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Case Applications of Remote Sensing for Vegetation Damage Assessment*

Advantages, pitfalls, successful techniques, and future approaches are discussed.

Advantages and Pitfalls

It is not too difficult to separate the wheat from the chaff in remote sensing literature—and there is a lot of chaff filtering in, unfortunately. However, most of the remote sensing work done on vegetation damage has been carried out by scientists with biological and statistical training, so that their results have validity and creditability. This is not always true of some environmentalists and geographers.

Advantages

Most of us are aware of the benefits in using remote sensing techniques. We can acquire data from parts of the electromagnetic spectrum other than the visible—such as thermal, microwave, and near infrared. In many cases, we can make a survey of equal accuracy with less money, less time, and with fewer people than by conventional ground survey methods (Wert and Rottgering, 1968). In order to justify a newer technique to the manager, the remote sensing technique must meet these criteria of speed and efficiency.

Aerial imagery covers large areas which cannot be seen from the ground. In vegetation damage assessment, we often need to see healthy vegetation to compare with insect or disease-affected vegetation. In the case of bark-beetle-killed conifers, which occur in random clusters, the use of either color aerial photography or sketch mapping has eliminated ground cruising almost entirely. Fewer than ten years ago, none of us had much experience in using satellite collected data (imagery or computer processed). The broad synoptic view (185 kilometres square for Landsat) does furnish a sampling frame from which we can design damage assessment surveys. The crude level of damage appraisal from Landsat data (even for defoliators) does not offer the land manager the kind of answers he needs, in my opinion.

Successive remote sensing surveys, made over one season or several years, do furnish baseline data on insect or disease trends and losses due to mortality (Heller, 1974).

Pitfalls

All of us working with remote sensing data and techniques need to guard against overselling. We should be past the "Gee Whiz" syndrome at this point. For example, on Apollo 9 photographs, the Mississippi River showed up well with all its bends and oxbows. The first exclamations of viewers were, "Gee whiz, that must be the Mississippi River!" Sure enough it was. But we don't have to clutter the literature with this kind of information. Of more interest to hydrologists was the fact that new oxbows and twists in the stream channels could be identified when compared with their maps. Biologists have been a bit guilty of the simplistic approach. For example, if we know where severe defoliation is occurring, we go to our satellite images, locate ourselves, and see a slight spectral change there and then report success. However, in many cases, the same spectral change is present on other parts of the image, not caused by defoliation, but by some other anomaly such as reduced vegetation density. I trust we are moving away from this kind of reporting and that we will provide quantitative results showing our errors of estimate at predefined confidence limits.

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ABSTRACT: *The assessment of vegetation damage by remote sensing has reached a fairly sophisticated level. This paper identifies the advantages, pitfalls, current practical applications, and future possibilities of the use of remote sensing for this purpose. Advantages include: (1) the use of many parts of electromagnetic spectrum; (2) the saving of time, money, and manpower; (3) the ability to cover large areas; and (4) the use of successive remote sensing surveys to follow damage trends. Some pitfalls included: (1) the overselling of remote sensing techniques without adequate quantitative data showing errors of estimate at pre-defined confidence limits; (2) using very expensive remote sensing systems on a transitory phenomenon; (3) the inability of some Landsat users to recognize that reflectant values are relative subject to atmospheric attenuation and amplified signals; (4) the poor design of Landsat wavebands for vegetation damage assessment (need a yellow-orange waveband, 0.58 to 0.62 μm); (5) a need for better statistical techniques to check classification accuracies; and (6) using color or color infrared films to obtain previsual detection of coniferous tree damage.*

Current practical applications for assessing vegetation damage include: (1) visual observation techniques (sketch mapping and strip recording); (2) color and color infrared (CIR) photography (both large and very small scale) when properly matched with damage symptom, host type, and atmospheric conditions; (3) multistage sampling; and (4) risk rating systems using aerial photos to define factors such as aspect, slope, elevation, and stand density that contribute to susceptibility of vegetation to damaging agents.

