Describing Signatures: a Key to Successful use of Remote Sensing for Forest Damage Assessment

Descrevendo Assinaturas: a Chave para o Uso Bem Sucedido do Sensoriamento Remoto para Avaliação dos Danos Florestais

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Abstract

Forest damage caused by a variety of agents: wildfire, climatic events, mammals, insects and diseases is often highly visible and can be assessed by remote sensing. Certain characteristics of the damage, as seen via remote sensing, can provide clues to the identity of the agent(s) responsible for the damage. These include the ability to recognize the host tree(s) affected, color and texture of the foliage of affected trees, distribution of damage, size of affected trees and portion of tree crown affected. Examples are provided from the United States and southern Brazil of how combinations of these characteristics are helpful in the identification of damaging forest agents during aerial sketchmap surveys, interpretation of large to medium scale aerial photos or airborne video imagery.

Key words: aerial sketchmapping; signatures; forest damage; remote sensing.

Resumo

Danos florestais causados por uma variedade de agentes: incêndios, eventos climáticos, mamíferos, insetos e doenças é frequentemente muito visível e pode ser avaliado por sensoriamento remoto. Certas características do dano, como vistos por sensoriamento remoto, podem proporcionar indícios para identificar o(s) agente(s) responsável pelo dano. Estas incluem a habilidade em reconhecer a(s) árvores hospedeiras afetadas, a cor e textura da folhagem da árvore atacada, a distribuição do dano, o tamanho das árvores afetadas e as partes da copa afetada. Exemplos são fornecidos dos Estados Unidos e do sul do Brasil de como as combinações dessas características são valiosas

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na identificação dos agentes causadores de danos durante os levantamentos aéreos expeditos, a interpretação de fotografias aéreas em escalas grandes a médias ou de imagens aéreas de vídeo.

Palavras-chave: mapeamento aéreo expedito; assinaturas; danos florestais; sensoriamento remoto.

Introduction

Forests are subject to damage by many forces, chief among them being fire, insects, diseases, mammals, parasitic plants and storms. Damage caused by some of these agents, especially those that kill trees or damage the foliage, is often visible from long distances and, therefore, can be assessed via various remote sensing technologies. Certain characteristics of forest damage, when seen from small aircraft, on large to medium scale aerial photos or other high resolution remote sensing products can enable aerial observers to identify, with reasonable accuracy, the causal agent(s) responsible for the damage. Ability to recognize these characteristics, or signatures, is critical to the success of aerial forest health surveys conducted annually in the United States. Recently, detailed documentation of forest damage signatures has been summarized for the forests of the western U.S. (Ciesla 2006). The purpose of this paper is to describe the common aerial signatures of forest damage in the U.S., with emphasis on damage caused by insects and diseases, and discuss opportunities for signature recognition of forest damage in southern Brazil.

What is a signature?

A signature is a signal that consists of one or more unique characteristics that can be used to identify something - an object, a person, etc. A person's name, written in his or her own handwriting, is the classic example of a signature. Because everyone's handwriting is unique, people are identified by their signatures. Another example of a signature is the theme music played at the beginning of a radio or TV show. The tempo and melody of the music, often composed especially for that show, identifies the show to the listener. In the context of forest entomology, the galleries engraved by bark beetles in the cambium layer of host trees are referred to as signatures. These patterns, in combination with the host tree attacked, are usually sufficient to permit identification of the bark beetle at least to genus and sometimes to species.

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

Crown Characteristics of Trees

Some damaging agents, especially forest insects and diseases tend to be host specific. Therefore, the ability to recognize tree species or at least species groups is essential to the recognition of forest damage signatures. By identifying from the air the tree species and forest types present in the areas surveyed, the observer can narrow the complex of potential damaging agents that could be present. Crown characteristics used to identify healthy tree species or species groups on medium or large-scale aerial photographs are a combination of foliage color, crown form, crown margin, branch patterns and foliage texture. These characteristics are especially helpful for recognition of species and species groups (*e.g.* white or soft pines) in the coniferous forests of the western U.S. (CIESLA, 2006, figs. 1-3, table 1).

Location of trees and forest types, relative to landscape features such as elevation, aspect and proximity to water is also helpful in identification of tree species or species groups via remote sensing.

