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ERTS IMAGERY . . . PROBLEMS AND PROMISES FOR FORESTERS

by

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ABSTRACT

In July 1972, the U. S. National Aeronautics and Space Administration (NASA) sent into orbit its Earth Resources Technology Satellite (ERTS-1) to photograph land and other resources. Interpretation results to date are experimental and tentative. Widespread application of ERTS imagery to solve forestry problems does not appear to be practical as yet. Clouds have prevented full photographic coverage and seasonal comparison of forested sites. Quality of the color composites has varied widely. The locational accuracy of points on images may exceed 500 meters. The low resolution of photographs obscures forest roads. Users must have access to expensive equipment, including optical combiners, computers, and darkroom facilities, to process and use the imagery. And there have been long delays in obtaining imagery from NASA or the U. S. Geological Survey. Notwithstanding these limitations, ERTS imagery does offer some promises. On good images, foresters have a broad synoptic view of vast areas that would be useful in planning when taken together with existing maps. In temperate zones, forest vegetation shows up best in spring, fall, and winter on the red channel (0.6 to 0.7 μm) or on the infrared color combination. Summer imagery is poorest for forest discrimination in these zones. In zones of scant summer rainfall or where conifers predominate, however, summer imagery may be excellent. The use of imagery to record land use changes in forest land shows the greatest promise. Forest and nonforest (and possibly conifers from hardwoods) classes can be discriminated when forests are young to mature. But transitional forest classes, such as seedlings and brushfields, are difficult to classify correctly. If accurate forest delineation is possible from ERTS imagery, computer analysis of the data may speed up the first stage of a multistage sampling process to inventory forest lands.

INTRODUCTION

The Earth Resources Technology Satellite (ERTS-1) launched on July 23, 1972, by the U. S. National Aeronautics and Space Administration (NASA) allows foresters to see for the first time what the earth looks like from more than 900 kilometers in space. The imagery produced by this experimental satellite offers considerable promise in forest management and inventory.

color

But in the one year that ERTS-1 has been orbiting, the problems in using satellite imagery have also become evident. And because our experience with ERTS has been relatively short, any conclusions drawn from the results of our tests should be considered tentative.

