REMOTE SENSING FOR FOREST DAMAGE ASSESSMENT IN THE UNITED STATES

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ABSTRACT

The use of two remote sensing tools, aerial sketchmapping and aerial photography, for assessment of forest damage caused by insects, diseases and climatic events in the United States is described. Aerial sketchmapping has been widely used for overall forest health assessments since the late 1940's. Technologies that have been integrated into aerial sketchmapping include use of geographic information systems for analysis, storage and retrieval of survey data, global positioning systems to aid in navigation and flight following and touch screen computers linked to global positioning systems for data recording. In recent years, training of aerial observers has become more formalized. Aerial photography, using color or color infrared films, in a variety of photo scales and film formats, has been used where more detailed information is required. Applications of aerial photography include inventory of tree mortality caused by outbreaks of bark beetle outbreaks, large area mapping of forest defoliation, assessment of pest management activities and use of oblique photos for localized damage mapping.

Introduction

Damage caused to forests by insects, diseases and climatic events, such as storms, are highly visible from long distances. Therefore, various remote sensing technologies lend themselves to rapid assessment of forest damage. This paper reviews the use of two remote sensing methods: aerial sketchmapping and aerial photography for assessment of forest damage caused by insect and disease outbreaks and severe storms.

Aerial Sketchmapping

Aerial sketchmapping is the most widely used remote sensing method used for assessment of forest damage. The technique consists of one or two trained aerial observers flying in a high-wing aircraft and recording the location of areas affected by forest damage on topographic maps, usually of a scale of 1:100,000. Aerial sketchmapping has been used for forest damage assessment since the end of World War II. Presently about 2/3 of the forests of the United States are flown each year. Aerial surveys, designed to detect and assess forest damage by insects and diseases are a cooperative program, which involves USDA Forest Service and state forestry agencies (Ciesla 2000 McConnell et al. 2000).

Operational Parameters

Aerial surveys are flown at an average altitude of 1000 to 1500 feet (300-450 meters) above the terrain at an average airspeed of 100-120 miles/hour (160-190 km/hour). Flights are generally made between the hours of 8:00 AM to 2:00 PM. In the western United States, aerial surveys are conducted during July and August.

Information obtained from these surveys is used to plan and conduct pest management operations designed to reduce losses from major pest species. In addition, these data provide a valuable historical record of pest outbreak occurrence, which, in some cases, can be used to help predict the occurrence of future outbreaks.

Advantages of this technique are that large areas of remote forest lands can be surveyed in a relatively short time (ca 200,000 acres or 81,000 ha/day) and at a relatively low cost (<$US 0.01/acre or $US 0.025/ha). In addition, the data are available to forest land managers within 1-2 days. The disadvantage of aerial sketchmapping is that the data are subjective and its accuracy depends on the experience and skill of the aerial observers, weather and light conditions and other factors.

A variety of small aircraft are used for aerial surveys. In most areas, the Cessna 182, 185, 205, 205 and 210 high wing aircraft are most widely used (Fig. 1) Other aircraft that have been used include the twin engine Partnavia P-68, the Aero Commander 500 and the DeHaviland Beaver.

Figure 1 – This Cessna 205 high-wing aircraft is one of several aircraft types used for aerial surveys of forest damage.

Qualifications of aerial observers include: an ability to read maps and know their precise location at all times, ability to recognize the various signatures of vegetation types and forest damage, normal color vision and little or no susceptability to motion sickness. Approximately 100 hours of flight experience are needed before an aerial observer becomes proficient.

Two aerial survey techniques are used. In rugged mountainous terrain, contour surveys are conducted where the flight path conforms to drainages and ridges in the survey area. In level or gentle terrain, straight flight lines, either east-west or north-south, spaced at about 3 mile (5 km) intervals are flown.

Damage types that are most frequently mapped include defoliation/discoloration of the foliage, tree mortality, most frequently caused by various species of bark beetles (Coleoptera: Curculionidae: Scolytinae), or mechanical injury such as windthrow caused by severe storms.