Future remote sensing possibilities predicted are (1) increasing standardization of color and CIR photography and greater use of small-scale CIR (1:32,000); (2) the availability of lightweight, inexpensive radar and laser altimeters together with better electronic guidance systems for repetitive flights; (3) faster service for receipt of Landsat data products which will be geometrically corrected and enhanced; (4) improved Landsat computer classified images with accuracy statements; (5) better resolution available on Landsat D (thematic mapper) with narrower wavebands which should improve classificatory procedures and accuracies; and (6) improvements in other sensors such as side-looking radar, charge coupled detectors, and microwave imagers.

In assessing vegetation damage, we must realize that we are dealing with a transitory phenomenon, both in time and space. An *Ips sp.* bark beetle outbreak may kill thousands of pine trees in southern Georgia in the early summer, but be in endemic status with no tree killing by the fall. How much money and what kind of survey is needed to assess such a problem? In other words, we must mesh our survey system with the seriousness of the damages to the environment, the value of the crop, and the likelihood of continued damage. In some cases, it is not practical or realistic to use expensive sensors, data processing equipment, and sophisticated computer programs to assess the situation. For example, it may take too much time to get Landsat images (six weeks to four months) or computer compatible tapes (CCT's) to make an assessment which will be useful to the land manager.

Landsat data, remarkable as they are, have some shortcomings which are often not recognized by the user. The reflectant energy from the Earth is filtered and scattered by the atmosphere which changes every day. These atmospheric changes alter the reflectance values over the same object. Also, the reflectance signal is further filtered into four wavebands and amplified. Amplifiers are analog electronic devices which are notoriously difficult to calibrate, even on the ground. NASA scientists calibrate the signals as best they can, but Landsat data users often mistakenly assume that reflectance values are absolute and free of bias instead of realizing that the values are relative.

Landsat wavebands are too broad to help the vegetation damage analyst as much as might be possible if the wavebands were narrower and more selective. For example, most vegetation under stress begins to appear chlorotic—yellow to orange (yellow-red). These yellow-orange wavebands (0.58 to 0.62 micrometres (μm) are integrated into the top of the green Landsat waveband (0.50-0.60 μm) and the bottom of the red waveband (0.60-0.70 μm). Even Landsat D (thematic mapper), due for launching in 1979 or 1980, does not separate out this important feature that I feel would be useful to detect vegetation damage. Similar conclusions for aircraft scanners were reached by Weber and Polcyn (1972).

Another pitfall in using Landsat data is the lack of good statistically designed controls for computer-assisted or optical classification of vegetation damage. Some studies lead one to beleive training sample accuracies will be found on other parts of a Landsat scene. This is not true. Van Genderen *et al.* (1977) describe one approach that can be used to check classification accuracies. Even simple contingency tables will point out omission and commission errors; they at least tell the investigator what his object is confused with—albeit without accuracy statements.

Some method of checking our remote sensing surveys will always be needed to lend credibility to our data. A sufficient number of ground truth observations (usually 20 to 30) should be taken to calculate a sampling error at a selected confidence level. Because vegetation damage is so ephemeral, forest entomologists agreed to accept an error estimate of 25 percent at one standard deviation following a forest survey meeting in Fort Collins, Colorado (Anonymous, 1951). Ground checks should be built into our damage assessments whether they are made from large-scale color photographs, visual observations from low-altitude aircraft, or on-site ground visits.

I should like to warn you of other pitfalls based on past studies:

(1) Films, including normal color and color infrared, are not good previsual detectors of coniferous tree damage. Extensive film, filter, and scale tests were made over ponderosa pine, *Pinus ponderosa* Laws, infested with mountain pine beetle, *Dendroctonus ponderosae* Hopk., in the Black Hills of South Dakota. The tests showed that neither film could detect stress before visible coloration changes occurred in the foilage (Heller *et al.*, 1972).

(2) Side-looking airborne radar (SLAR) is an unlikely sensor to use for vegetation damage because resolution is too coarse (about 15 metres for X band, 3.3 centimetres), and energy return is based primarily on differences in plant structure and dielectric properties. In the latter case, the structure of the damaged plant would be essentially identical to the healthy plant and with similar dielectric properties.