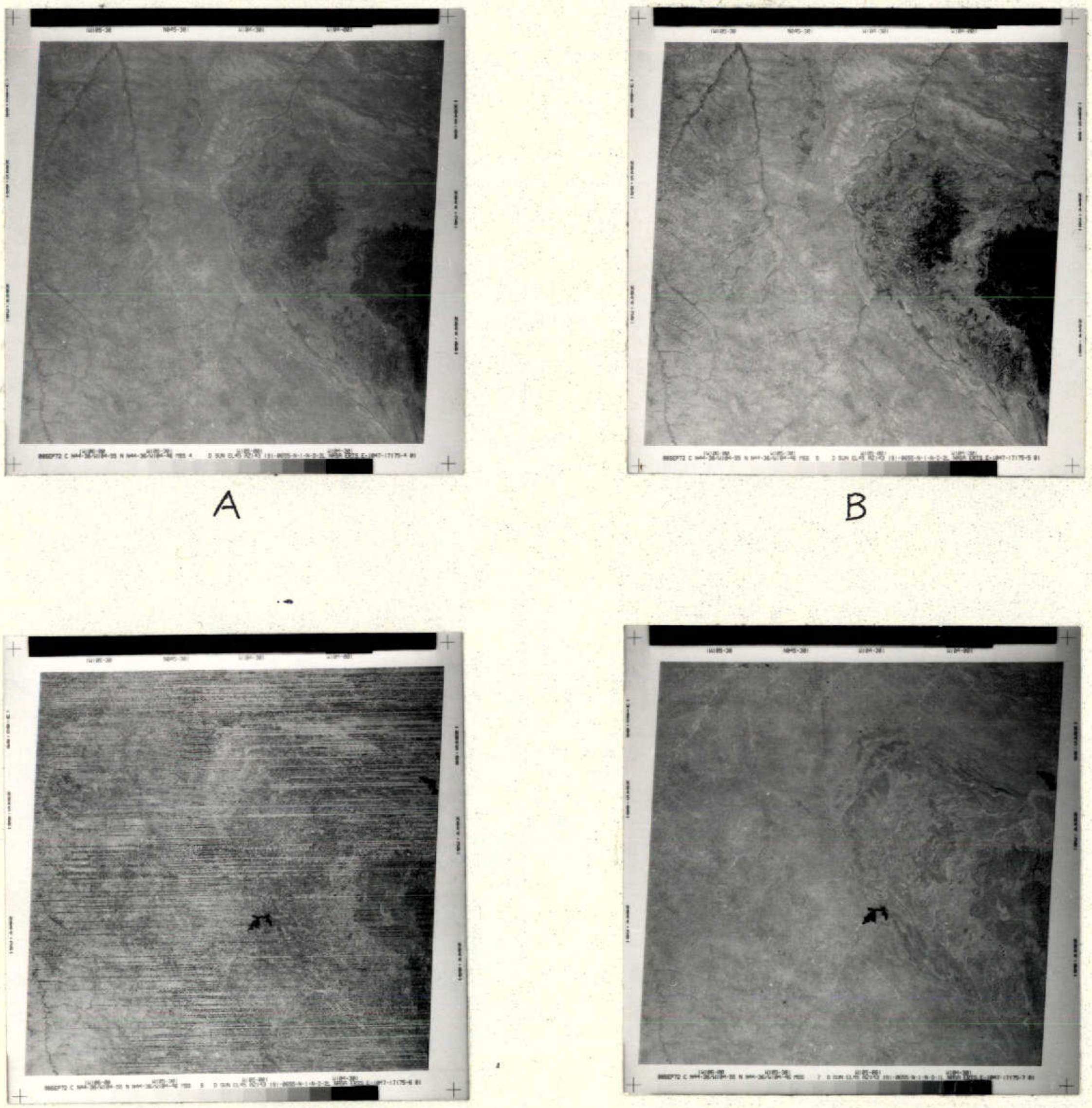
PROBLEMS

Foresters are familiar with aerial photography, but most of them have had little experience with images which look like photographs but which are produced by sensors. The optical scanner in ERTS produces four discrete images by means of detectors that transmit electrical signals of reflectance received from the earth in four separate bands of the visible and near infrared (IR) portion of the electromagnetic spectrum (EMS). These bands are green (0.5 to 0.6 μm), red (0.6 to 0.7 μm), far red (0.7 to 0.8 μm), and near IR (0.8 to 1.1 μm) (Figure 1). (The ERTS Users Handbook provides a complete description of the satellite, its peripheral equipment, expected image quality, and positional accuracy.) Thus, some of the early problems facing ERTS forestry experimenters were: unfamiliarity with a new instrument, dealing with four images instead of one, and lack of knowledge about actual resolution and accuracy of location.

Clouds have been the bane of ERTS users. Except in arid and semiarid regions of the world, clouds have obscured test areas where foresters have gathered ground information to correlate with satellite imagery. For example, the U. S. Forest Service's remote sensing research unit at Berkeley, California, has three test sites in three widely separated areas of the United States; these areas are near Atlanta, Georgia, Lead, South Dakota, and Colorado Springs, Colorado (Figure 2). During the time ERTS imagery has been available, we have been successful in getting cloud-free coverage of all sites only 19 percent of the time (Table 1). Foresters working on California test sites have had more favorable weather and have obtained more ERTS images.

On cloud-free days, the lack of coincidence of the ERTS orbit and the center of each test site frequently meant that only a small part of a test site would be covered. Lack of coverage frequently occurred during an entire season (no imagery was possible in spring, summer, or fall for our Black Hills (South Dakota) site). Consequently, seasonal comparisons could not be made. Late summer and fall in the Black Hills is the period of maximum differences in radiance between green healthy and yellow to yellow-red dying pines. Thus, conclusions about detectability of forest stress in conifers on ERTS imagery cannot be drawn because, first, no imagery was cloud-free during the critical discoloration period, and second, baseline ERTS imagery was not available from an earlier season because clouds or snow had obscured the trees.

Occasionally, NASA technicians have had technical difficulties in processing images and making computer compatible tapes (CCT's). This problem is



A B C D

Figure 1. Each 70 mm ERTS multispectral scanner (MSS) scene was transmitted in four wavebands: (A) green, 0.5 to 0.6 μm; (B) red, 0.6 to 0.7 μm; (C) far red, 0.7 to 0.8 μm; and (D) near IR, 0.8 to 1.1 μm. Scene is of western corner of Black Hills (South Dakota) test site, 8 September 1972. Band C has missing radiance data along scan lines. Scale is 1:3,690,000; area of each image is about 32,400 square kilometers. (ID 1047-17175)

