REMOTE SENSING APPLICATIONS IN FORESTRY

A report of research performed under the auspices of the

Forestry Remote Sensing Laboratory,
School of Forestry and Conservation
University of California
Berkeley, California

A Coordination Task Carried Out in Cooperation with

The Forest Service, U. S. Department of Agriculture

For

EARTH RESOURCES SURVEY PROGRAM
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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INVENTORY AND ANALYSIS OF NATURAL VEGETATION AND RELATED RESOURCES FROM SPACE AND HIGH ALTITUDE PHOTOGRAPHY

by

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Range Management Program
Agricultural Experiment Station
Oregon State University

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ABSTRACT

A high altitude photo mosaic resource map of Site 29 was produced which provided an opportunity to test photo interpretation accuracy of natural vegetation resource features when mapped at a small (1:133,400) scale. Helicopter reconnaissance over 144 previously selected test points revealed a highly adequate level of photo interpretation accuracy. In general, the reasons for errors could be accounted for.

The same photo mosaic resource map enabled construction of interpretive land use overlays. Based on features of the landscape, including natural vegetation types, judgments for land use suitability were made and have been presented for two types of potential land use. These two, agriculture and urbanization, represent potential land use conflicts.

Further activity was conducted in demonstrating the usefulness of the natural vegetation (and related features), agriculture and land use legends. Specifically, the broader hierarchical categories are shown in examples of how a space imagery indexing system might be annotated on an individual frame basis.

Several meaningful contacts were made with potential user groups during the fiscal year. Greatest interest centered around the potential value of resource inventory and analysis as shown by using the Site 29 high altitude photo mosaic and interpretive overlays. One formal and two informal seminars have been held with National Forest Service groups in Oregon. Two additional USFS forest supervisor's offices have expressed an interest in learning of our approach to resource inventory. In Arizona, contact has been established with a state planning agency as well

as with Arizona congressmen involved in state planning. An inquiry has been received from a third state agency which is interested in our research products. Future developments with these and other users are anticipated as there becomes greater realization for practical application of our research.

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INTRODUCTION AND BACKGROUND

At the time of our initial involvement in the Earth Resources Survey Program of the National Aeronautics and Space Administration, late in 1966, little attention had been paid to the potentialities for vegetational interpretations from space photography. In December of that year C. E. Poulton of Oregon State University and Ed Roberts of the Forestry Remote Sensing Laboratory organized and conducted the first on-site evaluation of the potentiality for mapping and identification of natural vegetational features of the earth's surface from a frame of Gemini IV photography taken in the Tucson, Arizona vicinity (Carneggie, Poulton and Roberts, 1967). These results were sufficiently encouraging that a research program was proposed through the Forestry Remote Sensing Laboratory to develop rangeland vegetational inventory and analysis capability through the use of space photography. In the following year, this program was modestly funded through the FRSL and serious investigation and procedural development research initiated. The new research was able to build on a background of some four years of resource analysis research and many years of range ecology research in diverse environments that had been carried out by Poulton and his graduate students at Oregon State University.

From this initial work by Roberts and Poulton, the following were evident:

1. Many kinds of vegetation-soil systems were uniquely imaged on the Gemini photography.

2. When rangeland resources are considered in the context of vegetation-soil systems as the group at Oregon State University had traditionally been doing since the early 1960's, the more openly vegetated areas presented unique advantages over forested lands for investigating the potentials and limitations of space photography as a resource inventory and analysis tool. In these environments it is possible to see the whole ecosystem, that is, usually to see all layers of the vegetation and in arid environments, the amount of exposed soil surface that is normally expressed in each ecosystem.

3. While scale is small and resolution much reduced over aerial photography with which we were accustomed to using, space photography presented some unique advantages through its synoptic coverage. The smaller scale also enhances the economic feasibility of color and color infrared photography.

4. Depending on vegetation density, image characteristics were controlled on the one hand by vegetational features (in moderately dense to dense vegetations) and by soil surface features in the more sparsely vegetated areas. Because of the success of our prior research on vegetation-soil relationships that had repeatedly and successfully related phytosociological vegetation classes to soil taxonomic classes, we felt that there was tremendous potential interpretive power for meaningful image delineation and identification through understanding the vegetation-soil relationship.

5. Especially in the desert environment, relationships between landforms and vegetation were good. Thus another important photo identification technique became possible through reading the landforms and relating these to the ecosystems that comprise the landscape (vegetation-soil systems).

6. Comparisons of our initial mapping attempts with existing synoptic vegetational resource maps of the region show very clearly that many highly meaningful corrections in vegetational resource maps could easily be made through the use of space photography.

7. Certain important vegetational features could not be discriminated or identified from the space photography. Therefore, in spite of the power of this new system, ground work would still be important in operational surveys and more sophisticated remote sensing systems should be investigated for their discriminating power in these instances.

Also in 1966, Carneggie and Poulton set the stage for a comprehensive approach to rangeland resource inventory problems. By putting together a comprehensive assessment of rangeland resources, including distribution and an evaluation of current range resource understanding, we were able to suggest possibilities for meaningful investigations. To the best of our knowledge, this was the first time that a comprehensive statement had been made about the potential importance of rangeland resource areas of the nation and the globe in the NASA Earth Resources Survey Program, and the strength that might be derived through proportionate concentration of effort on these kinds of resource areas.

Long before "ecology" and "ecosystem" became common words of the street and press, range resource professionals were in the habit of looking at the resources in terms of an ecosystem. We were used to thinking of resource areas in the context of integrated resource management; concepts of multiple use and coordinated use by domestic livestock, wild animals and man were inherent in our professional nature. It was, therefore, second nature for us to approach these problems by considering all features of the vegetational resource in relation to the soil environment, and these, in turn, in relation to the multiplicities of uses that may impinge on each area of land. This was the philosophy from which our investigations were approached.

The ecological approach has been thoroughly demonstrated in Europe, Canada, Australia, South Africa and the United States and has guided our research effort. When all of the plant species that occupy each unique kind of landscape are considered, vegetation is classifiable into discrete units if the proper plant sociological principles, concepts and procedures are followed in deriving the classifications. These vegetational classes do, in fact, mirror the effective environments they occupy; that is, they provide a sound, biological integration of all of the separate and numerous unknown or unmeasured environmental factors into a summation known by resource ecologists as "site" or effective environment. An understanding of these ecological units is essential to the understanding of environment and to the manipulation of man's activities in relation to his environment. Such an understanding tells us which portions of the landscape are virtually identical or analogous, which portions are similar with a suggestion of the degree of similarity, and which portions are different or contrasting. The secret is in learning to read the ecology of the landscape, the area of prime expertise of the range resource scientist and resource ecologist. Since these vegetational units do mirror the biologically relevant soil environments, the vegetation-soil systems are the earth surface features that cause the patterns in remote sensing imagery taken across such landscapes. In addition, these unique ecosystems, because of their features of species composition, spacing, soil cover and soil surface characteristics, directly give rise to the identifiable features of each image whether they are recorded in broad-band photographic mode, multispectral or even multidate modes. Thus the understanding not of individual plant species but of plant communities and vegetation-soil systems is the key to interpretation of remote sensing imagery for resource inventory and analysis purposes in all naturally vegetated landscapes.

Building on these concepts, our research has moved ahead since 1966 with the central purpose of developing and demonstrating how these ecological and resource concepts can be applied in the analysis of space and high altitude imagery to produce maps and associated information of value in making decisions about naturally vegetated landscapes, and in enabling man to optimize his use of these resources and minimize adverse impact of his activity on the terrestrial environment.

We soon realized the tremendous advantage of synoptic coverage in showing complex interrelationships of resources and land use, and in establishing a base for decisions in land use policy and planning at the county, state, regional and national level. The central thrust of our research to date has been on preparing those kinds of ecological resource inventories that meet these needs as society seeks to guide and direct the activities of man in relation to his environment.

With the advent of the synoptic coverage of space photography and the capability of looking repetitively at whole regions and continents in a short time span from space platforms, we could no longer tolerate the individuality of dozens and dozens of legend systems for annotating features imaged. We were profoundly impressed by the need for a common legend system for expressing vegetational, land use and key environmental features and which, as a minimum, must be applicable in spite of land ownership boundaries, political boundaries and agency responsibilities throughout the region and, hopefully, throughout the nation and the world. We set about to develop and test such a legend system. We feel that we have put together a concept that is valid, logical and workable on an operational basis, as well as being highly compatible with the objective of information computerization, data handling and management; we have successfully demonstrated its adaptability in much of the desert region of southwestern United States. Work is continuing to provide leadership in further adaptation to different ecological regions and provinces. We feel that this "common language" for describing landscapes is one of our major contributions because we were not only able to achieve this goal but to make our natural vegetation legend system compatible with the land use and extractive industries legend that is already widely in use in the United States (U. S. Department of Transportation, 1969; Johnson, C. W., et al., 1969).

The two strongest features of the legend system are:

1. It provides for hierarchical treatment from broad levels of generalization to highly specific levels of detail within the same system.

2. It makes possible a unified symbolization of natural vegetational features, land use, landform, surficial geology and soils characteristics

of specific landscapes at a level of detail appropriate for a broad spectrum of resource, land use and environmental problems.

We have been highly successful in putting together and carrying to user groups a resource inventory and examples of land use analysis of a major part of Maricopa County, both with the use of Apollo 9 photography and high altitude photography provided by NASA. Work on a similar photo mosaic map for the Ft. Huachuca Test Site 220 will be completed in the next few months. In relation to future programs of the National Aeronautics and Space Administration, the primary value of these high altitude photographic maps in Test Sites 220 and 29 will be as ground truth documents against which the performance of ERTS, SKYLAB and subsequent satellite systems can be judged and from which more effective operational systems can be developed. This work as a basis for land use planning, zoning and legislation has been presented to many groups. Interest in the work and reception has been very good. Willingness to make real life application has been repeatedly expressed but time has not yet permitted realization of this goal. The door to this eventual payoff is open and the welcome mat is out.

