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NATURAL RESOURCE INFORMATION SYSTEM

REMOTE SENSING STUDIES

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by

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The studies described in this report were performed in support of the development of a computer-based Resource Information System under BIA contract no. K51C14200459. The effort was funded by NASA, EROS, and the BIA. Imagery was supplied by NASA. Base maps for the land-use studies were furnished by the Arizona State Highway Department.

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1.0 INTRODUCTION

A major design objective of the Natural Resources Information System entailed the use of remote sensing data as an input to the system. Potential applications of remote sensing data were therefore reviewed and available imagery interpreted to provide input to a demonstration data base.

A literature review was conducted to determine the types and qualities of imagery required to satisfy identified data needs. Ektachrome imagery available over the demonstration areas was reviewed to establish the feasibility of interpreting cultural features, range condition, and timber type. Using the same imagery, a land use map was prepared for the demonstration area. Finally, the feasibility of identifying commercial timber areas using a density slicing technique was tested on multispectral (simulated ERTS) imagery available for a portion of the demonstration area. Details on each of these efforts are provided in the following sections.

2.0 LITERATURE REVIEW

Remote sensing has become a powerful data collection tool for the land manager. As word of its success spreads, so does the number of land managers interested in using remote sensing increase.

Faced with a particular data requirement and the belief or knowledge that it can be satisfied using remote sensing, an obvious first question is the type and quality of remote sensing that is needed. There is no simple direct way to calculate an answer to this question. The manager with sufficient background and experience can normally answer this question; the manager with little or no experience may be forced to rely on oft-quoted rules of thumb or other approximate methods.

The cost-conscious manager will recognize that obtaining data of a quality higher than required is wasteful. Covering a 50 by 100 mile area with 1/40,000 scale stereo photos (9 x 9 inch) requires only 1196 frames, 1/20,000 scale coverage would require 4590 frames. Clearly, there are strong advantages in obtaining only the minimum quality imagery needed to satisfy requirements. How can this level be established?

Probably the optimum method is testing. Imagery covering a likely range of scales and types is obtained, the data extraction task is attempted for each different imagery condition, and results are statistically evaluated. If the imagery must be flown, the process may be rather expensive. On a large scale project, however, the expense may well be justified.

An alternative to the acquisition of new imagery is the use of imagery already available at national, regional, and state data bases. If the planned image acquisition program is to be performed under contract, the contractor may already have sufficient imagery available to conduct the required testing.

A second method which can be used to establish , at least on a preliminary basis, the type and quality of imagery needed for a specific job entails review of the many studies which have been performed on remote sensing applications. Unfortunately, the number of studies which have been performed is considerable and many worthwhile studies are not readily available to the land manager. To partially alleviate this problem, a literature review was performed; the results of that review are presented in this paper. The intent of the review was to collect and record the results of those studies which provided data useful in specifying remote sensing requirements for land management applications.

2.1 Method

A total of 179 studies were reviewed. Of these, 89 proved to have sufficient quantitative data to allow conclusions to be drawn regarding the success or failure of a given task at a given level of image quality.

Many of the studies reviewed discussed quality only in terms of photo scale. With advances in emulsions and lens quality, photo scale is a relatively meaningless indicator of image quality. Films used for aerial photography range in low contrast resolution from 25 to 50 line pairs per millimeter or better. All other things being equal then, a 2 to 1 quality difference might be found between two photos taken on different films. A similar order of difference may be found with camera lenses. As a general rule, smaller format (35-70 mm) lenses show higher resolutions than large format (9 x 9 inch) lenses.

A loss in image quality occurs each time a reproduction step takes place. Photo reproduction materials show about a 10:1 range of resolutions. Paper is a particularly limiting medium. No matter what the resolution of the original, a paper print or enlargement is unlikely to show much more than 10-15 l/mm resolution. Enlargement, because of loss through the enlarger lenses, is generally more deleterious than contact printing. As a rough guide a 15-20% loss may be anticipated in enlargement as opposed to 5-10% in contact printing. Far greater losses can occur with sloppy darkroom practices.

A 2:1 resolution difference between photos of the same scale is not uncommon and the practical significance of this difference is considerable. In order to replicate the results of a particular study, photos of anywhere from one half to twice the reported scale may be required. This, in turn, may nearly halve or double the cost of a particular project.

In an attempt to alleviate this problem, data in this report have been presented, whenever possible, in terms of ground resolution.

Ground resolution is defined as the width, on the ground of the smallest line pair (bar and space) which can just be resolved on the image. Medium or high contrast tri-bar targets (Figure 2.1) are sometimes arrayed on the ground and photographed to establish the ground resolution of a photo or imaging system.

Where ground targets are not available, ground resolution may be roughly calculated if the resolution of the imaging system is known. The formula:

$$GR = SF/304.8 \times R$$

is used where GR = ground resolution in ft., SF = the scale factor of the image, and R = systems resolution in line pairs/mm. This calculation assumes that the resolution of a system is constant; it is not. The resolution of a particular camera/film combination will vary depending on atmospheric conditions, platform motion, and processing effects. Generally speaking, however, this variation

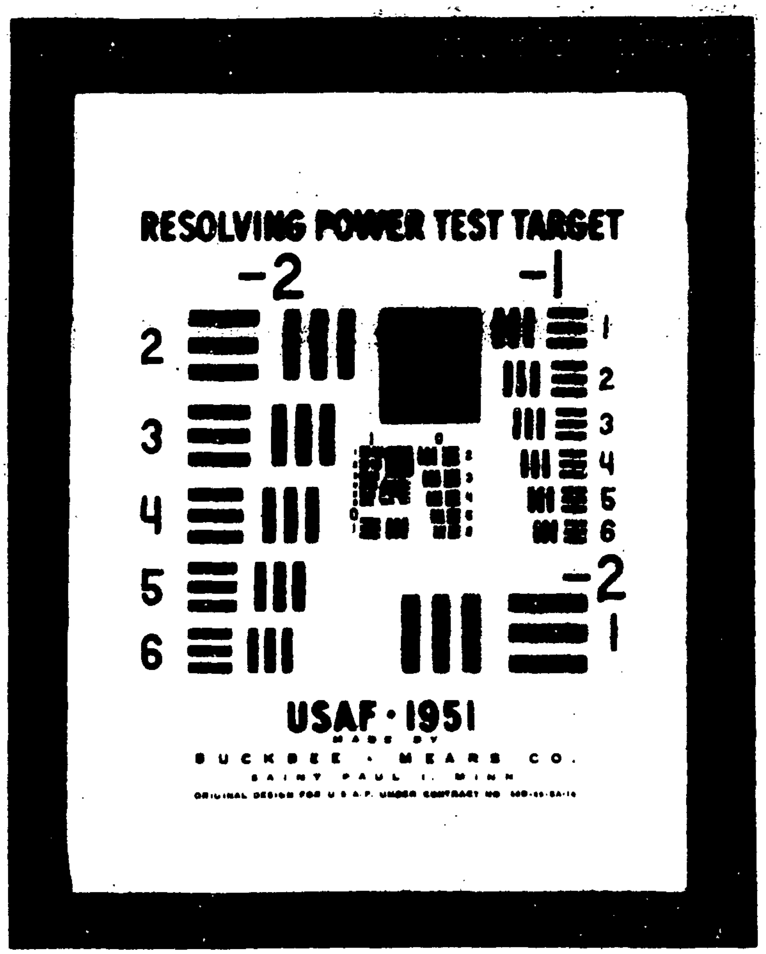

Figure 2.1 Standard Tri-Bar Resolution Target.

is less than $\pm 25\%$ and a useful approximation of original negative ground resolution can be obtained with knowledge only of systems resolution.

If the processing steps used to produce the final viewed material are know, a rough approximation of the ground resolution of the final copy can be made.

Similarly, if system resolution is known and a particular ground resolution is desired, flying height can be calculated by:

$$H = 304.8 \times R \times F \times GR$$

where
- H = flying height in feet
- R = Systems resolution in line pairs/mm
- F = camera focal length in feet
- GR = desired ground resolution in feet

If the number and types of processing steps are known, R can be adjusted downward accordingly using the rules of thumb previously expressed.

Unfortunately, as was noted previously, many of the studies reviewed reported neither ground nor systems resolution. In 82 of the 89 studies reported on here, only scale and a description of the imagery were provided. Fortunately, camera/film combinations of a given type provide roughly predictable resolutions and each photo processing step incurs a roughly predictable resolution loss. In general, the camera lens and atmosphere prove to be the major limiting factors in systems resolution and lenses of a given format tend not to differ in resolution by any great amount.

For those studies where resolution values were not directly provided, then, ground resolution values were estimated using the rules of thumb shown in Table 2.1. The values shown in Table 2.1 are not intended to be absolute; they were derived on the basis of past experience and have been used here only as rough indicators.

It should be emphasized that ground resolution does not define the ground size of objects which can be detected, recognized or identified. By definition, a ground resolution value is twice the width of just resolvable alternating black and white bars of 5:1 aspect ratio and a specific contrast. Very few interpretation tasks require this specific type of discrimination on analogous targets. For this reason no attempt should be made to directly extrapolate results to tasks or targets not specifically covered in the reviewed report.

2.2 Results

The data derived from the literature review are presented briefly in the following paragraphs. A more detailed presentation is provided in the appendix. It should be emphasized that the image quality values presented are not hard and fast requirements but simply represent the results of previous studies performed. It should also be pointed out that very few of the studies reviewed treated data statistically. For the most part, results were expressed as the judgement of the experimenter and simply

TABLE 2.1

RESOLUTION ESTIMATION VALUES

Format	Generation	Resolution (l.p./mm)
9 x 9	ON (1st)	25
	DP (2nd)	20
	Print (2nd)	12
70 mm	ON (1st)	35
	DP (2nd)	30
	Print (2nd)	15

indicated whether or not he had been able to perform a task using imagery of a specified type. For this reason, results should be treated with considerable caution; the reader with a specific remote sensing application in mind is urged to acquire and review the original reference wherever possible.

2.2.1 Range and Soils

A total of 19 studies involving range management and soils applications were reviewed. Table 2.2 summarizes the conclusions reached from these studies.

At ground resolutions of 0.5 ft. or less, range inventory, cattle inventory, detailed soils mapping, and inventory of range improvements can be accomplished. As ground resolutions decrease to 3 or 4 ft., the same tasks can be accomplished with less accuracy or greater reliance on optimum conditions; e.g., obtaining photos when IR reflectance differences are at a maximum. As resolution becomes poorer than 4 ft., reliability of vegetation and soils inventory decreases further and broader mapping units must be utilized. Animal and range improvement inventories are generally unsuccessful at these lower levels of resolution.

Two potential means of decreasing resolution requirements are the use of IR scanners for animal inventory and the use of sequential coverage for vegetation analysis. Both techniques have shown potential utility but sufficient results are not available to make specific resolution recommendations.

For vegetation and soils mapping, there is some tendency to favor the use of color or color/IR film. The use of these films provides effectively greater transfer of information (more contrast at a given scale or altitude). With the exception of vegetation vigor or disease, there is no indication that the color emulsions provide unique information not obtained from black and white emulsions.

2.2.2 Water Resources

In the area of water resources and hydrology there are a great number of applications of remote sensing that have been tested. These include studying drainage patterns where detailed map coverage is lacking; taking a census of water resource features, both natural and man-made such as springs, wells, ponds, detentions, diversions, canals; studying water quality in terms of industrial, mining or agricultural pollutants; and regional geomorphic analysis in order to understand the ground and surface water regimes.
A total of 22 studies covering hydrology applications were reviewed. Results are summarized in Table 2.3.

Because of the fact that water has a strikingly different thermal behavior than soil, vegetation and other earth materials, there is great potential for studying water bodies by means of their thermal infrared radiation. Night time thermal IR scanning

TABLE 2.2

RANGE AND SOIL

Task	Ground Resolution	Capability
Vegetation Analysis	< 1'	Species identification, range Condition inventory
	1'- 4'	Some species, vegetation type/ soil boundaries, inventory sampling
	5'- 20'	Vegetative associations at intermediate level of detail
	> 21'	Some vegetative associations but often requiring supplementary data and/or optimum conditions
Animal Inventory	< 1'	Successful with cattle if no cover and sufficient background contrast
	1'- 4'	Marginally successful with cattle under optimum conditions
Range Improvements	< 1'	Fencelines, roads, water control structures
	1'- 4'	Roads, some control structures, fencelines if they produce vegetation contrast changes
	5'- 20'	Generally unreliable
	> 21'	Same as 5'- 20'
Soil Mapping	< 1'	Soil Series
	1'- 4'	Soil type with some reliance on slope and vegetation
	5'- 20'	Broad soil type
	> 21'	Very broad type mapping, only partially successful

at 1:62,000 scale reveals standing water as hot spots and springs and water courses as cold spots (ref. 65). Thermal IR scanning also has applications in determining if a stream is gaining volume from groundwater inflow (ref. 35,88). Using conventional photography, detection of features such as springs and small water bodies would require a ground resolution on the order of 1 ft. (ref. 47,58).

For the study of the regional hydrology to predict spring locations, potential groundwater availability, planning of ditches and culverts for road building, color or color IR emulsions and a ground resolution of 5 to 7 feet are considered optimum (ref. 72). Any greater ground resolution does not markedly improve ability to interpret the hydrologic regimes and geomorphology (ref. 47, 7, 5, 38,18).

SLAR imagery also seems to have potential in mapping of drainage patterns. At 1:200,000 it can produce a drainage map as good as a 1:62,500 USGS topographic map and , in fact, with some interpretive work, it can serve as well as the 1:24,000 topographic map (ref. 46). At photo resolutions from 50 to 100 ft., the location of major diversion structures, canals, and major streams can be determined. Major pollution and sedimentation problems can be discovered in large streams and lakes at 100 ft. resolution, although locating the outfall accurately may require on the order of 10 ft. ground resolutions (ref. 87). For pollution and sedimentation studies, color or color IR is considered much more effective than panchromatic or black and white IR.

One further kind of hydrologic study that could be of value in arid regions such as southeast Arizona is repeated coverage of play lakes. These lakes could serve as a good indicator of the regional water budget over a time. At resolution of 100 ft., one can determine gross changes in water depth and at 4 to 8 ft., soil moisture, salt ridges, dessication cracks, and windblowing sand can all be studied. These should all provide an estimate of moisture conditions in the basin as a whole.

TABLE 2.3

HYDROLOGY

Ground Resolution	Capability
< 1'	Detection of hydrologic application; springs, wells, windmills
1'- 4'	Detection of water control facilities; ditches, canals, diversions
5'- 20'	Interpretation of regional ground and surface hydrology mapping of drainage net
> 21'	Prediction of potential ground water and availability, gross level pollution detection

2.2.3 Forestry

Forestry has a long tradition of applications of remote sensing. The uses of remote sensing in forestry run the gamut from the gross typing of vegetative cover, to precise measurement of individual tree and stand timber volume, to the specialized task of detecting and estimating the damage from many kinds of stresses (disease, infestation, lack of moisture). Table 2.4 summarizes results.

For interpreting broad vegetative types or associations for the purpose of making a general resource inventory, it seems certain that imagery of 10 ft. ground resolution (of almost any film type) is appropriate, and 70 to 90% accuracy of interpretation is often reported (ref. 54,45,40,44).

In almost all studies that compared film emulsions for vegetative cover type identification, color infrared films were found superior to all others either by virtue of interpreter accuracy, speed or both. The most effective tool for identifying major cover types has been found to be color infrared imagery taken in two seasons. This technique has been found successful in detecting and identifying Monterey pine, eucalyptus, mixed hardwood, chaparral and grassland at a ground resolution of 60 ft. Even at 200 ft. ground resolution it could distinguish grassland from the others and occasionally detect the other four types. In fact, color infrared at 200 ft. resolution in two-season coverage is as effective as color infrared at 60 ft. resolution, if one is using only a single season (ref. 45).

In the area of mensuration, work has to be done on the determination of tree height and volume as well as species identification. The successful work that has been done has been in the range of 0.1 to 0.2 ft. ground resolution (ref. 1, 43).

The literature does not point to a cut-off value, beyond which accurate measurement is impossible but at resolutions as good as two ft., the details of crown configuration may be lost, making species identification very risky, and without species identification, volume measurements are considered as suspect (ref.54). However, where there is ground truth known on the species composition and statistical studies have been done on the relationship and correlation of timber volume with a variable based on crown diameter and crown closure for the area in question, good results can be obtained at a resolution of 3 ft. (ref. 48,21).

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In the area of disease, infestations, and mortality sensing, there has been a great deal of experimentation. As in other aspects of forestry, remote sensing color infrared film is generally found to be the most effective sensor, followed by color film and then panchromatic emulsions. The poorest ground resolution that is attributed with any success in this area is about 2 to 4 ft., which is considered sufficient for detection of Ponderosa pine stressed by bark beetles in stands of more than ten trees (ref. 34). In the range of 1 to 2 ft. resolution, some of the accomplishments of remote sensing of mortality from Douglas fir bark beetle, southern pine beetle, size of infestation of balsam woolly aphid, and tussock moth, dwarf mistletoe, Dutch elm disease, red oak wilt (94,30,49, 82,34, 3,81). In some cases, volume of timber lost over a period of years was accurately determined on the basis of tree height and crown density, although most of these determinations are best carried out at ground resolutions of the order of 0.2 ft. (ref. 83,84,77,33).

One general study indicated that 1.6 to 1.3 ft. for large trees and 1.3 to 1.0 ft. for smaller trees was sufficient ground resolution for infestation and disease control and salvage management program (ref. 42).