A key aspect of aerial surveys is ground checking of areas mapped from the air. This is particularly important when an unusual or unrecognizeable signature is mapped or a pest is detected that has the potential to cause widespread and severe damage.

Applications in Brazil

In 2001-2002, a team from USDA Forest Service visited the south of Brazil to demonstrate aerial survey techniques for mapping of damage in pine plantations in the states of Paraná, Santa Catarina and Rio Grande do Sul. Damage types that were successfully mapped include: tree mortality caused by the wood wasp, *Sirex noctilio*; killing of the tops of pines and araucarias by capuchin monkeys, yellowing of pine plantations due to root fungi and groups of dead and dying pines, probably caused by lightning strikes.

Integration of New Technologies

Technolgies that have been integrated into the national aerial survey system during the past 20 years include: geographic information systems (GIS), global positioning systems (GPS), use of touchscreen computers for data recording and automayed flight following (AFF).

The capacity of GIS to store, analyse and retrieve spatial data on the status of insect and disease outbreaks in the United States was first investigated during the late 1970's and early 1980's. The use of this technology became operational during the late 1980s and today is used country-wide to store information on the status of major pests. GIS provides the opportunity to develop historical records of pest outbreaks and record the change in their status from year to year. In addition, GIS provides the opportunity to integrate data on the location of pest outbreaks with other resource information such as vegetation type, elevation, slopes, aspect etc. GIS maps showing the location of insect and disease damage by year are now available on the Internet for anyone to study (e.g. www.fs.fed.us/r2/resources/fhm/aerial**survey**/, www.fs.fed.us/r6/nr/fid/).

The network of orbiting satellites known as the Global Positioning System (GPS), which can be used to triangulate the position of a person, vehicle, ship or aircraft, anywhere on the Earth's surface has revolutionized the science of navigation. GPS has also proven to be a valuable tool in the conduct of aerial surveys for mapping and assessment of forest damage. GPS receivers, installed in survey aircraft, can be used to locate the starting and ending points of a day's aerial survey. During grid surveys, the starting and ending points of each flight line can be set in the GPS receiver and the unit can help keep the aerial survey pilot on the flight line.

More recently, the availability of touch screen computors, linked to GPS receivers have largely replaced paper maps for recording the location of forest damage (digital aerial sketchmapping). Units such as the Motion Tablet or Hammerhead, loaded with the Geolink software and linked to a GPS receiver via the Bluetooth wireless technology are now used in place of paper maps. A key advantage of these systems is that the data recorded can be converted into shape files, which can be entered directly into a GIS without additional scanning or digitizing. In addition, the system display shows the location of the survey aircraft on the survey map, thus eliminating the need for aerial observers to continuously locate themselves relative to terrain features (Schrader-Patton 2003) (Fig. 2).