Figures 1. 1. Descriptors of tree crowns used to aid in identification of tree species and species on large-scale vertical aerial photos (HELLER et al., 1964). 2. Crown shapes of common western U.S. conifers. 3. Vertical views of crown margins, branch patterns and foliage textures of several western conifers (CIESLA, 2006)

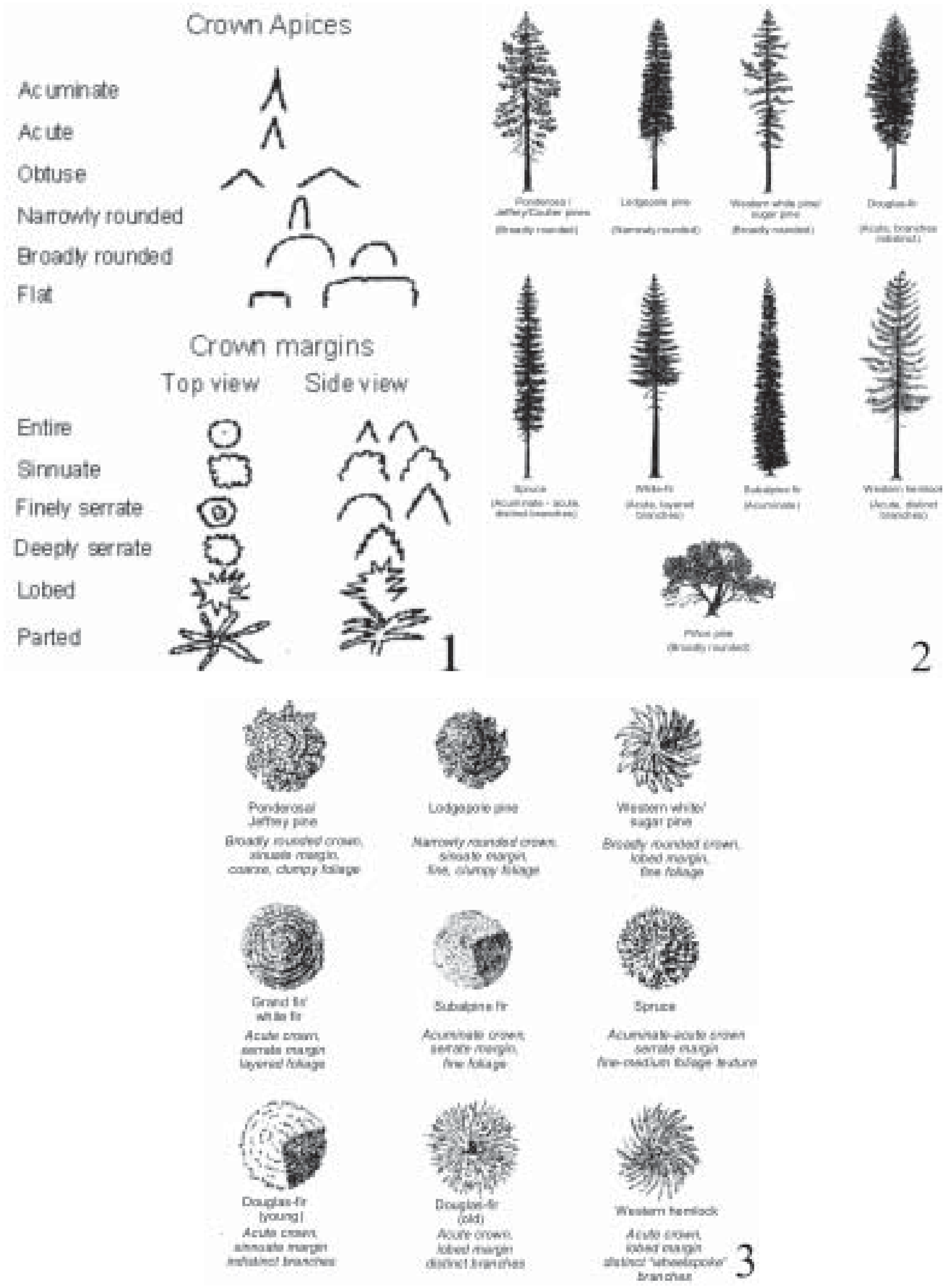


Table 1. Crown characteristics of commonly occurring conifers in western forests as seen from low flying aircraft or on large- scale color vertical aerial photos*