CONTACTS LEADING TO POTENTIAL PRACTICAL APPLICATIONS OF RESEARCH RESULTS

During the past year, considerable interest has developed among potential users relative to the resource analysis procedure and products developed by our laboratory personnel. Initial stimulation resulted from our resource mapping on Apollo photography in Maricopa County (Poulton, et al., 1970). Subsequent interest has been developed largely as a result of resource mapping which we have done jointly with personnel of the Forestry Remote Sensing Laboratory, using high altitude photography of the same area (Pettinger, et al., 1970). Summarized in that report is a section dealing with interest which the Bureau of Land Management has developed in our philosophies and techniques of remote sensing as they apply to resource analysis. It is the desire of the California State Directors Office of the BLM to use this approach to resource analysis for planning recreational and other activities in the California desert.

In May of this year, an invitational presentation was given to a Pacific Northwest regional group of United States Forest Service landscape architects. During the workshop, potential applications of remote sensing were described, with particular emphasis given to forest applications. Partly as a result of that interchange, a seminar was requested by the Mt. Hood National Forest Supervisor's Office to be given to project leaders of resource studies. The project leaders are involved in a pilot project to develop a system of resource analysis detailed enough for the district level yet broad enough for the supervisor level. As a result of that seminar, the project leaders expressed an interest in adopting the legend concept, field procedures and information display techniques all of which have been developed partially through our NASA supported research in Arizona. In midsummer, two similar seminars were held upon request for members of the Siuslaw Forest Supervisor's Office. Interest was expressed in utilizing high altitude and perhaps satellite imagery in conjunction with resource inventory and analysis for planning in the Siuslaw National Forest. Additional contacts are anticipated with Forest Supervisors' offices due to the previous USFS seminars on remote sensing applications.

More recent events and contacts have brought us closer to realizing a long standing goal, specifically that user groups find direct, practical use of our Arizona research results. The possibility exists that our natural resource inventory and analysis procedures, using remote sensing techniques plus the mapping work completed and underway in the Phoenix and Tucson areas, may be used in the planning and zoning of counties in Arizona.

The first event was a meeting with C. W. Myers of the Arizona Department of Economics, Planning and Development. The Department is preparing a mathematical model employing composite computer mapping to be used to recall stored information relative to specific geographical sites under consideration for development, and to conduct analyses which would evaluate each type of information. We were able to suggest how ecological inputs could be made by utilizing the resource inventory techniques and high altitude photo mapping which we have done in the Phoenix area. Meaningful ecological information as well as the socio-economic information being gathered by that group could be used in computer mapping. In the next few months we anticipate having the opportunity to carry this effort further by working with personnel of the Department to insure proper input and interpretations of ecological resource information. In this manner, planning of future developments in counties or larger regions could have ecologically and economically sound bases for decision making.

The second event was an informal meeting with Mr. Tim Barrow, Speaker of the Arizona House, and Mr. William Jacquin, President of the Arizona

Senate. This session resulted following an evening conversation with a man actively concerned with environmental problems and Arizona politics who asked us to make the presentation and arranged the meeting. Again, we presented an explanation of our NASA-supported research in southern Arizona and stressed the implications that such ecological inventories, conducted at a scale possible with space and high flight imagery, could have on regional policy, planning and zoning decisions. These men are definitely interested in the kinds of information we have, and especially the understanding that the information provides in light of current agricultural, urban and recreational expansion conflicts they now face in southern Arizona. They have invited us to make a presentation before a joint meeting of the House and Senate Natural Resources Committees and the Environmental Committee of the House. Both legislators feel that such a program would be enlightening for their lawmakers and would help direct their considerations for initiating legislation which might require, for instance, that counties accomplish zoning regulations that reflect a knowledge of the ecological classification of the lands being zoned.

The Arizona Department of Highways has recently requested a copy of the complete resource and land use legend that we have been using. Personnel of the Department, who are engaged in developing a land use classification scheme for the entire state, were especially interested in the format and procedures we have developed. A similar interest has been expressed by persons inventorying the resources and land uses of Cochise County. This work is being conducted for the purpose of planning the future development of that county. Most of western Cochise County is included in Test Site 220; consequently, some of our classification and mapping work directly pertains to the geographical area with which workers in that county are concerned.

Additionally, inquiries have come from an archeologist studying past Indian activity in northern Maricopa County, and from a citizens' group concerned with land use planning in Arizona.

Some of these contacts have been made by persons who first learned of our work from an article written by one of our crew and published in the Arizona Farmer-Ranchman (Faulkner, 1971).

INTERPRETATION ACCURACY CHECKS

Introduction

One of the main research objectives of the NASA funded Range Management group at Oregon State University has been to demonstrate that both high altitude photographs and space photographs are applicable to an ecological resource inventory. In so doing we have utilized currently available philosophies relating to natural vegetation classification and legend development. The legend system we have developed is ideally suited to various scales of photographic resource maps because it is based on a hierarchical classification scheme. One of the products of our resource classification and analysis work has been the production of a resource map displayed on a photo mosaic constructed from NASA high altitude photography. In December 1970, this high altitude photo mosaic map was presented to NASA as part of a report to the Earth Observations Division of the Manned Spacecraft Center (Pettinger, et al., 1970). Figure 4 is a reduced scale copy of this map.

The development of natural resource photo maps manifests unique problems related to the photo interpretation of natural vegetation and related features. First the vegetation must be classified. If this job has not already been done, the resource analyst must accomplish it and assign the identified units to proper positions in the legend. The same photography used as the mapping base can also be used for planning and carrying out the field work necessary for determining correct vegetation classification. By coordinating the photography with the field work, basic relationship information between vegetation subjects and photographic images can be compiled. In addition, a realistic assessment can be made of the image variability that can represent the same vegetation type and, conversely, of the vegetation variability that apparently can be represented by the same photographic image. This information can be fitted into a set of photographic interpretation aids. Even with this degree of background information, errors can commonly occur and usually can be grouped according to explanations of their occurrence. We have found that one frequent source of error results from interpretation of vegetation inter-grades and/or complexes. Also, interpretation identifications of a hierarchical classification scheme may be incorrect at one level, but correct at a level that is a step or two more generalized. A user of the photographic map soon realizes that some errors are less critical than others. A representative evaluation of error magnitude and import is presented in the section which follows.

Resource Map Development

The purpose of this section is to explain interpretation processes, accuracy checks and accuracy tolerance limits as applied to a representative resource mapping problem. The area selected was that portion of Maricopa County, Arizona covered by Apollo 9, S065 frame number 26A-3801. This area was later photographed by NASA as part of its high altitude photography program and designated NASA Test Site 29. High altitude ektachrome photographs (1:124,000) of this area, taken on July 28, 1970, were reproduced in black-and-white for use in making the photo mosaic map. Figure 1 shows the area covered by the photo mosaic as well as the locations of ground truth observations and areas covered by aerial reconnaissance.

Intensive ground truth information was collected along a strip north of Phoenix between Hassayampa Wash and the Mazatzal Mountains. Another block south and southwest of Phoenix (Rainbow Valley to South Mountain) was also ground checked. The ground truth information was obtained at sites selected on pretyped photographs. Each site was pin-pricked on the photograph and located with map coordinates for future reference. At each site a complete species list was made of the vegetation. Species prominence, cover and sociability were recorded. Information on landform and soil types also was noted. At each ground truth station other information pertinent to the ecosystem was obtained. This included estimates of watershed, aesthetic and recreational values, forage and wood products, possible land-use conversions and other potential uses, together with notes on animal use (Pettinger, et al., 1970). Enough ground information