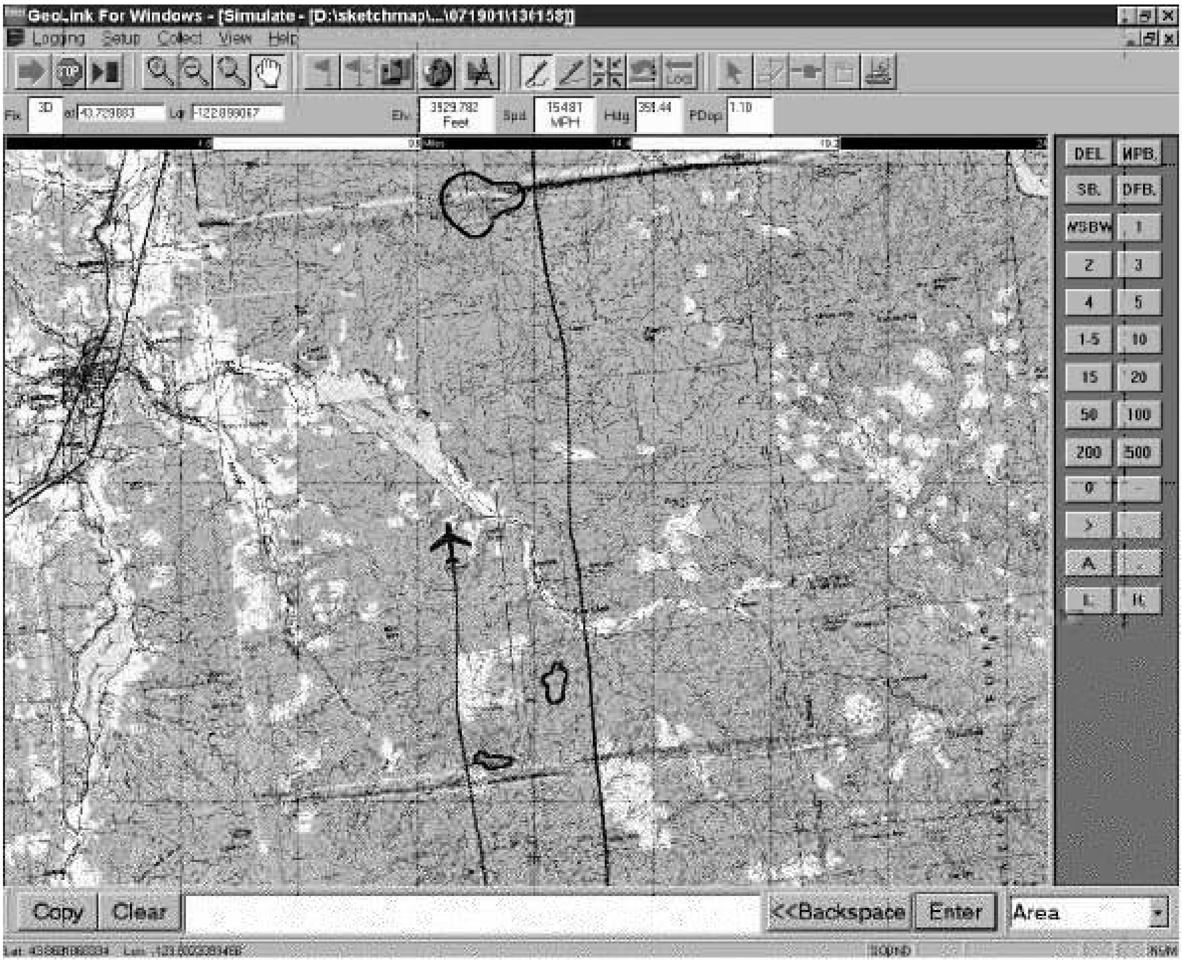

Figure 2 – Touch-screen computer display showing portion of a map of a survey area and the location of the survey aircraft.

One of the important issues regarding aerial surveys is safety. It has been standard operating procedure for the aerial survey pilot to advise a local USDA Forest Service Fire Dispatch Center via radio, the aircraft's location every 15 minutes. More recently automatic flight following (AFF) systems have been installed in most survey aircraft. This system triangulates the aircraft's location using a GPS receiver. The locational data is then transmitted to a comunications satellite, which, in turn, transmits the aircraft's location to the local dispatch center every two minutes. This significantly reduces response time in case the survey aircraft developes a problem.

Training of Aerial Observers

It has been recognized for a number of years that aerial observers must have about 100 hours of in-flight training before they become proficient in terms of recognizing the various signatures of damage and are capable of accurately locating the damage on maps. Recently, a guide to the recogniton of aerial signatures of forest damage has been developed for the western United States Ciesla 2006). A similar manual for the eastern United States is in preparation (Ciesla et al. 2008). In addition, aerial observers now receive training in aviation safety every three years. The safety training is a combination of on-line courses and a one week formal training session. The formal training is provided by a team of instructors including an aerial observer, a pilot, a contracting officer and an air operations officer.