Successful Remote Sensing Techniques for Vegetation Damage Assessment

Many investigators have reported on various techniques that have proved successful and are being used on a continuing basis by industry, state, or federal agencies. These techniques include visual observation, aerial photography, risk-rating vegetation, multistage sampling, and double sampling.

VISUAL OBSERVATION

Trained foresters and biologists can assess vegetation damage quite accurately by eye from slow-moving aircraft or helicopters—often more effectively than by more sophisticated sensing models. Two methods, sketch mapping on maps or available photographs or strip sampling with event recorders, are in use in the eastern and western United States and Canada.

Sketch mapping surveys for all kinds of forest damage (insect, disease, animal, meteorological) have been made since 1947 in Oregon and Washington (Wear and Buckhorn, 1955). The design of these surveys depends upon aircraft altitude, terrain, aircraft speed, and desired accuracy level. For example, on Oregon surveys, map scales of 4 miles per inch are most frequently used and the mountainous country is flown by watersheds. Observing distances are sometimes as great as 3 miles (5 km) and flight elevations 1,000 to 2,000 feet (300 m to 600 m) when looking into side hills. With good observers, lines can be drawn around major infestations within about one-fourth mile (0.5 km), or 1/16 inch on the map. Small infestations are difficult to see and properly map when looking from so great a distance and when plotting on such small-scale maps. By contrast, in the eastern and southern United States sketch mapping has been limited to much narrower strips, i.e., one-half to 1 mile (0.8 to 1.6 km), because of the more level terrain. In level terrain, the combination of low altitude (1,000 to 2,000 feet) and oblique viewing angle prevents observers from seeing infestations, regardless of size, which may be hidden by depressions or high points of land (Aldrich *et al.*, 1958).

Event (or operations) recorder surveys are always systematic strip sampling designs made at some percentage of area seen. A description of the operation recorder technique is given in some detail by Heller *et al.* (1952) and Wert and Roettgering (1967). Because most of the observations are made at low altitudes (150 m to 300 m [500 to 1,000 feet]), very low levels of damage can be detected; however, the method is more useful in flat-to-rolling terrain. These kinds of sampling surveys have been made in repetitive years for both defoliator (Figure 1) and bark beetle damage at very nominal costs—20 to 40 cents per thousand acres (400 ha) of total area.

AERIAL PHOTOGRAPHY

Color and color infrared aerial photographs have proved to be more reliable and accurate sensors for detecting change in vegetation than black-and-white films or eyeball estimates. The photographs offer a permanent record which can be used as baseline data and can be subsequently checked with new photography at a future date. However, the user must realize that aerial photography can be 5 to 20 times more expensive than visual observation surveys.

Often aerial photography has been taken as part of an active insect or disease outbreak and, indeed, the color or color IR photos proved efficient tools for the land manager. But the tools were put away once the outbreak subsided and it seems we must train a new set of managers, entomologists, and pathologists at each new outbreak. Such attrition is normal, but we must provide for continuous updating and retraining of new people.

Ciesla (1977) has aptly summarized the optimum uses of color and color infrared films for forest insect damage in the United States. He identifies which film to use for different insects, forest types, and atmospheric conditions. Murtha (1972) devised a valuable forest damage guide for photo interpreters that can be applied in both Canada and the United States. It contains

