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REMOTE SENSING IN FORESTRY - PROMISES AND PROBLEMS

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INTRODUCTION

My subject "Remote Sensing in Forestry - Promises and Problems" implies that we have a few skeletons in our closet that need to be laid to rest. Let us see if I can put these promises and problems in proper perspective. First, I will describe briefly those sensing systems and new techniques available and most useful to foresters and then those that do not look promising because of cost, poor image quality, or present state of development.

Remote sensing is exciting, for it deals not only with space-age electronics, satellites, and automatic mapping systems but also with some old and more familiar standbys, such as aerial photography. Our keynote speaker at this annual meeting, Dr. Stephen Spurr, became well known among foresters for his pioneering book Aerial Photographs in Forestry (Spurr, 1948). I doubt that he is now spending much time looking through a stereoscope at those puny trees around Austin, Texas, but his early work did provide a tremendous impetus toward greater use of aerial photographs by foresters.

What exactly is remote sensing? The term was coined about 10 years ago and may be defined as a means to detect and identify objects at some distance from the objects. Thus, remote sensing could conceivably include three of our five senses--sight, hearing, and smell. Touch and taste imply physical contact which eliminates them from consideration. However, radio tracking of wild animals, sonar detection of objects in the water, magnetometry for mineral location, and even water divining are considered remote sensing examples by some people. Foresters, however, consider the term to include primarily the collection of information from airborne platforms (balloons, airplanes, helicopters, and satellites).

Airborne detection may use instruments that sense in many parts of the electromagnetic spectrum--usually from the ultraviolet (0.30 μm) to radar and microwaves (5 cm). Most of these instruments are essentially passive, for they rely on reflected and emitted energy from the objects. On the other hand, radar is an active system, for it sends out electrical pulses and measures the time it takes the pulses to strike an object and return.

Most of us are familiar primarily with images formed by cameras on photographic film (reflectance in the visible and near infrared [0.38 μm to 0.90 μm]), but other remote sensors, such as scanners, television, and radar, can also produce photolike images that may help foresters identify objects. Objects may be separated and identified because they have different physical shapes, molecular structures, and spectral reflectances. These differences provide us with clues as to the identity of a tree species, range type, or land-

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I will not go further into remote sensing theory or descriptions of instruments. These subjects are fully described in a recent publication by the National Academy of Sciences: Remote Sensing with Special Reference to Agriculture and Forestry (Shay, 1970). Moreover, let me bring to your attention the forthcoming two-volume Manual of Remote Sensing to be published in 1973 by the American Society of Photogrammetry. It will cover all sensors, techniques, and applications for user groups. One chapter is on "Forestry Applications" and should be of interest to all of you. Finally, let me refer you to a recent Journal of Forestry article on remote sensing by Latham and McCarty (1972).

PROMISES AND PROBLEMS

Remote sensing is not an end in itself; it is used to make our forest management job more efficient. And like everything else, it has many capabilities as well as some drawbacks. Ideally, remote sensing data should be integrated into a suitable information system. Then, once we have mapped our forest resources on a geographic coordinate system, we can update and integrate changes, such as timber cutting, recreation development, and other management treatments, into our natural resource data base.

The storage and processing capabilities of large computers now enable us to store and retrieve vegetation and land-use data collected from large areas. For example, recently the state of Minnesota was gridded into 40-acre blocks and classified from small-scale photographs into nine land-use categories; from these data, a computer-drawn map was made (Orning and Maki, 1972). New York State also completed a detailed land-use map by breaking areas into smaller units (Belcher, 1969). In this land-use map, however, forests were only classified as forest brushland, forest land, and forest plantations. Obviously a forest manager needs more detail. Amidon (1966) developed a computer-based system called MIADS that enabled forestry data to be encoded from source maps and displayed as maps or in tabular form. As mapping units decrease in size and the required level of information (timber type, soil, aspect, volume, etc.) increases, the complexity of producing a viable information system grows exponentially. Thus, forest units should be kept large (5 hectares or more), and more rapid ways--such as optical enlargement of small-scale photography--to classify our forest resources should be investigated.