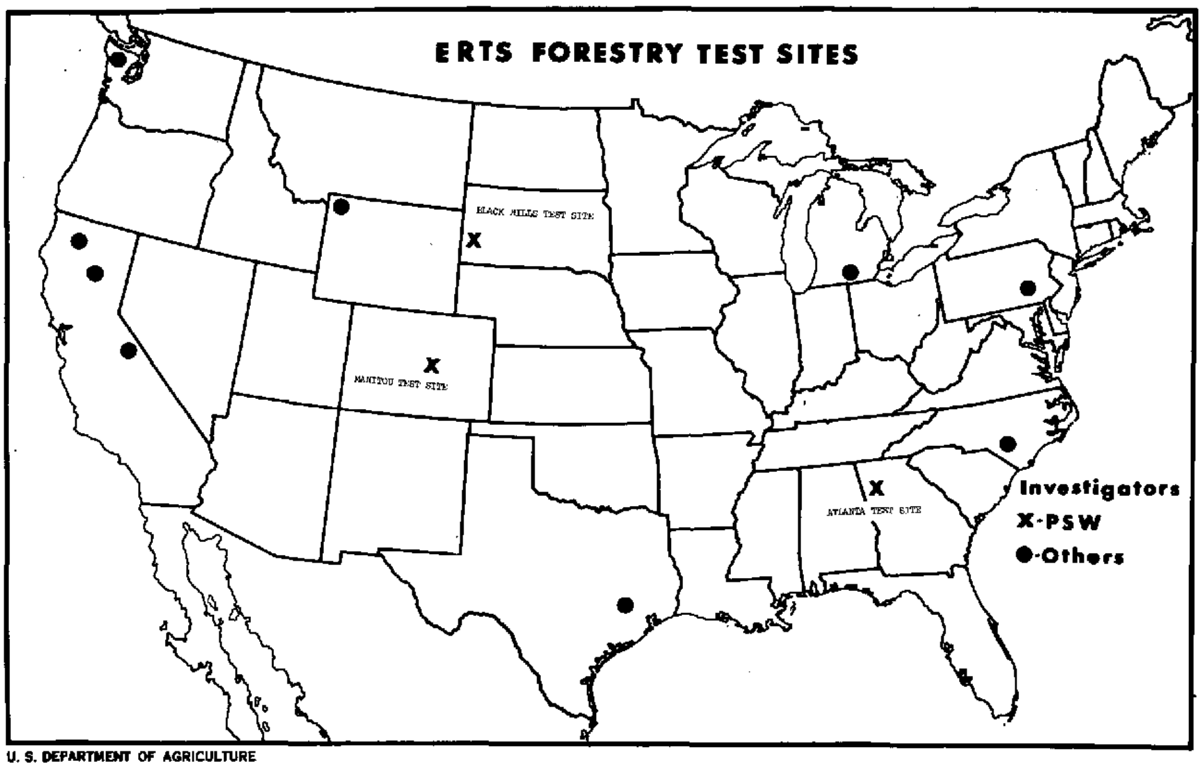


Figure 2. Three forest and range test sites being studied by Forest Service researchers in the United States are identified by X's. Other forestry sites are shown by O's.

TABLE 1. ERTS Coverage of Forest Service Test Sites
July 23, 1972, until August 1, 1973

Test Site	Total number of scenes[1]	Cloud-free scenes		Less than 20 percent cloud cover[2]	
		number	percent	number	percent
Black Hills (226A), South Dakota	44	15	34	17[3]	39
Atlanta (226B) Georgia	82	14	17	26	32
Manitou (226C) Colorado	25[4]	0	0	12	48
All sites	151	29	19	55	36

[1] An ERTS scene may include only a small portion of the test site; for example, the Black Hills site was completely imaged only seven times during the year.

[2] The maximum acceptable cloud cover was 20 percent.

[3] Black Hills test site had no scenes where 100 percent of site was covered except for snow-covered scenes.

[4] Data acquired between July 23 and October 1, 1972, and between April 1, and August 1, 1973.

not unexpected because of the extreme complexity and volume of data outputs. Such difficulties cause degradation of the images or tapes used by the forest experimenters. For example, the far-red band in Figure 1 shows about one-fourth of the scan lines as being devoid of useful information. Yet, this band is one of the most vital in detecting forest stress. On many CCT's every sixth scan line has had a stronger signal than the preceding five. This difference means that computer programmers must average out or eliminate the oversaturated scan line before accurate forest signatures can be identified.

We have found that negatives produced by NASA are extremely dense and consequently lose most of the vegetative and forestry detail found on the transparencies. The density of these negatives falls high on the shoulder of the film gamma curve. High density levels cut out most of the lower and critical densities representative of vegetation. Myhre (1973) has devised a scheme for making negatives having a full density range from ERTS transparencies. His scheme permits 35X print enlargements of good quality in a darkroom. Such a procedure enables the forester to compare aircraft imagery with ERTS enlargements. Furthermore, good enlargements are useful for field checking.

A data product available to ERTS experimenters from NASA is a color composite transparency or print (23- by 23-cm format) made from three ERTS bands. The quality of the transparencies has varied from excellent to poor. For example, of two transparencies received of the same scene of Lake Tahoe, in California, made on the same processor at NASA's processing facility, one is excellent and the other only marginally useful (Figure 3). Consistency in the quality of the transparencies would help foresters define more accurately forest boundaries from other vegetation types. One uncontrollable factor that reduces the clarity and radiance differences of the data products is atmospheric attenuation. On hazy days or around industrial centers where smoke is prevalent, the ERTS images are less clear than on other days away from industrial areas.