TABLE 2.4

FORESTRY

Ground Resolution	Capability
< 1'	Precise measurement of volumes and census of diseases and infestations and the volume of timber lost because of disease and infestation, census of trees by species
1'- 4'	Census of trees by species in some cases, stress detection on a gross scale, volume estimates (provided considerable ground truth and correlation studies have been done)
5'- 20'	Gross vegetative cover types can be mapped accurately at resolutions of ten feet or better
> 21'	Gross vegetative cover types if multi-season imagery is available

3.0 PRELIMINARY INTERPRETATION STUDIES

Prior to utilizing the available high altitude Ektachrome imagery as a source of data for a demonstration of the natural resources data base, three preliminary studies were performed to establish information content. The first investigated the utility of the photos for range vegetation analysis, the second evaluated accuracy of cultural feature delineation, the third tested accuracy of timber mapping.

3.1 Range Vegetation Study

In the range study, the ability to predict vegetation species and condition (forage factor) using geologic, topographic and image tone and texture data was tested. Several one-square-mile areas on the photos (1/117,000 scale Ektachrome, 30 ft. ground resolution, NASA MSN 155) are delineated on the basis of hue and texture. Three hues (tan, gray, green) and three texture categories (even, speckled, mottled) were used. A total of 45 areas were delineated. For each delineated area, rock type, elevation (500 ft. increments) and land form was recorded. The extent to which these six pieces of information could be used to predict species and forage factor was then tested. A range survey map which delineated vegetation (3 predominant species), and provided forage factor for each delineated area, served as ground truth. The map was last revised in 1955, the imagery was acquired in 1971. For this reason, prediction errors were presumably partly the result of the prediction technique and partly the result of changes occuring over the 16-year period between map compilation and imagery acquisition.

Results indicated 68% accuracy in predicting two of three species in a delineated area. This level of accuracy was significantly better than chance (x^2, $p < .02$). For forage factor prediction, results showed 38% success in predicting to an accuracy of $\pm$ .02 and 68% accuracy in predicting to a level of $\pm$ .05. In the area listed, forage factors ranged from .01 to .26. Accuracy at the $\pm$ 0.5 level was better than chance (x^2, $p < .02$), and the $\pm$ 0.2 level it was not.

Since the criterion data was out of date, no firm conclusion could be drawn regarding the success of the method. Results appeared sufficiently promising, however, to warrant further work with more accurate ground truth data.

3.2 Cultural Features Study

This study investigated the accuracy with which roads, fencelines, buildings and waterholding structures could be delineated on 1/117,000 scale Ektachrome transparencies. The study area was in central Cochise County, Arizona.

All roads, fencelines, buildings and waterholding facilities were delineated on two 3 x 3 mile areas covered by the high altitude color imagery. Each delineated road was also classified as paved, unpaved heavy use, or unpaved light use.

Accuracy of results was determined by comparison with two Ektachrome IR photos taken over the same areas. Scale of these photos was 1/22,000, ground resulution was 5 ft. (as compared to 20 ft. for the high altitude color). Results are summarized in Table 3.1. With the exception of paved roads, results indicated that accurate mapping of the features tested was not feasible.

TABLE 3.1

RESULTS OF CULTURAL FEATURES STUDY

Task	% Accuracy Area A	Area B
Detection of:		
Paved roads	No Data	100%
Unpaved roads	64%	66%
Fencelines	69%	No Data
Buildings	58%	25%
Water structures	66%	83%
Road Classification:		
Paved	No Data	100%
Unpaved, heavy use	100%	78%
Unpaved, light use	37%	54%

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3.3 Timber Mapping

The timber mapping study investigated the accuracy with which commercial timber could be identified on 1/117,000 scale Ektachrome transparencies. A four-township area in the northwest corner of the Fort Apache Indian Reservation was used for the study. Timber type maps prepared in 1969 at a scale of 1/24,000 were used as ground truth.

In each of the four townships, 20 sample areas were selected. Selection was essentially random but was somewhat biased by the need to use areas which could be located on the type map.

The imagery was given to an interpreter and he was asked to identify each sample area as containing grass, juniper/chaparral, or commercial timber (Ponderosa pine). Imagery was viewed using a B & L Zoom 70 at 7x magnification. Results are summarized in Table 3.2. The relatively low accuracy in identifying commercial timber areas apparently resulted primarily from a tendency to erroneously classify younr (11.0 - 16.9 in. d.b.h.), pole and seedling areas as non-commercial. Accuracy on commercial timber areas having an overstory formed predominantly of stems greater than 17.0 in. d.b.h. was 89%.

TABLE 3.2

TIMBER STUDY RESULTS

Category	No. of Areas	% Correct
Grass	16	94%
Juniper/Chaparral	31	74%
Commercial Timber	33	51%
TOTAL	80	69%

4.0 LAND USE MAPPING

A land use map was prepared for a 9,600 square mile area in S.E. Arizona (Figure 4.1). A 23-category land use classification system was employed. High altitude Ektachrome imagery, supplemented by available maps, was used as source material.

4.1 Classification System

The classification system used for delineating land use categories was a modification of the system originally proposed by Dr. Anderson (Ref.90). For several months, this system has been undergoing review and modification by persons and agencies involved in the EROS program; the final classification scheme is proposed for use in the EROS program.

Dr. Anderson's classification is shown in Table 4.1. After reviewing this system in conjunction with the imagery available for mapping and the objectives of the mapping system, a revised classification was developed. Table 4.2 summarizes the revised system, modifications to the original Anderson system being marked with an asterisk. The working definitions for each of these categories was as follows:

I. Resource production and extraction

A. Agricultural

1) Crop production (cropland) - All areas where crops are planted and harvested by man except: orchards, groves, vineyards, cropland used only for pasture, and cropland not planted and harvested.

a) Cropland irrigated through canals, tubewells, springs, or direct stream flow.

b) Non-irrigated crop production

2) Fruit and nut culture (orchards, groves, vineyards)

a) Irrigated fruit and nut culture

b) Non-irrigated fruit and nut culture

B. Grazing (grassland and shrubland) - Land suitable for grazing of wildlife and livestock including sheep and goats, having a cover of less than 25% tree canopy except for large desert shrubs such as mesquite, creosote bush or acacia sp. The vegetation may consist of native or introduced grasses, legumes, shrubs, or brush and covers at least 1% of the ground area.

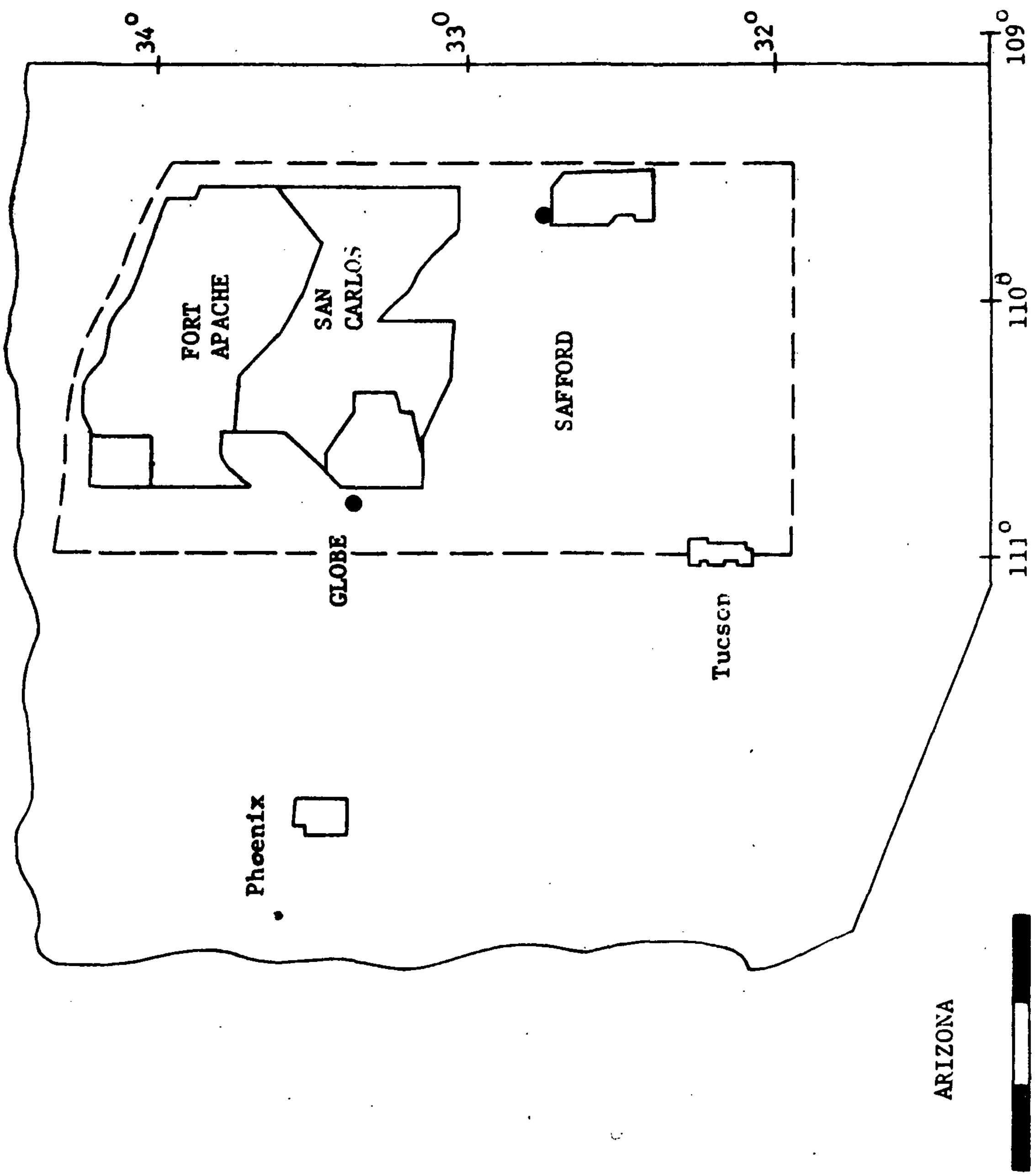

Figure 4.1 APPROXIMATE BOUNDARIES OF LAND USE MAPPING AREA

TABLE 4.1

ANDERSON LAND USE CLASSIFICATION SYSTEM

LEVEL 1	LEVEL 2	LEVEL 3
I. Resource Production & Extraction	A. Agricultural	1. Crop Production a. Irrigated b. Non-irrigated 2. Fruit/Nut Culture a. Irrigated b. Non-irrigated
	B. Grazing	1. Rangeland (Grazing) 2. Livestock Pasture
	C. Forestry	1. Non-commercial Tree Raising 2. Lumbering & Pulping
	D. Mining & Quarrying	
II. Transportation, Communication & Utilities	A. Motoring (Highways) B. Railroading (Railroads) C. Flying (Airports) D. Communications & Utilities	
III. Urban Activities	A. Urbanized Livelihood Areas (1970 Census Bureau Definition) B. Other Urban (population > 2500 but not urbanized)	1. Industrial 2. Commercial 3. Residential 4. Other Livelihood
IV. Towns & Other Built-up Areas		
V. Recreational Activities	A. Mountain Oriented B. Water Oriented C. Desert Oriented	
VI. Low-Activity Areas	A. Marshland Oriented B. Tundra Oriented C. Barren Land Oriented	
VII. Water Using Activities		

TABLE 4.2

ANDERSON LAND USE CLASSIFICATION SYSTEM (MODIFIED)

LEVEL 1	LEVEL 2	LEVEL 3
I. Resource Production & Extraction	A. Agricultural	1. Crop Production a. Irrigated b. Non-irrigated 2. Fruit/Nut Culture a. Irrigated b. Non-irrigated
	B. Grazing*	
	C. Forestry	1. Non-commercial* 2. Commercial*
	D. Mining & Quarrying	
II. Transportation, Communication & Utilities	A. Roads B. Railroads C. Airports D. Communications & Utilities	
III. Urban Activities**	A. Urbanized Livelihood Areas (1970 Census Bureau Definition)	1. Industrial 2. Commercial 3. Residential 4. Institutional* 5. Other Urban Land
	B. Other Urban (Population > 2500 but not urbanized)	Same as III A*
IV. Towns & Other Built-up Areas **		Same as III A* plus 6. Residential Development
V. Recreation	A. Mountain Oriented B. Water Oriented C. Desert Oriented D. Other(Golfcourses, parks, etc.)*	
VI. Low-Activity Areas	A. Marshland Oriented B. Tundra Oriented C. Barren Land Oriented	
VII. Water Using Activities	A. Standing (Lakes, Oceans, etc.) B. Flowing (Rivers)	

* Indicates changes from the Anderson system.
** Mapping of urban and built-up areas do not go beyond Level 1.

C. Forestry

1) Non-commercial tree raising-areas having a tree canopy cover of more than 25% consisting of species that are not usually harvested for lumber or wood fiber products. These species include the arid woodland association of Pinyon pine/Juniper, and also riparian woody vegetation such as cottonwood. Such areas may be of value for watershed protection, grazing, wildlife habitat and recreation.

2) Commercial-lumbering and pulping

a) Areas having a tree canopy cover greater than 25% consisting primarily of species which are usually managed for perpetuation and harvested for lumber or wood fiber products. These species include Douglas fir, Ponderosa pine, White pine, and Sitka spruce. Burned, cut, and Aspen inclusions up to 160 acres may be included in delineation.

b) Areas greater than 160 acres formerly fitting the definition of (a) above which have been recently logged or burned, but which are apparently intended for regrowth of timber, including those areas currently supporting Aspen.

D. Mining and quarrying

The limited area adjacent to and including mining excavations, dumps, and tailings ponds where mining activity precludes any other use.

III. Urban activities

A. Urbanized livelihood areas

Areas of continous settlement having a population of greater than 10,000 and gaps not greater than 1 mile wide between its various segments.

1) Industrial (industrial lands)
2) Commercial (commercial lands)
3) Residential (residential lands) - Areas containing more than 20 houses and apartment buildings per 40 acre unit.
4) Areas larger than 40 acres containing buildings and facilities devoted to non-industrial or commercial services such as administration, imprisonment, health care, research, and education.
5) Other urban livelihood (other urban land) - Including areas of empty land surrounded by urban land.

B. Other urban livelihood (other urban land)

Areas of continuous settlement having a population of greater than 2500 but less than 10,000 and gaps not greater than 1 mile wide between its various segments.

1)2)3)4)5) Identical to subdivisions of III A.

IV. Towns and other built-up livelihood areas (town and built-up land)

Settled areas greater than 40 acres but having less than 2500 population.

A. Industrial, including mining related plants
B. Commercial
C. Residential
D. Institutional
E. Residential development site - Areas containing few houses, but with a dense pattern of roads laid out in a residential pattern.

V. Recreational Activities

Recreation facilities including playgrounds, golfcourses, boating and skiing facilities, campgrounds, gardens, etc.

A. Mountain oriented (skiing, parks and campgrounds in mountain areas)
B. Water oriented (boating facilities, parks on a lake)
C. Desert oriented (rockhound areas, archaelogical sites, etc.)
D. Other - including urban activities (facilities not requiring an association with mountain, water, or desert areas)

VI. Low Activity areas (other lands) (Excluding land of these types on which land-using activities are found)

A. Low-activity marshland oriented (marshland)
B. Low-activity tundra oriented (tundra)
C. Low-activity barren land oriented (barren land) - Including land where salinity, erosion, lack of soil, or shifting sand prevent the growth of vegetation.

VII. Water-using activities (water bodies)

A. Standing bodies larger than 40 acres delineated at the high water line
B. Flowing water - Streams shown as solid double lines on county highway maps (1/125,000 scale).

The rationale leading to modification of the original Anderson system was as follows:

Grazing - No reliable destinction could be made on the available imagery between rangeland and pasture. Further, in the area mapped it is a common practice to fence a small area of range (native vegetation) and call it a pasture; it is also a common practice to seed or otherwise modify rangeland.

Forestry - The subdivisions of the forestry category were changed to reflect BIA/BLM practice. The distinction between commercial and non-commercial was made on the basis of species considered merchantable in the area ofinterest. No attempt was made to remove non-operable areas from the commercial category.

Institutional - A category of institutional use was added to the urban activity classification. Large institutional facilities could be identified on the imagery used for mapping. In addition, in several instances institutional facilities occurred in isolation and appeared to warrant separation from the category "towns and other built-up areas".

Other Urban - The classification at Level 3 used for urbanized areas was extended to smaller built-up areas.

Residential Development - In suburban areas, it is common to find areas where a street pattern is laid out but no houses have been constructed. Evidence suggests that the area will ultimately be residential, but the possibility exists that development will be halted and the land will revert back to some other use. Further, the street pattern itself does not preclude other uses such as grazing. To allow for this possibility, the category"residential development"was created.

Other Recreation - This category was created to accommodate all those recreation facilities not associated or requiring an association with mountains, water, or desert. This would include such items as golf courses, urban parks and gardens, and campgrounds not in or adjacent to water, desert or mountains.

Water Using Activities - Because of the nature of the data storage system envisioned, water bodies were classified as standing or flowing. Standing water bodies were those which could be represented as areal features (polygons), flowing water bodies (streams and rivers) could be shown as linear features.

A 40-acre limit was imposed on the delineation process in order to reduce data storage requirements. To further reduce storage requirements and because of the basic interests of BIA and BLM, mapping of urban and built-up areas was not carried beyond Level 1.

4.2 Interpretation and Delineation

Mapping was primarily performed on Ektachrome positive transparencies at a scale of approximately 1/117,000. The imagery was obtained on NASA Mission 155 in January 1971. Taken with an RC-8 camera at 60,000 ft. altitude, the images were determined to have a ground resolution of 20 ft. One frame on this mission showed a tri-bar resolution target on the ground, the ground resolution value was obtained by reading this target.