Aerial Photography

Forest aerial photography had its beginning in Germany in 1887 when the newspaper Berliner Tageblatt published pictures of beech, pine, and spruce stands taken from a balloon. In 1920 Canadian foresters, who had to cover great expanses of unmapped timberlands, were the first to use aerial photographs extensively for preparation of forest stock maps (Craig, 1920). We, in the United States, had a brief introduction to aerial photographs in the early 1930's when stereoscopic photos were taken by the U. S. Agricultural Adjustment Administration in some parts of the country. Probably most foresters then did not know how to use the photos stereoscopically, but intuitively they could foresee the advantages of finding roads and timber stands not plotted on conventional maps.

After 1945 and the wartime exposure of many foresters and engineers to military reconnaissance photography, an upsurge in the use of forest aerial photography began. Many of the forestry schools began teaching forest photogrammetry and photo interpretation. Panchromatic and infrared (IR) film taken with a minus blue (Wratten 12)[1] filter at scales of 1:15,840 to 1:20,000 were used almost universally. For most foresters who had never used these photolike maps, aerial photographs became highly coveted tools.

In late 1946 the Forest Survey of the Forest Service, U. S. Department of Agriculture, began using aerial photographs as a sampling frame for stratifying timber stands to estimate timber volumes for a national timber inventory. Many public and industry foresters were being trained in photo interpretation, photogrammetry, navigation in the woods with photographs, and sampling designs for forest inventory. This program also served as a catalyst to encourage foresters to use aerial photos.

About 1950 aerial photography taken with black-and-white infrared films through a minus blue filter was considered a panacea in solving all forest management problems. Extravagant claims were widely heard, for example, that individual species could be identified, that ground checks were not needed, and that accurate photo volume tables were easily constructed. Subsequent investigations did not bear out the claims. For example, in northern California Jensen and Colwell (1949) found that panchromatic film with a minus blue filter was superior to IR film for species differentiation. One pulp and paper company in the South would not pay the aerial survey contractor for IR coverage because conifers could not be reliably separated from hardwoods. And so a period of disenchantment set in.

Several factors, which we now better understand, were responsible for this development. Most forestry aerial photography taken before 1965 was taken with World War II-vintage uncalibrated cameras which had low resolving power. These cameras could discriminate only about 10 lines and spaces per millimeter. Emulsions were coated on acetate-base films which shrink and stretch five times as much as present polyester-base films, and these distortions affected the ability to make accurate measurements.

Aerial cameras and films have been greatly improved since the mid-1960's. Contracts for forest photography now specify the use of precision cameras having resolving power at least four times greater (40 line pairs per millimeter) than the older cameras. All aerial film emulsions are now coated on nonshrink polyester-base films. These new films are finer grained, have increased sensitivities, and are available in panchromatic, infrared, color negative, color positive, and color infrared emulsions.

Color and color infrared films have not only improved substantially in the past 10 years, but also a decline in their cost has resulted in their growing use in forestry (Hostrop and Kawaguchi, 1971). For example, color prints made from color negative film cost little more than traditional black-and-white prints. At present, all or parts of 15 National Forests have been photographed with color negative film.[2] And medium-scale color prints of

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[1] Trade names and commercial enterprises or products are mentioned solely for information. No endorsement by the U. S. Department of Agriculture is implied.

[2] Personal communication from C. L. Coultice, Division of Engineering, U. S. Forest Service, Washington, D. C. 1971.

this aerial photography (1:15,840) are available to forest engineers and managers at surprisingly low cost ($2.25 per print).

Normal color (NC) and color infrared (CIR) photographs will probably remain the most useful remote sensing tools for foresters for some time to come. On large-scale color photographs (scale 1:1,584), for example, tree species can be identified with greater than 90 percent accuracy (Heller et al., 1964). Normal color and CIR transparencies are particularly useful for detecting and locating tree damage by insects and diseases (Ciesla et al., 1967; Heller and Wear, 1969; Wert and Roettgering, 1968).

