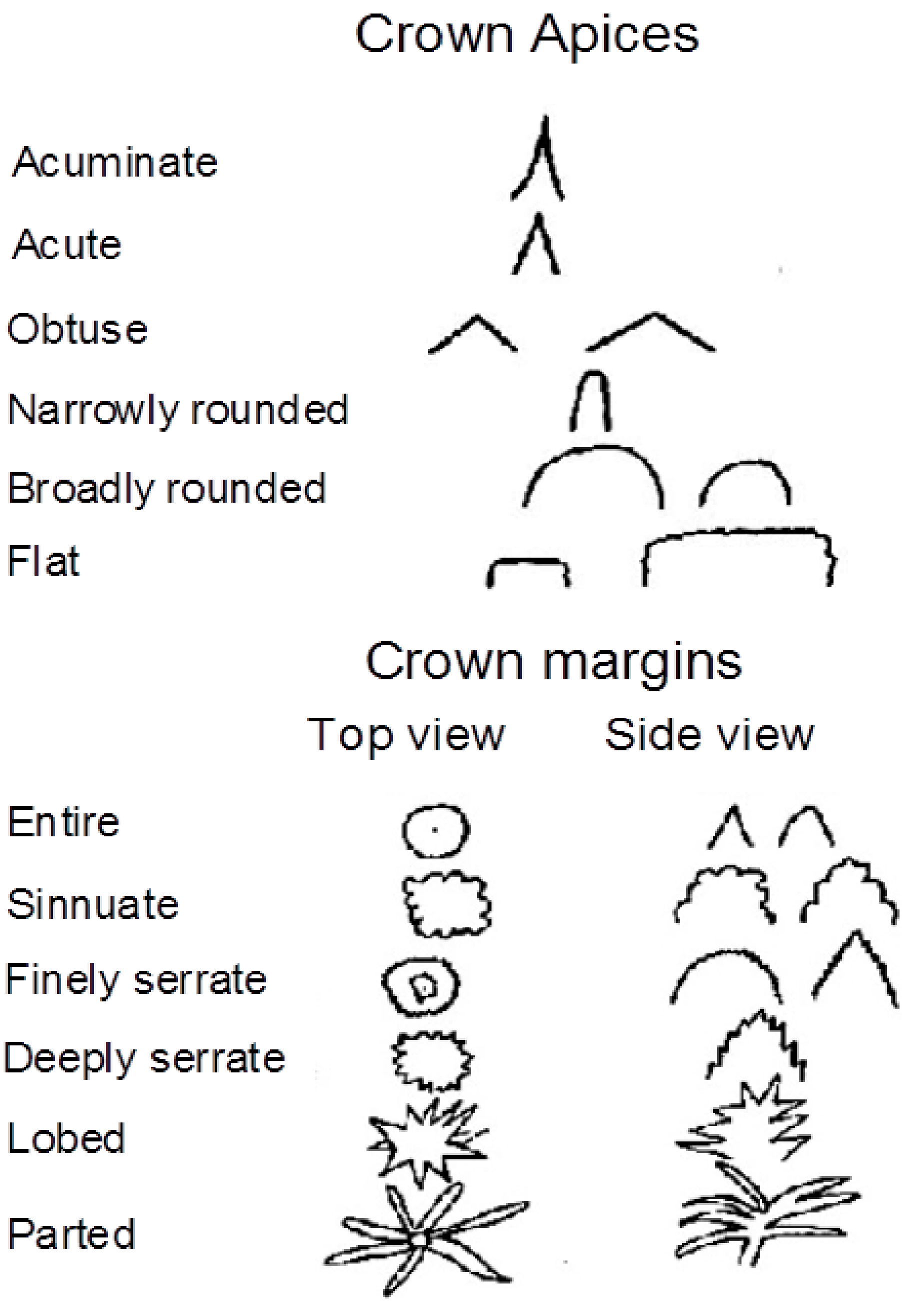


Figure 1 – Descriptors of tree crowns used to aid in identification of tree species and species groups on large-scale vertical aerial photos (Source: Heller et al. 1964).