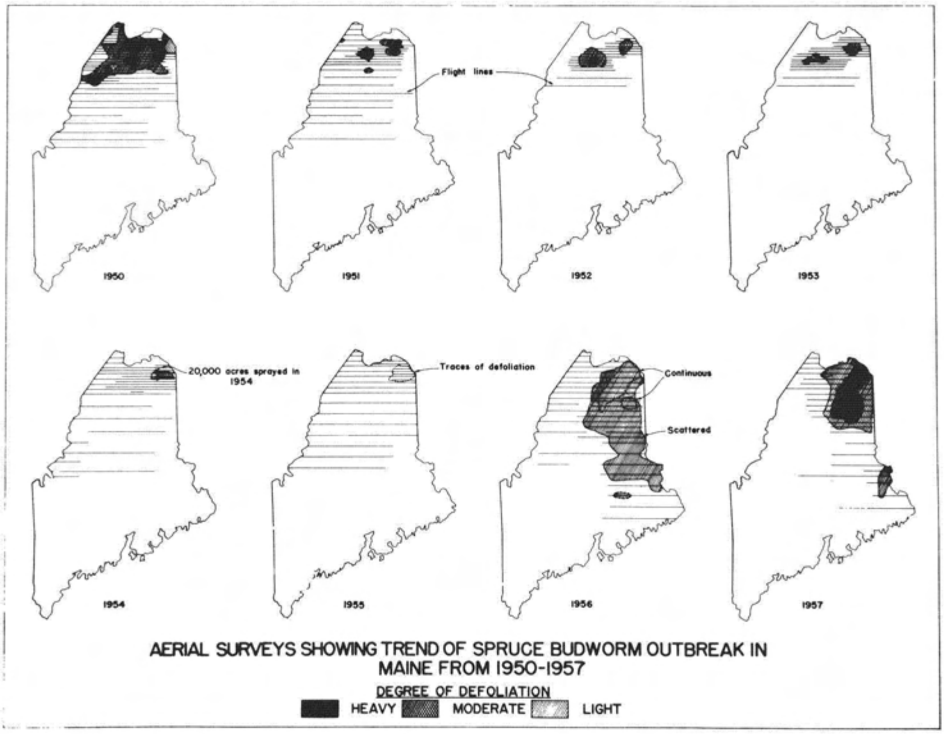

Fig. 1. Repetitive operation recorder surveys for defoliation of balsam fir by the spruce budworm, *Choristoneura fumiferana* (Clem), in Maine from 1950 to 1957.

excellent color stereograms of different kinds of damage and a dichotomous key which aids the photo interpreter to pinpoint probable forest damage causes through classification of damage syndromes.

Stevens and Sartwell (1975) reported that color aerial photographs taken over natural and thinned stands of ponderosa pine in the Black Hills illustrated the effectiveness of silviculturally reducing the basal area of dense stands. Invariably, thinned ponderosa pine stands were free of mountain pine beetle attack while in the natural stands many infestations showed up on the photos, often to the very edges of the thinned stands. Replicated visual evidence like this convinces the forest manager that thinning is the proper management action to keep his ponderosa pine stands free of this pest problem.

Small-scale color infrared (CIR) photos (1:32,000 to 1:120,000) can be used to map forest insect damage with certain restrictions. Ciesla (1974) had access to U-2 CIR photos (scale 1:120,000) taken over western Montana where two defoliators—western spruce budworm, *Choristoneura occidentalis* Freeman, and pine butterfly, *Neophasia menapia* (F. and F.)—and mountain pine beetle were present. Only severe pine butterfly infestations were evident when pure stands of ponderosa pine had a grass understory. This scale of photography was only partially effective in registering stands suffering heavy tree mortality due to bark beetle infestations. Somewhat similar findings were reported by Heller *et al.* (1972) for mountain pine beetle infestations in the Black Hills of South Dakota. In this case, a scale of 1:32,000 was most efficient if small infestations of one to two trees could be overlooked. Of course, attendant with use of small-scale photos are the efficiencies in cost of acquisition and need for fewer photos during the photo interpretation process.

Urban forestry can benefit by the use of CIR photography to assess vegetation damage to roadside trees. For example, Kennewag and Hildebrandt (1973) were able to determine the vitality of 10,000 roadside trees in Freiburg, W. Germany on 1:5,000 scale CIR photos. Stressed trees were mapped and related to sources of stress: human activity, air pollution from vehicular traffic, and de-icing salt. The feasibility of using small-scale CIR photos (1:15,840 and 1:24,000) taken with a Wratten 21 filter of roadside trees infected with oak wilt, *Ceratocystis fagacearum* (Bretz) Hunt, was demonstrated by Ulliman (1977). His study covered a three-year period with photos taken over a portion (105 ha [260 acres]) of North Oaks, Minnesota. While commission errors (21 to 61 percent) occurred at the small scales, omission errors were negligible (< 5 percent). With increased emphasis on urban forestry, remote sensing tools will become increasingly important.