For assessing land use for forest survey and rangeland evaluation, CIR photos are superior to NC. For identification of forest stands, very small scales (1:400,000) can be used with CIR film because vegetation is a good IR reflector and shows up in reddish color, which is in strong contrast to nonvegetative objects (Aldrich, 1971). Because CIR film is taken with an atmospheric penetrating filter (minus blue, Wratten 12), clearer pictures are possible from high altitude than when panchromatic or NC film is used. Of course, with small scales greater efficiencies are possible in obtaining photo coverage and in interpreting fewer pictures. Driscoll et al. (1970) found that large- (1:600) to medium-scale (1:3,600) CIR transparencies are preferred for identification of range species and for assessing the trend of rangeland over time.

With our increasing concern for environmental quality and the need to map our forest resources, we will find that color photography permits more rapid and accurate analysis of existing vegetation. The demands of the U. S. Environmental Protection Agency to furnish environmental statements for support of management actions mean that more accurate natural resource data are needed. Remote sensing can assist in collecting, analyzing, and furnishing base line data to the resource manager.

Although aerial photography has been a vital tool for foresters, it has not been without problems. Let me list some of them:

1. Standardization of color emulsions. Both NC and CIR emulsions have greatly improved, but one emulsion lot can differ from the next despite present quality control by the film manufacturer. To quantify the reflected energy from the forest to the film, sensitometric wedges should be put on all films. This addition enables a measure of control to be exercised in film processing. Similarly, exposure of a few frames of film over a neutral gray surface, such as an airport runway, before forest mapping would indicate dye shifts in the emulsion when processed. Corrective printing, viewing, or densitometer analysis with filters can be done once the shift in hue from the normal gray has been identified. None of these measures are now being taken routinely.

2. Color dyes in films are only approximations to actual spectral reflectance characteristics of vegetation. Absolute comparisons cannot be made (Specht et al., 1966).

3. Good quality control in the printing of black-and-white and color prints is needed. Despite the use of electronic dodging printers, some prints are of poorer quality than those made with less sophisticated equipment 20 years ago.

4. More trained photo interpreters are needed to do the forest resource job facing us. On-the-job training and short courses should be available to foresters, range specialists, hydrologists, recreationists, and engineers.

Multiband Photography and Image Enhancement

To set the growing use of remote sensing photography in perspective, let me describe briefly the principles of color multiband photography.

As long ago as 1820, Thomas Young discovered that when three primary colors are projected onto a screen, one upon the other, white light evolves, and when the primary colors are properly mixed, the three complementary colors--yellow, magenta, and cyan--result (Teevan and Birney, 1961). Recent investigators (Yost and Wenderoth, 1967; Land, 1959) have borrowed on this principle by exposing film through three or more identical lenses onto single- or multiple-format cameras. Over each lens a different waveband filter is used. For example, an object of particular interest might have a unique spectral reflectance. By using a narrow bandpass filter which includes this spectral signature but excludes all others, we can find our object of interest on resulting imagery. Often enhancement of images is possible by changing filters and amplifying the light sources. If the filter and object reflectances match well spectrally, good discrimination of targets is possible. If there is considerable overlap of reflectances with other objects, discrimination is impossible.

In some disciplines, image enhancement through multiband small-scale photography is advantageous. Determination of water depth and identification of underwater objects lend themselves to this kind of analysis. Separation of crop species at certain times of year has been reported successful by Wenderoth and Yost (1971). In forest studies, the advantages of using a multiband system are not superior to those of well-exposed color films.

Useful multiband photography requires that the camera lenses are matched and that all bands are properly exposed, processed to uniform gamma densities, and projected through a matched lens system to permit proper registration of all wavebands. Finally, a color picture must be taken of the enhanced image to record the results. The camera and projection systems are expensive and the processing of film critical for the nebulous advantages to foresters.

Other enhancement techniques include density slicing of black-and-white or color transparencies by electronic or darkroom techniques. Bizarre images can be created by the assignment of different colors to separate density levels. One enhanced image from the Apollo 9 CIR photo over Atlanta, Georgia, attempted to separate 13 land-use classes, which included pine, pine-hardwood, and hardwood forest types. Misclassifications of forest types were severe away from the center and on the shaded side of the photograph.