Additional imagery was available for portions of the mapping area (Table 4.3) but was used only for checking interpretation accuracy.

Land use category delineation was performed on mylar overlays to the imagery. The imagery was displayed on a variable intensity light table. A 2x mirror stereoscope and a 3.5x to 60x stereo microscope were used for viewing.

Arizona State Highway maps at a scale of 1/126,720 were available for use as supplementary reference for most of the mapping area. They were also used as basic source material for the classification categories shown in Table 4.3. The remainder of land use categories were mapped from the imagery.

Three interpreters performed the initial imagery classification. One handled all the timber classification, a second handled the agriculture and rangeland classification, the remainder of the classification was performed by the third interpreter.

After completion of the initial image delineation, a radial line plotter was used to transfer delineations to base map overlays. The base map was prepared by gluing paper maps to a mylar grid. Arizona Highway Maps (1/126,720 scale) were used for approximately 75% of the area, enlargements of 1/250,000 scale USGS topographic maps were used for the remainder.

4.3 Results and Discussion

A total of 61 land use overlays were prepared. Figure 4.2 illustrates one of the overlays. Linear features were mapped separately from polygons since all overlays were to be digitized.

An additional set of overlays was also prepared to show administrative boundaries. Federal land ownership and city and town boundaries as shown on the base map were recorded.

Approximately two hours were required to delineate each of the 100 stereo models. An additional one-half to one hour was required to transfer each model overlay to the base map overlay.

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TABLE 4.3

CLASSIFICATION CATEGORIES EXTRACTED FROM BASE MAP

	LEVEL 1		LEVEL 2
II.	Transportation, Communication & Utilities	A.	Roads
		B.	Railroads
		D.	Utility Rights of Way
III.	Urban Activities	A.	Urbanized LIvelihood (map boundary)
VII.	Water-Using Activities	B.	Flowing (double line streams)

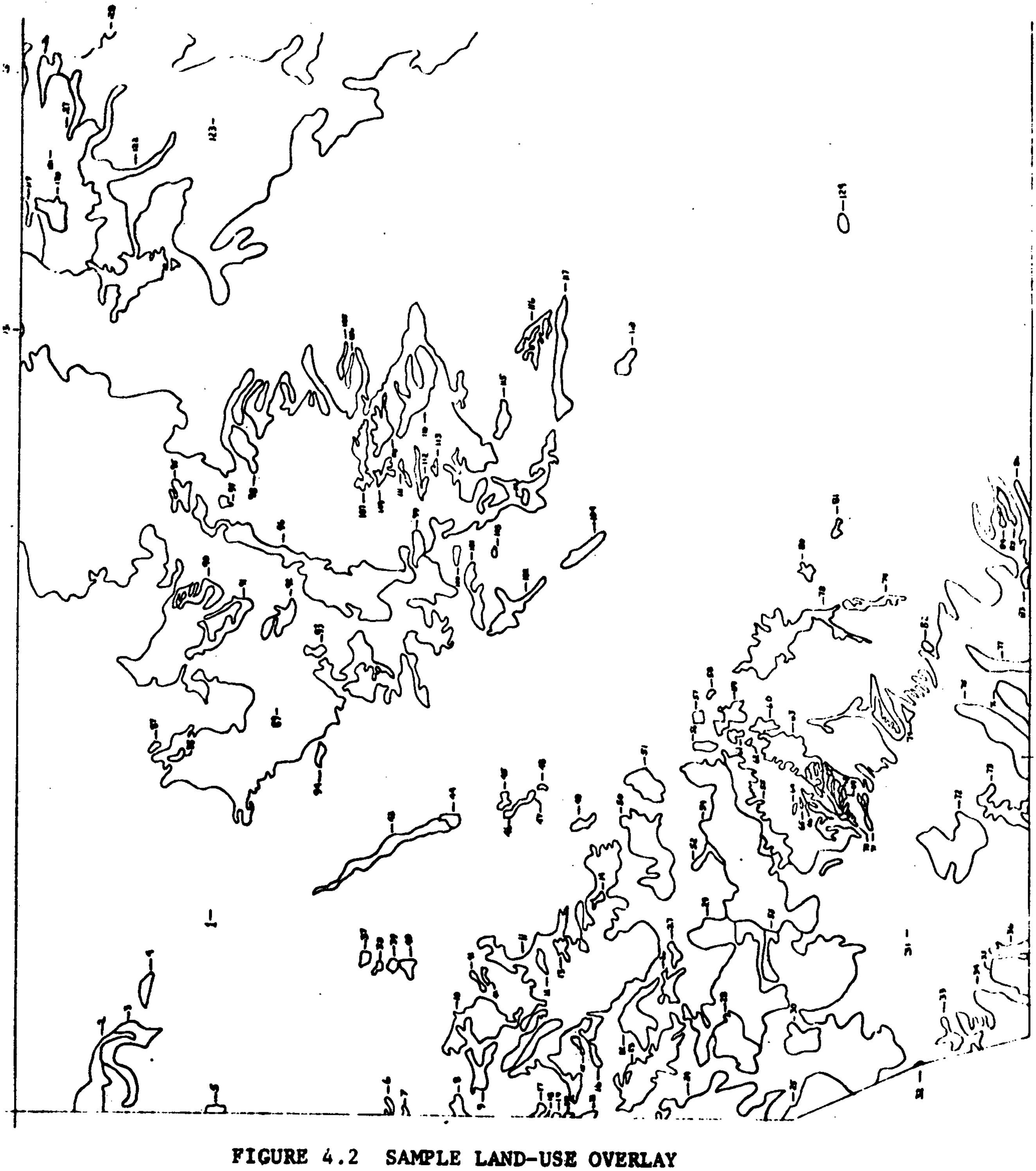

FIGURE 4.2 SAMPLE LAND-USE OVERLAY

Another one to two hours was consumed in preparing each map overlay for digitizing. This process included the numbering and recording of land use classification for all polygons. A total of 1904 polygons were required to cover the total areas.

The major problem encountered in the overall program was that of defining the land use mapping categories. The initial Anderson classification categories were not always interpretable on the imagery and the imagery contained features which did not seem to fit any of the classification categories.

Once this problem had been overcome, classification difficulties were encountered only in the area of timber classification. The distinction between commercial species and the juniper/chapparal association was difficult. Color was not a reliable indicator; texture was found to be more useful.

The scale at which overlays were prepared (1/117,000) led to some difficulties because of the small size of some delineations. A criterion of 40 acres had been selected as the smallest area to be delineated; a 40-acre square occupied about a 1/8 x 1/8 inch area on the photo.

Enlarging the photos would have alleviated the delineation problem, but would have compounded the photo processing and handling problem. At a scale of 1/60,000, four times as many overlays would be required.

Some difficulty was encountered because of cloud cover, holidays, and excessive tilt on a few frames. Areas of cloud cover and holidays were mapped as such; a few photos were delineated monoscopically because of the tilt problem.

It was concluded that 1/117,000 scale Ektachrome imagery was generally adequate to classify land use in accord with the revised Anderson land use system. The imagery was not adequate for delineation of some linear features such as roads and utility rights of way, at least on a 100% accuracy basis. Supplementary reference material was required for such features. Difficulties encountered in timber delineation might be alleviated by obtaining imagery at a different time of year.

5.0 TIMBER MAPPING STUDY

Using spectral reflectance as the basis for discrimination, it is possible to automatically prepare maps of discriminated categories and compute the area covered by each category. The equipment required to perform this operation consists of an image converter and a computer.

The converter is used to scan an image and convert it to a digital record of X-Y cell addresses and density values. The computer processes the data to establish those cells which fall within a pre-selected range of density values; those selected cells are then read out on the converter. A cell count is maintained and used to calculate the area falling within a given classification.

The key to the process is of course the existence and identification of discriminable density values associated with the categories of interest. Because of the difficulties previously discussed in classifying commercial timber areas on high altitude Ektachrome imagery, a study was conducted to establish whether density discrimination could be performed on multispectral (simulated ERTS) photos available over the study area.

5.1 Method

Spot density measurements were made on two sets of simulated ERTS images. Analyses were performed on the data to determine whether discrimination of grass, juniper/chaparral and commercial timber could be performed on the basis of image transmission values.

5.1.1 Imagery

Imagery utilized for the study was obtained on NASA Mission 155, flown in January of 1971. Imagery characteristics are shown in Table 5.1. Third generation enlarged negatives were used for measurement.

5.1.2 Study Area Description

The study area was located in S. E. Arizona on the northwest corner of the Fort Apache Indian Reservation (Figure 5.1). The area covered is Townships 8, 9, and 10 N; Ranges 16 and 17 E.

Elevation ranges from 5,000 ft. in the southern end of the area to 8,000 ft. in the northern end. Mean annual rainfall increases from 20 inches in the southern portion to 34 inches in the northern. A general transition in vegetation follows the increase in elevation with grass in the southern end of the area, large areas of pinyon, juniper and chaparral in the central

TABLE 5.1

IMAGERY CHARACTERISTICS

Film	Scale	Format	Ground Resolution
Plus-X, 25A filter (red)	1/508,000*	70 mm*	≈ 80'
Plus-X 58 filter (green)	1/508,000*	70 mm*	≈ 80'
IR, 89B filter (IR)	1/508,000*	70 mm*	≈ 80'

* For use in the study, these materials were enlarged to a scale of 1/117,000.

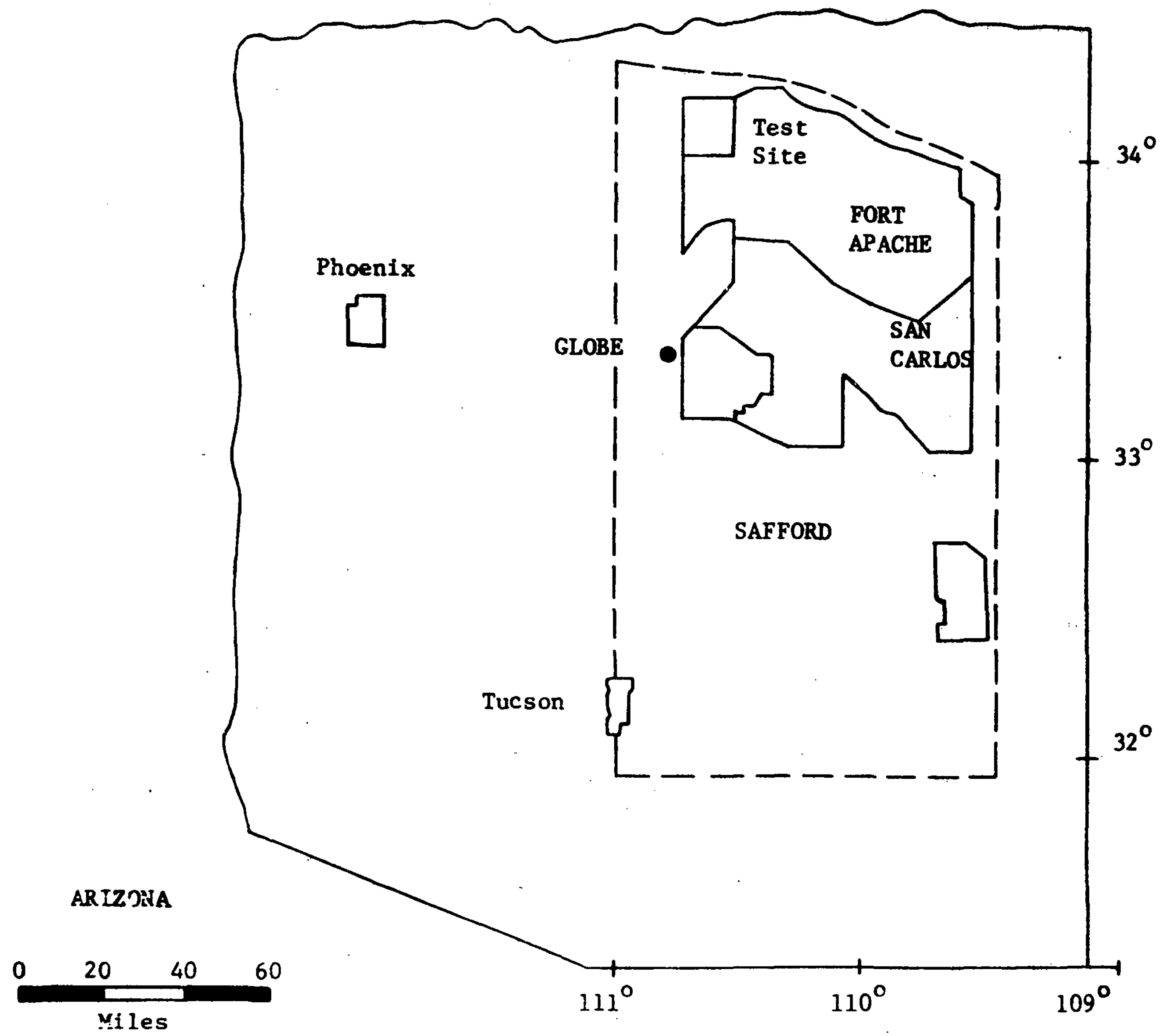

FIGURE 5.1 LOCATION OF TIMBER MAPPING TEST AREA

portion and predominantly Ponderosa pine in the northern portion. Stands of pine are interspersed throughout the entire area, however. Mixed conifer stands also occur throughout the area.

The most common site quality classification is 5; 75 to 99 ft. at maturity. Crown density of the merchantable timber is predominantly classed as 10-39%. Pole and seedling crown density is more often classed in the 40-69% range. Table 5.2 shows the characteristics of the sample points used for the study.

5.1.3 Sample Selection

A total of 120 sample areas were selected for measurement (Table 5.2). Twenty areas were picked from each of six type maps; each type map covered one township. Sample areas on each map were selected so as to obtain a distribution of areas in each of the major classification categories (grass, pinyon/juniper/chaparral, timber) roughly equivalent to the total area occupied by these categories on the map. An attempt was made to distribute the areas evenly over the map. However, it was necessary to select areas which could be usually located on the photos and as a result there was a tendency to select areas near type boundaries, stream intersections, and trail intersections.

One measurement was made within each sample area. The sample areas covered roughly 1/8 by 1/4 mile on the ground and 2 by 4 millimeters on the photos. An one millimeter aperature was used for all density measurements, placement of the aperature within the sample area was not done in any systematic fashion. This aperature covered a 380 ft. diameter ground area.

5.1.4 Ground Truth

Ground truth data were obtained from timber type maps prepared in 1969. The maps were at a scale of 2 inches per mile and provided information on species, size, site quality, and crown density. Figure 5.2 illustrates one of the maps utilized.

5.1.5 Measurements

All readings were made with a MacBeth Quantalog Macrodensitometer. One reading was made for each point on each multispectral photo using the "visual" filter. The instrument was calibrated before and after every 60 readings. A total of 360 density readings were obtained.

TABLE 5.2

SAMPLE DESCRIPTION

		No. of Sample Points Per Category		Timber	
Township	Range	Pinyon/Juniper/Chaparral	Grass	17.0 DBH*	17.0 DBH*
8N	17E	5	8	2	5
9N	17E	9	0	3	8
10N	17E	9	0	7	4
8N	16E	5	8	2	5
9N	16E	9	0	4	7
10N	16E	7	0	11	2
	TOTAL	44	16	29	31

* indicates predominant stem size in overstory.

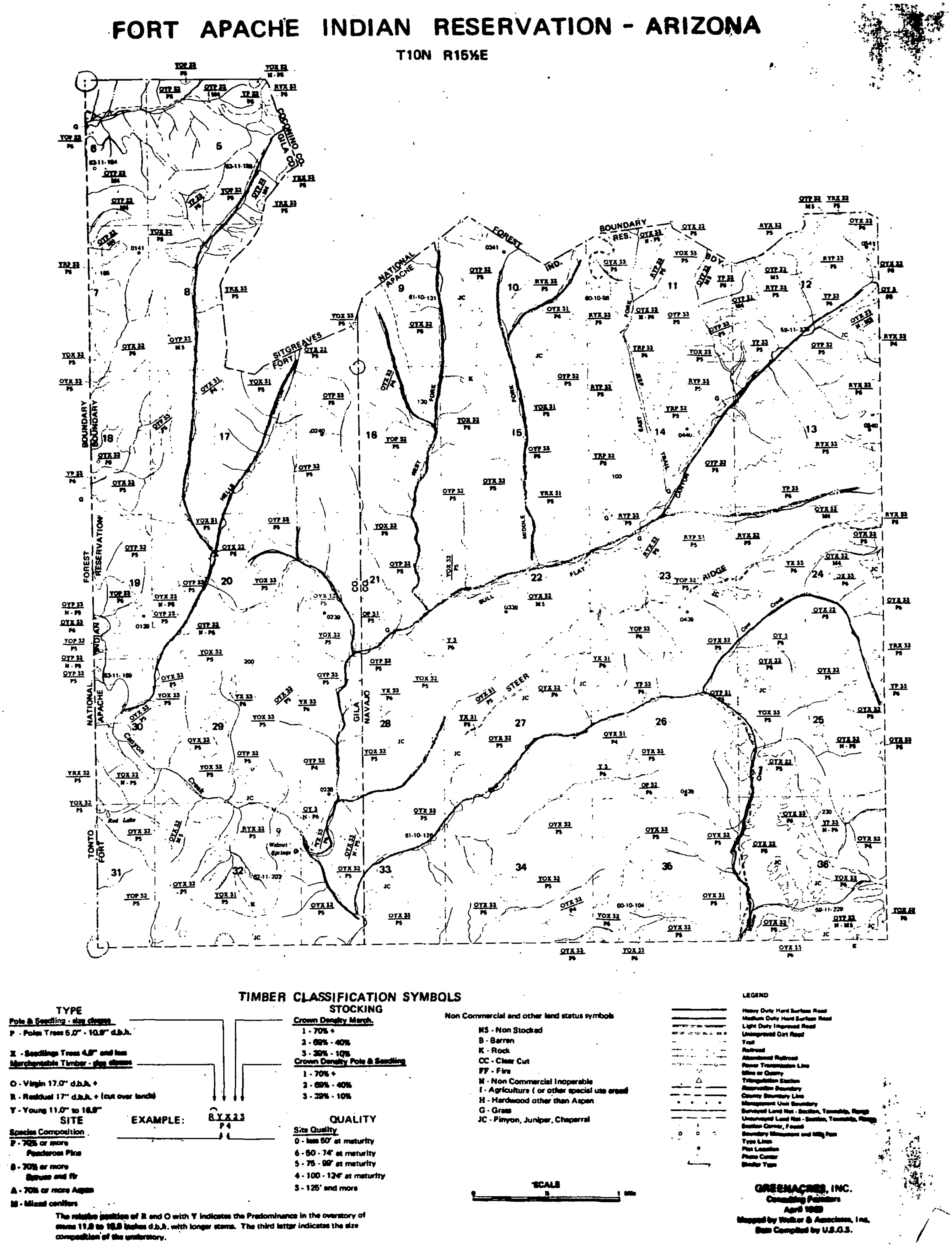

FIGURE 5.2 SAMPLE TIMBER TYPE MAP

5.2 Results

All density readings were converted to transmission values before analysis. Table 5.3 shows mean values and standard deviations for each spectral band and target category. Although differences among means were obtained, none showed a statistically significant difference (one-way analysis of variance, $\alpha = .05$).