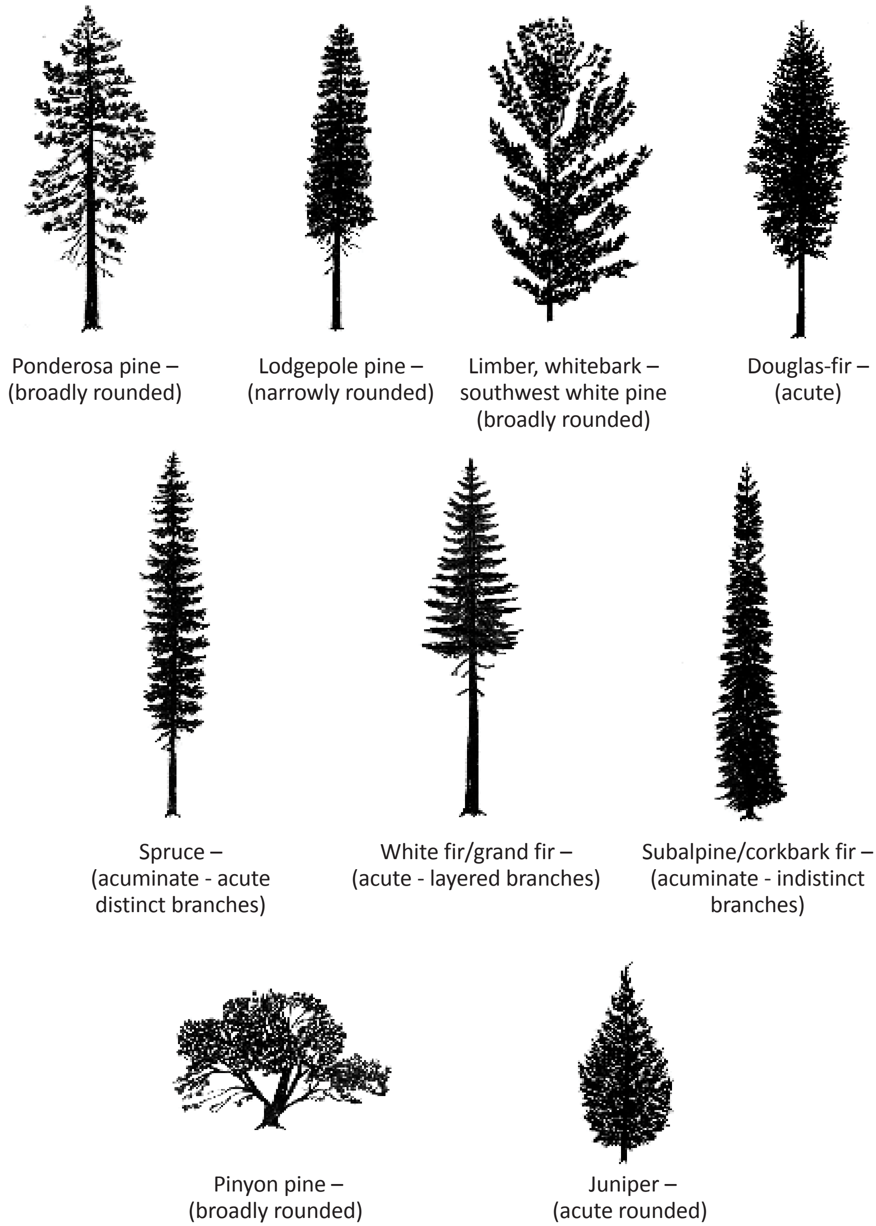
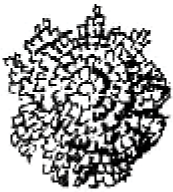
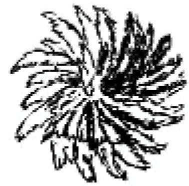


Figure 2 – Crown profiles of conifers found in the Rocky Mountains.

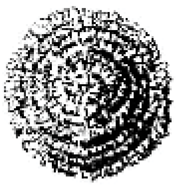


Ponderosa pine – (broadly rounded crown, sinuate margin, course, clumpy foliage)

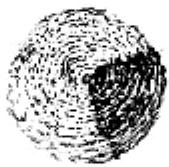
Lodgepole pine – (narrowly rounded crown, sinuate margin, fine, clumpy foliage)



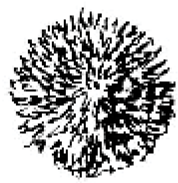
Limber, whitebark, southwest pines – (broadly rounded crown, lobed margin, fine, clumpy foliage)



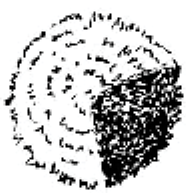
White fir/grand fir – (acute crown, serrate margin, layered branches)



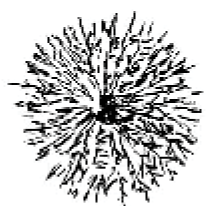
Subalpine/corkbark fir – (acuminate crown, serrate margin, fine foliage)



Spruce – (acuminate/acute crown, serrate margin, fine-medium foliage texture)



Douglas-fir – young (acute crown, sinuate margin, indistinct branches)



Douglas-fir – old (acute crown, lobed margin, distinct branches)

Figure 3 – Vertical views of tree crowns of conifers found in the Rocky Mountains.