The positional accuracy of ground locations on ERTS images when compared to first-order maps presents problems to satellite data users. On system-corrected (bulk) images, longitude tick marks have been displaced as much as 2,000 meters (m). Aldrich (1973) has studied the displacement of identifiable points on ERTS images within the forestry test site in Georgia. On bulk data, he has found that the forest stands have been displaced an average of 520 m. On precision images, his templates show a smaller displacement of 300 m. McEwan (1973) reported that bench marks and control points were randomly in error on bulk images by 300 to 500 m and on precision images by 200 m. But positional accuracy of ERTS products received six months after the satellite was launched was improved over earlier ones.

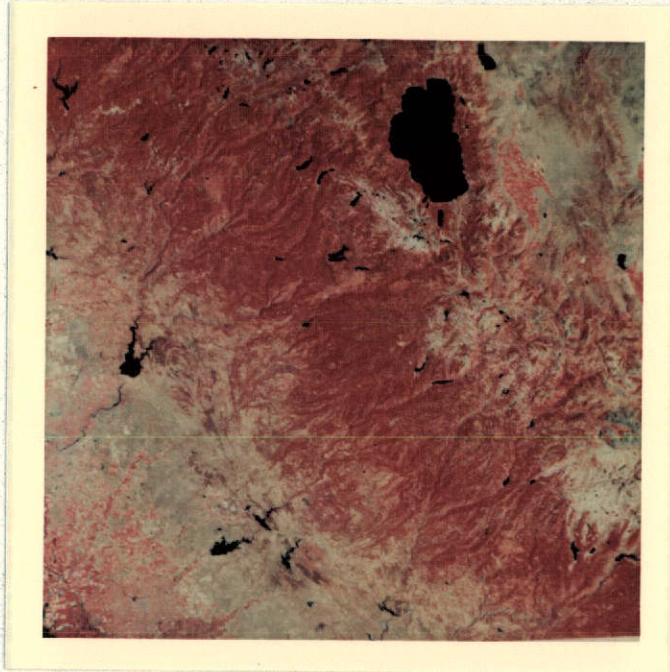


Figure 3. Copies of two NASA-produced color transparencies of the same scene near Lake Tahoe, California. ERTS MSS image of bands 4, 5, and 7, 25 July 1972. Scene at bottom is one of the few RBV images taken on same date. It was made from a color composite of green, red, and far-red bands. (ID 1002-18131)

The displacement of forest stands and other images from their true position causes other problems. The displacement makes it difficult to undertake an unbiased experiment to determine whether correct identification of different sizes and species of forest stands is possible on ERTS images. Aldrich (1973) has found that he can get fairly good positional accuracy by limiting the viewing area to one 15-minute quadrant of his 23- by 23-cm ERTS transparency at a time. Using a Bausch and Lomb Zoom Transfer Scope[1] he compares a quadrant of the ERTS image with templates accurately drawn from film composites of the original first-order map plates. By including prominent rivers, lakes, and major highways, as well as geographic coordinates, he is able to reduce positional errors considerably.

Resolution of forest images on ERTS imagery may be too low to make management decisions about species or volumes. Olson (1964) found that radiance (or reflectance) differences between forest species are similar especially during summer; greater radiance differences occurred during late summer and fall. These differences have been demonstrated with both aerial photography and satellite imagery. Atmospheric interference causes lowered contrasts of all objects for both aircraft and satellite imagery. It is difficult, for example, to separate green healthy trees (peak reflectance 0.56 μm) from yellow dying trees (0.59 μm) when resolution is low, the targets relatively small (300 m), and the atmospheric attenuation high. Aldrich (1973) found that ERTS imagery taken in summer over the Southern United States is not as useful for forest inventory as that taken late fall, winter, or spring. Forest roads seldom show up on ERTS images because they are narrow, often curved, and often covered by branches, whereas paved roads with wide shoulders usually are discernible.

Finally, the forester faced with analyzing ERTS imagery should realize that a sizeable investment in equipment and people is needed. Image combiners for registering the multiband 70 mm images permit image enhancement and copying to larger formats. However, they are expensive--ranging in price from \$5,000 to \$12,000. We have found that a well-equipped color darkroom, for making color internegatives from the image combiner and black-and-white enlargements of individual bands, is a tremendous benefit for office and field study. If analysis will be made from CCT's, programmers, computer programs (software), and access to computers and plotting equipment are needed. Other peripheral equipment which may aid in analysis of ERTS data includes a varying magnification comparator such as a Zoom Transfer Scope, a scanning microdensitometer, and high-intensity light tables. All of these items are expensive.

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

PROMISES

Because ERTS is an experimental satellite, it has induced many researchers from varied disciplines and land-managing agencies to investigate ERTS data to solve their particular problems. Because of the broad synoptic view offered on each frame, some surprising and heretofore unknown phenomena have been reported. For example, Fischer, et al. (1973) showed that ERTS imagery over northern Alaska revealed major faults that were undiscovered by aerial photography. Hallberg, et al. (1973) mapped the devastations of a major flood in Iowa on the color composite ERTS image. Miller (1973) demonstrated that the low-level resolution qualities and broad coverage of each ERTS frame aided land use planners in Alaska.