Transmission readings for each band were next converted to proportions of the sum of all three bands. Results are shown in Table 5.4. Although this technique considerably reduced variance, a one-way analysis of variance performed on data for each spectral land showed no statistically significant differences between means. Inspection of the data indicated that no discrimination was taking place in the green band and that variability in readings for grass were significantly higher than for other categories.

Examination of the original data indicated that readings for grass areas showed two quite different groupings of density values for measurements on grass which appeared to be related to photo differences (Figure 5.3). The data further suggested that any discrimination taking place was occurring with the sets of readings having higher density values. Figure 5.4 compares density readings for grass and those readings on commercial timber obtained in the same townships (and photos).

To further investigate this problem, an additional sample of 19 grass areas was taken. The 19 areas fall partially within the overlap area of two photos and wherever possible, the areas were measured on both photos.

Figure 5.5 shows the two sets of density readings obtained on the 19 additional areas. Seven of the areas were measured on both photos. Figure 5.6 shows readings of areas common to both photos. A comparison of measurements made on the two photos showed a significant difference in all three bands (t test, significant at $< .05$).

On the assumption that the difference in density readings on the two photos may have obscured differences among the target classes, all readings on Photo 1 were dropped and new mean values computed for Photos 2 and 3. Results are shown in Table 5.5. Reductions in both variability and mean differences among object classes were noted. One-way analysis of variance showed no significant differences.

The possible reasons for photo differences were next examined. All of the photos showed evidence of a vignetting effect and the possibility also existed that reproduction differences had introduced error.

TABLE 5.3

MEAN TRANSMISSION BY TYPE AND BAND

Type	N	Value	Spectral Band Red	Green	I R
JC	44	$\bar{X}$	.526	.501	.454
		σ	.205	.214	.176
G	15				
G	15	$\bar{X}$	.461	.517	.541
		σ	.309	.344	.215
O	29	$\bar{X}$	.424	.398	.365
		σ	.180	.198	.131
Y	31	$\bar{X}$	.489	.497	.452
		σ	.156	.214	.170

TABLE 5.4

TRANSMISSION BY BAND AS A PROPORTION
OF TRANSMISSION FROM THREE BANDS

Type	N	Value	Spectral Band Red	Green	I R
JC	44	$\bar{X}$	.355	.333	.308
		σ	.058	.037	.042
G	15	$\bar{X}$	.304	.332	.394
		σ	.176	.166	.143
O	29	$\bar{X}$	.357	.328	.316
		σ	.073	.044	.040
Y	31	$\bar{X}$	.351	.337	.314
		σ	.088	.055	.041

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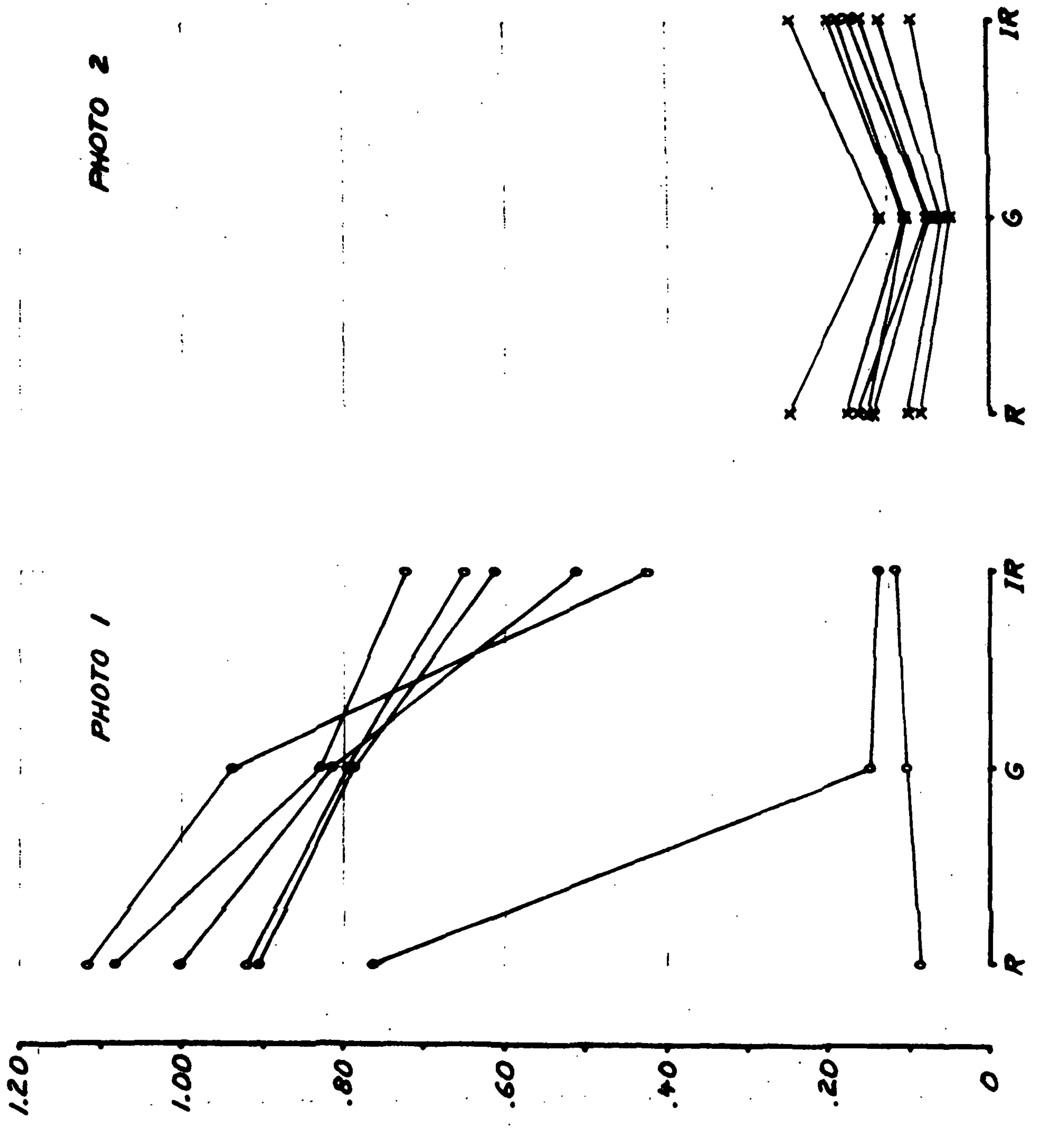