Murtha[3] has reported a case in which electronic image enhancement of a pine stand infected with *Fomes annosus* was successful. A red filter was placed over the television camera that was focused on a CIR transparency of the infected pine trees. The thinness of foliage of the affected trees

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[3] Personal communication from Peter A. Murtha, Forest Management Institute, Department of Environment, Ottawa, Ontario, Canada. July 24, 1972.

had more image density than the healthy trees, and a different color was assigned to the damaged trees on the television monitor. This enhancement was identifiable partly because the area of infection was known. Accuracy of identifying Fomes on other areas has not been tested.

Multistage and Multiseasonal Photography

Multistage photography is a concept involving 3P (probability proportional to prediction) sampling (Grosenbaugh, 1965). The concept is based on the assumption that a forester or photo interpreter can gather increasingly more accurate information about the forest as he is provided larger and larger images. The more accurately he can make classification decisions on the basis of this information the lower his expected error of estimate will be. Another desirable characteristic of 3P sampling is that while most of the sampling effort is directed toward areas of interest (volume estimates, mortality, etc.), the error of estimate is still unbiased.

Multistage photography with ground sampling was used first in making damage appraisals--(1) in northwestern California, of damage from the Douglas-fir beetle (Dendroctonus pseudotsugae Hopk.) (Wert and Roettgering, 1968); (2) in South Dakota, of damage from the mountain pine beetle (Dendroctonus ponderosae Hopk.) to ponderosa pine (Pinus ponderosa Laws.) (Heller and Wear, 1969); and (3) in southern California, of smog injury to ponderosa pine (Wert, 1969). Most of the errors of estimate were about 10 to 20 percent. The Douglas-fir beetle survey was calculated to be 100 times cheaper than a ground survey of comparable accuracy.

With these successes in tow, we then used this technique with Apollo 9 space imagery in surveying two areas in the South--Vicksburg, Mississippi, and Atlanta, Georgia (Aldrich, 1971). The objective of this study, made in March 1969, was to estimate the timber volume by using the space CIR photographs as the first level of information. Multistage sampling was combined with low-resolution satellite photography, supplemented with additional high-resolution aircraft photography and ground inspection. The ground sample was about one hectare in one million. The results were so encouraging that further investigation of satellite imagery is now under way.

One operational application of multistage aerial photography deserves mention. A timber volume inventory on the Stanislaus National Forest in central California was completed in 1971 as a pilot study between the U. S. Forest Service's Pacific Southwest Forest and Range Experiment Station and California Region. Fifty-six 70-mm sample strips of varying length (1/2 to 1 mile) were photographed in color at a scale of 1:3,960. The strip locations were based on the expectation of representative timber volumes by a priori knowledge (available resource photography and type maps). The technique has proved so successful that in 1972 three additional National Forests will use this combination of multistage photography with 3P sampling.

Multiseasonal photography has long been advocated as a technique to identify and separate forest species. Because of the phenological and cultural changes which occur over time, a comparison of photographs taken at different seasons shows species differences; recent timber cuttings; and highway, urban, and power line encroachments.

Draeger et al. (1971) described a good example of multiseasonal photography. They developed a means of determining crop type, acreages, and yields from small-scale (1:400,000) CIR photography over the Imperial Valley of California. By tying together planting dates with color responses on the CIR film and with sampled ground data, they were able to estimate crop types and yield.

Forest managers probably could not afford multiple flights of complete aircraft coverage; however, within areas of expected management treatments, repetitive sampling flights may be worthwhile. Until we learn more of the capabilities of satellite imagery, it will be difficult to know whether microscale imagery can track phenological and cultural changes to the level required in forest operations. Of course, repetitive coverage every 18 days as in the Earth Resources Technology Satellite (ERTS), which was launched on July 23, 1972, would be desirable in spring and fall, when maximum spectral changes occur. But such coverage would not be needed in midsummer or midwinter when changes are minimal. Cultural changes would be difficult to detect more frequently than every four months (Aldrich, 1971).