Through computer enhancement procedures of the CCT's, Algazi (1973) could show water circulation patterns and turbidity in San Francisco Bay not discernible on the original 70 mm ERTS imagery. By using software programs developed at the Laboratory for Agricultural Remote Sensing (LARS) at Purdue University, Baumgardner, et al. (1973) could discriminate crop types, water resources, and soil boundaries in western Texas.

All of the successful applications of ERTS data had several factors in common; the objects being identified had long linear features (faults in Alaska, flooded land in Iowa) or had large areas of homogeneous objects (water turbidity and large regular-shaped agricultural fields). On the other hand, most forest stands grow in irregular shapes and are frequently of mixed species. These characteristics increase the variation in stand type identification. Even though the main discrimination that can be made with confidence on ERTS is limited to forest versus nonforest, this capability is useful to forest planners. In no other way can a forest manager see 34,500 hectares (ha) on one picture. Two-time enlargements from the 70 mm images show clearly the synoptic coverage of forested land in four parts of the United States (Figures 4, 5, 6, and 7). Enlargements of one ERTS band to scales of 1:250,000 and 1:125,000 can be made and at these scales can be compared with first-order maps.

Under ideal weather conditions (low atmospheric interference and absence of clouds) forest signatures developed for one part of an ERTS frame are valid for all other parts. The very narrow angle of view of the scanner (11.5°) and the extreme altitude (915 km) make the earth's surface almost flat. Thus, reflectances from similar objects on different parts of the ERTS frame are identical.

From our first year's analysis of ERTS imagery, we can generalize about the most useful bands for forestry analysis and outline some techniques that proved helpful to us.

1. For two-band analysis, bands 5 (red, 0.6 to 0.7 μm) and 7 (near IR, 0.8 to 1.1 μm) identify vegetation best when combined on an optical combiner.