FIGURE 5.3 DENSITY READINGS FOR GRASS AREAS

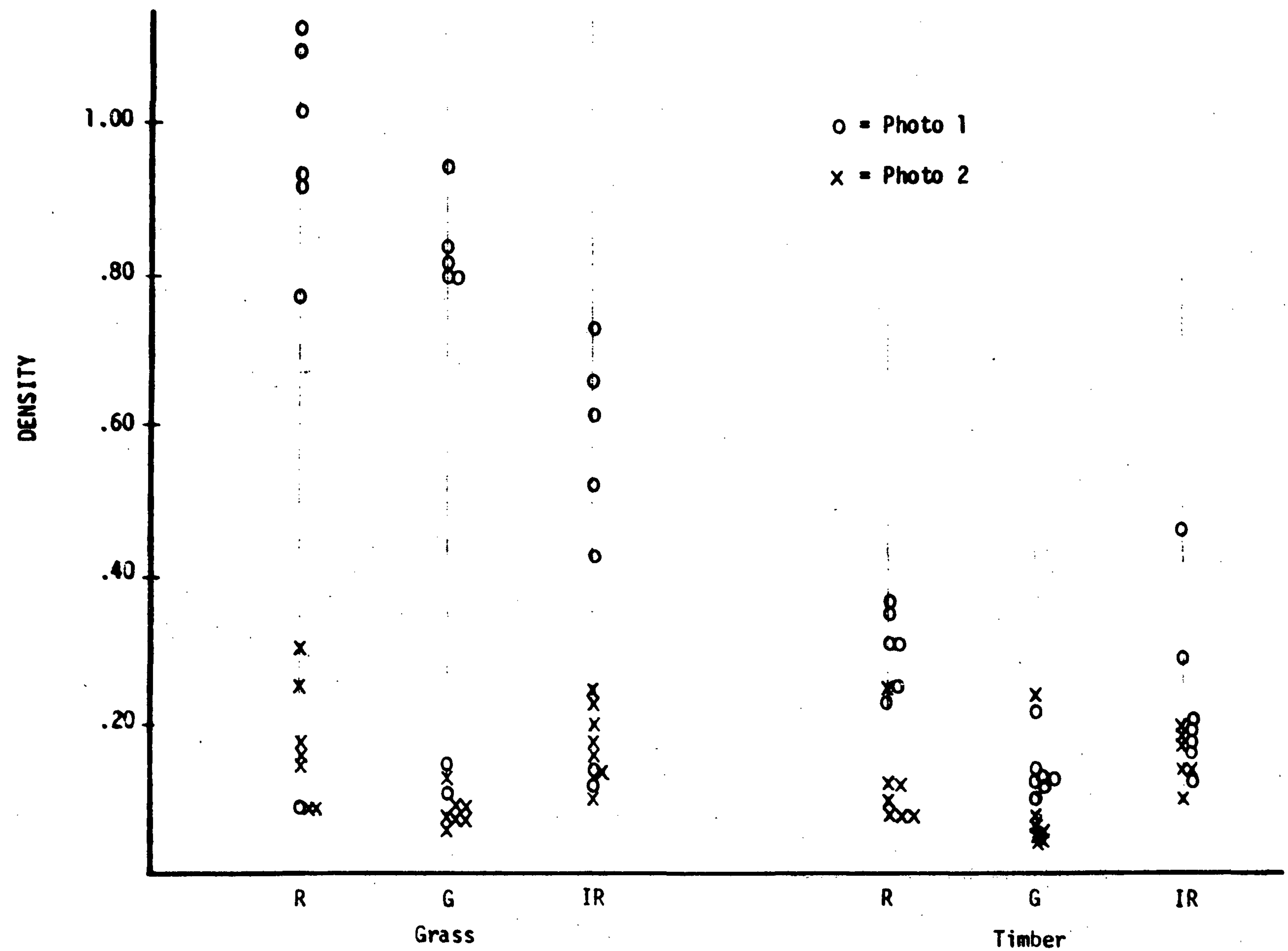

Figure 5.4 DENSITY READINGS FOR GRASS AND COMMERCIAL TIMBER AREAS

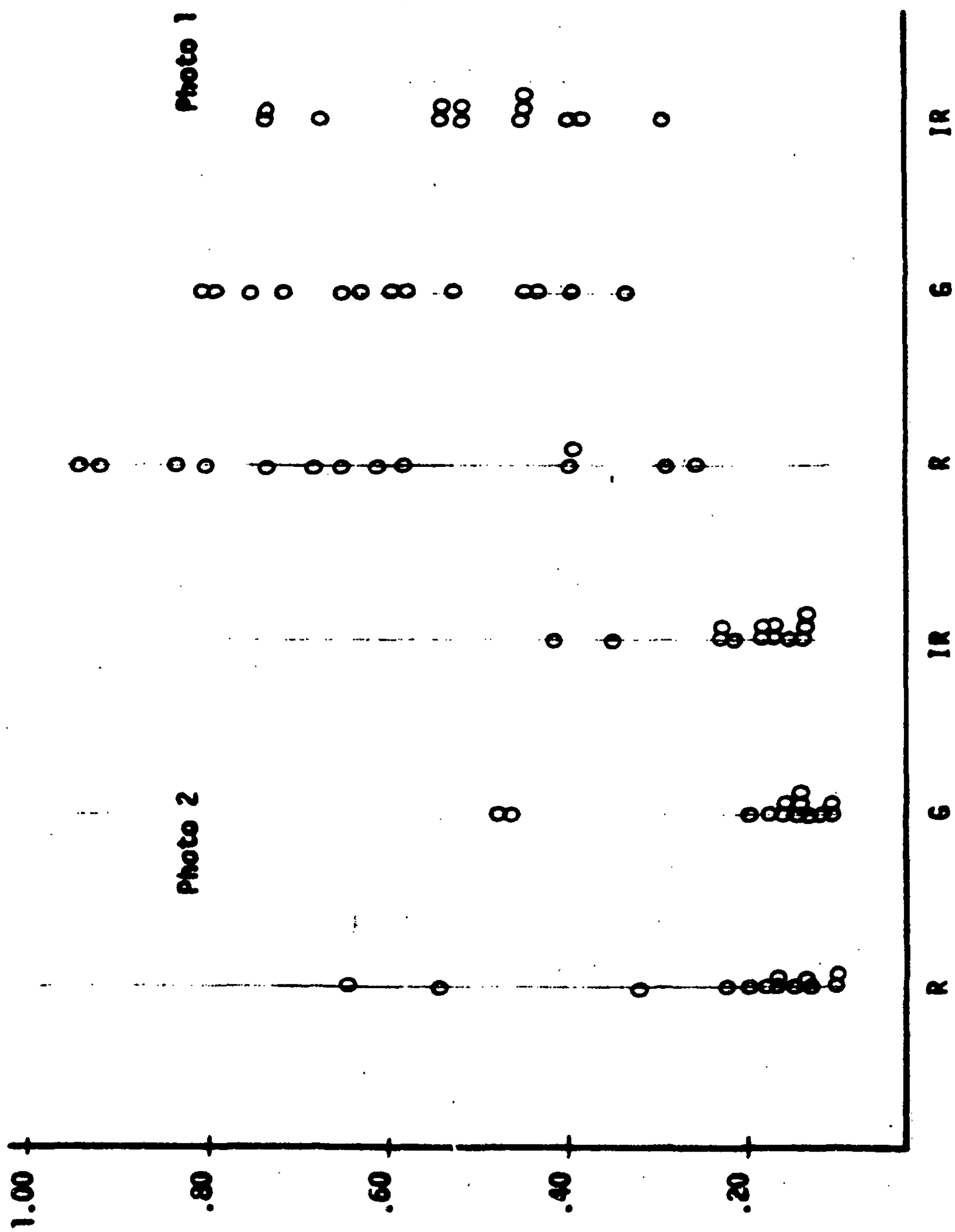

Figure 5.5 DENSITY READINGS FOR GRASS ON TWO DIFFERENT PHOTOS

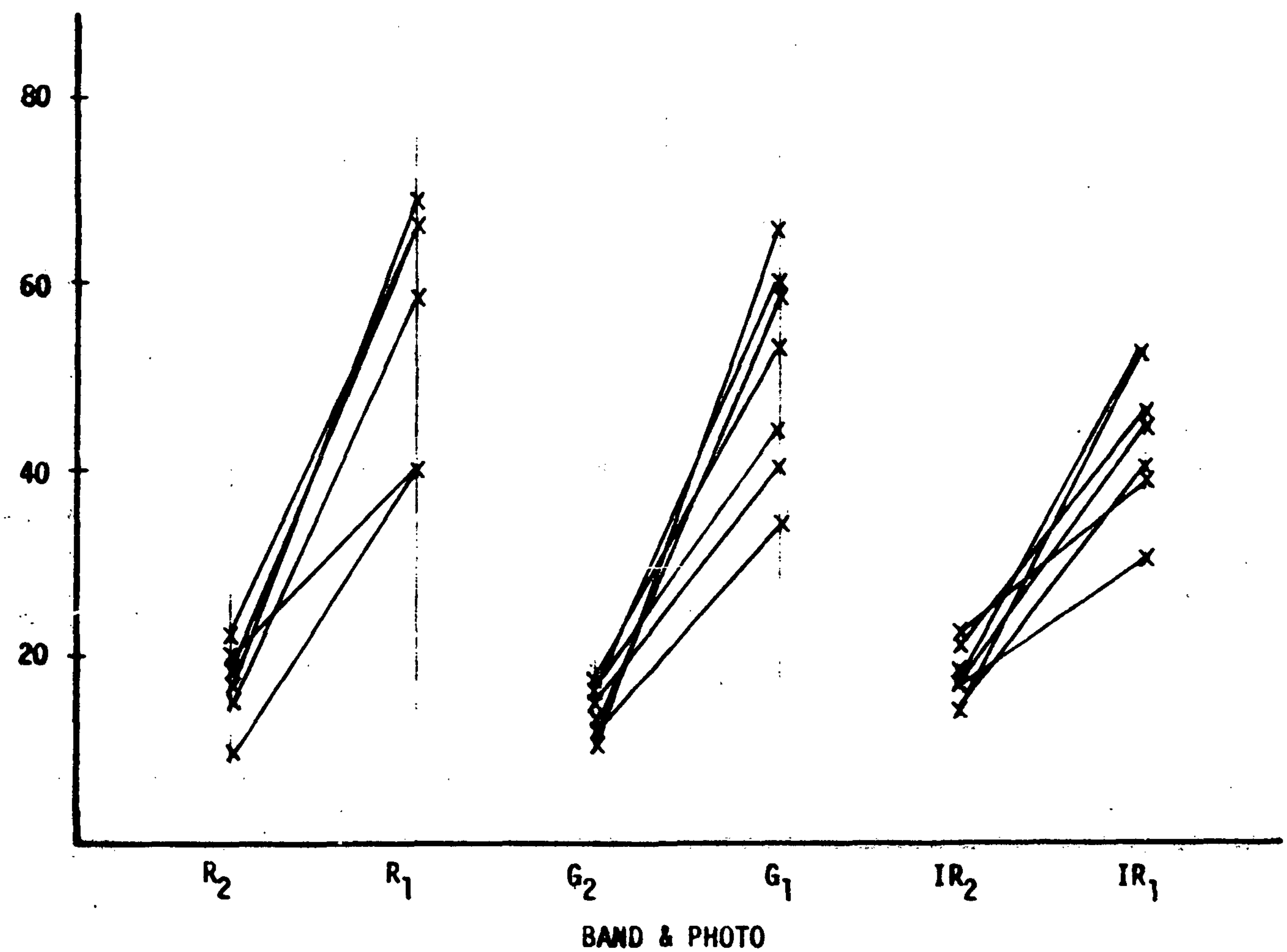

Figure 5.6 COMPARISON OF DENSITY READINGS MADE ON SAME GRASS AREAS ON TWO DIFFERENT PHOTOS

TABLE 5.5

TRANSMISSION BY BAND AS A PROPORTION OF TRANSMISSION FROM THREE BANDS

Type	N	Value	Spectral Band Red	I R
JC	39	$\bar{X}$	.360	.302
		σ	.038	.035
G	21	$\bar{X}$	.343	.331
		σ	.112	.041
O	27	$\bar{X}$	.362	.318
		σ	.073	.038
Y	26	$\bar{X}$	.364	.309
		σ	.087	.041

The effects of vignetting were examined by analysing data on a township-by-township basis. Figure 5.7 illustrates the approximate location of each township on each photo. Results indicated that differences did exist as a function of position on the frame and these differences accounted for a major portion of the frame differences.

Examination of D/log E curves plotted for each of the nine enlarged negatives showed that, although processing had introduced some variability, differences were not sufficient to account for observed photo differences. Results also indicated that enlargement had increased the density range of the objects of interest slightly, gamma being equal to about 1.2. The density region of interest on the original 70 mm positions ranged from about 0.75 to 1.30.

5.3 Conclusions and Discussion

It was concluded that a discrimination among grass, juniper/chaparral and commercial timber (Ponderosa pine) could not be reliably made on the basis of density measurements on the photos used for the study. Density slicing could therefore not be used to map commercial timber in the area of interest.

A number of factors probably contributed to the problem. The photos were obtained in January when vegetation could be expected to be in a dormant state. Some snow was present and may have introduced variance even though an attempt was made to avoid snow-covered areas. Because of relief, heavily shadowed areas were present. This probably contributed further to variance. No attempt was made to control fir crown density and several areas had crown densities ranging from 10 to 39%. Density readings on these areas thus included grass as well.

Photo processing introduced some additional variance, vignetting produced large differences in density across the frame. The effect was not the same for each of the three bands.

It would be possible to remove or reduce the processing and vignetting effects computationally or optically but the results of this study suggest that discrimination would still not be possible. The apparent differences shown for grass in Table 5.3 are believed to be an artifact resulting from location of points on the photos.

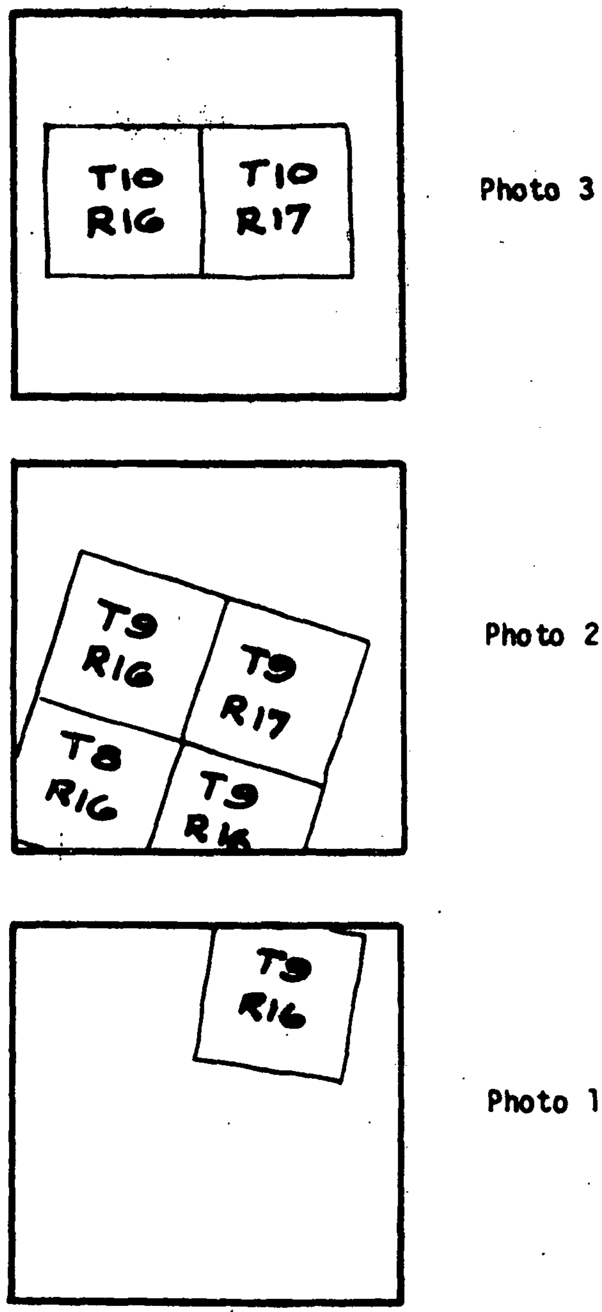

Figure 5.7 LOCATION OF MEASURED TOWNSHIPS ON PHOTOS

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A P P E N D I X

The following sets of tables summarize the results of the remote sensing literature review. The scale column provides the scale of the imagery used as well as information on the imaging system and the location of the study. Category refers to the discrimination or identification task tested in each study. Results are presented in the column labeled success.

SOILS AND VEGETATION

Ref.	Scale	Resolution	Category	Success	Remarks
39	1:5000 IR with Wratten 89b Filter Calif.	.62'	Livestock Inventory .Cows against green grass .Sheep against green grass .Cows & sheep against brown grass	 .Successful .Unsuccessful .Unsuccessful	
39	1:8000 Aerial Ektachrome Panchromatic IR Calif.	1.3'	As above	.Often satisfactory but not as consistently accurate as 0.62'	The best season in Calif. is in early Spring after the Winter rains but before the vegetation in shallow soils turns brown. The best time of day is sunrise ± 3 hours. Advantages: .Animals in open .Long shadows aid ident. Disadvantages: .Low light prevents high resolution film .Shadows of slopes, trees, etc. obscure
39	1:2500 Aerial Ektachrome Calif.	.23'	Livestock Inventory Recommended as 1/10 - 1/15 random sample of sub areas plus groups of animals in conjunction with complete 1:5000 pan coverage	.Not tried	

Ref.	Scale	Resolution	Category	Success	Remarks
12	1:640 - 1:1000 70mm Maurer KB-8 h=300-500' June 10, July 25, Oct. 25, 1967 Anscochrome D-200 Type 7230 Wratten 1-A Ektachrome IR 8443 Wratten 12 Harvey Valley N.E. Calif.	.1'	Identification of range plants .Buckwheat .Bitterbrush (Purshia Tridentata) .Big Sage Brush (Artemisia Tridentata) .Rabbit Brush (Chrysothemus) .Smooth Brome Grass (Bromus Inermus) .Fire Hair Sedge (Carex exserta) .Thistle (Circum) Plant Vigor .Bitterbrush + other range shrubs	.Good in July (in flower) only .Poor in June; good in July Fair in October Best on IR .Good in October only. .Successful occasionally .Good on June & October photos .Good on IR in July only .Successful; relative vigor in July on IR	Ground Truth: Simultaneously determined plots showing: 1. Important range plant species 2. Soil surface features were marked off with lath in June and photographed from a step ladder with a graflex camera-BxW polaroid, identification and condition of feature marked on photo. At each flight date, plots were rephotographed 4 x 5 Tri X pan Kodachrome (35mm) Ekta-Aero IR (35mm) and notes taken on: 1. Phenology 2. Change in foliage condition 3. Plant & soil color (Munsell) 4.Soil surface conditions or disturbance Stereoscopic interpretation performed in field as soon as possible with more detailed interpretation later in office relying heavily on field notes.

Ref.	Scale	Resolution	Category	Success	Remarks
12	1:640- 1:1000 (continued)	.1'	Soil surface .Erosion, rock, cattle tracks & droppings, rodent cast & burrows	Easily detectable	
			Vegetation Parameters .Plant cover Density Overlay points .Plant cover - Comparitor .Plant height - Stereoplotter	Untired, but potentially possible	
41	1:2000 Aerial Ektachrome Calif.	≈.25'	Forage Evaluation .Density .Species composition	Successful	The season is very important. May is best in California followed by Dec., July & March in order of decreasing preference of months tried.
			.Weight .Height	Unsuccessful	
Panchromatic				Contrasts less than with color so untried.	

Ref.	Scale	Resolution	Category	Success	Remarks
19	1:5000 Aerial Ektachrome (Negative) K-17, 12" Focal Length 5000' Alt. May 28, 1959	.5'	Mapping Soil series on bases of color prints	Accurate	Photo tones are not the same as soil colors observed in the field, but are consistant for a given soil color. Munsell color charts used as standard.
	B x W Prints on Panallure From above	1'	Mapping Soil series on basis of grey tone on B x W prints	Unsuccessful	Grey tone affected by many factors besides color.

Ref.	Scale	Resolution	Category	Success	Remarks
39	1:5000 Aerial Ektachrome Calif.	≈ .62'	Livestock Inventory in .Fields w/man-made objects .>5% obscured by trees .Trees & brush around border but <5% in field .Open fields	Cattle Sheep Other All .710 2.167 8.000 .874 .000 1.000 .042 1.008 1.015 .000 1.007 .995 1.341 .500 1.277 Success = $\frac{IC}{GE}$ = Image Count / Ground Elevation	Ground checked counts equaled by photos except around buildings, man-made shade & trees. Ground truth was obtained by asking farmer to fill out a questionaire. Farmers were sometimes unsure. Real time ground checks must be made to develop adjustment factors for partially obscured domains.
39	1:5000 Panchromatic	≈ .62'		Most cost effective but slightly less accurate than color	
39	With Wratten 12 Filter With Wratten 25A Filter			Filter increases contrast Denser shadows and more contrast between animal & green grass. Disadvantage: Not feasible under marginal light or when animals are in shadow.	Overlap is worth a sacrifice in scale because of movement of animals and stereo 3D.

Ref.	Scale	Resolution	Category	Success	Remarks
61	1:2400 Mauer KB-8A 70mm Anscochrome D-200 Color IR 6/5/69 Southern Ariz.-N.M.	.25'	Largest scale sub-sample for Apollo 9 interpretation Number of shrubs (Creosote Bush)	≈41% standard error. Unacceptable	Error could be decreased by: 1. Increase in sample size 2. More meaningful stratification of types Immediate sub-sample for 1:20,000 Five areas within Apollo frame#A59-26A-3806 selected for sub-sampling at 1:80,000, 1:20,000 and 1:2400 Ground truth collected consisted of: 1. Identification of individual plant species 2. Determination of relative composition of plant communities 3. Relative amounts of exposed soil-stoniness
8 11	1:8500 June, 1966 N.E. Calif. Harvey Valley Exper. Range Zeiss 6" 4 Film Types	6"-12" (given)			Same area photographed 1:8500, 1:28,000 Three weeks earlier ground teams had determined ground truth during overflv bv 18 channel mechanical optical scanner.

Ref.	Scale	Resolution	Category	Success	Remarks
8 11	1:8500 June, 1966 (Continued)				
	Plus X (2401) Minus Blue Filter		1. Mapping vegetation - Soil boundaries 2. Moisture regime	Most boundaries can be determined Not consistantly successful	
	IR Aerographic Wratten 89B		1. Distinguishing lush meadow vegetation 2. Veg.-soil boundaries	Good Relatively poor	
	Ektachrome 8442 Haze Filter		1. Soil types from color 2. Inferred productivity from soil color	Most useful Sometimes	
	Ektachrome IR 8443 Wratten 15		1. Vegetation-soil boundaries 2. Changes in soil surface 3. Moisture regimes 4. Relative cover of forage (productivity 5. Identification of browse. Species, e.i., Bitterbrush vs. Big Sagebrush	 Most useful	

Ref.	Scale	Resolution	Category	Success	Remarks
41	1:10,000 Aerial Ektachrome Calif. Foothills Dec.,March May, July	1.3'	Forage Evaluation .Density .Species Composition .Weight .Height	Only species composition detectable	Season of photography is very important. May is best in Calif. followed by Dec., July, & March in order of decreasing preference of months tried.
	BxW Same as Above	1.6'		Contrasts between types less than with color, so not used for type deliniation.	
10	1:10,000 June Summer Pasture in Sierra Nevada of Calif. Pan .4-.7μ Aerographic IR .7-.9μ	2.2'	Distinguishing: 1. Overgrazed land 2. Pure Kentucky bluegrass 3. Perennial grass & herbs in moist areas 4. Hardwoods vs. conifers 5. Mapping vegetation boundaries 6. Forage crops & pastures vs. natural range 7. Detecting understocked non-productive or waste areas 8. Boundaries of undesireable brush or palatable brush	1. Successful-light on pan; dark on IR 2. Successful-intermediate tone on both 3. Successful-dark on pan; light on IR 4. Successful-hardwoods light on IR 5. Successful 6. " 7. " 8. "	1:6000 - 1:8000 recommended as a better scale

Ref.	Scale	Resolution	Category	Success	Remarks
10 (Continued)			9. Presence of water 10. Detecting eroded areas	9. Successful 10. "	
11	1:15,000 Probably 70mm San Pablo Res. Calif. 4-27-66	1'-2'			During 1966, weekly observations of development of annual vegetation made starting in April & continued through 1967
	Panchromatic	1.4'	Detection of vetch	Successful on optimum Spring date photography	
	Aerographic IR Wratten 89b	1.4'	Detecting stream courses & water bodies	Successful-best film type for this purpose	--
	Ektachrome	1.4'	.Upland vs. bottomland sites	.Successful	Photograph after uplands turn brown, but bottomland while green
			.Amount of residual dry matter i.e., grazing use	.Qualitatively Successful	Photography in Dec.-Jan.
	Ektachrome IR	1.4'	.Dry vegetation vs. healthy	.Successful-best film type	
			.Amount of residual dry matter, i.e., grazing use	.Qualitatively Successful	Photography in Dec.-Jan.
			.Vegetation in arid areas	.Theoretically poor but untried	
10	1:15,840 1:20,000 Summer Pasture Area in the Sierra Nevada	3.5' 4.4'	Range inventory	Poor-much field checking necessary	Poor ground resolution imagery taken at wrong season

Ref.	Scale	Resolution	Category	Success	Remarks
60	Index Mosaic from 1:15000-2000 prints	Unknown	Range Inventory .Selection of 10% sample parcels on the basis of type and access	Successful	Not an experiment
	1:15,840 1:20,000 BxW Prints	3.5' 4.4'	Soil and vegetation survey	Successful	Use largest scale available and get height tone quality prints. Ground crew backs up photo-interpreter for uncertain interpretations. Interpreter should shift from one scale to another or between photo taken at different times of the year as little as possible.
23	1:20,000 BxW Soil Conservation in New York State near NYC	4.4'	Recreation .Inventory of potential sites for outdoor recreation	Successful, but criteria not suitable for the Southwest	Primary criteria: 1. Water body or potential water body 2. Tree cover 3. Access
			.Identify trends in agricultural land to forest and urban by comparison of new and old photos	Successful	

Ref.	Scale	Resolution	Category	Success	Remarks
67	Not given: Probably 1:16,000	3'- 4'	Comparison of the: .Grid reconnaissance .Grid ft.^{2} density .Aerial photo recon. .and Aerial ft.^{2} density methods of range vegetation and forage value surveying	% Variability for: 3 Mi.^{2} 9 mi.^{2} 9 5 14 8 7 4 9 5 Aerial recon most dependable, and cheapest if films and planimetric maps available with out cost. If photos not available, grid recon at 2 strips/sec. on gentle topography. If photos & maps not available or if topography is rough, photo cost can be justified. (1944 figures)	Estimates with 12-16% variability on 1 mi.^{2} satisfactory for planning effective livestock distribution on allotment. Estimates with 10% variability on 3 mi.^{2} can be used for duration & intensity for major subdivisions of allotments.
79	Not given; Probably about 1:16,000 BxW	3'	Soil Mapping .Boundaries controlled by change in slope or land form .Flatland boundaries	.Successful, true boundaries can be drawn even without experience .Only detectable after field check	Soil properties of interest were combined by analysis into a single varient. Boundaries should be placed along lines where the rate of change of the component is maximum or minimum. Soil properties were measured in auger holes along a traverse across the photo area.