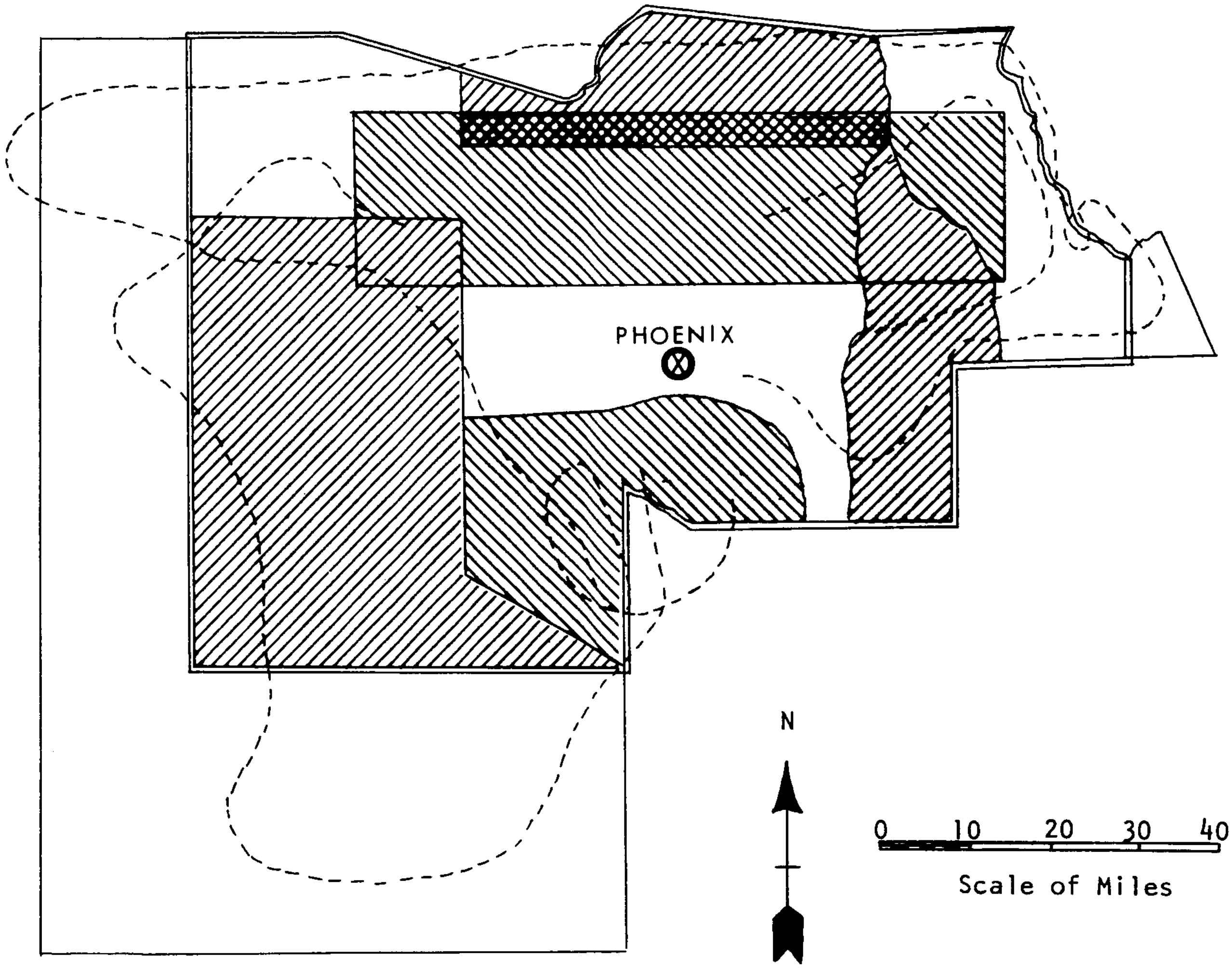


Figure 1. Location of ecological resource inventory and classification activities within Maricopa County, Arizona.

-------- Flight path of aerial reconnaissance.

═══ Area of county included within photo mosaic resource map (see Figure 4)

Areas of intensive ground information.

Areas of photo interpretation accuracy check.

was obtained to give our crews confidence that we had sufficient samples from each photographic image class in the intensive sampling areas. It was from this ground truth information that the legend units were assigned to vegetation-soil systems and descriptions made of those systems. In addition, the photographic images were carefully analyzed until we had confidence that we knew the subject-image relationships in the ground truth areas.

In addition to the actual ground information, low altitude aerial reconnaissance flights were conducted using fixed-wing aircraft. These reconnaissance flights were used to determine the range and location of the vegetation-soil systems, and to determine whether new legend units or additional ground truth was necessary for a complete description of the county.

Using a combination of ground truth data, aerial reconnaissance information and photo interpretation, we made a space photo map of the area, using three 9" x 9" enlargements of Apollo 9 color IR photos (Poulton, et al., 1970). Photo interpretation was necessary to expand the ground truth information to peripheral areas of the county. This map showed the broad landform and vegetational features of the landscape and served as a stratification for the high altitude photo mosaic map.

In preparation for a more detailed resource map on larger scale photographs, the legend was slightly revised and a photo mosaic constructed of high altitude photography. Using basically the same information as with the space photo map, the high altitude photographs were mapped at a more detailed level. The completed map displayed natural vegetation resources, agriculture and urban land use in a portion of Maricopa County, Arizona. As on the space photo map, these map delineations and annotations were based largely on photo interpretation decisions. To check interpretation accuracy a simple test was designed.

Procedure

Through the cooperation of the U. S. Air Force and personnel of Luke Air Force Base a helicopter was made available which enabled a crew to visit several remote sites within the interpreted areas. Arrangements for this military support were made by Robert H. Miller, USDA Remote Sensing Technical Coordinator. Sample sites were preselected to represent all the natural vegetation types. The number of sample sites for each type varied in proportion to the area covered by that type. Sample site locations were chosen by first randomly selecting the interpreted units to be sampled; then uniformly scattering the actual sample points. Care was taken to avoid possible vegetation boundaries and yet to spread the samples throughout the delineated units.

A total of 256 Potential sample sites were selected. These were grouped into six areas arranged in priorities. The highest priorities were placed on areas that had: (1) the minimal amount of ground truth information, and (2) topography that insured safe use of the helicopter. The helicopter was available for only two days at the time when the accuracy check was being conducted. This necessitated a reduction in the anticipated number of sites that could be visited. In the final analysis, three of the highest priority areas were selected for sampling (Figure 1). In all, 144 samples (spot checks) were taken. Although not all sites nor types were sampled this still enabled us to compile meaningful statistics.

The preselected sample sites were plotted on a slightly reduced (1:133,400) scale copy of the high altitude photo mosaic* and a tentative flight path determined. At most sites the helicopter was put into a tight circle about 200 feet in diameter just far enough above the ground to give a good overview of the vegetation below, while plant species presence and associated prominence ratings were recorded. In hilly terrain the helicopter maintained a forward attitude following the contour and aspect as close to the preselected site as possible. Thus information was recorded from a strip approximately a quarter mile long rather than a circle as in more level areas. When closer examination of the vegetation was necessary a near hover was maintained just above terrain. While on site no attempt was made to associate this information with the previous photo interpretation or to assign legend units.

Results and Discussion

The sampling information was utilized in the lab in four ways. First, individual sites were classified according to the natural vegetation legend. Second, a comparison was made with the previously described legend units to determine if there was evidence suggesting that new units were needed or that descriptions required changing. Next, the sample site information was compared with the interpreted map; accuracy

*The copy used in the accuracy check was "naked", that is, without the resource overlay. The purpose of using a naked copy of the mosaic was to minimize the change of bias on the part of the spot checking crew.

levels and other statistics were then compiled. Finally, work was initiated to update both the photo map and the legend where necessary. Such work has not yet been completed as of this writing.

Table 1 graphically displays the legend units involved in the accuracy check. This is a comparison between the units shown on the interpreted portion (interpretation units) of the photo mosaic map and the accuracy check information (actual units). This table also shows a comparison between correct interpretations, errors of omission and errors of commission. The errors shown in this table are absolute errors; a more meaningful presentation of the comparison between interpreted units and accuracy checks is shown in Table 2. This table displays the same information but summarized by broader legend units. This second table along with Table 3 shows that the interpreters did a better job than was initially indicated in Table 1. Table 3 is a summary of the types of differences found and the seriousness of each interpretation error. Nearly 57 percent of the samples agreed with the interpreted areas they represented. Twenty-five percent disagreed only at the most specific level of legend classification and in 2.8 percent a major component of the unit was omitted. These errors total 27.8 percent and represent the misinterpretations which would not seriously affect judgments relative to land use planning. In most cases these units differed in the presence or absence of a single key plant species. This species often was a low shrub that did not greatly affect the photographic image (Figure 2). Another type of interpretation error that became apparent was due to the inconsistent relationship displayed by the interfluve/runnel complex in a vegetation-soil system. In many cases distinct vegetation

Table 1. Comparison Between Legend Units Displayed on Interpreted Photo Mosaic Map and Units Determined through Helicopter Accuracy Checks.

The numbers (321.11, 321.21, etc.) in the row across the top of the table represent those legend units identified by photo interpretation of high altitude photography and delineated and annotated on the photo mosaic map. These units are explained in the descriptive legend accompanying the mosaic (Figure 4).

The column at the left indicates those legend units identified from the data gathered at the accuracy check points. Each row of the table begins with one of these legend units and the distribution of the numerals along a row indicate how the representatives of the legend unit were identified by photo interpretation. For example, in the row designated 321.11 nineteen check points had been previously and correctly photo interpreted as 321.11, and seven were incorrectly identified as 321.21. Because these latter seven were actually 321.11 units interpreted as another subject they represent "errors of omission".

In the column headed 321.11 the numerals indicate that nineteen 321.11 accuracy check points had been previously interpreted correctly. There were other subjects (321.12, 321.15 and 321.21) which had also been identified as 321.11 when they were not. These incorrect identifications are called "errors of commission".

Calculation of percent correct, omission and commission is demonstrated in the following example. Interpreted units (denoted A) are sampled in the accuracy check (denoted B). A comparison is made between the interpreted units (A) and the accuracy checked units (B).

Correct = A agrees with B
Omission = Area identified in B not included in A
Commission = Area interpreted in A does not agree with B

$$\% \text{ Correct} = \frac{\text{Number of A's that agree with B's} \times 100}{\text{Total number of B's}}$$

$$\% \text{ Omission} = \frac{\text{Number of areas identified in B not included in A} \times 100}{\text{Total number of B's}}$$

$$\% \text{ Commission} = \frac{\text{Number of areas interpreted in A not agreeing with B} \times 100}{\text{Total number of A's}}$$

		INTERPRETED UNITS										Actual Total Number	% Error of Omis-sion
		321.11	321.21	321.22	321.23	321.23	321.41	321.9	321.93	331.	342.1		
ACTUAL UNITS	321.11	19	7									26	27
	321.12	5										5	100
	321.15	11	9									20	100
	321.21	4	11	4	7			1				27	59
	321.22		1	18	3							22	18
	321.23		2	2	26		1					31	16
	321.9							1				1	0
	321.92							1	1			2	50
	321.93								2			2	0
	331.2									1		1	0
	342.1										3	3	0
	361.2										1	1	100
	100								1			1	100
	400					1						1	100
	484					1						1	100
	Total Number Inter-preted	39	30	24	36	2	1	3	4	1	4	144	
	% Error Commission	51	63	25	28	100	100	33	50	0	25		

Table 1. (See caption on facing page.)