Multispectral and Thermal Scanners

Optical-mechanical scanners (OMS) have a long history of use by the U. S. Department of Defense. But only in the last seven to eight years have serious efforts been made to investigate their use on forestry/agriculture problems. The scanner is a complex airborne instrument which has a much narrower field of view (< 1.5 to 3 milliradians) than an aerial camera (1 radian or more). It collects reflected and emitted energy on a high-speed rotating mirror in the form of photons; the optics focus the energy on a detector or series of detectors. This energy is then amplified to readable voltage signals, and a record is obtained either on magnetic tape or through a modulated light source--known as a glow tube--to film. The images are built up--scan line by scan line--in a direction perpendicular to the line of flight; the scan angle from one side of the airborne platform to the other is usually 60 to 120 degrees. By contrast, the ERTS oscillating scanner has a very narrow scan angle of about 6 degrees.

Multispectral scanners (MSS) break up the electromagnetic spectrum into narrow wavebands (channels) through the use of filters; some scanners have up to 24 separate channels--from 0.38 μm to 13.8 μm. The ERTS scanner has only four channels--from 0.6 μm to 1.1 μm. A major improvement in scanner technology in 1971 permits all incoming energy to be simultaneously recorded through a single aperture or field of view. Heretofore, visible waveband data were recorded separately from reflective IR and from thermal IR data. Simultaneous recording of all wavebands permits the use of electronic computers to identify targets of interest and to optimize the selection of channels for identifying that target.

Scanner studies in the Black Hills of South Dakota to detect previsual symptoms of tree death (Weber and Polcyn, 1972) have shown that four to seven channels are optimum for species identification and stress detection. This number of channels is probably the maximum required for natural resource users. A combination of preprocessing of MSS data on a digital computer with analog processing of the best channels on an analog computer offers the forester the greatest potential of automatic image interpretation now available. Recent work by Olson[4] in classifying forest species in Michigan

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[4] Personal communication with Dr. C. E. Olson, Professor, University of Michigan, School of Natural Resources, Ann Arbor, Michigan. August 1972.

indicates the potential of this technique.

Thermal scanners operate in exactly the same manner as multispectral scanners, but they collect photons only in longer wavebands of the IR spectrum (3.5 µm to 5.5 µm and 8.0 µm to 14.0 µm). They rely upon differences in emitted energy (radiant exitance) for detection of objects. These thermal differences can be imaged on film or recorded on magnetic tape as with MSS. Nonclassified detectors can separate differences in radiant exitance as small as 0.2° C.

The Forest Service has developed a two-channel thermal scanner (Hirsch, 1971) which can detect incipient forest fires--a difficult task by conventional fire tower or by aircraft visual reconnaissance. A fire-mapping scanner developed by Hirsch and Madden (1969) has seen four years of operational use. This instrument is useful to the fire boss on large fires because it can be used at night or through smoke and haze--something not possible with aerial cameras.

Scanners sound like a panacea to all our forest remote sensing problems. And eventually they might be. Except for the application to fire detection, however, they do not solve any of our forest problems. They are expensive to buy, lease, or contract for. And they require highly trained electronic engineers and technicians to operate and to maintain them.

Another problem with scanners is the effect of shadows, topography, and sun angles. These angles affect scanner image responses from one side of the scan line to the other even though reflectance and emittance values are identical. Also, skew, crab angle, and sigmoidal distortion make scanner imagery difficult to rectify with geographic coordinates. Its positional accuracy is much poorer than that from precision aerial cameras. The usual procedure is to locate oneself on the scanner imagery by using an aerial photograph as a reference. Then, corrections for distortions and radiance values can be determined and programmed before target signature analysis begins. Such corrections slow down the ultimate imagery output.

Another problem in using scanner data is the time lag between time of data collection and analysis. For example, the Forest Service Remote Sensing Work Unit in Berkeley sometimes has not been able to analyze data until six months to one year after the data were originally collected. This delay is partly because of the state of the art and partly because processing is done at other locations.

Using scanner data to locate dying trees is not accurate enough for operational use. Both omission and commission errors are numerous. Every new test shows improvement, but we have a long way to go.

Digital analysis techniques from scanner data, such as those developed at the Laboratory for Agricultural Remote Sensing, Purdue University, show promise in being able to produce a digital recognition map. But forestry data are much more variable than crop data, so that almost every resolution element must be used in forestry analysis, whereas sampling can be used for agricultural analysis (every eighth resolution element and every eighth scan line). Thus, forest analysis is not only more time-consuming but also more costly if digital methods are used exclusively.