In-flight training of new aerial observers has become more formalized. Initially, an aerial observer trainee flies with an experienced aerial observer. Later the trainee receives "front seat" training and has the opportunity to work with the pilot to direct the course of the survey. Their hours of flight experience are logged much in a manner similar to the way that pilot's flight hours are logged.

Aerial observer training is a continuing activity. In some regions of the United States, aerial observers meet annually, usually several weeks prior to the aerial survey season, to review new aviation safety procedures, aerial signatures of pest damage and to learn new technologies that are being integrated into the survey process.

Aerial Photography

Of all of the remote sensing tools currently available, aerial photos provide the highest resolution imagery. Aerial photos have been used for assessment of forest damage where more detailed information is needed than can be acquired from aerial sketchmap surveys (Ciesla 2000).

Photographic Parameters

Because most forest damage first appears as a change of color, which does not appear on black and white aerial films, only color and color infra-red (CIR) aerial films are used for the assessment of forest damage.

Color aerial films record information in colors as seen by the human eye and, for this reason, are relatively easy to interpret. CIR film is a false color film, sensitive to visible light and the near infrared region (to 0.9 meters) of the electromagnetic spectrum. This film was developed during World War II for a military application: the detection of camoflaged objects hidden among vegetation. Healthy vegetation is higly reflective in the near infrared region. Therefore, a sharp contrast between a camoflaged object, with low reflectance in the near IR region and healthy vegetation would be expected. This worked well until a near IR reflecting camoflage paint was developed.

During the late 1960's, CIR film was de-classified and made available for other than military applications. Several investigators tested this film for its potential to detect early (previsual) stages of disease in plants because loss of IR reflectance was believed to be an early symptom of disease. This was met with only marginal success. CIR film is of great value, however, in forestry and other natural resource applications because it can easily penetrate atmospheric haze and there is a greater contrast between certain vegetation types than can be seen by the human eye or on normal color film. For example, broadleaf forests often appear as a bright red color and conifer forests appear a dark red brown or magenta color.

Color films are available that can be processed to either negatives for production of photo prints or to positive transparencies. For forest health applications, color transparencies are preferred because they have higher reolution than do prints. CIR film is available only as a transparency film. Attempts to process CIR film to a negative for photo prints has resulted in a loss of image quality.

A variety of film formats have been used for aerial photographic assessments of forest damage. These include:

Small Format – 35 mm or 70 mm aerial photos.

Mapping Format – 230 mm (9-inch)

Panoramic Format – 115 mm x 965 mm (4.5 x 38 inches)

The most widely used film for forest damage assessment has been the 230 mm mapping format.

A range of photo scales have also been used with varying degrees of success. These range from 1:500 – 1:2000 for small format photography, 1:4,000 to 1:8,000 for mapping format photography and 1;30,000 for high resolution, panoramic format photos. A photo scale of 1:8,000 is generally considered optimum for forest damage assessments where individual tree crowns are counted.

Applications

The use of aerial photos for forest health assessments has several aspects that should be considered:

Biological – Knowledge of the damaging agent and its habits should be known so that the damage appearing on the aerial photos can be properly interpreted.

Statistical Design – Applications often require sampling of large areas with aerial photos and ground checking of a smaller sample. The design of the survey must be sound to produce valid results.

Acquisition and Interpretation of Photos – Photo acquisition must coincide with the peak expression of damage. Photo interpreters must be familar with the type of damage that is being assessed and with other signatures that have a somewhat similar appearance.

Acquisition of Ground Data – The individuals responsible for acquisition of ground data should be familar with the biology and ecology of the pest and with related species with which the damage could be confused.

Data Analysis – The data acquired must be subject to the appropriate analytical procedures and statistical tests.