		INTERPRETED UNITS				Actual Total Number	% Error Omission
		321.1x*	321.2x*	321.9x*	Other Units		
ACTUAL UNITS	321.1x*	35	16			51	31
	321.2x*	4	74	1	1	80	8
	321.9x*			5		5	0
	Other Units			1	7**	8	---
	Total Number Interpreted	39	90	7	8	144	
	% Error Commission	10	18	29	---		

* The x (as in 321.1x) refers to all types represented by the other digits (as 321.1 types).

** Four of these were correct interpretations.

Table 2. Summary of Interpretation Accuracy Data by Broader Legend Groupings. See Table 1 for detailed groupings.

Degree of Acceptability	Situation	Number in Sample	Percent of Total
No error	Complete agreement between accuracy check and interpreted map.	82	56.9
Errors present but land use implications not greatly affected	Units differ only at most specific digit on legend system (differ only among secondary species).	36	25.0
	Units differ only by one major species.	4	2.8
Some land use implications would be affected	A complex of units where a lesser component was interpreted instead of the major one.	16	11.1
Unacceptable errors	Other errors.	6	4.2
TOTAL		144	100.0

Table 3. Summary of Accuracy Check of High altitude Photo Mosaic Map by Type of Error.

Figure 2. Ground photo of 321.12 type (Larrea tridentata with Franseria dumosa). Note the low, gray shrub (Franseria dumosa) scattered between the taller, greener Larrea. The presence of this shrub is the difference between a 321.11 legend unit and the 321.12 shown here. The color, size and distribution of this shrub do not sufficiently affect the aerial photo image to enable a photo interpreter to distinguish these vegetation/soil systems from 321.11 which contains only Larrea (with annuals during portions of some years). Note especially the light tone of the Franseria and the lack of contrast between it and the soil surface.

boundaries exist between runnels and interfluves while in other cases runnel vegetation is also found on the interfluves. This is the basic reason why several misinterpretations existed between 321.1 types and 321.21 types as shown in Tables 1 and 2. From these tables it can be seen that the greater share of misinterpretations was in interpreting 321.1 types as 321.2 types rather than the reverse. Figure 3 shows a photo image which is composed of units we have classified as 321.21 and 321.11 vegetation types. From a photo interpretation standpoint, the lower left hand portion of the photo would be classified as 321.21 while the remaining two thirds of the frame would be called 321.11. Ground observations might reveal, however, that the presence of "runnel type" vegetation on the interfluves in the area labeled 321.11 would necessitate a change to 321.21 for at least part of the area. Larger scales of photography would help prevent this type of photo interpretation error.

In addition to the accuracy statistics compiled for the high altitude photo mosaic map, accuracy checks were made on the space photo map (Poulton, et al., 1970) of the same area. The same accuracy check information was used for both resource maps. The summary given in Table 4 shows that the accuracy levels were quite comparable. A slightly larger percentage (60.4 percent compared to 56.9 percent) of the areas checked were correctly interpreted on the space photos. There was also a higher percent (11.1 percent compared to 4.6 percent) of "not acceptable" errors on this map. The types of errors were basically the same.

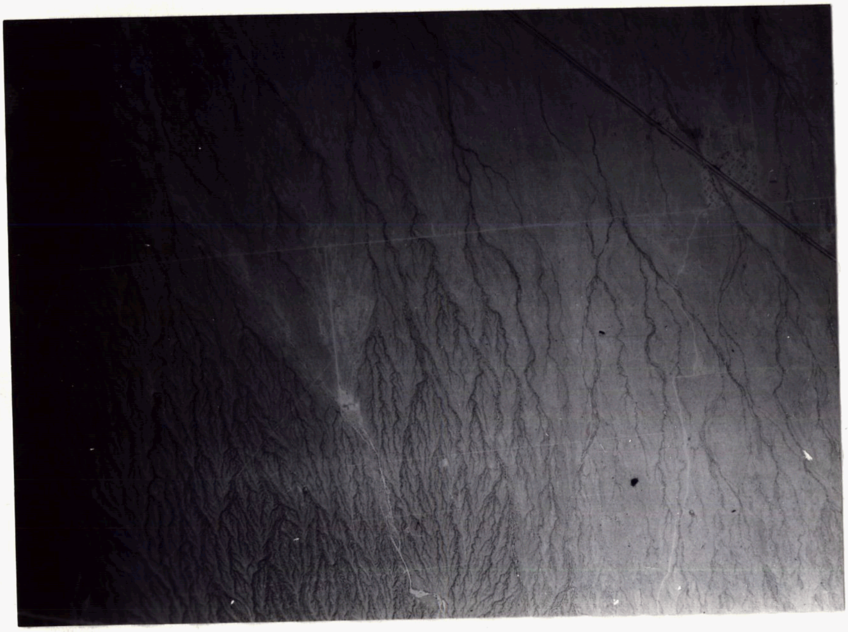


Figure 3. Portion of high altitude photo showing different runnel/ interfluve complexes. Note the spacing and complexity of the runnels. In the upper right portion of this photo the runnels are widely spaced while in the opposite corner they are quite close together. In both cases, the land is flat and the runnels are only slight depressions. Interpretation of the widely spaced runnel system would be based almost entirely on the interfluve vegetation/soil system. The other areas are more difficult to interpret due to the intricate pattern, although the same vegetation may continue across the entire photo.

Degree of Acceptability	Situation	Number in Sample	Percent of Total
No error	Complete agreement between accuracy check and interpreted map.	87	60.4
Errors present but land use implications not greatly affected	Units differ only at most specific digit on legend system (differ only among secondary species).	27	18.8
	Units differ only by one major species.	3	2.1
Some land use implications would be affected	A complex of units where a lesser component was interpreted instead of the major one.	11	7.6
Unacceptable errors	Other errors.	16	11.1
TOTAL		144	100.0

Table 4. Summary of Accuracy Check of Space Photo Mosaic Map by Type of Error.

Summary

In presenting a resource map it is highly desirable to display the most accurate product available. Complete accuracy, however, would depend upon complete ground truth information. The question then is how much error and what kinds of errors can be allowed for the map to still be useful. We feel that the levels indicated here of 4.2 percent unacceptable errors and the total 15.3 percent error that would affect land use decisions are within the tolerance limits. This test enabled us to specify the types of errors that were most commonly made, the legend units that were most often involved and, in each instance, the percent error that was present. The results which we obtained strongly suggest that high altitude photographs of the quality and scales (1:124,000) provided by NASA in Test Site 29 are highly compatible with and desirable for display of broad scale ecological inventories. Some specific uses of the photography are elaborated upon in the following section.