Forest plantation assessment with small format color photography shows promise where more intensive forest management is being practiced. Nelson (1977) reported on a system being instituted on Weyerhaeuser lands in North Carolina. For the assessment and measurement of sites prior to plantation establishment, 70 mm CIR film is exposed at scales of 1:12,000 to 1:24,000. For periodic detailed evaluations of established plantations, starting after the third growing season, larger scales are needed to determine survival, height growth, and area needing fertilizer treatment. Another assessment of plantations was made from color film taken at a very large scale (1:600) of 25 white pine plantations damaged by white pine weevil, *Pissades strobi* (Peck), in upper New York State (Aldrich *et al.,* 1959). Results from this survey determined whether plantations would receive insecticidal treatment.

MULTISTAGE SAMPLING

Multistage sampling has a place in our assortment of possible survey systems for damage assessment. The concept of using coarse resolution imagery at the first stage and finer resolution imagery in succeeding stages was first developed by Langley and Norick in 1968 at the Pacific Southwest Forest and Range Experiment Station in Berkeley. For vegetation damage analysis, we are interested in presence or absence of host vegetation and discernible damage. The first level of information may be from satellites, high-flight aircraft, or sketch maps made by visual observation. The important point to remember is that each level of information (air pollution damage, bark beetle kill, etc.) should show high correlation with what is actually present on the ground. Let me give some examples where two or more stages were used to estimate damage.

The first successful use of multistage sampling was demonstrated in northern California following severe blowdown of Douglas-fir, *Pseudotsuga menzsiesii* Franco, and followed by a Douglas-fir beetle outbreak, *Dendroctonus pseudotsugae* Hopk. (Wert and Roettgering, 1968). Data from a sketch mapping survey were used to stratify the infested area into blocks of light, moderate, and severe damage. Color photo triplets (1:8,000) were taken at increasing frequencies (1, 2, 4) according to the damage level estimated at the first stage. Individual bark beetle infestations were identified on the photos and trees were counted. In turn, the infestations were sampled on the ground with probability proportional to size (*PPS*). More details about the methodology and mathematical derivations can be found in Langley's dissertation (1975).

A similar survey was conducted in the Black Hills in order to estimate the seriousness of a mountain pine beetle outbreak (Heller and Wear, 1969). In this case, the second stage consisted of dividing the infested area into 1 by 10 mile (1.6 by 16 km) strips and selecting 10 strips based on the number of aerially plotted infestations falling within the strips. Infestations were plotted within the photo strips (color, 1:8,000) and a selection of infestations to be visited on the ground was done as above. Both of these multistage surveys were about 100 times cheaper than comparable ground surveys.

Finally, damage caused by air oxidants to ponderosa pine in the mountains east of Los Angeles was estimated by multistage sampling. The first task (or stage) was to determine the amount of ponderosa pine present along flight lines of existing aerial photographs. With equal levels of air oxidants present, the amount of air pollution damage is related directly to the amount of ponderosa pine present. The flight lines were selected for the second stage based on the proportion of pine present. Dual 70 mm cameras took color photos along the selected strips; one camera captured the entire strip at 1:8,000 while the second camera was cycled to take stereo triplets every 10 seconds at a scale of 1:2,000, which was the scale needed to evaluate the level of oxidant injury. The third stage was to visit one stereo triplet along the flight line based on PPS sampling. The number of trees affected were estimated with an 11 percent error at one standard deviation.

There have been many other examples of multistage sampling for other resources (timber volume, irrigated lands, land use, etc.) but only the ones listed above relate to vegetation damage. In my opinion, it is a technique that will see more use for damage assessment in the future.

RISK RATING SYSTEMS

Another remote sensing system which shows promise is risk rating. Our natural resource base is shrinking by encroachments from cities, increased designations of wilderness areas, freeways, power lines, etc. Better management of all resources on our most productive lands is the direction that most land managers are taking. With increased forest management practices, we finally may be able to exercise silvicultural treatments that will reduce our pest losses.