Bark beetles (Coleoptera: Curculioidae: Scolytinae) are the major tree killing insect pests of North American Forests. Information required for management of bark beetle outbreaks includes:

Location and area affected by the outbreak

An estimate of the number of trees infested

An estimate of the timber volume affected

Several multistage sampling techniques have been developed to inventory losses incurred by bark beetle outbreaks (Ciesla 2000). One approach is three-stage sampling where the area affected is stratified by aerial sketchmapping (Fig. 3). This area is sampled with aerial photo stereo pairs or triplets, of a photo scale of 1:4,000, 1: 6,000 or 1:8,000, on which the number of dying or "fading" trees is counted. A small subsample of the aerial photo plots is examined on the ground to correct the aerial photo sample and obtain data for volume loss estimates. A second approach is a two stage approach where aerial photo sampling is done over a disinct area of land, such as a National Forest, followed by ground checks.

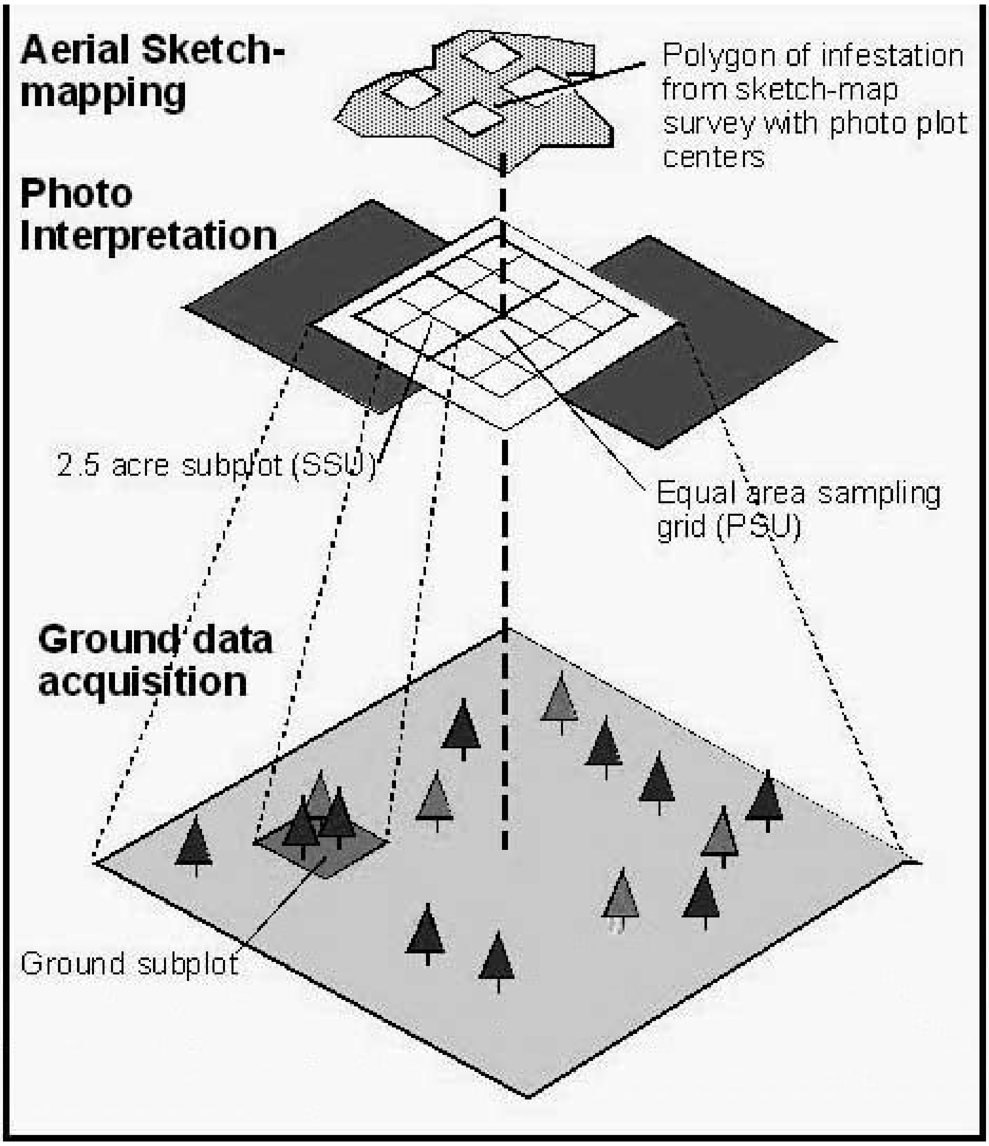

Figure 3 – Three stage survey design for inventory of bark beetle damage using a combination of aerial sketchmapping, aerial photos and ground surveys.

Aerial photos, taken from a flying height of 60,000 ft (18,300 m) have been used to map widespread defoliation of broadleaf forests by the introduced gypsy moth, *Lymantria dispar*, in the eastern US. This work was done during the mid 1980's when defoliation occurred over several eastern states to an extent that was too large an area for aerial sketchmapping. The aircraft used for these surveys was a NASA ER-2 reconnaisance aircraft. The aerial photos were acquired over a 2-3 day period when defoliation was at its peak, interpreted monoscopically and the location of defoliated areas was transferred to topographic maps.

Both color and CIR aerial photos have been used successfully to assess the effectiveness of pest management tactics directed against several insects. CIR film has been used to assess the degree of foliage protection achieved by aerial application of both biological and chemical insecticides directed against forest defoliators. In addition, color film has been used to show the effectiveness of thinning of pine forests to prevent attacks by the mountain pine beetle, *Dendroctonus ponderosae*.

In 2006, digital, oblique true color aerial photos, taken with a Nikon D70S camera were used to successfully map defoliation caused by a defoliator of aspen, *Populus tremuloides*, in Colorado. The insect involved was western tent caterpillar, *Malacosoma californicum.*