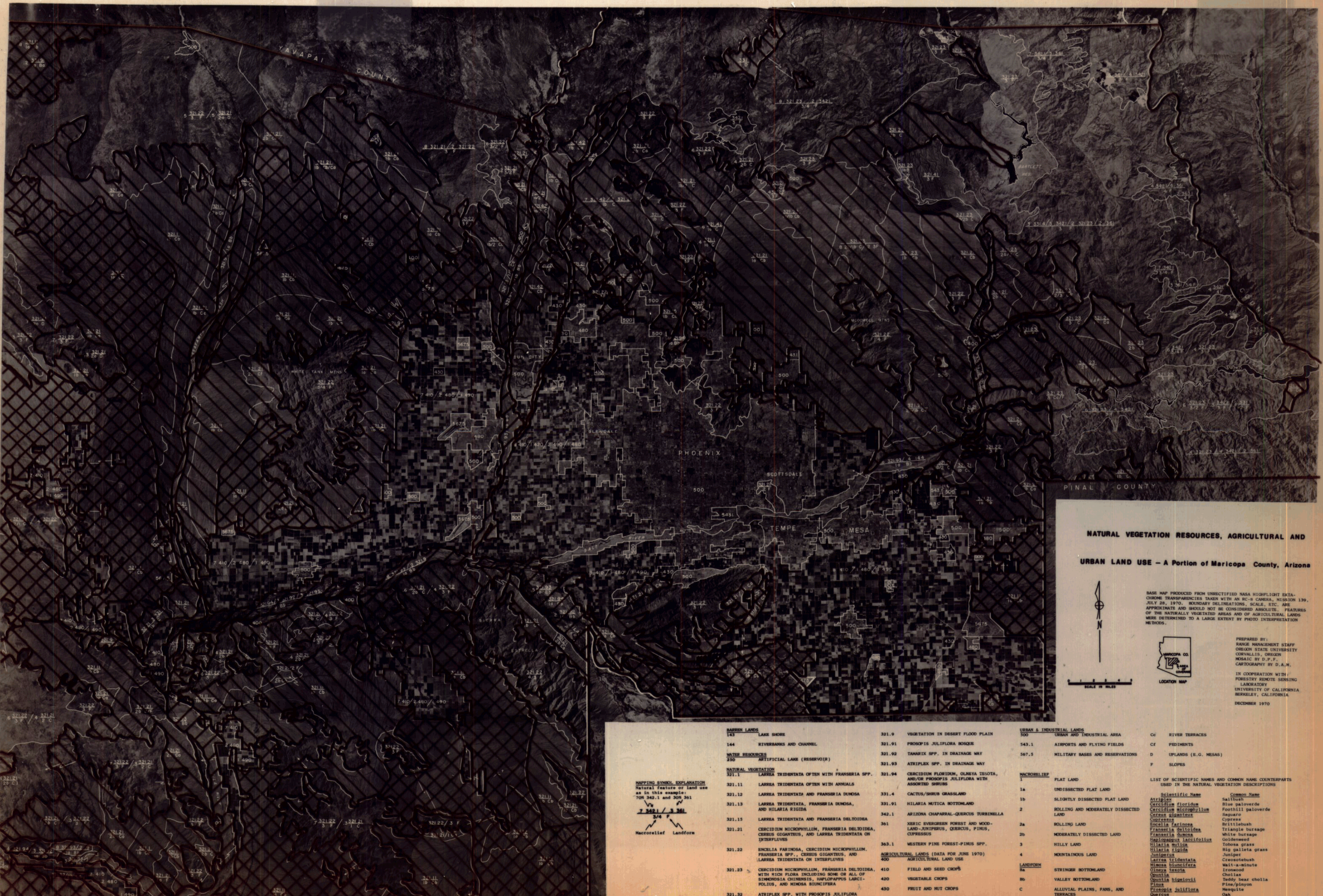
AN EXAMPLE OF ECOLOGICAL RESOURCE ANALYSIS FOR LAND USE PLANNING

As suggested by previous discussion and earlier reports, the primary emphasis by our crew is to utilize space and high flight photography for ecological resource inventory and classification. The inventory and classification of natural vegetation resources as well as the mapping of agricultural and urban land use classes are in themselves valuable; however, they are not in themselves the ultimate end products. Analysis of ecological resources leads to utilitarian products and follows inventory and classification. This section is devoted to a discussion of interpretative overlays* which have been derived from the resource inventory and classification research conducted in Test Site 29.

A generalized miniature of the interpretive overlay is shown as part of Figure 4. The original, full scale, 1:133,400, black-and-white photo mosaic resource map, which was produced by this lab, was presented in Pettinger, et al., 1970. The original overlays were drawn at the scale of 1:133,400. As stated elsewhere in this report, considerable interest among potential users in Arizona and Oregon has been shown for the type of approach and information displayed on the interpretive overlays of that resource map. It should be pointed out, however, that for maximum potential usefulness to be achieved, a complete resource analysis of the units classified in Figure 4 would be necessary. It should be evident that the relevance of such a photo map is affected by the direct relationship between the type of analysis that is to be made and the quality of information that is provided. The analysis, in turn, is strongly dependent upon the availability of a suitable supply of information regarding the primary current and potential value of the landscape units as well as reactions of those units to known land use practices. In many resource areas this type of information is already available and the major analysis task becomes merely one of finding the appropriate information and relating

* Interpretive overlays are a type of resource analysis product. The example in this section deals with land use potential based on characteristic qualitites of the natural vegetation and related resources which were inventoried, classified and mapped in Test Site 29. Other types of interpretive overlays may have less specific implications for land use planning. For example, it is possible to show all mountainous lands in similar overlays without necessarily relating this for specific purposes other than to pictorially show the extent and location of the mountains.


PHOENIX
TEMPE
MESA
SCOTTSDALE
PINAL COUNTY
NATURAL VEGETATION RESOURCES,
URBAN LAND USE – A Portion of Maricopa
N
SCALE IN MILES
BASE MAP PRODUCED FROM UNRECTIFIED NASA
CHROME TRANSPARENCIES TAKEN WITH AN RC-8
JULY 28, 1970. BOUNDARY DELINEATIONS.
APPROXIMATE AND SHOULD NOT BE CONSIDERED
OF THE NATURALLY VEGETATED AREAS AND OF
WERE DETERMINED TO A LARGE EXTENT BY PHOTO
METHODS.
MARICOPA CO.
LOCATION MAP
PREPARED
OREGON
CORVALLIS
MOSAIC BY
IN COOPER
FORESTRY
UNIVERSIT
BERKELEY.
DECEMBER
MAPPING SYMBOL EXPLANATION
Natural feature or land use as in this example: 70% 342.1 and 30% 361
.7 342.1 / .3 361
3/4 F
Macrorelief
Landform
BARREN LANDS
143 LAKE SHORE
144 RIVERBANKS AND CHANNEL
WATER RESOURCES
250 ARTIFICIAL LAKE (RESERVOIR)
NATURAL VEGETATION
321.1 LARREA TRIDENTATA OFTEN WITH FRANSERIA SPP.
321.11 LARREA TRIDENTATA OFTEN WITH ANNUALS
321.12 LARREA TRIDENTATA AND FRANSERIA DUMOSA
321.13 LARREA TRIDENTATA, FRANSERIA DUMOSA, AND HILARIA RIGIDA
321.15 LARREA TRIDENTATA AND FRANSERIA DELTOIDEA
321.21 CERCIDIUM MICROPHYLLUM, FRANSERIA DELTOIDEA, CEREUS GIGANTEUS, AND LARREA TRIDENTATA ON INTERFLUVES
321.22 ENCELIA FARINOSA, CERCIDIUM MICROPHYLLUM, FRANSERIA SPP., CEREUS GIGANTEUS, AND LARREA TRIDENTATA ON INTERFLUVES
321.23 CERCIDIUM MICROPHYLLUM, FRANSERIA DELTOIDEA, WITH RICH FLORA INCLUDING SOME OR ALL OF SIMMONDSIA CHINENSIS, HAPLOPAPPUS LARCIFOLIUS, AND MIMOSA BIUNCIFERA
321.32 ATRIPLEX SPP. WITH PROSOPIS JULIFLORA
321.41 CACTUS ASPECT-OPUNTIA BIGELOVII PROMINENT
321.42 CACTUS ASPECT-OPUNTIA (CHOLLAS) OTHER THAN O. BIGELOVII PROMINENT
321.9 VEGETATION IN DESERT FLOOD PLAIN
321.91 PROSOPIS JULIFLORA BOSQUE
321.92 TAMARIX SPP. IN DRAINAGE WAY
321.93 ATRIPLEX SPP. IN DRAINAGE WAY
321.94 CERCIDIUM FLORIDUM, OLNEYA TESOTA, AND/OR PROSOPIS JULIFLORA WITH ASSORTED SHRUBS
331.4 CACTUS/SHRUB GRASSLAND
331.91 HILARIA MUTICA BOTTOMLAND
342.1 ARIZONA CHAPARRAL-QUERCUS TURBINELLA
361 XERIC EVERGREEN FOREST AND WOODLAND-JUNIPERUS, QUERCUS, PINUS, CUPRESSUS
363.1 WESTERN PINE FOREST-PINUS SPP.
AGRICULTURAL LANDS (DATA FOR JUNE 1970)
400 AGRICULTURAL LAND USE
410 FIELD AND SEED CROPS
420 VEGETABLE CROPS
430 FRUIT AND NUT CROPS
480 NON-PRODUCING AND TRANSITION CROPLAND
490 RELATED AGRICULTURAL ACTIVITIES
URBAN & INDUSTRIAL LANDS
500 URBAN AND INDUSTRIAL AREA
543.1 AIRPORTS AND FLYING FIELDS
567.5 MILITARY BASES AND RESERVATIONS
MACRORELIEF
1 FLAT LAND
1a UNDISSECTED FLAT LAND
1b SLIGHTLY DISSECTED FLAT LAND
2 ROLLING AND MODERATELY DISSECTED LAND
2a ROLLING LAND
2b MODERATELY DISSECTED LAND
3 HILLY LAND
4 MOUNTAINOUS LAND
LANDFORM
Ba STRINGER BOTTOMLAND
Bb VALLEY BOTTOMLAND
C ALLUVIAL PLAINS, FANS, AND TERRACES
Ca FANS AND BAJADAS
Cb ALLUVIAL PLAINS AND VALLEY FILLS
Cc RIVER TERRACES
Cf PEDIMENTS
D UPLANDS (E.G. MESAS)
F SLOPES
LIST OF SCIENTIFIC NAMES AND COMMON NAME
USED IN THE NATURAL VEGETATION
Scientific Name
Atriplex
Cercidium floridum
Cercidium microphyllum
Cereus giganteus
Cupressus
Encelia farinosa
Franseria deltoidea
Franseria dumosa
Haplopappus larcifolius
Hilaria mutica
Hilaria rigida
Juniperus
Larrea tridentata
Mimosa biuncifera
Olneya tesota
Opuntia
Opuntia bigelovii
Pinus
Prosopis juliflora
Quercus
Quercus turbinella
Simmondsia chinensis
Tamarix
Saltbush
Blue paloverde
Saguaro
Cypress
Brittlebush
White bursage
Goldenweed
Tobosa grass
Juniper
Creosotebush
Ironwood
Chollas
Pine/pinyon
Mesquite
Oak
Jojoba
Tamarisk



NATURAL VEGETATION RESOURCES, AGRICULTURAL AND URBAN LAND USE – A Portion of Maricopa County, Arizona

SCALE IN MILES

LOCATION MAP

MARICOPA CO.

AREA OF COVERAGE

BASE MAP PRODUCED FROM UNRECTIFIED NASA HIGHFLIGHT EKTACHROME TRANSPARENCIES TAKEN WITH AN RC-8 CAMERA, MISSION 139, JULY 28, 1970. BOUNDARY DELINEATIONS, SCALE, ETC. ARE APPROXIMATE AND SHOULD NOT BE CONSIDERED ABSOLUTE. FEATURES OF THE NATURALLY VEGETATED AREAS AND OF AGRICULTURAL LANDS WERE DETERMINED TO A LARGE EXTENT BY PHOTO INTERPRETATION METHODS.