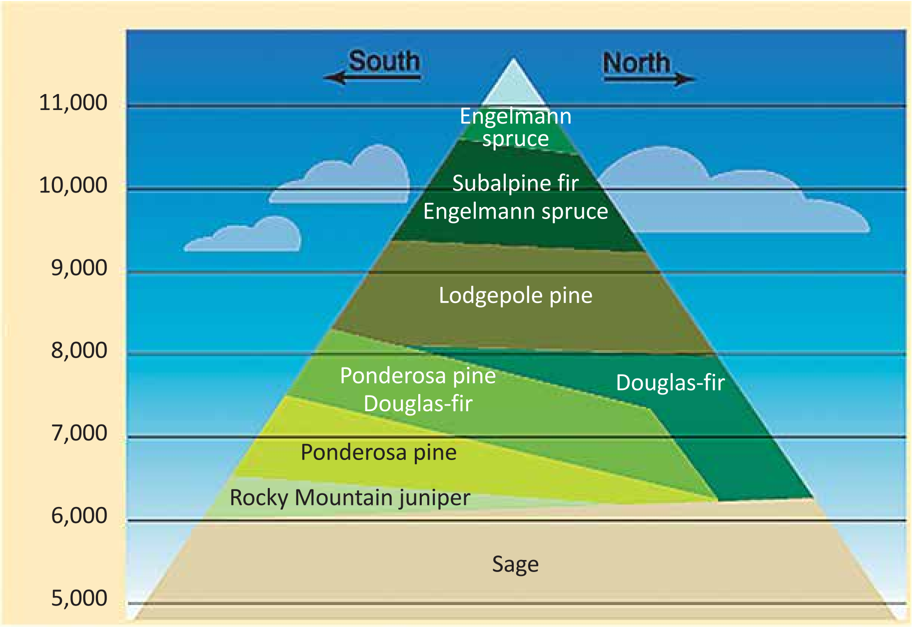


Figure 4a – Distribution of major tree species by elevation zones A – northern Colorado/southern Wyoming.

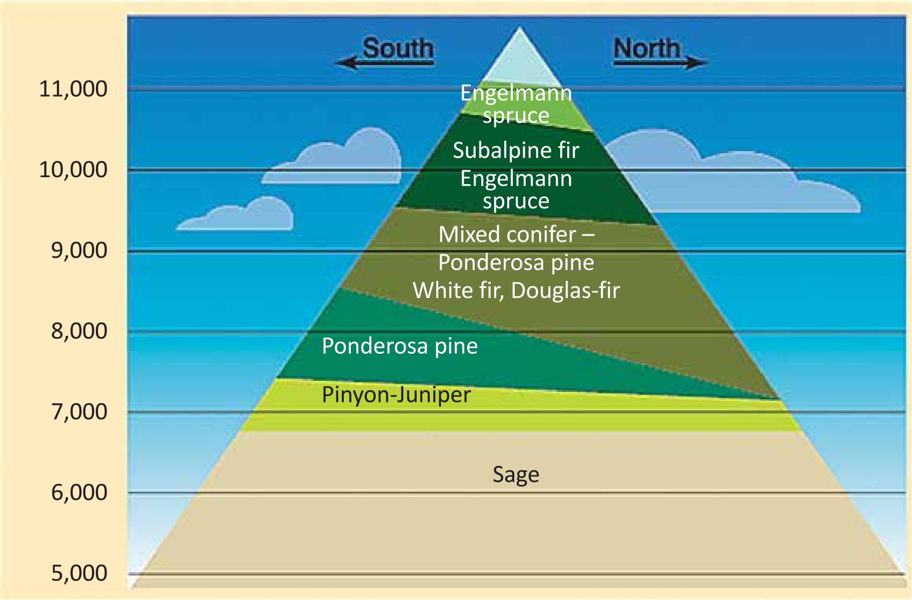


Figure 4b – Distribution of major tree species by elevation zone: B – southern Colorado/northern New Mexico (Source: Colorado State Forest Service 2010).