Ref.	Scale	Resolution	Category	Success	Remarks
36	1:15,840 Color BxW	3.5'	Soil Surveys .Mapping soils on basis of variability in vegetation .Moisture-vegetation variation of breaks in slope .Density of cover, intensity of erosion .Soil mapping where topography and vegetation are uniform .Low intensity soil surveys .Holding user interest	 Color excellent: provide more detail Emphasized by color Color more useful Color most useful BxW usually adequate Color more successful	Not a specific experiment. Study of the relative advantages of color & BxW photography for soils mapping. Color prints are 30% more expensive.
61	1:20,000 Mauer KB-8A Anscochrome D-200 Color IR 6-5-69 Southern Ariz.-N.M.	1.9'	Ecological category subsample for 1:80,000 .Creosote bush/fluffgrass hills .Creosote bush hills .Alkali sacaton swales	 25% standard error 1.4% standard error 22% standard error	See 61-1:2400 for ground truth information. This scale is suitable for sampling of strongly contrasting ecosystems on Apollo scale photography.
11	1:28,000 Zeiss 6" June 1966 Panchromatic Aerographic IR Wratten 89b Ektachrome Ekta IR	3'- 4'	Detecting presence & relative amount of foliage cover Differentiating Bitterbrush vs. Big Sage Brush	Successful, most useful film type Unsuccessful	Same area photographed 1:8500 - 1:28,000 using four film types. Ekta IR proved most useful and only its capabilities are discussed.

Ref.	Scale	Resolution	Category	Success	Remarks
59	1:20,000 9 lens multi-band Camera	3.5'	Identifying vegetation type from color additive images from 9 bands & panchromatic diapositive of Ektachrome electronically enhanced.		Study on experimental range area, Horsefly Mountain, Oregon.
	Ektachrome 1:11,000 blown up to 1:20,000 Horsefly Mtn., Oregon	2'	U. of Kansas	Detected % of Area: Training / Predictive	
			Pine Forest	70 / 55	
			Juniper - Pine mix	53 / -0-	
			Sagebrush shrub	47 / 28	
			Grassland	84 / 49	
74	1:20,000 RMK 15/23 Camera Pan. IR Ekta IR & 4 BxW Transparencies from Ekta IR by internegatives		Soil survey	Best success with panchromatic and green bond from Ekta IR. Worst with BxW print from all Ekta IR bands.	7 similar areas interpreted by 7 equal interpreters, on 7 different image types. Each interpreter studies a different area for each image type after familiarization with the general area. Ground truth consisted of the interpretation of 3 senior staff using all image types and existing soil maps at 1:25,000 for part of the area. Boundaries were divided into 4 categories of visibility and their length measured, then interpretations were overlayered and length of coinciding hues measured. Statistical evaluation shows panchromatic most suitable.
	IR	4'			
	Green	4'			
	Red	4'			
	All	4'			
	Netherlands				

Ref.	Scale	Resolution	Category	Success	Remarks
89	1:38,000 4 lens multi-spectral Kodak #5424 Combinations of filter to sense Blue 395-510mm Green 480-590 Red 585-715 IR 700-900 + 2 K24 Cameras Aerial Ekta #8442 Ekta IR #8443 Harvey Valley Calif. 1430 8-7-67	6.2' 5'	1. Distribution of meadow grasses. 2. Vigor of rushes & sedges. 3. Low sage brush vs. big sage brush. 4. Reseeded Bromo Inermus grass. 5. Relative productivity of sites. 6. Ponderosa Pine. 7. Manzanita	Successful	All 6 cameras shutters were syncronized. Multi-spectral camera was calibrated using gray scale panels under daylight. Spectral distribution and intensity of solar illumination was measured using a spectro radiometer. Exposure in each band was controlled by ground monitoring during flight. Interpretation used color additive image enhancement.
61	1:80,000 70mm KB 8-A Anscochrome D-200 Color IR 6-5-69 Southern Ariz.-N.M.	7.5'	Ecological Category .Creosote bush/fluff grass hills .Creosote bush hills .Alkali sacaton swales	67% underestimate compared to 1:20,000 sub sample .Successful (same as 1:20,000) 96% overestimate	Creosote bush/fluff grass hills and alkali sacaton swales cannot be readily distinguished at this scale. See 61 - 1:2400 for experiment details.

Ref.	Scale	Resolution	Category	Success	Remarks
63	1:124,000 RC 8 9 x 9 Ektachrome Mission 127 2775-2785 Mancopa County	16.3'	Intermediate Intensity, Pretyping of desert vegetation	Initial recognition of ecologically similar areas helped. Better information about roads, trails & general accessibility than other sources.	
62	1:715,000 Color-Apollo 1:200,000 Color Tombstone Arizona	67'	Multistage mapping of ecological types	(Comparison of the 1:215,000 map with the 1:200,000 map)	Done by Poulton's mapping techniques. Location: near Tombstone, Arizona
			Microphyll-Thorn shrub Desert, Whitehorn, Creosote, Tarbush	23% low	
			Mortonia, Whitehorn	21% low	
			Whitehorn, Wright Lippia, Ocotillo	76% low	
			Steppe- Soaptree, Yucca, Grassland	50% high	
			Mesquite, Burroweed, Grassland	207% high	
			Woodland and/or Chaparral	155% high	
	1:715,000 Color-Apollo 1:200,000 1:20,000 Both Color	67' 26' 2.6'	Multistage mapping of ecological types	(Comparison of the 1:715,000 map with): 1:200,000 1:20,000	Comparison of the 1:200,000 to the 1:20,000
			Microphyll- Thorn Shrub Desert, Whitehorn, Creosote, Tarbush	44% high 90% high	32% high
			Mortonia, Whitehorn	32% low 20% low	10% high
			Steppe- Soaptree, Yucca, Grassland	5% low 37% low	30% low
			Mesquite, Burroweed, Grassland	31% low 297% low	2% high

Ref	Scale	Resolution	Category	Success	Remarks
66	1:944,000 35mm Nikon Blown up to 1:250,000 H=65,000 F=21mm Mission 4 7-15-69 Mission 7 9-30-69	54' (given)	Vegetation Types Forest	Units can be deliniated, but ther is little correlation with a ground truth vegetation map. Ekta IR & pan red better than Aero IR or green.	Interpretation was done using a Giannini viewer with the: Blue green band - blue filter, Wratten 47 Red band - green filter, Wratten 58b Near IR - red filter, Wratten 25A
	Ekta IR 8443 Wratten is EF 2200		Grasslands	Different types cannot be identified without correllative data.	
			Fence Lines	Some can be distinguished.	
	Panatomic Y 3400 Wratten 58B (green)		Soils	Successful - Correllation between interpretation & geologic map showing parent material high.	Stereo used. No correlative data. Much more detail than on simulated ERTS.
	Infared Aerographic 5424 Wratten 89b		Cultural Features		
	Panatomic Y 3400 Wratten 25A (red)		Flood control structures. Grade Control structures. Spreaders Canals	Best on red band. Successful	
			Wells Road Surfacing	Unsuccessful	

Ref.	Scale	Resolution	Category	Success	Remarks
9	Color IR in June, October	100' (given)	1. Changes in moisture regime - Springs & intermittent streams.	Probable (speculative)	Not an experiment
			2. Rate of growth or drying & when soil is dry enough for grazing.	Probable with sequential photography at short intervals (speculative).	
			3. Extent of use by reflectance change.	Perhaps possible (speculative)	
66	1:944,000 35mm Nikon 21mm lens Blown up to 1:750,000 & degraded to 200 per TV line resolution for ERTS simulation Same film data as 122-1:944,000	100' Photo ground resolution 200'/TV line (given)	Vegetation Deliniation of:		Degradation done optically. Studied monoscopically.
			Grasslands	Possible but no details distinguishable.	
			Fence lines	Not visible	
			Stream channels	Fair, fewer visible than on Apollo	
			Soils	Poor, only grass boundaries could be extracted.	

Ref.	Scale	Resolution	Category	Success	Remarks
63	Apollo 6 as 6 1442	300'	Interpreter performance in determining macro-relief categories from space photography.	% of area assigned to each type by 6 interpretation.	Stereo coverage. Ground truth at 1:250,000. Interpreters given written instructions & photo 1443 with example of each class indicated.
				1 2 3 4 5 6 GT	
			1. Flat & smooth, slopes <10%	35 30 9 20 5 9 25	
			1a. Flat w/dissection	3 17 24 42 38 29 13	All interpreters made the mistake of assigning a dissected bajada comprising 7% of the total area to class 2a. instead of class 3 as indicated by ground truth. If the error is compensated for, the generalized results are as indicated below.
			2. Rolling or hilly	20 10 0 2 0 7 <1	
			2a. Moderately too strongly dissected planar surface.	17 16 41 17 31 29 28	
			3. Hilly to submountainous.	14 22 10 15 15 12 26	
			4. Mountainous	11 5 16 4 11 14 7	
			Relatively flat topography (1., 1a. & 2., 2a.) Plus 7%	68 66 67 74 67 67 67	
			Hilly or mountainous (3. & 4.) Less 7%	32 34 33 26 33 33 33	
63	1:760,000 after enlargement Apollo 9 Ekta IR AS-9-26A-3800 through 3802	300'	Low intensity deliniation pre-typing of vegetation through changes in macro-relief and image color plus agricultural land & urban complexes.	Successful. Map on page 13 was produced when photo information was combined with ground truth.	

Ref.	Scale	Resolution	Category	Success	Remarks
66	1:2,250,000 Blown up to 1:750,000 70mm Hasselblond Zeiss Planar 80mm lens April 1969		Drainage	Best on red band	
			Drainage containing water	Best on BxW IR	
			Vegetation, Forest & Range	Color IR best. Interpretation showed poor correllation with ground truth map of forest species	Range map of U.S. & Forestry [illegible] used as correllative data
	Ektachrome IR 50-180 Wratten 15 (Dark Yellow)	= 293' (given)	Soils	Boundaries could be drawn but they were not compared to any ground truth.	
			Cultural .Fence lines	.Some could be identified on vegetation contrasts.	
	Panatomic X 3400 Wratten 58b Green	222' (given)	.Roads vs. railroads	.Successful	
			.Small towns	.Difficult to locate <2000 only 33% detected.	
	IR Aerographic 50 246 Wratten 89b (very dark red)	262' (given)	.Urban boundaries	.Aero IR & green poor, other good.	
	Panatomic X 3400 Wratten 25A (red)	222' (given)			

Ref.	Scale	Resolution	Category	Success	Remarks
61	1:2,800,000 Color IR Hasselblond 70mm w/Zeiss 80mm lens 4-12-69 9:30 am Southern Ariz.-N.M.	= 293'	Macro relief Drainage Pattern	Successful Successful	No stereo coverage taken during the Winter dormancy; little could be determined about vegetation. Repeated seasonal coverage is the best hope for vegetation typing at this scale. On color IR: March - only evergreens red April/May - Desert shrubs Late August - Grass & Steppe & Desert shrub w/understory of grass.

Ref.	Scale	Resolution	Category	Success	Remarks
11	Not given H=2000' U. of Mich. 18 channel Optical Mechanical Scanner .32-14μ 5-18-66 N.E.Calif. Harrey Valley	> 12"			Ground based teams took photographs and documented condition of vegetation and soil.
	.62-.68μ		Soil Vegetation typing	Most useful of bands studied	Compared to maps made from 1:8,500 Color IR photography. Poor resolution limits typing to tone variations.
	.8-.10μ		Detection of dense bush meadow vegetation	Most responsive of bands studied	
	.8-.14μ		Moisture Regimes	Successful - only one of 5 bands studied to image these.	
	1.5-1.8μ .32-.38μ		Soil-Veg. type	Best for occasional types but did not contribute much additional information over visible spectral bands.	
			Perimeter of standing water crossing boundary lines	Best on 1.5-1.8μ	

Ref.	Scale	Resolution	Category	Success	Remarks
59	HV radar		Detecting openings in vegetation	Successful	
	K band radar		Discrimination of trees, shrubs, bare or sparsely vegetated areas	Successful	
8	Unknown Thermal IR on Poloroid Film using Barnes Engineering Thermal IR Camera	Low	Identification of vegetation type, ie., meadow vs. forest	Some repeated observations during the day as temperature cross-overs for various vegetation types occur mitigates poor resolution.	Repeated observations
			Vegetation changes within or between seasons	Successful at indicating change	
	8-13μ Thermistor Bolometer		Livestock counts especially at night or in shadows	Successful but low resolution limits it to altitudes <3000'	
	3.5-5.5 Indium Antimonide				

HYDROLOGY

Ref.	Scale	Resolution	Category	Success	Remarks
17	1:7200 Ektachrome IR, Filter #12, CC208, CC30M Gila River Flood Plain San Carlos Reservation	1.0'	Determination of saltcedar density on the floodplain	Successful "differences in the amount of energy reflected by areas dominated by different volumes of saltcedar can be discriminated by Ektachrome IR film"	Analyzed by a digital densitometer calibrated by cultural features
35	sensor was a calibrated fixed field infrared radiometer, Barnes Eng. Co. PRT-5, precision radiation thermometer, recorded on Westronics D11E potentiometric strip chart recorder Maryland & Delaware		Determine quantity of ground water inflow to a stream	Successful: within 11% for quantity of inflow within 7.5% for downstream discharge	The process takes 1/2 to 1 hour in the field vs. flight and relatively simple data analysis but it still requires one field station (gaging station).
88	high altitude Lehigh River Penn.	Reconofax IV infared imager 8–14 um band	Detection of ground water inflows to stream and determination of magnitude	Successful in detecting springs of as little as 1 gal. per minute, but many were missed because seepage was into stream bottom. Unsuccessful in determining magnitude	Had a problem with automatic gain control, causing the stream to appear all hot or all cold. There are relatively few appropriate times for such tests.

Ref.	Scale	Resolution	Category	Success	Remarks
47	1:10,000 or 1:20,000 Panchromatic	2' - 5'	Ground water detection in an arid region: detection by plant cover.	Successful	Suggestions of several Russians. All must be correlated with core data.
	1:25,000	5.5'	Detection by general landscape interpretation.	Successful	
	1:10,000	2.2'	Detection by individual elements: sink holes, deflation basins, old channels, flat bottomed depressions.	Successful	
	1:5,000	1.1'	Detail interpretation of artificial structures, wells, springs and plant communities.	Successful	
65	1:62,000 IR scanner 8-14 u band	no data	mapping geology	Successful in discerning tertiary volcanics from PreCambrian granite and gneiss.	
between Cordsburg & Silver City, N.M.			hydrology	Successful in discerning water courses as dark streaks, cold springs as dark patches, standing water as bright spots	
			culture	Successful in discerning buildings (dark) paved roads (bright)	
			topography	Unsuccessful	

Ref.	Scale	Resolution	Category	Success	Remarks
86	No data-very large scale various film types	No data very high	detect soil moisture	impossible if tone of airdried sample is not known. On a glacial soil increase in density proportional to increase in soil moisture to near the Sterberg plastic limit; with further moisture the density drops.	Distorted by organic content and unequal drying and micro relief.
58	1:10,000 color IR	1.1'	determining of 162 land use elements	most successful	a well constructed test on interpreters subjective opinions, a high degree of unanimity between them.
	1:10,000 Color	1.3'		next most successful	
	1:10,000 B+W	2.2'		least successful	
	Thermal IR + Color IR	no data / no data	to sense changes in soil moisture by combined use of both sensors first with thermal IR then color IR to distinguish between effects of vegetation and moisture.	successful	

Ref.	Scale	Resolution	Category	Success	Remarks
51	Calibrated Stoll-Hardy Model #HL-4 thermal radiometer		Detection of plant moisture by detecting temperature difference between wet and dry plants at various times of day	Successful	
			Separation of moisture stress from salinity by use of 750 mu-1300 mu vs. 500mu - 2500 mu	Successful	
5	1:20,000 Ektachrome	2.6'	Perform a general terrain analysis including drainage maps, vegetation maps, soils maps, culture maps and respond to specific questions about 42 predetermined ground checked points.	Ektachrome & Ektachrom IR both satisfactory. Ektachrome was most successful on culture and soils.	Interpretation done with mirror stereoscope with 6x lenses and a stereometer done by experienced photo interpreters and map makers
	1:20,000 Ektachome IR	2.4'			
	1:20,000 Panchromatic	4.4'		Ektachrome IR was most successful on vegetation and drainage.	
	Bennetsville, S. C.				
7	1:60,000 Ektachrome	7.9'	Important land pattern elements and gully shapes	Unsuccessful at 1:60,000 Successful at 1:40,000	Interpreted by a soils scientist unfamiliar with the area
	1:40,000 Ektachrome	5.2'		Successful at 1:20,000 (but no more quickly than at 1:40,000)	
	1:20,000 Ektachrome	2.6'			
	Phoenix, Az. test site				