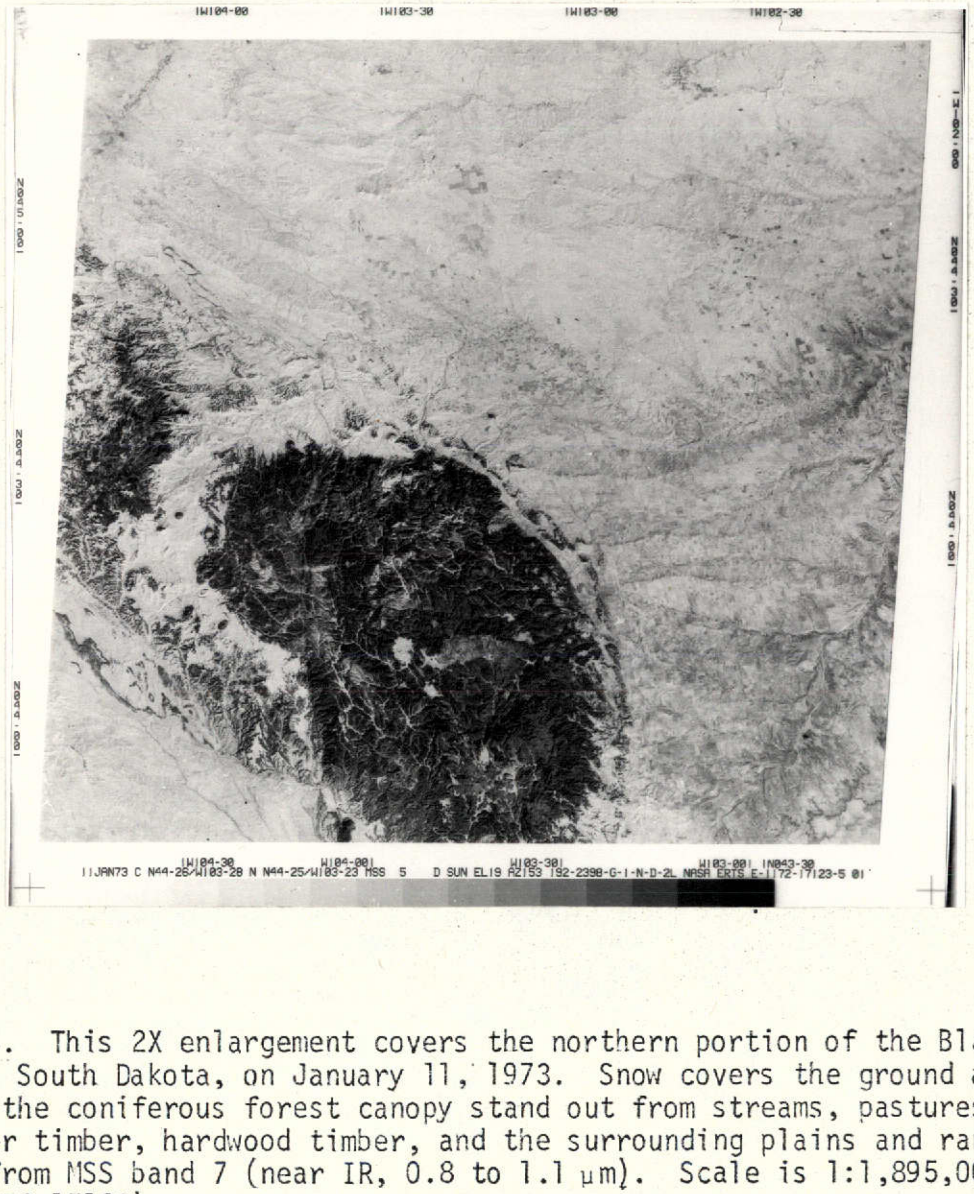

Figure 4. This 2X enlargement covers the northern portion of the Black Hills, South Dakota, on January 11, 1973. Snow covers the ground and makes the coniferous forest canopy stand out from streams, pastures, cutover timber, hardwood timber, and the surrounding plains and rangeland. Made from MSS band 7 (near IR, 0.8 to 1.1 µm). Scale is 1:1,895,000. (ID 1172-17123)

Figure 5. Atlanta, Georgia, test area on October 15, 1972. Band 5 (red, 0.6 to 0.7 μm) permits good discrimination of southern pines (<u>Pinus sp.</u>) from other land uses. When used in combination with band 7 (near IR, 0.8 to 1.1 μm), the combination distinguishes waterways and bottomland hardwoods. (ID 1084-15433)

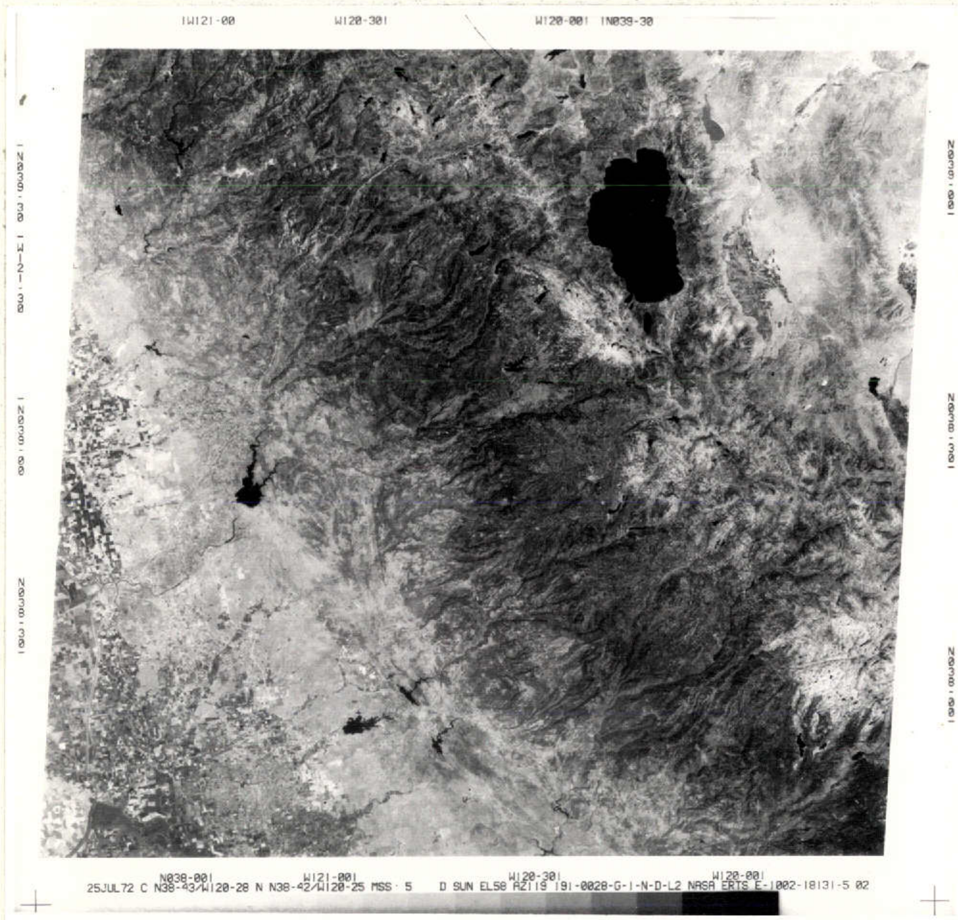

Figure 6. Middle California near Lake Tahoe (upper right) and timberland along the Sierra Nevada. Vegetation reflectance is low (chlorophyll absorption) in the red band (channel 5, 0.5 to 0.6 μm). Urban areas (City of Sacramento) are difficult to find because of high reflectance of dead grasses in Sacramento Valley at this time of year. Oak/brushlands can be separated on combined channels 5 and 7 from dead grasses and coniferous timber quite accurately. In upper center of photo, a wide roadway (U. S. Interstate Highway 80) cuts through timber. Image obtained 25 July, 1972. (ID 1002-18131)