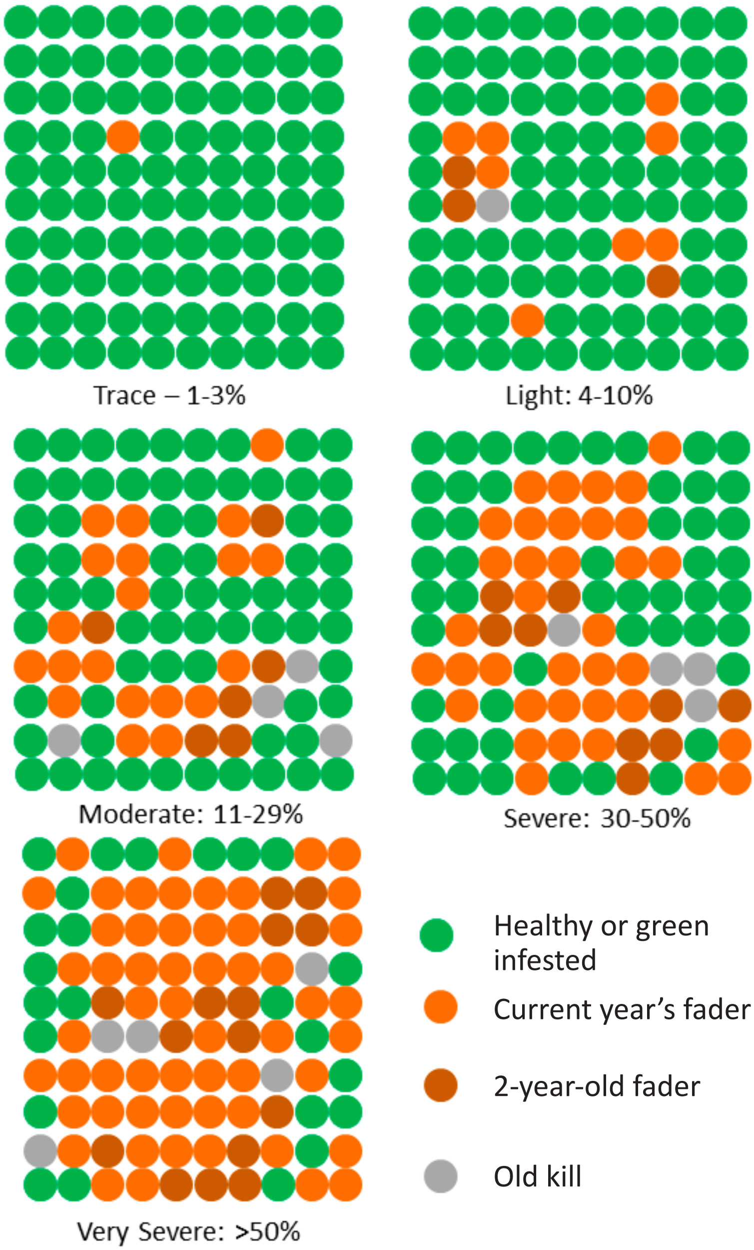


Figure 5 – Patterns of various intensities of tree mortality caused by bark beetles. Values represent the percent of current year's faders in relation to the total forested area within the polygon.

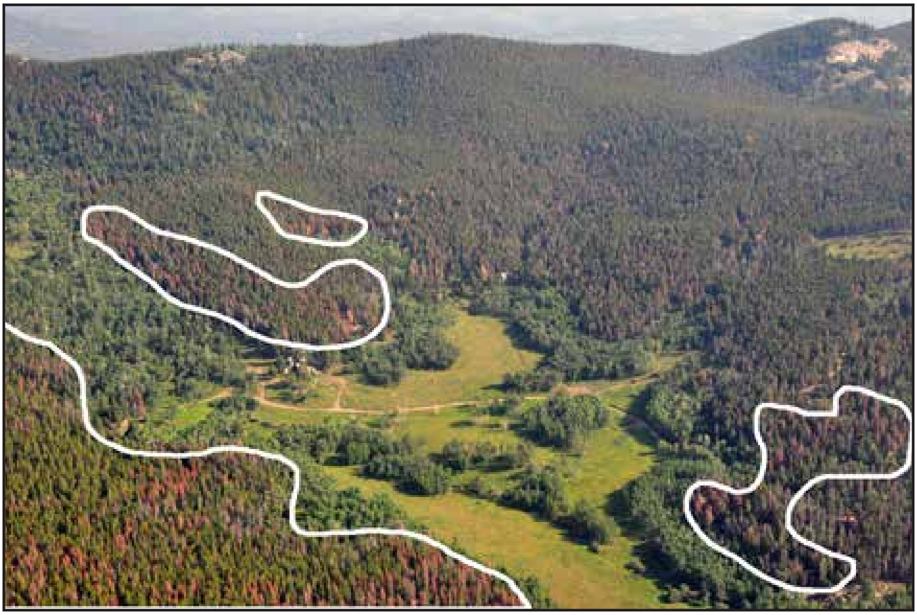


Figure 6 – Moderate damage by mountain pine beetle (Roosevelt National Forest, Colo.).

Figure 7 – Severe damage by mountain pine beetle (Black Hills National Forest, S.D.).