Ref.	Scale	Resolution	Category	Success	Remarks
80	no data at 23,000' Aero Neg. Color film	no data	Mapping lake bottom sediments, topography, and vegetation down to 20-30 ft.	Successful	
	no data at 18,000' Panchromatic Lake Tahoe	no data	"	successful, best with no filter or green filter	
37	no data Panchromatic Indiana	no data	groundwater capacity mapping of 400 sq. mi.: literature search, marking of photos, transfer, preparation, lab checks, field check, write up	successful: it required 740 man hours.	
73	1:100,000 Ektachrome IR	12'	water pollution: detection of current patterns.	successful	The opinion of an expert in this field.
	1:5,000 Ektachrome IR	6'	fish kills	successful	
	1:2500 Ektachrome IR	3'	typing of vegetation	successful	

Ref.	Scale	Resolution	Category	Success	Remarks
52	1:60,000 color	8'	Playas:		
			detection of grass soil moisture changes e.g. standing water, soil moisture & salt boundaries	Successful	
	IR imaging radiometer		soil discrimination	successful day and night	
	1:1,000,000 color (Gemini)	100'	gross variation in water depth	successful	color is the best sensor from satellite: good with 80mm lens, superior with 250mm.
	1:20,000 color	2.5'	detection of salt ridges	suggested	
	1:30,000 color	4'	detection of giant desiccation fissures and windblow sand	suggested	
	1:40,000 color	5.5'	detection of vegetation	suggested	
20	1:21,300 poor quality color IR trans- parencies Tennessee	3.5'	Recreation site choice	site choice 85% correct, choice by type of activity 83% correct	on a Tennessee resevoir, done by an interpreter with no local experience, working with only a set of recreation site guidelines

Ref.	Scale	Resolution	Category	Success	Remarks
46	1:200,000	no data	drainage analysis in place of 1:62,500 (15') topo map	Successful: SLAR at 1:200,000 is as good as topo map at 1:62,500	Tested on a variety of terrains
			Drainage analysis in place of 1:24,000 (7-1/2') topo map	Successful: There is a consistent mathematically relationship between data from SLAR and data from large scale (1:24,000) topo maps.	Correlations derived for SLAR to map significant to 0.001
38	1:20,000 Panchromatic	6.6'	Determine water resources condition surface	Successful: it required 3 man hours per sq. mi.	
	Indiana		Groundwater	Successful: it required 2 man hours per sq. mi.	
18	1:20,000 Panchromatic Merrimack River	6.6'	Determine land use in various zones of flood frequency	Successful in the author's opinion	
72	1:25,000 Arizona Panchromatic	7'	Determine size of drainage area, determine location for culverts & ditches and sizes thereof. For highway planning.	Successful compared to 7-1/2' quadrangle map had 19% error while photo had 1% error in drainage area.	"Considerable savings in time and labor"

Ref.	Scale	Resolution	Category	Success	Remarks
67	Orbital photos		Detection of water quality:		
	color	100'-400'	Detection of sediment, pollution, mapping lake-marine hydrodynamics, and spotting areas needing multispectral coverage (e.g. plumes into reservoirs)	Suggested	
	panchromatic	100'-400'		not particularly useful	
	multispectral	100'-400'		great potential but as yet unproven	
	B+W IR	100'-400'		limited	
	Color IR	100'-400'	detection of sediment/organic pollution distribution in open water	suggested but on the whole rather limited use	
	Aircraft photos				
		1'-10'	Detecting the location of pollution outfalls, local	Suggested	
		1'-20'	Detecting effluent patterns in rivers	Suggested	
		10'-200'	Detection of effluent patterns marine/terrestrial interface	Suggested	

Ref.	Scale	Resolution	Category	Success	Remarks
55	scanner w/indium antimonide detector filtered to 4.5-5.5 microns		Detection of land use classes: prior to field experience		near mid day - July
	6,000 - 10,000 ft.		cultivated vs. non-cultivated	70% correct	
			wooded vs. non-wooded	71% correct	
	Leelanau Co. Mich.		tree species	10% correct	
			after field experience in a neighboring area		
	Wright Co. Minn.		cultivated vs. non-cultivated	90% correct	
			wooded vs. non-wooded	86% correct	
			brush vs. pasture	31% correct	
			tree species	44% correct	

FORESTRY

Ref.	Scale	Resolution	Category	Success	Remarks
42	Pan 1:5000 1:8000 1:10,000 1:12,000 Color IR 1:5000 1:8000 1:10,000 1:12,000	 0.5' 0.8' 1.0' 1.2' 0.6' 1.0' 1.3' 1.6'	Detect damage to western pine and mixed conifer forests by various insets	Pan film is considered inferior for this work. Color IR at 1.6'-1.3' resolution is successful for use in control and/or salvage operations for large timber. 1.0'-0.6' resolution is recommended for control and/or salvage on small timber. If crown detail is needed, a ground resolution of 0.6' or better should be used.	Costs of an aerial survey are one half those of ground surveys
75	1:3960 Fairchild F-56, 8-1/4" FL Ekta-Aero 6-5/8 x 7"	.5'	Classify spruce bud worm defoliation into categories; light, medium, or heavy. Also dead tops & dead trees - Four interpreters were used. Also compare photo with aerial survey.	Analysis showed a significant difference between estimated defoliation and tree damage among plots; A significant difference in defoliation estimates among interpreters, but no significant difference in their counts of dead tops or trees; significant lower estimates of defoliation and counts of dead tops than the ground record, but no significant difference between the photo and ground counts of dead trees.	The aerial observation method is more accurate, economical and more convenient, ie., can be done under wider weather conditions than aerial photo. Cost (for 10% sample) Aerial operation $0057/ acre Aerial Photo $.0514/acre Based on 6,870 acres

Ref.	Scale	Resolution	Category	Success	Remarks
69	Pan BxW IR Color 1:7000	~ 1.0'	Identify forest vegetation of a boreal forest; Spruce, Fir & hardwoods	Color and Pan were inferior to BxW IR	
84	Ansco D/200 K-17 Fairchild 9 x 9 " Color 1:8000 (Transp.)	1'	Determine the boundary of Tussock moth infested areas	Quite successful; no quantitative measure	
84	1:1584 Maurer 70mm Ansco D/200 Color (Transp.)	.2'	Classify white fir damaged by Tussock moth into categories; live, dead, thin, top kill, or normal.	Correlation between ground truth & Photo interpretation ranged from .54 (top kill) to .95 (dead).	Mortality estimates within 5% of ground cruise = 3x longer to perform adequate ground survey than aerial survey.
30	Ekta/ Color Transp. 1:7920	1'	Detection of beetle damage to trees	Experienced interpreters were able to count faded trees on photos within 5% error.	
16	Color 70mm Transp. 1:7920 1:1584	 0.9' 0.2'	Detect ash dieback	0.2' resolution resulted in 100% better detection than the 0.9' resolution	It is difficult to identify ash amongst other deciduous trees.

Ref.	Scale	Resolution	Category	Success	Remarks
54	Pan BxW IR Color Color IR 1:12,000 1:20,000	~ 2.5' ~ 3.5'	Identify forest cover type	No significant difference in accuracy between scales. Pan was the poorest film type. Color & BxW IR about equal. Color IR the best.	Both of these scales are too small to distinquish crown shape, a very important criteria in species identification.
5	Pan Color Color IR 1:20,000	~ 3.5'	Identify vegetation, soils, drainage, roads, railroads & buildings.	Color IR superior to Color & Pan for vegetation and drainage. Color superior to color IR & Pan for soils & culture.	
26	Pan Color Color IR 1:5000	~ 0.8'	Identify stand age for hardwood & softwood. Also measure tree heights in a Boreal forest.	Pan is best for ground detail, such as downed logs and trails. Color IR is best for distinguishing between hardwood & softwood.	
83	70mm Ansco D/200 1:1584	0.1'	Detect killed and damaged white fir by tussock moth	90% accuracy in distinguishing live from dead trees.	
31	70mm Pan prints 1:3960 1:1584 1:1188 Color transparency 1:3960 1:1584 1:1188	 0.9' 0.3' 0.26' 0.5' 0.2' 0.15'	Identify 15 boreal forest trees	Color superior to Pan.	Greater consistency among interpreters on Color than on Pan.

Ref	Scale	Resolution	Category	Success	Remarks
49	Ekta IR 9 x 9" 1:9600 1:6000	1.3' 0.8'	Detect trees dead or dying from Dutch elm disease and oak wilt.	No difference between 1.3' and 0.8' in ability to detect these diseases. 60% of the infection centers were detected by photo interpretation.	Ekta IR superior to regular color.
14	Ansco D/200 Ekta IR 1:3960	0.65'	Estimate the extent of Southern pine beetle infestation	Ekta IR was superior to Ansco D/200	Ekta IR was able to discriminate hardwoods from pines and penetrate haze.
77	70mm Super Ansco Color Transp. 1:1584	0.2'	Determine cubic foot volume losses of white spruce and balsam fir by spruce bud worm ; estimate volume by tree height and crown closure	Successful estimation of volumes	
40	See Tables 1–4				

TABLE 1. Rating of Film-Filter Combinations for the Identification of Vegetation - Cover and Other Land Status Elements at 1:20,000 and 1:15,000 Photo Scales In the Pine and Redwood Regions of California

Region and Element	Photo scale and film-filter				
	1:20,000		1:15,000		
PINE REGION	P-MB	IR-MB	P-MB	IR-MB	PG
Commercial conifers	+	++	++	++	++
Lodgepole pine-Mt. Hemlock type	++	++	++	++	0
Noncommercial conifers	+	-	++	-	0
Hardwoods	+	++	++	++	++
Chaparral	++	-	++	-	++
Bushy herbs	+	--	+	+	0
Grass	+	-	++	+	++
Bare ground	+	-	++	-	++
Rock	+	-	++	+	0
Cultivated	++	++	++	++	++
Urban - Industrial	+++	++	++	++	0
REDWOOD REGION					
Commercial conifers	+	-	+	+	+
Noncommercial conifers	++	++	++	++	0
Hardwoods	+	-	+	+	+
Chaparral	++	-	++	-	++
Sagebrush	+	-	+	-	+
Bushy herbs	+	+	+	++	+
Grass	++	-	++	-	++
Marsh	0	0	+	+	0
Bare ground	++	-	++	-	++
Cultivated	++	+	++	+	++
Urban - Industrial	++	++	++	++	0

P panchromatic film; IR infrared film; MB minus-blue filter; G green filter; ++ generally and easily identifiable; + generally identifiable but sometimes requiring close study; - inconsistently identifiable; -- generally unidentifiable; 0 no example.

TABLE 2. Rating of Film-Filter Combinations for the Identification of Age Class Elements Among Timber and Hardwood Trees at 1:20,000 and 1:15,000 Photo Scales in the Pine and Redwood Regions of California

Region and element	Photo scale and film-filter				
	1:20,000		1:15,000		
	P-MB	IR-MB	P-MB	IR-MB	P-G
PINE REGION					
Commercial conifers					
Mature	++	++	++	++	++
Large immature	+	++	++	++	++
Small immature	+	++	++	++	++
Reproduction	-	-	+	+	+
Lodgepole pine - Mt. hemlock type					
Mature	+	+	++	++	0
Immature	+	+	++	++	0
Hardwoods					
Mature	++	++	++	++	++
Immature	+	++	++	++	++
REDWOOD REGION					
Commercial conifers					
Mature	++	++	++	++	++
Large immature	++	++	++	++	++
Small immature	+	-	+	+	+
Reproduction	-	--	+	--	0
Hardwoods					
Mature	+	+	++	+	++
Immature	+	-	+	+	+

P panchromatic film; IR infrared film; MB minus-blue filter; G green filter; ++ generally and easily identifiable; + generally identifiable but sometimes requiring close study; - inconsistently identifiable; -- generally unidentifiable; 0 no example.

Table 3. Rating of Film-Filter Combinations for the Identification of Vegetation Densities at 1:20,000 and 1:15,000 Photo Scales in the Pine and Redwood Regions of California

Region and element	Photo scale and film-filter				
	1:20,000		1:15,000		
	P-MB	IR-MB	P-MB	IR-MB	PG
PINE REGION					
Sawlog timber stand	+	++	++	++	++
Total timber stand	+	++	++	++	++
Total woody vegetation cover	++	-	++	-	++
REDWOOD REGION					
Sawlog timber stand	++	++	++	++	++
Total timber stand	+	-	+	+	+
Total woody vegetation cover	++	-	++	-	++

P panchromatic film; IR infrared film; MB minus-blue filter, G green filter; ++ generally and easily identifiable; + generally identifiable but sometimes requiring close study; - inconsistently identifiable.

Table 4. Rating of film-filter Combinations for the Identification of Timber Cropland Criteria at 1:20,000 and 1:15,000 Photo Scales in the Pine & Red Regions of California

Region and element	Photo scale and film-filter				
	1:20,000		1:15,000		
	P-MB	IR-MB	P-MB	IR-MB	P-G
PINE REGION					
Occurrence of commercial conifers	+	++	++	++	++
Form and vigor of commercial conifers	+	-	++	+	++
Density of tree stands	++	++	++	++	++
Density of chaparral stands	++	-	++	-	++
Indicator species of hardwoods and chaparral	-	+	-	+	0
Exposed rockiness	+	-	++	+	0
Soil drainage	++	++	++	++	++
Intensive land use	++	++	++	++	++
REDWOOD REGION					
Occurrence of commercial conifers	+	-	+	+	+
Density of tree stands	++	++	++	++	++
Density of chaparral stands	++	-	++	-	++
Indicator species of hardwoods and chaparral	+	++	++	++	++
Intensive land use	++	++	++	++	++

P panchromatic film; IR infrared film; MB minus-blue filter; G green filter; ++ generally and easily identifiable; + generally identifiable but sometimes requiring close study; - inconsistently identifiable; 0 no example.

Ref	Scale	Resolution	Category	Success	Remarks
29			Detection of Ponderosa pine trees under stress from insects or pathogenic organism		Color IR is as good and often better than regular color
	1:7920	~ 1'		Needed to detect a new epidemic infesting only 1-3 trees.	
	1:31,680	~ 3.5'		Considered best for a general survey	
15	See Table 5				
33	Super Ansco Color 70mm Transp.		Detect & estimate damage to balsam fir by the balsam fir woolly aphid		Best compromise of cost & accuracy considered to be 1:1188, 0.1' ground resolution
	1:1980 1:3960	0.2' 0.4'	Specifically, count stem-attacked trees	90% accurate at 0.2' 70% " " 0.1'	
	1:792 1:1188 1:2376	0.08' 0.1' 0.2'	Specifically, count gouted trees	83% " " 0.08' 72% " " 0.10' 44% " " 0.2'	

TABLE 5. Feasibility of Identifying Various Natural Resource Features on Aerial and Space Photography Based on Studies Conducted at NASA Test Sites in California and Arizona

TYPE OF RESOURCE FEATURE	Photographic Scale and Film-filter Combination											
	Scale 1/10,000				Scale 1/30,000				Scale 1/1,000,000			
	Pan 12	IR 89B	Ekta RF-1	IR Ekta 12	Pan 12	IR 89B	Ekta RF-1	IR Ekta 12	Pan 12	IR 89B	Ekta RF-1	IR Ekta 12
VEGETATION RESOURCES												
Vegetated or not	**	**	**	**	**	**	**	**	*	*	*	**
Wild or cultivated	**	**	**	**	**	**	**	**	*	*	*	**
Fields with crops	**	**	**	**	**	**	**	**	*	*	**	**
Fallow fields	**	**	**	**	**	**	**	**	—	*	*	*
Mature conifers	*	**	**	**	*	*	**	**	—	*	—	*
Mature Hardwood	*	**	**	**	—	*	*	**	—	*	—	**
Open brushfields	**	*	**	**	**	*	**	**	*	*	*	*
Riparian vegetation	*	**	**	**	*	*	*	**	*	*	*	**
Aquatic vegetation	*	**	**	**	*	**	**	**	—	*	*	*
Meadow or grassland	**	**	**	**	*	*	*	**	*	*	*	*
Sparce or drying vegetation less than 3 feet high	—	—	*	**	—	—	—	*	—	—	—	*
Vegetation not yet in leaf	—	—	*	**	—	—	*	**	—	—	—	—
Herbaceous vegetation in standing water	—	**	*	**	—	*	*	**	—	—	—	*
Sprayed brushfields	*	*	**	**	*	—	**	**	—	—	—	—
Dead or dying vegetation greater than 3 feet high	—	*	*	**	—	—	*	**	—	—	*	*
Snags or other downed timber	*	—	**	**	*	—	—	—				
Burned areas	*	**										
Windrowed brush		*		*								

Continued next page.