Radar

The use of radar imagery for mapping and land-use classifications is a relatively recent development (Holter et al., 1970). Consequently, not much work has been done on vegetation analysis (Morain and Simonett, 1967)--including forestry.

Beginning in 1971, the Brazilian Department of Mines and Energy had more than one million square miles in the Amazon River Basin surveyed from the air by Litton Industries Aero Service Corporation. The radar used was the Goodyear Aerospace SLAR (side-looking airborne radar) (9.6 mc in the x band 3.3 cm). The object of this survey was to obtain imagery for location of mineral and agricultural resources. Very little of the vast area had been surveyed with aerial photography because of the constant cloud cover. SLAR can penetrate clouds (except heavy rain clouds) and be used at night. It covers wide areas on each flight run--a strip 32 km wide (8 to 40 km to one side of the flight line at 13,000 meters). With this particular instrument, geodetic position is accurate to 10 meters.

The Brazilian study shows that there is conflicting evidence as to what can be seen on radar imagery. Miller (1972) reported that tonal or textural variations of vegetated surfaces can show boundaries of different types of vegetation and damage from fires. He suggests that timber inventories can be made by classifying vegetation types for subsequent logging operations. On the other hand, van Roessel[5] found that Brazilian interpreters were able to separate vegetated areas from nonvegetated areas, but differentiation of forest species was not possible. Resolution of radar imagery is relatively low; expected resolution from a jet aircraft at 13,000 meters is about 20 meters. This level of resolution explains why only the gross structure of the landform can be differentiated. Associations of forest type were made with the geomorphology of the sites since it was known that different species of timber grow at different altitudinal zones.

Satellite Imagery

In this Age of Aquarius, we have almost become blasé at the mention of satellites. Television news programs are now relayed by COMSAT (Communications Satellite), and most of us are aware of the weather pictures beamed down from the NIMBUS meteorological satellites. These two systems are obviously successful and will expand and improve in the future.

You may not know about the potential benefits from the earth resources satellite launched by NASA from Lompoc, California, this summer. This experimental satellite, projected into a near polar orbit, can completely image the United States every 18 days. It has two sensing systems aboard--a four-waveband multispectral scanner and a three-waveband return beam vidicon (television). Both systems operate in the visible and reflective infrared parts of the spectrum. Reflectance data from ERTS will be transmitted to the Goddard Space Flight Center in Greenbelt, Maryland, where images of the earth (100 nautical miles on a side) will be constructed at the Center's data processing facility. Forest targets have higher spectral reflectances than other targets in the reflective IR. This difference provides a higher contrast ratio from surrounding objects and permits accurate

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[5] Personal communication from Jan van Roessel, Forest Photogrammetrist, Earth Satellite Corporation, Berkeley, California. August 1972.

forest identification. The images will be sent to 328 principal investigators in the United States and abroad at no cost. The pictures also will be available for sale to the public from the U. S. Geological Survey, Sioux Falls, South Dakota. The satellite can also relay remotely collected ground sensor data, such as soil moisture, precipitation, and spectral reflectance, back to three receiver stations in the United States. In turn, these data can be routed to the investigator by mail or computer link. This part of the ERTS program is called the Data Collection System.

Many of us have seen the spectacular oblique color photos taken by astronauts from Mercury and Gemini spacecraft. Many resource analysts believed that good color representations could not be filmed from 120 miles above the earth because of atmospheric scattering of light. One of the near-vertical photos of the Gulf of California permitted mappers from U. S. Coast and Geodetic Survey to plot siltation and water depth of the Colorado River Delta by the changes in color. Two of the Apollo missions--VI and IX--had photographic experiments of the earth included in their flight plans. Apollo VI had one 70-mm camera which exposed color film on flight paths across Southern United States and northern Africa. These transparencies had good color rendition and sufficient resolution to permit range analyses to be made near Wilcox Playa, Arizona, and Los Alamos, New Mexico (Poulton et al., 1969; Driscoll, 1969).