PREPARED BY:
RANGE MANAGEMENT STAFF
OREGON STATE UNIVERSITY
CORVALLIS, OREGON
MOSAIC BY D.P.F.
CARTOGRAPHY BY D.A.M.

IN COOPERATION WITH:
FORESTRY REMOTE SENSING LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA

DECEMBER 1970

MAPPING SYMBOL EXPLANATION
Natural feature or land use as in this example:
70% 342.1 and 30% 361

$\frac{.7\ 342.1\ /\ .3\ 361}{3/4\quad F}$

Macrorelief Landform

BARREN LANDS

143	LAKE SHORE
144	RIVERBANKS AND CHANNEL

WATER RESOURCES

250	ARTIFICIAL LAKE (RESERVOIR)

NATURAL VEGETATION

321.1	LARREA TRIDENTATA OFTEN WITH FRANSERIA SPP.
321.11	LARREA TRIDENTATA OFTEN WITH ANNUALS
321.12	LARREA TRIDENTATA AND FRANSERIA DUMOSA
321.13	LARREA TRIDENTATA, FRANSERIA DUMOSA, AND HILARIA RIGIDA
321.15	LARREA TRIDENTATA AND FRANSERIA DELTOIDEA
321.21	CERCIDIUM MICROPHYLLUM, FRANSERIA DELTOIDEA, CEREUS GIGANTEUS, AND LARREA TRIDENTATA ON INTERFLUVES
321.22	ENCELIA FARINOSA, CERCIDIUM MICROPHYLLUM, FRANSERIA SPP., CEREUS GIGANTEUS, AND LARREA TRIDENTATA ON INTERFLUVES
321.23	CERCIDIUM MICROPHYLLUM, FRANSERIA DELTOIDEA, WITH RICH FLORA INCLUDING SOME OR ALL OF SIMMONDSIA CHINENSIS, HAPLOPAPPUS LARCIFOLIUS, AND MIMOSA BIUNCIFERA
321.32	ATRIPLEX SPP. WITH PROSOPIS JULIFLORA
321.9	VEGETATION IN DESERT FLOOD PLAIN
321.91	PROSOPIS JULIFLORA BOSQUE
321.92	TAMARIX SPP. IN DRAINAGE WAY
321.93	ATRIPLEX SPP. IN DRAINAGE WAY
321.94	CERCIDIUM FLORIDUM, OLNEYA TESOTA, AND/OR PROSOPIS JULIFLORA WITH ASSORTED SHRUBS
331.4	CACTUS/SHRUB GRASSLAND
331.91	HILARIA MUTICA BOTTOMLAND
342.1	ARIZONA CHAPARRAL-QUERCUS TURBINELLA
361	XERIC EVERGREEN FOREST AND WOODLAND-JUNIPERUS, QUERCUS, PINUS, CUPRESSUS
363.1	WESTERN PINE FOREST-PINUS SPP.

AGRICULTURAL LANDS (DATA FOR JUNE 1970)

400	AGRICULTURAL LAND USE
410	FIELD AND SEED CROPS
420	VEGETABLE CROPS
430	FRUIT AND NUT CROPS

URBAN & INDUSTRIAL LANDS

500	URBAN AND INDUSTRIAL AREA
543.1	AIRPORTS AND FLYING FIELDS
567.5	MILITARY BASES AND RESERVATIONS

MACRORELIEF

1	FLAT LAND
1a	UNDISSECTED FLAT LAND
1b	SLIGHTLY DISSECTED FLAT LAND
2	ROLLING AND MODERATELY DISSECTED LAND
2a	ROLLING LAND
2b	MODERATELY DISSECTED LAND
3	HILLY LAND
4	MOUNTAINOUS LAND

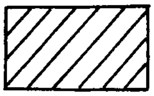
LANDFORM

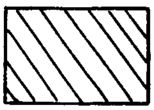
Ba	STRINGER BOTTOMLAND
Bb	VALLEY BOTTOMLAND
C	ALLUVIAL PLAINS, FANS, AND TERRACES
Cc	RIVER TERRACES
Cf	PEDIMENTS
D	UPLANDS (E.G. MESAS)
F	SLOPES

LIST OF SCIENTIFIC NAMES AND COMMON NAME COUNTERPARTS USED IN THE NATURAL VEGETATION DESCRIPTIONS

Scientific Name	Common Name
Atriplex	Saltbush
Cercidium floridum	Blue paloverde
Cercidium microphyllum	Foothill paloverde
Cereus giganteus	Saguaro
Cupressus	Cypress
Encelia farinosa	Brittlebush
Franseria deltoidea	Triangle bursage
Franseria dumosa	White bursage
Haplopappus larcifolius	Goldenweed
Hilaria mutica	Tobosa grass
Hilaria rigida	Big galleta grass
Juniperus	Juniper
Larrea tridentata	Creosotebush
Mimosa biuncifera	Wait-a-minute
Olneya tesota	Ironwood
Opuntia	Chollas
Opuntia bigelovii	Teddy bear cholla
Pinus	Pine/pinyon
Prosopis juliflora	Mesquite
Quercus	Oak

Overlay Legend

 Lands having a potential for intensive agricultural development.

 Lands having a potential for some degree of urbanization.

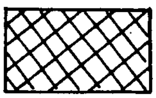
 Lands having a potential for either urbanization of agriculture.

Figure 4. Miniature photo mosaic resource map and generalized interpretive overlay showing areas of potential intensive agricultural and/or urban development. Discussion is found in the text explaining how these types of land use were identified for their indicated potential. The original, full scale, 1:133,400, black-and-white photo mosaic which was produced by the lab was presented in Pettinger, et al., 1970.

it to the proper units of the ecological classification. The interrelationships of inventory, classification and analysis processes are diagramatically presented in Figure 5.

The same illustration can be used to show why our emphasis is on inventory and classification. It is at these two stages that the proper specifications for aerial and/or space imagery (in terms of film-filter combination, spatial resolution, etc.) are essential. Suitable imagery is also highly desirable for conducting various phases of the analysis, but the imagery procured for inventory and photo mapping will ordinarily suffice.

The ecological approach to vegetational and related resource analysis emphasizes identification and classification of areas having equivalent effective environments as evidenced by the vegetation which each area supports. As a result of classification, the resource analyst can monitor responses of classified units to various land uses. Identical or similar units can be expected to have analogous responses to land use; thus, classification enables extrapolation of response from one unit to other units of similar character. The responses are environmental reactions to land use practices that may vary from non-use to complete alteration of the classified resource unit. Substantial alteration occurs with activities such as intensive agriculture and urban development. The prediction of responses to possible land uses is the essence of an ecological resource analysis. Many of our current environmental problems, particularly those related to resource degradation, have resulted from an absence of plans based, at least in part, on ecological resource analyses.

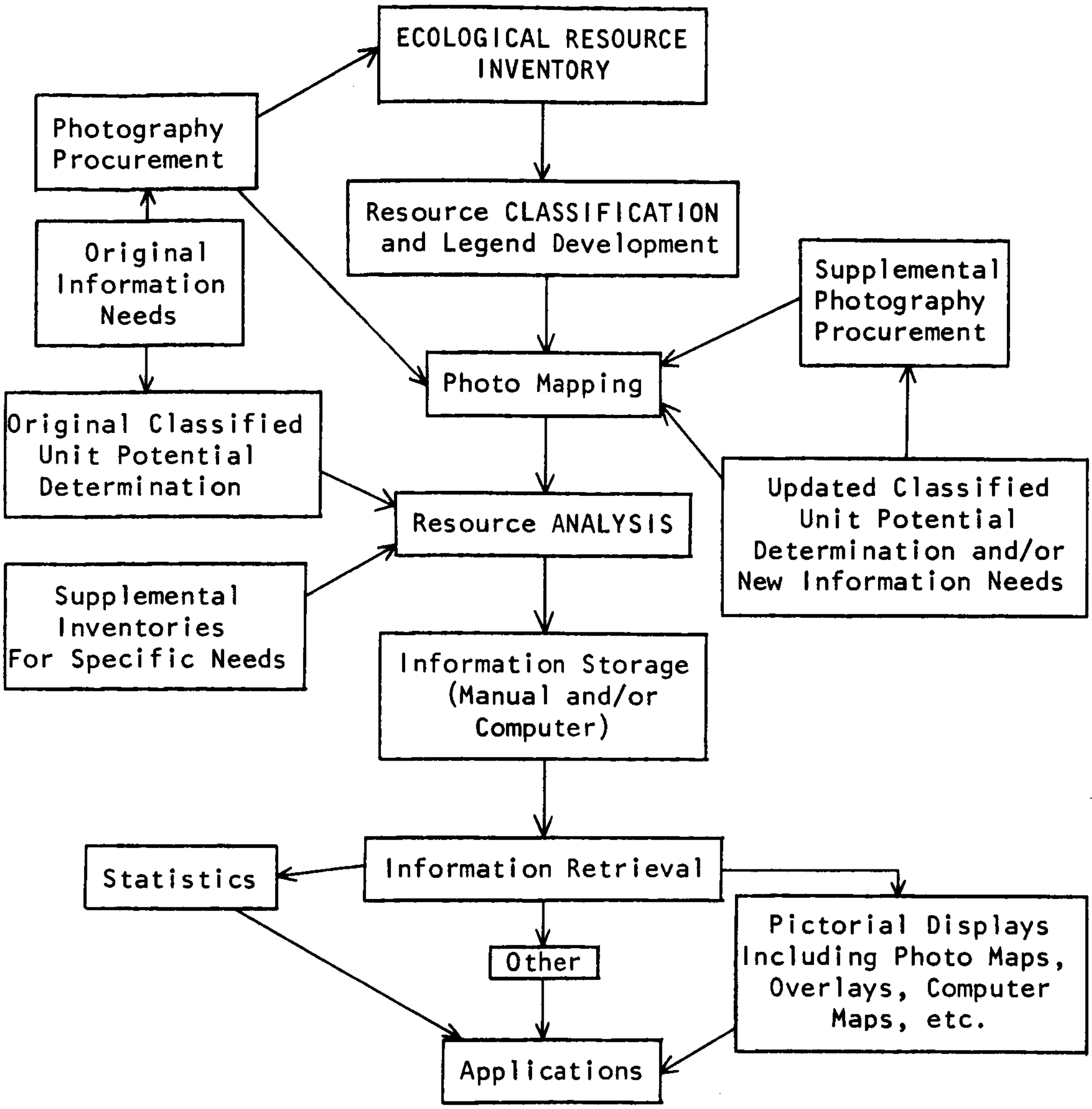


Figure 5. The Basic Interrelationships of Ecological Resource Inventory, Classification and Analysis as Related to Information Needs, Photographic Requirements and Information Retrieval. Notice that needs for updated information or new kinds of information affecting unit potential do not necessitate a revision of the inventory or classification scheme. The OSU range management remote sensing crew is concentrating on applications of space and high altitude photography to inventory problems and to subsequent classification problems, with limited emphasis on the analysis phase.