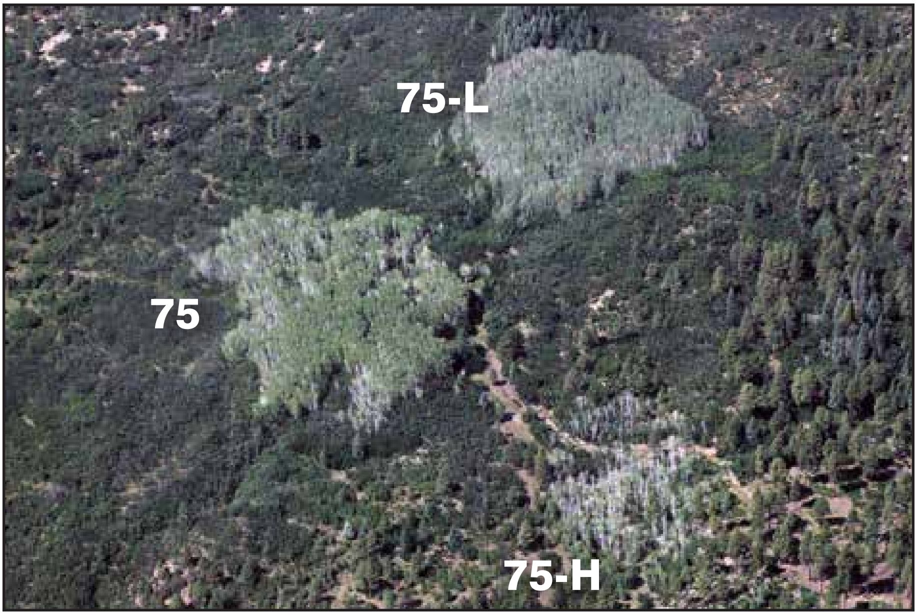


Figure 8 – Varying intensities of sudden aspen decline. Stands at left have early stages of decline (75), stand at upper center has light to moderate mortality (75-L) and stand at lower right has heavy mortality (75-H) (Santa Fe National Forest, N.M.).

Figure 9 – Lodgepole pine faders due to mountain pine beetle attack as they appear in mid- to late-June. Bark beetle-infested pines at this early stage of fading are not readily visible during aerial forest health surveys (Roosevelt National Forest, Colo.).

Figure 10 – Smoke and haze from active fires can significantly reduce visibility (Wet Mountains, Colo.).

Figure 11 – Quaking aspens near peak of fall color. The brilliant fall color of broadleaf trees can mask aerial signatures of forest damage (near Aspen, Pitkin County, Colo.).

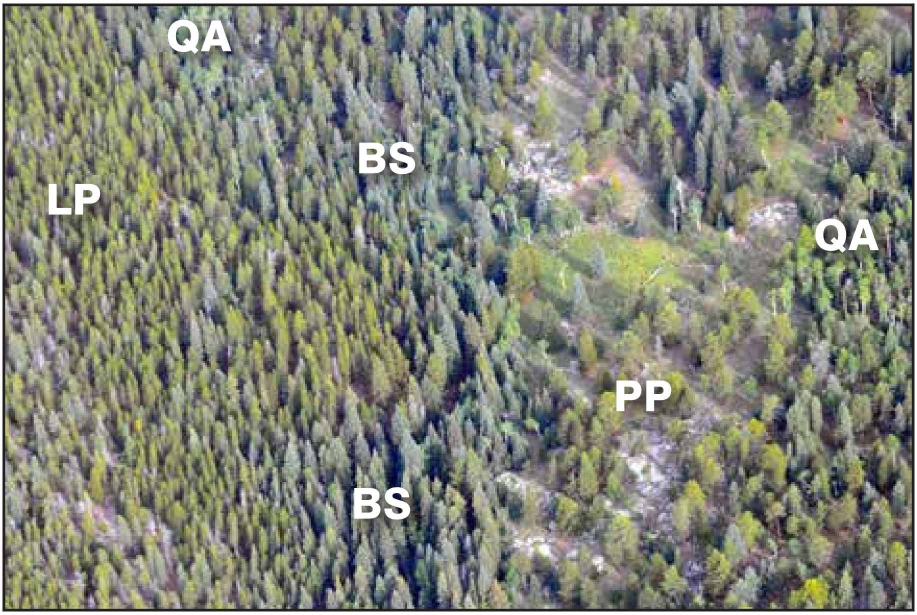


Figure 12 – Low- to mid-elevation forest stands: the left is dominated by lodgepole pine (LP), the center is blue spruce (BS) in a riparian zone, the right is ponderosa pine (PP). Small stands of quaking aspen (QA) also are seen (Turkey Creek Basin, Jefferson County, Colo.).

Figure 13 – A small patch of Colorado blue spruce with distinct blue cast to foliage is typical of early morning on an east-facing slope. Surrounding trees are predominantly Douglas-fir (Mosquito Range, Park County, Colo.).

Figure 14 – Color and shape of fading trees can provide clues as to the bark beetle and host tree involved. Both ponderosa (light yellow) and lodgepole (red-orange) pines are under attack by mountain pine beetle (Lower Big Thompson River Basin, Larimer County, Colo.).

Figure 15 – Ponderosa pines in early stages of fading due to mountain pine beetle are yellow-green in color (Moraine Basin, Rocky Mountain National Park, Colo.).

Figure 16 – Current year's ponderosa pine faders due to mountain pine beetle attacks tend to be light yellow-orange in color during mid- to late-summer (near Red Feather Lakes, Larimer County, Colo.).

Figure 17 – A large group of ponderosa pine faders in southern New Mexico. The location suggests that western pine beetle may be the causal agent (San Mateo Mountains, Cibola National Forest, N.M.).

Figure 18 – Top-kill in three ponderosa pines caused by ips engraver beetles amid a large number of total-tree ponderosa pine faders (near Ruidoso, Lincoln County, N.M.).