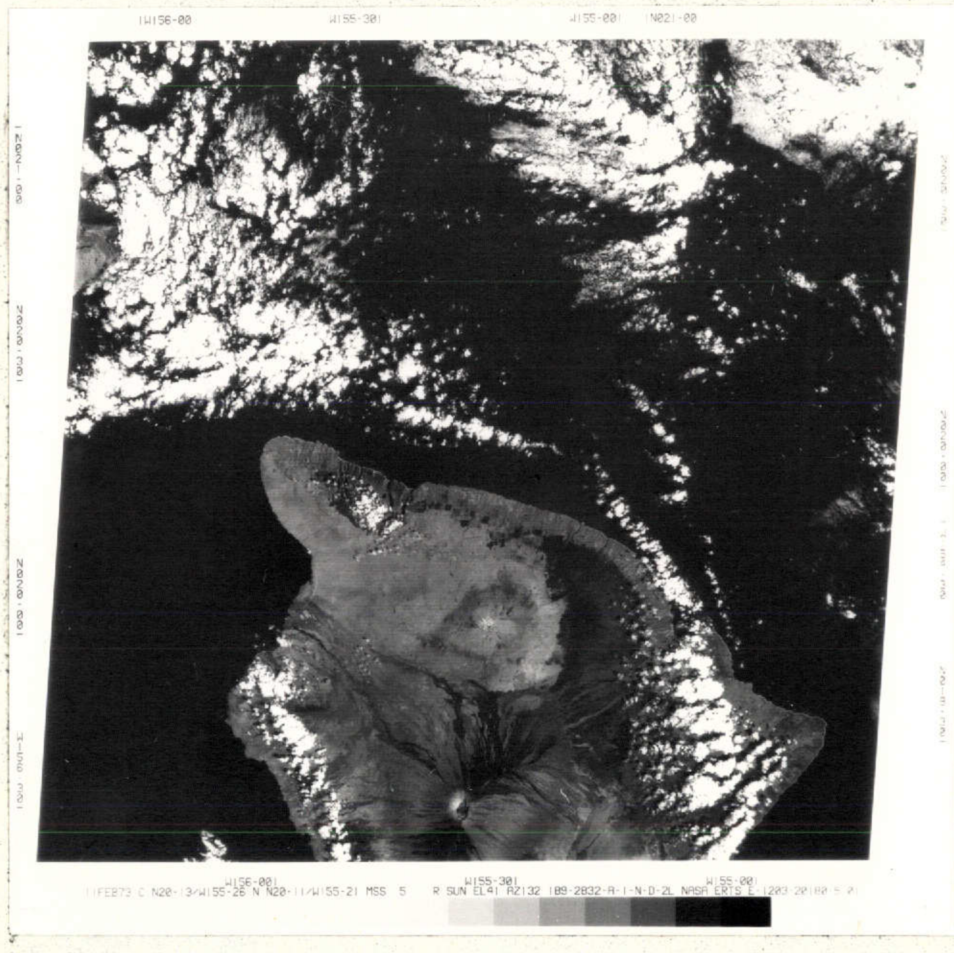

Figure 7. Island of Hawaii in the Hawaiian Islands imaged on February 11, 1973. Volcanic flows are discernible on channel 5 (red, 0.5 to 0.6 μm). The native hardwood vegetation (mostly <u>Ohia</u>) which grows between cultivated sugar cane fields along the eastern coast and the more northern volcano (Mauna Kea) are also identifiable. Dying ohia appears as a darker area on color composite of bands 5 and 7. (ID 1203-20180)

Band 4 (green, 0.5 to 0.7 μm) does not seem to furnish additional information and could be left out of the combined image. Band 6 (far red, 0.7 to 0.8 μm) does not identify water bodies and streams as strongly as band 7, but it often enhances changes in tree vigor more accurately than band 7.

2. For single-band analysis, band 5 enhances vegetation more than any other band. Band 7 enhances water bodies, rivers, and streams best.

3. All four bands are currently being used in developing computer signatures of forest land use types.

4. Forest vegetation shows up best in spring, fall, and winter in temperate zones on band 5. In semiarid areas summer imagery has greater contrast than winter imagery if major rainfall occurs in winter.

Band 7 can reduce contrast between snow on the ground and trees. The very high reflectance from snow obscures color differences in vegetation caused by stress. Band 5 is also useful for identifying snow boundaries. The high infrared reflectance in bands 6 and 7 and uniformly low red reflectance in band 5 makes it difficult to separate forest from other vegetation (except agricultural fields). Therefore, ERTS imagery is less useful in summer than at other seasons in temperate zones where rain falls throughout the growing season.