Considerations of ecological implications in land use planning can frequently come in direct conflict with short term economic goals. This conflict should, however, be viewed as a positive development because planning, when directed by ecological resource analysis, can be conducted with realization of what the total resource picture is, both in the short range and in the long range, for an ecological region or political subdivision such as a county, state or country. To this point ecological resource analysis _per se_ is separate from, and must not be biased by, such social practices as land ownership. Furthermore, many of the current attitudes and actions which govern the planning of land use must be altered if ecological resource analyses are to become a serious base for land use planning decisions. Among the more tangible re-evaluations needed will be those of tax structure and zoning laws, particularly when such laws have been derived basically from considerations of short term economics, with little regard for ecological resource analysis and other long term considerations. The following discussion points to a situation developing in northern Maricopa County where proponents of land use are involved in an increasingly critical conflict over natural environments, agricultural developments and urban developments.

Although our research goals most strongly address the related areas of ecological resource inventory and classification, some of the strongest points which support the approach which we advocate can never be made unless examples of potential analysis and application are shown. Some extremely important implications of resource analysis can easily be drawn from the inventory, classification and mapping of natural vegetation and related features in Test Site 29. Two of these implications have been portrayed in the overlay of Figure 4.

The area judged as having an agricultural potential, not now developed, is shown on that overlay. Characteristics used in the evaluation were those of vegetation, soil, macrorelief, landform and evidences such as current land use, present conversion patterns and direction of expansion. Mapped units having the following mapping legend designations were deemed potential agricultural land.

	Category One	Category Two
	High likelihood of agricultural potential*	Questionable likelihood of agricultural potential*
Numerator must be	321.1, 321.11, 321.15 or 321.12	321.32, 321.9x **
Denominator must be	1a	1a

* For mapping complexes both numerator and denominator must have equaled or exceeded 70% of the mapping unit in order to have been considered potential agricultural lands.

** 321.9x refers to all 321.9 types.

The distinction between "Category One" and "Category Two" agricultural potential was not maintained in the miniature interpretive overlay. In Category One types, the factor most strongly limiting conversion to intensive agricultural use would be unavailability of irrigation water. Additional factors might restrict agricultural development in Category Two. First, vegetation types 321.32 and 321.9x commonly occur in areas having high flood potential, along drainageways. For some drainageways this factor alone might prevent development unless flood waters could be confined to more restricted areas, the costs of which might be prohibitive considering the limited amount of arable drainageway lands. Additionally, the types tend to occur on soils that may have sufficiently high accumulations of salt to limit productivity of some crops.

We recognize that for several reasons actual potential agricultural lands may deviate somewhat from the areal boundaries indicated. Greatest likelihood of variation may result from (1) use of the original photographic scale (1:124,000) which can prevent detection of some suitable areas and erroneously suggest suitability for others, and (2) other errors in photo interpretation as previously discussed in this report. In spite of these potential errors, reasonable reliability can be assumed both for location and total acreages of potential agricultural lands within the area mapped.

Areal statistics are a further product of ecological resource analysis that provide vital information for land use planning. When used in conjunction with interpretive overlays like the one of Figure 4, statistics of the type summarized in Table 5 enable the overlays to take on even greater meaning. While overlays or other types of interpretive maps provide a feeling for locations, statistics enable quantification. Thus the potential agricultural lands, as shown in the overlay of Figure 4, total approximately 1,900 square miles. More specific statistics are also possible depending on user needs. For example, in naturally vegetated areas, statistics for combinations of vegetation type -- landform or vegetation type -- macrorelief are readily derived.

A second type of analysis, potential for urbanization and/or

	MACRORELIEF CLASS (In Square Miles)				
	Flat Land	Rolling Land	Hilly Land	Mountainous Land	Total
Barren Lands and Water Resources					21
Natural Vegetation	2232	677	1287	106	4302
Potential Agricultural Lands	1924				1924
Potential Urban Lands	2026	599			2625
Agricultural Lands	780*				780
Urban Lands					292
Total Area Inventoried					5395

* Not actually classified according to macrorelief; however, occurrence is mostly on flat lands.

Table 5. Summary of Areal Statistics Derived from the Natural Vegetation and Land Use Photo Map which is Reproduced in Miniature as Figure 4.

suburbanization, also relates to land use planning and is portrayed in the interpretive overlay of Figure 4. The criteria utilized in making judgments for potential urban development were based primarily on a consideration of macrorelief. More specifically, all of the flat land types (1a and 1b) as well as the rolling and moderately dissected macrorelief types (2a and 2b) were considered suitable for some intensity of urbanization whether it be urban sprawl or large acreage suburban development. In total about 2,600 square miles of land not presently intensively used are considered suited for development. Two types of areas were excluded in addition to the hilly (3) and mountainous (4) macrorelief types. Those are, respectively, (a) the areas along drainageways, washes or arroyos, and (b) a botanically unique vegetated area (321.41) just to the east of Camp Creek and south of the road from Carefree to Bartlett Reservoir.

The types of interpretive information shown with the figure are of value when considered separately, but they contain even greater meaning when considered simultaneously. In viewing the overlay, one finds it revealing to notice that most of the potential agricultural land falls within the area designated potential for urbanization and/or suburbanization. On the other hand, much of the potential urban-suburban land is not highly suitable for agricultural development. Areas of intensive development in the region tend to occur first on flat lands. Intensive land use expansion in the area generally follows the pattern of agricultural development, portions of which are later converted to urbanization. Thus one intensive use of land (agricultural) succumbs at the expense of a second intensive use (urbanization).

This type of rather simple analysis, derived from an ecological resource inventory and classification, clearly portrays conflicts over land use without even considering other ecologic factors or the multitude of socio-economic factors which are extremely important in land use planning. Although the overlay of Figure 4 serves to illustrate an example of land use conflicts, it has, perhaps, even greater value by allowing an overview of solutions to potential land use conflicts. In this simple example of an agriculture-urbanization conflict the two types of potential land use should be carefully balanced. If the desire is to allow for maximization of both types of land use expansion, the simplistic answer for minimizing conflict is to minimize urban expansion in the areas suited to agricultural development. It is probable, however, that this type of solution could only be implemented through changes in tax structure and zoning laws as mentioned earlier.

SUGGESTED CLASSIFICATION AND KEY WORDS FOR DESCRIBING PRIMARY SURFACE RESOURCES AND LAND USE IN A BROWSE FILE OR CATALOGUE OF SPACE IMAGERY

Accompanying the accumulation of space imagery is a pronounced need for information describing, in general terms, the procured imagery. This will become particularly apparent with the advent of ERTS satellites. This information will need to be efficiently gathered and stored for ready access by users who will need to know the suitability or usefulness of individual imagery frames. The work reported in this section was forwarded in March 1971, to Goddard Spacecraft Center for consideration in preparing for this problem.

The following suggests a system for describing primary surface resources depicted on satellite imagery. These suggestions are an outgrowth of descriptive legend concepts developed in our NASA-supported research program. The legend system has been applied to space, high altitude and conventional aerial photography. The broader legend categories are used here to demonstrate their applicability for setting up key words and descriptive symbols for annotation of a browse file.

In developing an indexing system for features which can be seen on space imagery, the greatest utility will be achieved when the index contains a listing of those features which may be of interest to potential users of the imagery. From an earth resources standpoint, the index should include several major categories such as:

1. Names of continent, island, ocean and/or sea.

2. Political name, e.g., country, province, state.

3. Cultural features such as urban centers, surface mineral extraction areas and agricultural land. Where appropriate these can be identified by proper names, such as city names.

4. Water resources. These should be identified both by feature and, where appropriate, by proper name.

5. Vegetation resources, by broad ecologically meaningful classes.

6. Gross geomorphologic features including macrorelief.

It would appear that a knowledge of the above information classes should enable most users to decide on usability of imagery -- the primary objective of the browse file and image annotation. Vegetational classes are indicative of the environment in which they occur and, because many geological processes are related to broad macrorelief classes, knowledge of these two features of the imaged areas should be most helpful to a maximum number of potential users. This annotation technique makes use of broad classes developed by our Oregon State University team working in the southern Arizona test areas.