Species or species group	Foliage color	Crown form	Crown margin	Branch pattern	Foliage texture
Ponderosa pine/Jeffrey pine/Coulter pine	Yellow-green	Broadly rounded	Sinuate	Indistinct	Small clumps
Lodgepole pine	Olive-green	Narrowly rounded	Sinuate	Indistinct	Very small clumps
Western white and sugar pines	Blue-green	Broadly rounded	Lobed	Indistinct	Fine
Limber pine	Blue-green to gray green	Broadly rounded	Lobed	Indistinct	Fine
Colorado bristlecone pine	Olive green	Broadly rounded	Lobed	Indistinct	Fine
Piñon pine	Dark green	Broadly rounded	Serrate	Indistinct	Small clumps
Douglas-fir	Gray-green to medium green	Acute	Sinuate to lobed	Indistinct (young trees) Distinct (old trees)	Variable
Blue spruce	Blue-green	Acute	Serrate	Layered	Fine-medium
Engelmann spruce	Gray-green	Acuminate – acute	Serrate	Layered	Fine-medium
Grand fir	Green	Acute	Serrate	Layered	Fine
White fir	Blue-green	Acute	Serrate	Layered	Fine
Subalpine fir	Dark green to dark blue green	Acuminate	Finely serrate	Layered	Fine
Western larch	Light green	Acute to narrowly rounded	Lobed	Distinct scraggly branches	Fine
Western hemlock	Dark green	Acute	Lobed-parted	Distinct "wheelspoke" pattern	Fine
Port Orford cedar	Yellow-green	Broadly rounded	Sinuate	Indistinct	Lacey, transparent
Junipers	Gray-green, blue green or dark green**	Broadly rounded	Entire to sinuate	Indistinct	Fine

** Based on data from Ciesla and Hoppas (1990), Croft et al. (1982) and author's experience*
*** Juniper cones are typically blue in color, therefore heavy cone crops can give trees a blue cast regardless of foliage color*
Source: Ciesla (2006)

Damage Characteristics

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

- color and texture of the affected crowns;
- distribution of damage;
- size of trees affected;
- portion of the tree crown affected.

Crown Color and Texture

Most tree damage caused by insects and disease first appears as a change in the crown color. The foliage of trees killed by bark beetles or other tree killing pests changes from green to yellow, orange, red or brown. This process is referred to as fading and dying trees, especially conifers, are called "faders." The color of fading provides a clue to the identity of the affected trees. For example, the foliage color of ponderosa pines, *Pinus ponderosae*, killed by bark beetles fades first from green to yellow-green, progresses to a straw yellow, and becomes dull red-brown before dropping from the trees (fig. 2, in this paper all the photos are in color). Lodgepole pines, *P. contorta*, fade differently. Lodgepole pines fade first to yellow-green then progress to red-orange and red-brown before needle fall (fig. 3). The color difference in fading is striking between the two species even when attacked by the same bark beetle.

Figure 2. Group of Pinus ponderosa killed by mountain pine beetle, *Dendroctonus ponderosae*. Yellow green to yellow orange crowns were attacked one year ago. Trees with dull red brown crowns were attacked two years ago

Figure 3. Lodgepole pines, *P. contorta*, killed by mountain pine beetle, fade to a bright red-orange color

Douglas-fir fades to a red hue and trees attacked during the same year can fade at different rates. Grand fir, *Abies grandis*, and white fir, *A. concolor*, fade to a red-orange hue. Subalpine fir faders are red. The fading foliage of true firs can remain on trees for three to five years, gradually changing to red brown or even a purple hue. Spruces attacked by bark beetles are often difficult to detect because initially they fade to a pale yellow-green color, yet needles can drop from trees while they are still green. Regardless of species involved, all trees suffering foliar injury typically take on a red-brown to gray hue and their crowns often appear thin (fig. 4).

Distribution of Damage

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

Figure 4. Brown to gray colored, thin crowns are an indicator of defoliation or foliar injury. In this photo, a forest of Douglas-fir, *Pseudotsuga menzeisii*, has been defoliated by Douglas-fir tussock moth, *Orgyia pseudotsugata*.