5. Forest/nonforest type separations can be made when forests are young to mature but are difficult to make when forests are in a transitional state--such as from brushlands, newly planted stands, or partially cutover stands.

6. Long, straight objects more than 100 m wide that infringe on forest land can usually be detected. These include power lines, wide roads or freeways (Figure 6), and clearcutting in long strips.

7. Land use changes, when fairly extensive, can be detected on ERTS imagery. On the Atlanta test site, our researchers are measuring changes showing up on ERTS images and comparing them with aerial photography. The minimum size of change and whether the change affects forested areas will be determined. Current imagery must be compared with an earlier generation of aerial photographs or ERTS. Changes which may be detected include: new power lines, roads, urban encroachment, and large clearcut areas.

8. Computer analysis and plotting of ERTS electronic signals from CCT's is a technique which is improving and developing a wider base of information. Because computer techniques have grown tremendously in accuracy and sophistication, it is likely that within two years we will be able to compute crude area estimates of forest land with 80 percent accuracy. From the maps, subsamples can be drawn by using multistage sampling methods developed by

Langley (1969) and others. This procedure has not yet been tried at the Atlanta test site, but it is included in our plans.

DISCUSSION

Now how do these ERTS promises and problems relate to the work of practicing foresters? One problem Doyle (1972), former president of the American Society of Photogrammetry, has identified is that remote sensing specialists have been guilty of the "gee whiz" syndrome. We have tended to look at places which we know a great deal about and say, for example, "We know this is coniferous timber on the ground, it looks like conifers on aerial photos, and sure enough it is coniferous timber on satellite imagery." Of course, we must use ground truth to develop training sets for our interpreters and computers, but we must also be objective and see if our analytical methods hold true for unknown and previously unchecked areas. It is only after we have obtained statistics on accuracy levels, variances, and estimates of error that we can confidently use satellite imagery for practical application.

Finally, let me try to identify, in my opinion, the usefulness of ERTS imagery for countries such as Germany, France, England, and others that practice intensive forestry. Then, I will review the possible application of ERTS imagery for such countries as Canada, United States, Australia, and others that practice more extensive forestry.

Intensive Forest Management

Where intensive forest management is practiced, the manager knows a great deal about his property and condition of the timber. Most areas have been planted, are generally small in size, and are well documented on maps and in management plans. Nevertheless, the forest manager would benefit by having one good ERTS image of his property for planning purposes. It would provide him with a broad synoptic view, showing him his entire forest holdings in one maplike view.

Because many forest stands in intensively managed areas are small (less than 20 ha), it is unlikely that ERTS imagery could be useful to estimate timber volume or species. Furthermore, most stands are already mapped and well documented.

Forest hydrologists and recreationists might benefit from ERTS images by being able to plot snow coverage accurately. When snow coverage is associated with depth and water content of snow, hydrologists can predict runoff accurately. For example, Haefner (1973) has plotted snow cover in the Swiss Alps very accurately on band 5.

Insect and disease infestations are usually detected on the ground before catastrophic losses occur in intensively managed areas. Consequently, ERTS imagery would be of little benefit in such applications.

On small private timber holdings in the United States (less than 2,000 ha), conventional aerial photographs will continue to be of more benefit than ERTS images.

Extensive Forest Management

No resource agency in the United States is now ready to base management planning on information derived from ERTS. The details of how to use ERTS data to develop management plans, determine timber stands to cut, protect, thin, or plant are not yet available to forest managers. The acquisition and use of ERTS data are still experimental, and the practicality of interfacing satellite data into management plans must be proved before such data can be used. This combination may take some time.

The U. S. Forest Service's nationwide Forest Survey may benefit from the application of ERTS imagery because of recent developments in land use classification by computer signature analysis. It may be possible to use computer-located and computer-sized forest stands as the basis to select stands for sampling with air photography and on the ground (multistage probability sampling). This has not yet been tried to compare with existing methods on a Forest Survey Unit; accuracy levels from interpretation of ERTS data must be determined first, and costs must favor use of ERTS data over existing methods.

According to Robert C. Aldrich, member of our remote sensing research staff, land use changes in forested areas may be detected on ERTS imagery and provide an updating of Forest Survey data. He is studying ERTS imagery over seven Georgia counties and comparing changes with older aerial photography. Again, this effort is experimental and not ready for immediate use.

To date, we have had only one year's experience in using ERTS data at the Pacific Southwest Forest and Range Experiment Station. At least six months of the year have been spent in developing techniques to use the data most effectively. Other foresters, such as Donald Lauer at the University of California, Leo Sayn-Wittgenstein and others at the Forest Management Institute in Canada, may have other conclusions to draw. On the basis of our experience, I would conclude that the promises--and benefits--of ERTS-1 outweigh the problems that have become evident. And future satellite systems will be greatly improved because of what scientists have learned from working with ERTS.

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