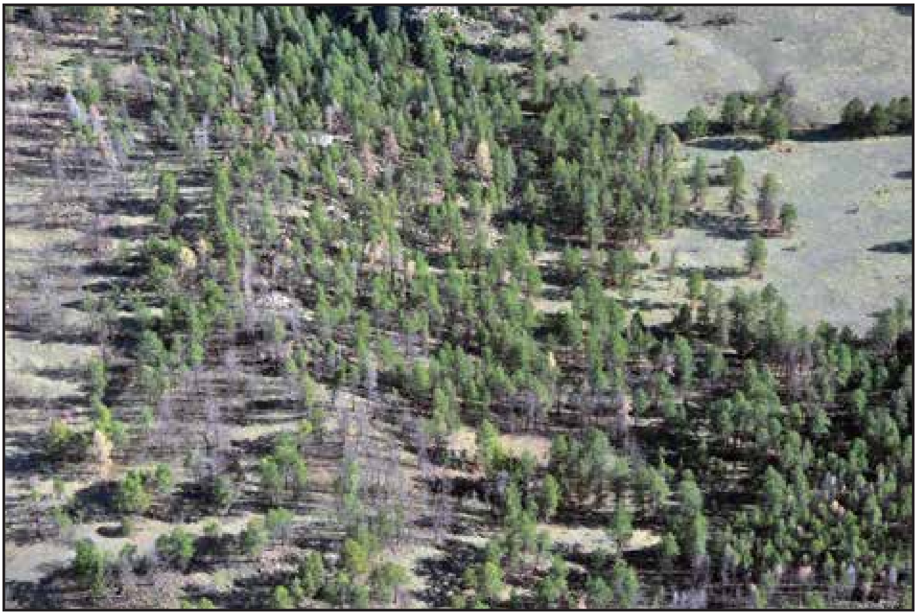


Figure 19 – Scattered tree mortality in ponderosa pines adjacent to a recent wildfire is indicative of attack by ips engraver beetles (Nash Ranch Fire near Guffey, Park County, Colo.).

Figure 20 – Lodgepole pines attacked by mountain pine beetle fade to a bright red-orange (Buckhorn Creek Basin, Roosevelt National Forest, Colo.).

Figure 21 – During the early stages of an outbreak, mountain pine beetles prefer large-diameter lodgepole pines (Colorado State Forest, Jackson County, Colo.).

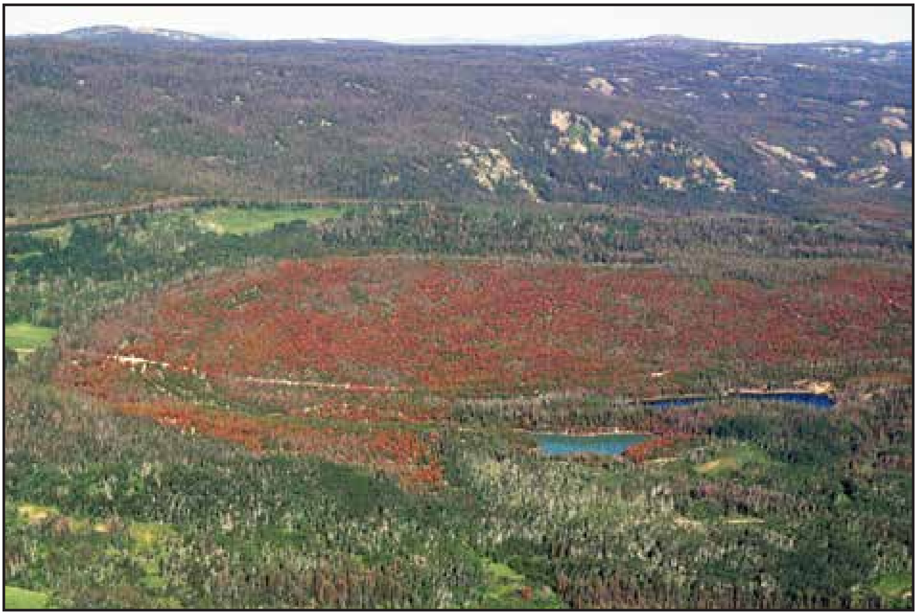


Figure 22 – Characteristic pattern of tree mortality in lodgepole pine during the advanced stages of a mountain pine beetle outbreak (Laramie River Basin, Roosevelt National Forest, Colo.).

Figure 23 – Mountain pine beetle damage in limber pine is characterized by broadly rounded crowns of fading trees (South Boulder Creek Basin, Boulder County, Colo.).

Figure 24 – Mountain pine beetle damage in high-elevation whitebark pine forest (Wind River Range, Wyo.).

Figure 25 – Damage to bristlecone pine twigs by a twig beetle (*Pityophthorus boycei),* and adult beetle in twig (insert) (Thirtynine Mile Mountain, Park County, Colo.).

Figure 26 – Aerial view of discoloration of bristlecone pines by the twig beetle (*Pityophthorus boycei)* (Thirtynine Mile Mountain, Park County, Colo.).