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TYPE OF RESOURCE FEATURE	Photographic Scale and Film-Filter Combination											
	Scale 1/10,000				Scale 1/30,000				Scale 1/1,000,000			
	Pan 12	IR 89B	Ekta RF-1	IR Ekta 12	Pan 12	IR 89B	Ekta RF-1	IR Ekta 12	Pan 12	IR 89B	Ekta RF-1	IR Ekta 12
WATER RESOURCES												
Deep ponds or lakes	**	**	**	**	*	**	**	**	*	*	*	**
Shallow ponds or lakes	*	**	*	**	*	**	*	**	-	-	-	*
Streams and rivers	*	**	*	**	*	**	*	**	*	*	*	**
Waterweeds and algae	*	**	**	**	*	**	**	**	-	*	*	*
Degree of turbity	*	*	*	**	*	*	*	**	-	-	-	*
GEOLOGIC RESOURCES												
Gross landforms	**	**	**	**	**	**	**	**	**	**	**	**
Igneous rock masses	*	*	*	*	*	*	*	*	*	*	*	*
Sedimentary rock masses	*	*	*	*	*	*	*	*	*	*	*	*
Metamorphic rock masses	*	*	*	*	*	*	*	*	*	*	*	*
Granitic outcrop covered with lichens	*	**	*	**	-	*	-	**	-	-	-	-
Granitic talus	**	-	**	**	*	-	*	**	-	-	-	-
Serpentine rock	*	-	*	**	-	-	-	*	-	-	-	-
SOILS RESOURCES												
Alluvial soils	**	**	**	**	**	**	**	**	*	*	*	*
Eolian Soils	*	[illegible]	*	*	*	*	*	*	*	*	*	*
Glacier-derived soils	*	*	*	*	*	*	*	*	-	*	*	[illegible]
Resident soils	*	*	*	*	*	*	*	*	-	-	-	-
Serpentine-derived soils	*		*	**	-	-	-	*	-	-	-	*

Legend: ** generally [illegible] study; - [illegible]

Ref.	Scale	Resolution	Category	Success	Remarks
64	80mm Altitude 105 mi. =1/200,000	26.2'	Inventory vegetation and and related resources from space photography	Ideally suited to mapping vegetation at synoptic scales	For use by those who must set resource policy & perform broad planning functions. Not suited to use by resource managers who work on the land.
2	70mm Super Ansco 1:1580 transp.	.14'	Identify trees of 8 species	Most species could be identified with 90-100% accuracy	
4	Pan 1:20,000 Prints S.E.U.S.A.	4.4'	Determine the efficiency and accuracy of stratifying timber volume on single photos, rather than stereo pairs	Single photo method almost as good as stereo	
34	Ekta & Ekta IR 1:7920 1:15,840 1:31,680 1:126,000 1:174,000	1.0' 2.1' 4.2' 16.5' 22.8'	Detect ponderosa pine trees under stress as a result of bark beetle infestation	At 1.0' ground resolution, small infestations could be detected with 68-85% accuracy. At 2.1-4.2' infestations of >10 trees could be detected. At 16.5' and 22.3', infestations could not be dete[illegible]	There was no difference between Ekta and Ekta IR for detecting infestations.
8[illegible]	Ansco/ D/200 film 9" x 9" Color 1:8000		Identificat[illegible] [illegible]-killed dougla[illegible] fir trees by stratif[illegible] [illegible] probabil[illegible]	Provided an "effic[illegible]" survey" of trees kill[illegible] [illegible] douglas fir [illegible]	

Ref.	Scale	Resolution	Category	Success	Remarks
57	Test of feasibility of multi-spectral sensing		Detect changes in the morphology & physiology of trees under stress through changes in light reflectance & transmittance	Could detect drought and high salinity pre-visually by increase of reflectance of several λ. Low salinity was also detectable by increased reflectance in other λ.	Drought & high salinity show up in λ= 1430, 1940 & 2190. Low salinity in λ= 800, 1000, 1200.
21	Ekta IR 1:30,000	3.0'	Determine gross timber volume on small scale imagery but developing a formula to relate the product of % crown closure and average crown diameter to timber volume	The photo derived calculated timber volumes had a correlation of .916 with ground truth	
44	See Tables c-9				

TABLE 6. Timber Typing on Sma[illegible] Aerial Photography-San Pablo Reservoir Test Site

Infrared Aerographic Film: Wratten 89B Filter; Scale, 1/33,500
Date of Photography: August 28, 1966

(Figures in darkest rectangles indicate accuracies achieved. Figures in other rectangles indicate errors made.)

TIMBER TYPE	No. of Stands	Total Area	Identified as: MP	PP	E	MH	LO	CB	W	Other Conifers	Out
Monterey pine (MP)	30	6424	5086 79%	0 0%	0 0%	76 2%	99 2%	0 0%	0 0%	18 0%	1145 18%
Ponderosa pine (PP)	7	660	37 5%	455 69%	0 0%	0 0%	0 0%	0 0%	0 0%	65 10%	103 16%
Eucalyptus (E)	14	4028	70 2%	56 1%	3210 80%	279 7%	50 1%	0 0%	0 0%	22 1%	341 8%
Mixed hardwood (MH)	42	19016	9 0%	0 0%	132 1%	15,274 80%	102 1%	586 3%	58 0%	0 0%	2855 15%
Live oak (LO)	15	2068	0 0%	0 0%	14 1%	1824 88%	47 2%	0 0%	0 0%	0 0%	183 9%
California bay (CB)	5	1200	0 0%	0 0%	18 2%	435 36%	0 0%	711 59%	0 0%	0 0%	36 [illegible]
Willow (W)	11	728	0 0%	0 0%	0 0%	152 21%	0 0%	0 0%	130 18%	25 3%	[illegible]
Other (O)	5	453	141 31%	0 0%	8 2%	0 0%	0 0%	0 0%	0 0%	225 50%	79 [illegible]

Broad Vegetation Types	No. of Stands	Total Area	Conifers	Native Hardwoods	Eucalyptus	[illegible]
Conifers	42	7537	6027 80%	175 2%	[illegible]	[illegible]
Native hardwoods	62	22[illegible]84	[illegible]	19037 84%	[illegible]	[illegible]
Eucalyptus	14	4028	1[illegible] 3%	[illegible]	[illegible] 8[illegible]	[illegible] 9%

TABLE 7. Timber Typing on Small Scale Aerial Photography-San Pablo Reservoir Test Site

Ekta Aero Infrared Film; Wratten 12 + EF 2200 Filter; Scale 1/33,500
Date of Photography: August 28, 1966

(**Figures in darkest rectangles indicate accuracies achieved. Figures in other rectangles indicate errors made**).

TIMBER TYPE	No. of Stands	Total Area	Identified as: MP	PP	E	MH	LO	CB	W	Other Conifers	Out
Monterey pine (MP)	30	6424	5177 81%	93 1%	0 0%	79 1%	44 1%	0 0%	0 0%	0 0%	1031 16%
Ponderosa pine (PP)	7	660	69 10%	358 55%	0 0%	0 0%	0 0%	0 0%	0 0%	69 10%	164 25%
Eucalyptus (E)	14	4028	12 0%	27 1%	2817 70%	280 7%	0 [illegible]	58 1%	5 0%	0 0%	829 21%
Mixed Hardwood (MH)	42	19016	82 0%	0 0%	201 1%	14221 75%	121 1%	1286 7%	20 0%	0 0%	3085 16%
Live oak (LO)	15	2068	107 5%	0 0%	0 0%	1516 74%	298 14%	54 3%	0 0%	0 0%	[illegible]
California bay (CB)	5	1200	22 2%	0 0%	12 1%	550 46%	7 0%	588 49%	0 0%	0 0%	21 2%
Willow (W)	11	728	36 5%	0 0%	0 0%	225 31%	0 0%	0 0%	187 26%	0 [illegible]	280 38%
Other (O)	5	453	29 6%	249 56%	0 0%	0 0%	0 0%	0 [illegible]	0	110	65

Broad Vegetation Types	No. of Stands	Total Area	Identified as: Conifers	Hardwoods	Eucalyptus	Out
Conifers	42	7537	6154 82%	123 1%	0 0%	1260 17%
Native hardwoods	62	22284	[illegible] %	[illegible] 84%	213 1%	3195 14%
Eucalyptus	14	4028	[illegible]	[illegible]	2817 [illegible]	829 [illegible]

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TABLE 81. Timber Typing on Small Scale Aerial Photography-San Pablow Reservoir Test Site

Aerial Ektachrome Film; HF-5 (Haze-cutting)FFilter; Scale, 1/33,500
Date of Photography: August 28, 1966

(Figures in darkest rectangles indicate accuracies achieved. Figures in other rectangles indicate errors made).

TIMBER TYPE	No. of Stands	Total Area	Identified as: MP	PP	E	MH	LO	CB	W	Other Conifers	Out
Monterey pine (MP)	30	6424	5324 83%	22 0%	0 0%	86 2%	0 0%	0 0%	0 0%	31 0%	961 15%
Ponderosa pine (PP)	7	660	50 8%	210 32%	30 4%	0 0%	4 0%	0 0%	0 0%	241 37%	125 19%
Eucalyptus (E)	14	4028	76 2%	22 0%	3115 77%	226 6%	0 0%	0 0%	0 0%	56 2%	533 13%
Mixed Hardwood (MH)	42	19016	29 0%	0 0%	203 1%	15303 81%	351 2%	71 0%	48 0%	0 0%	301[illegible] 16%
Live oak (LO)	15	2068	0 0%	0 0%	26 1%	1611 78%	181 9%	38 2%	0 0%	0 0%	212 10%
California bay (CB)	5	1200	0 0%	0 0%	25 2%	751 63%	[illegible]	[illegible] 24%	0 0%	0 0%	8[illegible] 6%
Willow (W)	11	728	36 5%	0 0%	0 0%	110 15%	0 0%	0 0%	[illegible] 29%	0 0%	37[illegible] 51%
Other (O)	5	453	18 4%	157 35%	0 0%	0 0%	133 29%	0 0%	0 0%	16 3%	12[illegible] 29%

Broad Vegetation Types	No. of Stands	Total Area	Identified as: Conifers	Hardwoods	Eucalyptus	
Conifers	42	7537	6069 81%	223 3%	30 0%	[illegible]
Native hardwoods	62	22284	29 0%	18705 84%	256 1%	[illegible]
Eucalyptus	14	4028	[illegible] 4%	[illegible] 5%	[illegible]	[illegible]

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TABLE 9: Timber Typing on Small Scale Aerial Photography-San Pablo Reservoir Test Site

Panchromatic Film; Wratten 12 Filter; Scale 1/33,500
Date of Photography: August 28, 1966

(Figures in darkest rectangles indicate accuracies achieved. Figures in other rectangles indicate errors made).

TIMBER TYPE	No. of Stands	Total Area	Identified as: MP	PP	E	MH	LO	CB	W	Other Conifers	Out
Monterey pine (MP)	30	6424	4755 74%	2 0%	25 1%	474 7%	0 0%	0 0%	0 0%	0 0%	1168 18%
Ponderosa pine (PP)	7	660	69 10%	410 62%	34 5%	0 0%	0 0%	0 0%	0 0%	0 0%	147 23%
Eucalyptus (E)	14	4028	104 3%	0 0%	3011 75%	272 7%	19 0%	0 0%	0 0%	0 0%	622 15%
Mixed Hardwood (MH)	42	19016	0 0%	0 0%	160 1%	14,707 78%	240 1%	271 1%	42 0%	0 0%	3596 19%
Live Oak (LO)	15	2068	47 2%	0 0%	71 3%	1421 69%	151 7%	96 5%	0 0%	0 0%	282 14%
California bay (CB)	5	1200	0 0%	0 0%	31 3%	799 67%	0 0%	269 22%	0 0%	0 0%	101 8%
Willow (W)	11	728	0 0%	0 0%	25 3%	103 14%	15 2%	0 0%	123 18%	0 0%	462 63%
Other (O)	5	453	157 35%	165 36%	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%	131 29%

Broad Vegetation Types	No. of Stands	Total Area	Identified as: Conifers	Native Hardwoods	Eucalyptus	Out
Conifers	42	7537	5558 74%	475 6%	59 1%	1446 19%
Native Hardwoods	62	22284	47 0%	17996 81%	262 1%	3979 18%
Eucalyptus	14	4028	104 3%	291 7%	3011 75%	622 15%

Ref.	Scale	Resolution	Category	Success	Remarks
1	Pan Film 1:1,200 4x prints	0.1'	Identification of tree species (boreal forest) and estimation of tree volume from photo measurement of crown cover and tree height	Accuracy was ± 15% of groundrestimated plot volumes with 95% confidence. Only about 17% of the trees were incorrectly identified as to their species group; pine, spruce, fir or hardwood	
45 Part #1	1/32,000 Pan film Wratten 12 1/32,000 Ekta IR Wratten 15	5.5' 4.5'	Identification of pine (2 species), hardwood, redwood, eucalyptus, chaparal, grassland, orchard	77% accuracy with Pan film. 89% accuracy with Ekta IR film	
45 Part #2	See Table 10				

TABLE 10. Feasibility of Interpreting, on Low resolution Photography, the Identifying Characteristics of the Five Major Vegetative cover types Found to Occur Within the San Pablo Reservoir Test Site

Vegetation Type	Identifying Characteristic	Sensor Specification	Ground Resolution = 6'		Ground Resolution = 60'			Ground Resolution = 200'		
		B & W Plus X Single Season	Color Infrared Single Season	Color Infrared Two Seasons	B & W Plus X Single Season	Color Infrared Single Season	Color Infrared Two Seasons	B & W Plus X Single Season	Color Infrared Single Season	Color Infrared Two Seasons
MONTEREY PINE	Tone or Color	+	++	++	-	+	++	--	-	+
	Crown Detail	-	+	+	--	--	--	--	--	--
	Height/Density	+	+	+	--	--	-	--	--	--
	Physiography	+	+	++	-	-	+	--	--	--
EUCALYPTUS	Tone or Color	+	++	++	-	+	++	--	-	+
	Crown Detail	-	+	+	--	--	--	--	--	--
	Height/Density	+	+	+	--	--	-	--	--	--
	Physiography	+	+	++	-	-	+	--	--	--
MIXES HARDWOOD	Tone or Color	+	++	++	-	+	++	--	-	+
	Crown Detail	-	+	+	--	--	--	--	--	--
	Height/Density	+	+	+	--	--	-	--	--	--
	Physiography	+	+	++	-	-	+	--	--	--
CHAPARRAL	Tone or Color	+	++	++	--	+	++	--	-	+
	Crown Detail	-	+	+	--	--	--	--	--	--
	Height/Density	-	+	++	--	-	+	--	--	--
	Physiography	-	+	++	--	-	-	--	--	--
GRASSLAND	Tone or Color	++	++	++	+	++	++	--	+	++
	Crown Detail	-	-	--	--	--	--	--	--	--
	Height/Density	+	+	++	[illegible]	-	+	--	--	--
	Physiography	+	++	++	--	-	+	--	--	--

Legend: ++ consistently detected and identified; + occasionally detected and identified; - rarely detected and identified; -- not detected and identified.

Ref	Scale	Resolution	Category	Success	Remarks
48	1:20,000 Positive Transp. 3x Enlargement ∴=1:8,000	2.0'	Estimate the rate of dwarf mistletoe spread and compute the volume lost to this disease (black spruce forest). Volume estimated from photo plots using local photo volume tables and crown closure and stand height.	Spread of dwarf mistletoe infection successfully detected and volumes were estimated.	
81	1:8,000 Ansco D/200 Color 9" x 9" Transp.	1.4'	Determine the mortality of douglas fir as a result of an epidemic of douglas fir bark beetle in California	Proved to be an efficient survey of trees killed. Cost = $0.005/acre	Used the photo interpretation and a stratified two stage probability sampling design.
32	70mm Transp. Super Ansco (ASA 125) Color 1:3960 1:1584 1:1188 Plus X Aero (ASA 80) 1:3960 1:1584 1:1188	 0.5' 0.2' 0.15' 0.9' 0.3" 0.25'	Identify, using various configurations of film and scale, 14 tree species in Ely, Minn. The species are fir, spruce, pine & hardwoods.	Color film is superior to Pan for identifying individual tree species. Accurate identification (>67% correct) of species requires color film of 0.2' ground resolution or better. At 0.9' the accuracy was <63%.	

Ref.	Scale	Resolution	Category	Success	Remarks
3	Super Ansco 1:7920 Transp.	1.7'	Estimate Fraser fir mortality and balsam woolly aphid infestation trend [illegible] years.	Regression analysis between photo interpretation and ground estimates was significant at the 95% confidence limit.	
28	6-5/8" x 7" format Transp. Pan (A25 Filter) 1:3960 1:7920 1:15,840 Color (A25 Filter) 1:3960 1:7920 1:15,840	 1.1' 2.2' 4.4' 0.65' 1.20' 2.6'	Determine and compare the interpretation accuracy of photographs and scale in determining southern pine beetle-killed trees.	Interpretation on color film was more accurate than that on Pan. A scale of 1:7920 was the best compromise of accuracy and cost. Ground cruising proved to be the most expensive and time consuming.	
56	1:4000 1:10,000 1:16,000	0.4' 0.9' 1.5'	Laboratory determination of reflectance in trees due to changes in moisture content and salinity ($CaCl_2$, NaCl)	Previsual detection was unsuccessful using Kodachrome II w/no filter, or Infrared (Ekta IR w/Wratten #12 filter)	

Ref.	Scale	Resolution	Category	Success	Remarks
56	70mm Pan/Wratten #12 filter IR Aero/ Wratten #39B filter Ekta (Aerial) Ekta IR/ Wratten #12 Filter 3" F.L.	No data	Field identification of poplar, moisture stressed trees Field identification of oak moisture stressed trees.	Moisture stressed trees could not be distinquished from control plots on any of the imagery Moisture stressed trees were readily apparent by all imagery	
68	Color IR 1:3960 1:7920 Super Ansco 1:3960 1:7920 Transp.	 0.5' 1.0' 0.5' 1.0'	Compare films and scales in their ability to identify oak wilt disease	The greatest success was with the super Ansco at 1:3960 (0.5' Resolution)	Compared to "conventional" methods, remote sensing as tested here proved no more effective and yet it cost 20 times what conventional techniques cost.
22	Pan 1:60,000 1:40,000 1:20,000 Color 1:60,000 1:40,000 1:20,000 Color IR 1:60,000 1:40,000 1:20,000	 13.1' 8.7' 4.4' 7.9' 5.2' 2.6' 7.9' 5.2' 2.6'	Compare photo interpretation from various film and scale configurations	Color photography recommended for: 1) Mapping cultural features 2) Military photo interpretation 3) Mapping agricultural field crops by type & soils. Color IR recommended for: 1) Studies of canals and waterways 2) Identification of diseased trees or vegetation features 3) Mapping drainage patterns Panchromatic is inferior to both Color & Color IR.	