We reported earlier in this paper how Apollo IX CIR transparencies were used successfully in a multistage sampling inventory of timber volumes in Mississippi and Georgia. The cameras used in that experiment were of small format (70 mm) and had uncalibrated lens systems. Nevertheless, the broad synoptic view of large expanses of the earth's surface provided foresters with information about timber location for more intensive sampling at lower altitudes. When resolution is in the order of 100 meters, only the broadest of judgments can be made. As we receive more satellite imagery, we should learn more about its applications to forestry.

As satellite sensing systems improve and orbital altitudes are reduced, we expect better resolution and increased usefulness of satellite imagery for foresters. For example, Skylab--a manned orbiting laboratory--will fly lower (250 nm) than ERTS (496 nm) and will have seven calibrated cameras and a high-resolution MSS on board. It will have other sensors available, but those mentioned will be most useful to natural resource specialists. Launch date for Skylab is April 1973. Earth resources experiments and sensing instruments are now being planned for the space shuttle flights due for launch about 1976. During slowdown and prior to entry into the earth's atmosphere, the spacecraft will be at altitudes of about 100 nm. Again, lower altitudes and improved sensors should increase the resolution capabilities needed by foresters.

Although satellite imagery shows much promise as a forestry management tool, its use poses some problems:

1. Very low resolution prevents accurate forest classification.

2. Very high data collection capability but low data analysis capability. Too few trained interpreters are available to review imagery on a nationwide scale. Also, the state of the art for automatic analysis of imagery is not advanced far enough to handle repetitive coverage.

3. The expense of obtaining satellite imagery is an unknown factor. The cost-benefit ratios are difficult to make until we learn the extent of the benefits. For example, Katz (1969) concluded that high-flying jet aircraft would be cheaper than a satellite program, would provide better quality imagery, and would have fewer political implications.

4. Likelihood of cloud interference over forest land is quite high and may preclude the possibility of making seasonal comparisons, although seasonal comparisons are not as critical in forest applications as with agricultural analysis. One or two good coverages per year may be adequate for forest managers.

Automatic Image Interpretation

Automatic photo or image interpretation could help improve the rate of image analysis and speed up handling of great masses of data that can be collected by aircraft or satellites. On a clear day even a conventional airplane can expose enough photographs at a scale of 1:15,840 to keep four men busy for six months just drawing forest type maps for one National Forest. When one considers that investigators may receive repetitive coverage, multistage and multiband photography, and multispectral scanning imagery, some means of data compression, sampling, or automatic interpretation needs to be considered for handling this mass of information.

Remote sensing data must be transformed into electrical signals, storable on magnetic tape, and compatible to computer storage and analysis. Multispectral scanning imagery is almost routinely collected on magnetic tape; in this respect, it lends itself to computer analysis. Smedes et al. (1971) demonstrated that soil, rock types, and vegetation could be accurately depicted in Yellowstone Park by using digital and analog processing methods. Holter et al. (1970), using similar techniques, defined different crops in the Sacramento River Valley. Olson showed that 10 different tree species grown in adjacent plantations in Michigan could be separated from MSS data.[4]

These examples show the potentiality for doing automatic spectral classification from MSS, but there are still problems with nonorthogonality, sun angle, and distortion of the images which must be overcome before it can be put into operational use. Also, the melding of information from one flight line to the next--each with different sun angles--makes the processing job lengthy, tedious, and expensive.

Scanning of distortion-free color or CIR photographs on a microdensitometer or by television camera has certain advantages. For one, positional accuracy is good on the photograph and permits easier location of forest data into a geographic coordinate system. For example, Driscoll et al. (1970) have found that scanning of CIR transparencies (scale 1:600) can estimate accurately the vegetative covering of range lands. This information is useful to follow range condition and trend from one measurement period to the next.