Figure 27 – Group kills in pinyon pine caused by pinyon ips beetle (Four Mile Creek Basin near Cañon City, Fremont County, Colo.).

Figure 28 – Pinyon pine with heavy damage by twig beetles of the genus *Pityophthorus* (near Ludlow, Huerfano County, Colo.).

Figure 29 – Aerial view of pinyon pine damage. Ground checks indicated that the damage was caused by a combination of pinyon twig beetles and pinyon ips (near Ludlow, Huerfano County, Colo.).

Figure 30 – Large group of Douglas-fir killed by Douglas-fir beetle (Rampart Range, Douglas County, Colo.).

Figure 31 – Douglas-fir beetle infestation with variable rates of tree fading (near Ouray, Ouray County, Colo.).

Figure 32 – Blue spruce in a riparian zone killed by blue spruce engraver beetle (Culebra Range, Las Animas County, Colo.).

Figure 33 – Severe damage by spruce beetle to Engelmann spruce (Spring Creek Pass, Hinsdale County, Colo.).

Figure 34 – Engelmann spruce with yellow-green foliage indicative of spruce beetle attack amid spruce devoid of foliage from previous year's attacks. (Rio Grande National Forest, Colo.).

Figure 35 – Spruce beetle attacks in dwarfed Engelmann spruce (krummholz) at the edge of timberline (Weminuche Wilderness, San Juan National Forest, Colo.).

Figure 36 – Scattered tree mortality of white fir caused by fir engraver beetle (Wet Mountains, Colo.).

Figure 37 – Group kills caused by fir engraver beetle in white fir (Carson National Forest, N.M.).

Figure 38 – Fir engraver beetle infestation consisting of top-kill (arrow) and tree mortality (Wet Mountains, Colo.).

Figure 39 – Scattered tree mortality of subalpine fir caused by western balsam bark beetle (near Questa, Taos County, N.M.).

Figure 40 – Group of subalpine fir killed by western balsam bark beetle (Sangre de Cristo Range, Colo.).

Figure 41 – Light defoliation of ponderosa pine by the sawfly *Neodiprion autumnalis* (eastern Elbert County, Colo.).

Figure 42 – Moderate to severe defoliation of ponderosa pine by the sawfly *Neodiprion fulviceps* (Coconino National Forest, Ariz.).

Figure 43 – Defoliation of ponderosa pine by Pandora moth (Kaibab National Forest, Ariz.).

Figure 44 – Defoliation and discoloration of ponderosa pine foliage by western pine tussock moth (near Scott's Bluff, Scott's Bluff County, Neb.).

Figure 45 – Red-brown discoloration of lodgepole pine foliage due to an outbreak of rusty tussock moth (Bighorn National Forest, Wyo.).

Figure 46 – Yellow discoloration of ponderosa pine foliage caused by an outbreak of ponderosa pine needle miner (Rist Canyon, Larimer County, Colo.).

Figure 47 – Damage to current year's foliage by western spruce budworm (Ophir Creek Basin, Wet Mountains, Colo.).

Figure 48 – Defoliation and discoloration by western spruce budworm in the wildland-urban interface (Bear Mountain, Jefferson County, Colo.).

Figure 49 – Defoliation and discoloration by western spruce budworm over an extensive area of forest (Mt. Zwischen, Sangre de Cristo Range, Colo.).

Figure 50 – Defoliation and needle discoloration caused by an outbreak of Douglas-fir tussock moth in a mixed forest of Douglas-fir and white fir (Santa Clara Pueblo, Rio Arriba County, N.M.).

Figure 51 – Damage caused by Douglas-fir tussock moth in a pure Douglas-fir forest (northern Rampart Range, Douglas County, Colo.).

Figure 52 – Localized damage by Douglas-fir tussock moth (Slopes of Doublehead Mountain, Jefferson County, Colo.).

Figure 53 – Defoliation of quaking aspen by large aspen tortrix (Roaring Judy Basin near Almont, Gunnison County, Colo.).

Figure 54 – Defoliation and discoloration of New Mexico locust by a species of concealer moth (*Agonopterix* spp.) (Near La Veta, Huerfano County, Colo.).

Figure 55 – Defoliation of aspen by western tent caterpillar. Note “fuzzy” or out-of-focus appearance at the boundaries of defoliation (Mosca Pass, Sangre de Cristo Range, Colo.).

Figure 56 – Yellow discoloration of salt cedar or tamarisk caused by feeding of diorhabda beetle, a biological control agent (near La Junta, Las Animas County, Colo.).

Figure 57 – Discoloration of narrowleaf cottonwood caused by an outbreak of the poplar blackmine beetle, *Zeugophora scutellaris* (Big Thompson River Basin, Larimer County, Colo.).

Figure 58 – Discoloration and foliage thinning of pinyon pine caused by pinyon needle scale (near Bonanza, Saguache County, Colo.).

Figure 59 – Large area of quaking aspen forest with varying degrees of foliar damage caused by Marssonina blight (Grand Mesa, Colo.).