In 2008, a special aerial photo survey was conducted over a portion of the Wet Mountains in southern Colorado to map damage to Engelmann spruce, *Picea engelmanni*, forests caused by a severe storm in 2007. The photography is being used to obtain the precise location of all areas of blowdown so that the damaged trees can be salvaged, thus preventing a major outbreak of spruce bark beetle, *Dendroctonus rufipennis.*

Conclusions

In the United States, two important operational remote sensing tools are used for assesment of forest damage: aerial sketchmapping and aerial photography.

Aerial sketchmapping is widely used for annual assessments of forest health conditions. In a given year, about 2/3 of the country's forest area is covered by aerial sketchmap surveys. This technique has been used since the late 1940's and provides information for planning and conduct of various pest management operations. In addition the data obtained from these surveys provides a valuable historical record of pest occurrence, which can be used to predict future outbreaks.

Although aerial sketchmapping for forest damage assessment has been used for many years, new technologies are being integrated into operating procedures that increase the accuracy and efficiency of the technique and make the resulting data more usefull. Geographic information systems are now used to analyse, store and retrieve data collected via aerial surveys. Global Positioning System technology is used to help locate starting and ending points, especially for grid surveys conducted over level terrain. Touch screen computers, linked to GPS receivers are now used to digitally record the location and intensity of forest damage. Data from these systems can be entered directly into GIS databases. GPS technology also allows for automated flight following of survey aircraft.

Training of aerial observers in aviation safety, recognition of pest damage signatures and in-flight training has become more formalized in recent years.

Aerial photography is used in cases where more detailed data is required than can be obtained by aerial sketchmap surveys. Because forest damage usually appears as a change in the color of tree crowns, only color and color infrared (CIR) films are used. A variety of photo scales and film formats have been used for forest damage assessment with varying degrees of success.

Applications of aerial photography to assessment of forest damage include: inventories of bark beetle damage, large area mapping of defoliator outbreaks, assessment of the effectivenss of pest management operations and the use of oblique, digital photos to map forest defoliation.

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