Tree Size

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

Portion of Crown Affected

The portion of the crown affected also can provide clues to the causal factor responsible for the damage. Bark beetles of the genus *Dendroctonus* attack the mid and lower boles of their host trees. Consequently, when trees die the entire crown fades. Some species of ips engraver beetles prefer thin bark and initiate attacks in the upper quarter, third, or half of the crown, causing top kill (fig. 5). A similar attack pattern can occur with Douglas-fir engraver beetles and fir engraver, *Scolytus ventralis*. Top kill is usually most apparent on large trees growing in open stands, but is often difficult to see from operational aerial survey flying heights.

Figure 5. Upper crowns of *Abies concolor* killed by the bark beetle *Scolytus ventralis*

Foliage feeding by insects often begins in the upper crown and, during heavy infestations, can progress downward until the entire crown is defoliated. However, the reverse holds true for the larvae of at least one species of defoliator indigenous to the western U.S, the western hemlock looper, *Lambdina fiscellaria lugubrosa*, which feeds initially in the lower crowns of host trees. In Mexico, *Evita hyalinaria hyalinaria*, a defoliator of *Abies religiousa,* also begins feeding in the lower crowns of host trees.

Other Factors that Influence the Appearance of Damage

Peak Occurrence of Signatures

Data on forest damage should be acquired when damage signatures are at their peak, as defined by the seasonal history of the damaging agent. This is especially true for those agents that damage foliage. Failure to identify the optimum survey window could result data acquired too early, before all of the damage has occurred, or too late, when damaged foliage has been washed from trees by rains or is masked by new growth. In western forests, most of the important damaging agents can be mapped during July and August as part of an "aerial overview survey" (MCCONNELL et al., 2000). There are exceptions, however. Damage caused by larch casebearer, *Coleophora laricella*, on western larch, *Larix occidentalis*, occurs early and peaks in late June. Foliar damage caused by Swiss needle cast, caused by the fungus *Phaecryptopus gäumannii*, in coastal Douglas-fir forests of Oregon and Washington is at its peak in May immediately prior to bud burst.

Light and Shadow

Light and shadow can have significant effects on the ability to discern subtle differences in damage signatures. During mid summer (July and August), data acquisition can be done on most days from about 8:00 AM to 4:00 PM provided that turbulence, afternoon thundershowers and cloud cover are not limiting factors. Damage on east facing slopes is more visible during the early morning hours, while they are in direct sunlight and, conversely, west facing slopes during the afternoon.

Clouds can reduce the amount of sunlight that strikes the survey area, but less light is not always detrimental to the survey. High cirrus clouds can diffuse sunlight, reduce the sharp contrasts characteristic of full sunlight, and make damage signatures easier to classify. On the other hand, cumulus clouds can cause dark shadows interspersed with brightly lit slopes, thereby making signatures less visible. Late afternoon thundershowers and atmospheric haze can significantly reduce visibility and image quality, thereby making it difficult to detect and classify forest damage signatures (MCCONNELL et al., 2000).

Background Noise

At certain times of the year phenomena may occur that mask or mimic forest damage signature. The classic case is that of fall coloration of deciduous trees in September and October. Undoubtedly the most confounding in temperate and austral forests is the brilliant fall coloring of deciduous broadleaf trees. In some areas of the U.S., deciduous conifers, such as larches, *Larix* spp. in the northern regions and bald cypress, *Taxodium distichum* in the Southeast can cause similar masking of forest damage. Spring bud burst also produces myriad colors and could mask attempts to map certain kinds of foliar injury. In Brazil, an abundance of brightly colored flowering trees could possibly mask damage signatures. Late spring frosts, especially in broadleaf species, can cause a signature virtually identical to that of defoliating insects. Heavy cone crops, especially on spruce, can cause the upper crowns to have a brown cast, which can mimic defoliation or trees fading due to bark beetle attacks.

Applications in Southern Brazil

Identification of Tree Species

The forests of southern Brazil are considerably more diverse than those in North America. However, many of the concepts of tree species identification used during aerial sketchmap surveys or on large scale, high-resolution imagery can be applied. The dark green, broad umbrella-like crown of *Araucaria angustifolia* is easily recognized. The fine textured foliage of bracatinga, *Mimosa scabrella*, was easily detected during aerial sketchmap surveys conducted in Paraná and Santa Catarina States. *Eucalyptus*, *Pinus* and other plantations are recognized by their more or less regular geometric patterns, even texture and the foliage color of the species involved.