Figure 60 – Foliage discoloration of aspen caused by early stages of sudden aspen decline (South Park, Park County, Colo.).

Figure 61 – Advanced stages of sudden aspen decline, including tree mortality and patches of fallen trees (South Park, Park County, Colo.).

Figure 62 – Dieback and mortality of narrowleaf cottonwood (Rio Grande near Alamosa, Alamosa County, Colo.).

Figure 63 – Severe mortality of narrowleaf cottonwood (near Great Sand Dunes National Park and Preserve, Colo.).

Figure 64 – Blue spruce killed by flooding due to beaver dam construction (near Almont, Gunnison County, Colo.).

Figure 65 – Extensive, progressive damage to a spruce stand from flooding caused by beaver dam construction (Medicine Bow National Forest, Wyo.).

Figure 66 – Branch flagging and top-kill to lodgepole pine caused by porcupines (Owl Creel Pass, San Juan Range, Colo.).

Figure 67 – Mortality of ponderosa pines caused by nesting herons (near DeWeese Reservoir, Wet Valley, Custer County, Colo.).

Figure 68 – Discolored pines adjacent to a road damaged by deicing chemicals (Cucharas, Las Animas County, Colo.).

Figure 69 – Yellow discoloration of Gambel oak foliage indicative of a recent herbicide application (near Montrose, Montrose County, Colo.).

Figure 70 – Brown and gray discoloration of Gambel oak due to an older herbicide application (near Montrose, Montrose County, Colo.).

Figure 71 – Quaking aspen damaged by late spring frost (near Heber City, Wasatch County, Utah).

Figure 72 – Defoliation of a swath of broadleaf trees caused by a hailstorm in an urban area (Lakewood, Jefferson County, Colo.).

Figure 73 – Hail damage to a conifer forest composed predominantly of lodgepole pine (Tennessee Mountain, Boulder County, Colo.).

Figure 74 – Windthrow in a high-elevation Engelmann spruce forest (Sangre de Cristo Range, Colo.).

Figure 75 – Localized windthrow in a quaking aspen stand suggestive of a microburst (Wet Mountains, Colo.).

Figure 76 – Band of windthrow in Engelmann spruce-subalpine fir forest suggestive of a tornado (Pecos Wilderness, Santa Fe National Forest, N.M.).

Figure 77 – Quaking aspen stand defoliated by high winds (Wet Mountains, Colo.).

Figure 78 – Tree breakage caused by an avalanche (Elk Mountain, Medicine Bow National Forest, Wyo.).

Figure 79 – Leaf scorch on serviceberry (west of the Black Canyon of the Gunnison National Park, Colo.).

Figure 80 – Discoloration of ponderosa pine, believed to be the result of extreme dry conditions (west of Walsenburg, Huerfano County, Colo.).

Figure 81 – Winter drying or “red belt” of ponderosa pine foliage. Note that some needles on several of the affected trees are still green (La Veta Pass, Culebra Range, Colo.).

Figure 82 – Winter drying of Rocky Mountain juniper on an exposed slope (near Cheyenne Mountain, Colorado Springs, Colo.).

Figure 83 – Winter drying of Engelmann spruce krummholz. Note that only one side of some trees are damaged (near Telluride, San Miguel County, Colo.).

Figure 84 – Mosaic of varying intensities of wildfire damage (2011 Duckett Fire, Sangre de Cristo Range, Colo.).

Figure 85 – Low-intensity wildfire or prescribed burn in ponderosa pine forest. Note that only the lower portions of crowns are discolored along the edges of the burn (Upper Arkansas River Basin, Colo.).

Figure 86 – Ponderosa and lodgepole pine forest with both fire damage and active mountain pine beetle infestations. Bark beetle-damaged ponderosa pines have light yellow-orange fading crowns (2012 High Park Fire, Pendergast Creek Basin, Larimer County, Colo.).

Figure 87 – Aerial view of New Mexico locust at peak bloom. Note mottled appearance of tree crowns (La Veta Pass, Culebra Range, Colo.).

Figure 88 – Fading lodgepole pines in a stand dominated by quaking aspen resemble the aerial signature of mountain pine beetle attack. Ground checks indicated that the lodgepole pines had been girdled to favor the aspen component of the stand (Glacier Lake, Roosevelt National Forest, Colo.).

Figure 89 – Slash piles in a thinned lodgepole pine stand can mimic the appearance of fading pines, especially if surrounding stands are infested by bark beetles (Bennett Creek Basin, Roosevelt National Forest, Colo.).

Figure 90 – Discoloration caused by a fire retardant drop on a spot fire (2012 Waldo Canyon Fire, near Manitou Springs, El Paso County, Colo.).

Figure 91 – Fire retardant drop at the edge of a wildfire (2011 Crystal Fire, Larimer County, Colo.).

Figure 92 – Heavy cone crop in Colorado blue spruce (Buckhorn Creek Basin, Larimer County, Colo.).

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