Wickman and Eaton (1962) described how tree crown condition of ponderosa pine could be rated on the ground according to its likelihood to succumb to the western pine beetle, *Dendroctonus brevicomis* LeConte. When high risk ponderosa pines were removed from ponderosa pine stands in eastern Oregon and California, losses were negligible over a 20 year period. While the high risk selection was made from the ground, the success of the silvicultural treatment may be predicted for other areas with pest problems.

Site factors, such as slope, aspect, topographic location, and stand density, made certain southern forest areas more attractive for the southern pine beetle, *Dendroctonus frontalis*, Hopk. (Sader and Miller [1976], Daniels *et al.* [1978]). A similar relationship was found by Miller (1976) for the Douglas-fir tussock moth defoliatior, *Orygia pseudotsugata* (McD). Wayne Miller describes in detail how a forest manager may use his existing resource photographs to identify stands needing silvicultural treatment. These studies all used aerial photographs to identify the critical variables linked to a high hazard pest condition.

OTHER QUANTITATIVE METHODS

We should provide the land manager with quantitative data on the size of the area being damaged, or number of trees being affected, with an error statement attached. This point was identified earlier under *Pitfalls*, but is one worth repeating.

Double sampling with regression (Wear, Pope, and Orr, 1966), stratified random sampling, and random strip sampling of irregular blocks (Schumacher and Chapman, 1942) are useful statistical methods available to us.

FUTURE APPROACHES

What can we expect in the next decade for assessing vegetation damage? Without employing a gypsy or buying a crystal ball, there are some things I can say will happen. Others are only supposition.

Color and CIR aerial photography will continue to be mainstays. Both very large and very small scales will be used. We should see increasing standardization and calibration of these films. For the very high-altitude color and CIR photography we can expect the higher resolution films SO-242 and SO-131 to be used more frequently than types 2448 and 2443.

Compact and lightweight laser or radar altimeters should become available with light emitting diodes (LED) for imprinting altitude above ground onto 70 mm films. Such equipment would allow precise scale calculation for sampling surveys.

In conjunction with high altitude photography we may see more panoramic photography with scaled overlays for each frame. The geometry has been worked out and computer programs are available now in the Geometronic Unit of the Forest Service in Washington, D.C.

Regarding the satellite programs, we know that Landsat C will have a thermal waveband (10.4 to 12.6 μm) that may be helpful in detecting frost pockets during late spring and early fall. Fire detection may be improved in remote areas such as Alaska and northern Canada, particularly if the data products can be processed more quickly.

We can hope for faster service for Landsat data products from the EROS Data Center after July 1978. All images and tapes will be geometrically corrected and we can obtain data with haze removed, image enhanced, and considerable preprocessing accomplished.

Landsat D (thematic mapper) will have more than twice as good resolution (30 m) and have more (six instead of four) and narrower wavebands from which to select. Despite the fourfold data increase, we might expect to define vegetative damage better than we can now. With better data, classificatory procedures and accuracies will improve. Color output maps of classified scenes should match common map scales and be more useful to the resource manager.

We might expect to detect previsual symptoms of dying conifers by the use of an aircraft multispectral scanner (MSS) having five to seven selected wavebands.

More aircraft used for high altitude remote sensing will have inertial guidance systems installed. This will allow for precise orientation of the aircraft's position for original flights and flights in subsequent years. This feature will enhance the possibilities to make comparison of damage changes.

Other sensors which may help us in the future are microwave imagers and side-looking airborne radar with better than present day resolution. Their role would be to detect soil moisture deficiencies. Charge coupled detectors are arrays of silicon dioxide detectors that may replace MSS's in the visible and near IR wavebands because of their better geometric orthogonality, resolution, and sensitivity.

Finally, we should hope to see our remote sensing data in a form so that it can be overlain with other data sources such as base maps, soil types, topography, and land use.

Conclusions

In this paper I have discussed the advantages and pitfalls in our use of remote sensing data for vegetation damage assessment. The systems which are in current operational use are described and, finally, some of the approaches which we may hope to see in the future for damage assessment are explored.

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