Damage Signatures

Work in southern Brazil, as part of an EMBRAPA/USDA Forest Service cooperative program to introduce aerial sketchmapping for assessment of the woodwasp, *Sirex noctilio*, has led to the recognition of a number of distinct forest damage signatures (CIESLA et al., 1999, 2002, CIESLA and JOHNSON 2001, de OLIVEIRA et al., 2004). These include:

1. scattered tree mortality in plantations of *Pinus taeda* characteristic of damage caused by the European woodwasp, *Sirex noctilio*, which has been a pest in the south of Brazil since 1988 (fig. 6);
2. scattered killing of tops of trees in plantations of pines and *Araucaria angustifolia* caused by an indigenous monkey, *Cibus nigritus* (fig. 7);
3. yellowing or chlorosis of foliage in pine plantations. In at least one area of plantations in western Parana State, this signature has been linked to infection by a root infesting fungus of the genus *Armilaria* (fig. 8). However, other factors, such as soil nutrient deficiencies or feeding damage by a recently introduced complex of giant conifer aphids, *Cinara* spp., could cause a similar damage signature;
4. some group kills in pine plantations ranging in size from 5-20 trees. These closely resemble the classic signature of damage caused by bark beetles in North America (fig 9). Although this signature has not been investigated, some workers believe that it may be the result of lighting strikes;
5. A brown discoloration and thinning of the foliage of the indigenous conifer, *Podocarpus lambertii* caused by a combination of a needle fungus and defoliation by caterpillars (Geometridae);
6. Frost injury to foliage of *Eucalyptus*.

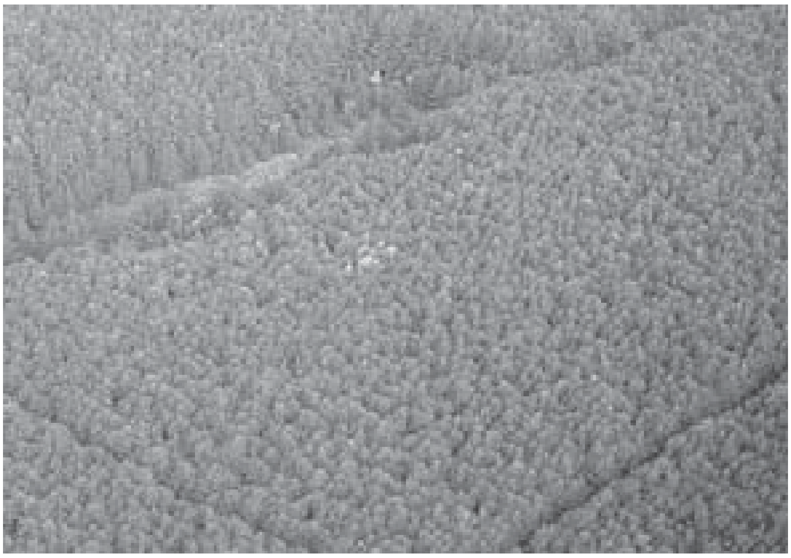
Additional opportunities exist for defining forest damage signatures in Brazil. For example, is foliage loss caused by infestations of the red gum lerp, *Glycaspis brimblecombei*, recently introduced into portions of Sao Paulo State and other states of Brazil (LUTINSKI et al., 2006) sufficiently visible to be assessed via aerial sketchmap surveys and/or oblique digital aerial photos?

Figure 6. Scattered tree mortality in a *Pinus taeda* plantation caused by infestations of European wood wasp, *Sirex noctilio*

Figure 7. Top kill in an *Araucaria angustifolia* plantation caused by stripping of bark by the capuchin monkey, *Cibus nigritus*

Figure 8. Chlorotic or yellow foliage on *Pinus taeda* associated with a root infesting fungus, *Armillaria* sp

Figure 9. Small group of dead and dying *Pinus taeda* in a plantation. Cause unknown



Conclusions

Forest damage caused by a variety of factors including fire, insects, diseases, mammals, parasitic plants and storms is highly visible and can be mapped using a variety of remote sensing technologies. 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. The aerial signatures of forest damage used to identify these causal agents are a combination of the characteristics the host trees affected and the pattern of damage. These have recently been documented in detail for the western US. Some forest damage signatures in the forests of Brazil have been characterized and opportunities exist for further work on Brazilian forest damage signatures, especially for forest plantations.

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