A second advantage is that obtaining high-quality photography is easier than getting high-quality MSS imagery. Density slicing of a photograph by a television camera and assigning colors to various density levels can produce a vivid image on a color television receiver. But the image analyst must know what each density level represents in terms of trees, roads, soil, water, etc. In forest species discrimination, often there is so much overlapping of density that the output is meaningless. On some density slicing instruments, a percentage of each density level, as represented by a separate color, can be read off. This characteristic can be highly useful if the analyst could be certain that there were no density ambiguities. But as of now, such ambiguities do exist. A television camera integrates a large mass of photographic data, since most TV cameras and receivers have only 525 scan lines per picture. In cases where small-scale imagery is used, the large TV raster pattern would obscure small stands of timber.

Microdensitometer scanning has the best positional accuracy for integration of data into a coordinate system. Again, density and spectral differences (for color and CIR film) must be associated with the targets of the user's interest. Research has been under way for 10 years to develop good signatures for densitometric analysis. From studies by Le Schack (1971) and Doverspike et al. (1965), not only spectral density differences but also spatial density frequencies must be used to separate forest species and land-use classes. In other words, image analysis by microdensitometer is not operational at present.

The military intelligence groups have long sought automatic interpretation equipment and have spent millions of dollars on its development. Even for distinguishing relatively simple targets, such as military vehicles, airfields, and ships, they found that detectability was not reliable enough with automatic systems. Trained photo interpreters are still used to make critical evaluations of weaponry. As Latham and McCarty (1972) point out: "We must be careful not to oversell the machine nor to undersell the human."

Other Considerations

The state of the art in remote sensing is in constant flux. Improvements in sensors, detectors, processors, enhancers, films, cameras, and whole systems are coming so rapidly that the user is afraid to buy equipment because something better is likely to come out the next month. And the better equipment is often smaller and less expensive. For example, Doppler radar for precise aircraft positioning in remote areas originally weighed about 500 pounds, cost almost $200,000, and was accurate to about ± 1 nm. Recently Singer-Kearfoot produced a model, weighing 80 pounds and costing $40,000, which can position the aircraft ± 0.1 nm. Such development makes it feasible to take repetitive sample photos of remote forest areas with considerable reliability from small aircraft.

The recent development of orthophotos for forest engineering provides foresters with photos having map fidelity and the detail needed in forest management operations. Enlargements to any convenient scale are possible, and topographic and cultural information can be imprinted (Bockes, 1970).

Much of our remote sensing technology was developed for military application--for example, SLAR, thermal scanners, Doppler radar, and panoramic and image motion compensating cameras. Civilian use has come about as systems were declassified. Obviously, further declassification of systems and equipment will have a beneficial impact on users, such as ourselves.

SUMMARY

1. Aerial photography of all kinds will continue to be the primary remote sensor used by foresters. Color and color infrared films and prints have been improved substantially in the past 10 years. We will undoubtedly

use all scales of photography--from very large to very small. Standardization of films, film exposure, and processing are still problems, but steps are being taken to improve this situation.

2. Multistage and multiseasonal photography has a place for forest application whenever sampling estimates will suffice. Surveys for insect evaluation, timber volume, and mortality will benefit most from large-scale color and CIR photographs. Because repetitive coverage is needed for multiseasonal photography, high cost will preclude foresters using this approach for routine management.

3. Optical-mechanical scanners (both thermal and multispectral) are some of the most promising sensors available to us. Because electrical signals from the scanners are amenable to automatic data processing, this kind of sensor will probably become more useful to foresters in the future. Present problems with positional accuracy and proper irradiance levels are rapidly being solved.

4. Radar sensors, particularly SLAR, will be useful for foresters where constant cloud cover precludes the use of photography or multispectral scanners. Forest hydrologists may find SLAR a useful sensor for stream delineation in heavily wooded areas and for detecting faults and slippages of soil. Not enough study has been made of SLAR imagery to determine whether there are enough structural differences in timber stands to permit accurate forest delineations.

5. The potential usefulness of satellite imagery in forestry is uncertain. We need more experience. Certainly it appears that forest vegetation can be separated form nonforest and thus can serve as a sampling frame for inventories in newly developing countries. Changes in forest boundaries from timber cutting, urban encroachment, and snow coverage in the mountains can be interpreted from satellite sensors. Low resolution and expense are the greatest drawbacks right now to greater use of such sensors.

6. Automatic photo interpretation is still in the developmental stage and is not ready for a production-type operation.

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