Presented herein are selected symbology and possible key words for indexing "primary surface resources and land use" as well as "macrorelief" classes. The appropriate portions of a unified legend which incorporates surface resource features with land use are presented in Tables 6 through 11. Subcategories for these major classes would only rarely, if ever, be used for feature identification on space imagery, especially for the purposes proposed here. This same legend, in greater detail, has been successfully used to classify land areas from photographs taken throughout the normal range of scales ordinarily obtained from spacecraft and conventional aircraft. In annotating ERTS imagery for the purposes proposed here, the five categories of primary resource and land use classes (Table 6) would probably provide sufficient detail. For other space imagery, specifically photographic types, some components of the subcategories (Tables 7 through 11) would prove valuable. Many of the subcategories would probably never be used to annotate space photography, but have been included for legend completeness where a companion category at the same level might be used. For example from Table 8, "211 --- Ponds" would not be useful, but "212 --- Lakes" would be needed.

For purposes of indexing broad subjects, it is suggested that the relative percentage be given of each class identified on space imagery. The following percentage class scheme has been widely used and is

PRIMARY RESOURCE AND LAND USE CLASS		
Mapping Sumbol	Key Word	Descriptive Legend
100	Barren lands	The prominent features of barren lands are bare mineral soils and/or rocks. Vegetation is lacking or so widely scattered that the overall aspect is of a denuded area. Barren lands do not include temporarily denuded lands such as those caused by cultivation or plowing. Man-made barren lands created by urbanization or industry are found within the 500 class.
200	Water resources	Only those areas perennially covered by water and lacking surface vegetation are classed as Water Resources. Vegetated water zones should be designated in 300.
300	Natural vegetation	Areas in which successional processes give an aspect of natural vegetation, even though the area may at one time have been strongly altered by man, are considered naturally vegetated. Areas such as logged-over forests or burns, left to successional processes, fit in this class.
400	Agricultural lands	Agricultural lands are those which are characterized by man's relatively constant manipulation of the vegetation and micro-environment; the presence of feed, food, or fiber crops; and the general control of both placement and growth of vegetation.
500	Urban and industrial lands	Those lands which have been altered by man for living, manufacture, transportation and related activities are considered urban and industrial lands. Because of the nature of some of these land uses, they do not necessarily obscure classes 100, 200 or 300, in which case mapping units may contain these classes along with one or more 500 class.

Table 6. Symbolic, key word and descriptive legend.

BARREN LAND TYPES		
Mapping Symbol	Key Word	Descriptive Legend
100	Barren lands	
110	Playas	Playas are undrained basins in the arid and semiarid regions. They are generally dry although they may contain shallow water for short periods at infrequent intervals. The soils are usually saline or alkaline and are fine to medium textured.
120	Dune lands	Where soil particles, especially sand, drift and pile into series of hills or ridges, the area is classed as dune lands. Dunes have been variously classified as to shape, origin, activity and size.
130	Rocklands	Rocklands are quite a diversified group with the main similarity being the presence of a high rock and/or gravel cover. Rocks will often occur together unsorted as to size or shape. Subclasses are formed according to rock origin.
140	Shorelines, beaches and riverbanks	Those land areas affected by the wave, tidal and seasonal variations of lakes, rivers, seas and oceans are classed together as shorelines and beaches. They vary greatly in width and components so are subdivided as to type.
190	Undifferentiated Barrens	Undifferentiated barrens include badlands, areas of mass earth movement, non-rocky erosional and fault scarps and soil slicks.

Table 7. Symbolic, key word and descriptive legend.

WATER RESOURCES	
Mapping Symbol	Key Word
200	Water resources
210	Ponds and lakes
211	Ponds
212	Lakes
220	Water courses
221	Rivers
222	Creeks
230	Bays and estuaries
240	Oceans and seas
250	Artificial ponds and reservoirs
260	Ice and snow
261	Perpetual ice or snow
262	Ephemeral ice or snow
290	Other water resources

Table 8. Symbolic and key word legend. Some of these descriptors are not suited to space imagery annotation in browse file use.

NORTH AMERICAN VEGETATIONAL PHYSIOGNOMIC TYPES		
Mapping Symbol	Key Word	Descriptive Legend
300	Natural vegetation	
320	Deserts	Deserts are typified by sparse vegetation and are located in the more arid regions of the southwestern U. S. and northern Mexico.
330	Steppes	Within steppes, the herbaceous layer, including both perennial grasses and forbs, is usually prominent. Low to medium height shrubs are scattered or lacking except in some grazing disclimax situations -- notably among Great Basin shrub-steppe types.
340	Shrub/ scrub lands	Medium to tall shrubs or small trees (scrub) are the prominent vegetation. These usually form a closed layer so that the herbaceous layer is completely subordinate. The herbaceous vegetation is highly variable but can be important.
350	Savannas	Dense stands of herbs overlain by scattered individuals of tall shrubs or trees.
360	Wooded and forested lands	The tree layer forms the prominent vegetational feature. This layer often forms a closed canopy over a variety of subordinate vegetation.
370	Alpine and arctic tundra	Tundra is characterized by cold temperatures and short growing seasons. The vegetation is usually low and lacks distinct layers.
380	Vegetation of aquatic environments	The vegetation of aquatic environments appears above the perennial water cover.

Table 9. Symbolic, key word and descriptive legend.

AGRICULTURAL LAND USE LEGEND	
Mapping Symbol	Key Word
400	Agricultural lands
410	Field and seed crops
420	Vegetable crops
430	Fruit and nut crops
440	Livestock facilities
450	Animal specialities
460	Pasture and rangeland
470	Horticultural specialities
480	Non-producing and transition cropland
490	Other uses

Table 10. Symbolic and key word legend. Adapted from Johnson, et al. (1969). Several of these descriptors are not suited to space imagery annotation in browse file use.

URBAN, INDUSTRIAL AND EXTRACTIVE LANDS	
Mapping Symbol	Key Word
500	Urban and industrial lands
510	Residential
520 or 530	Manufacturing
540	Transportation, communication and utilities
550	Trade
560	Services
570	Cultural, entertainment and recreational
580	Resource production and extraction. NOTE: Horticultural/agricultural production is used under "400", agricultural lands.
590	Undeveloped land and water areas. NOTE: These are land use categories and should not be confused with resource types. At appropriate scales both land use and resource type may occupy the same physical area.

Table 11. Symbolic and key word legend. Adapted from Standard Land Use Coding Manual (U. S. Department of Transportation, 1969). The initial "5" has been added to all of the Manual's code numbers as well as the decimals. Units 500 and 590 are probably the only ones useful for space imagery annotation in browse file use.

suggested to simplify proportion estimates in quick-look evaluation of imagery.

Cover Class	Class Range - Percent
1	0-5
2	5-10
3	10-25
4	25-50
5	50-75
6	75-95
7	95-100

This approach not only identifies features of primary interest but also gives an indication of the relative amounts of each features.

Macrorelief classes, Table 12, are not considered a part of the primary resources. They are, however, particularly suited to space imagery annotation because of their relative ease of identification and their interpretability in terms of geologic processes and land use. Subclasses have been developed for two of the four classes shown and have been used for mapping on space photography of an arid region. The application of these subclasses, however, is regional and of limited value for worldwide indexing of space imagery.

This annotation scheme may not meet the needs of all disciplines for a set of key-word descriptors in a browse file. The procedure should, however, be entirely adequate for description of vegetational resources and gross land surface relief at browse file level. Additional detail can be easily added within the framework provided. As an example, category

MACRORELIEF CLASSES		
Mapping Symbol	Key Word	Descriptive Legend
1	Flat lands	A generally flat landscape with prominent slopes less than 10 percent.
2	Rolling and moderately dissected lands	A rolling or moderately dissected landscape with prominent slopes 10 to 25 percent (side slopes may exceed that figure in the case of dissected planar surfaces).
3	Hilly lands	The landscape is hilly to submountainous; slopes are moderate to steep, predominantly exceeding 25 percent. Relief is generally over 100 feet but less than 1000 feet. Where relief approaches 1000 feet, the landform system appears to be relatively simple -- with smooth slopes. Drainage systems generally have the same base level.
4	Mountainous lands	The landscape is mountainous, having high relief, usually over 1000 feet. Slopes are moderate to steep, frequently exceeding 50 percent. The landform and drainage systems are usually complex, with drainage networks having base levels quite independent of one another.

Table 12. Symbolic, key word and descriptive legend.

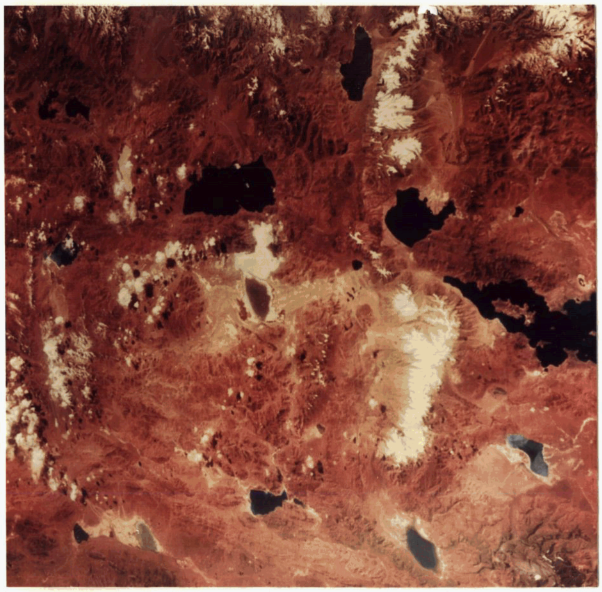
360, Wooded and Forested Lands (Table 9), can be subdivided to yield more specific information. The subdivisions might be tropical forest, semitropical forest, temperate forest, woodland and boreal forest.

Examples of how the indexing could work on space photographs are shown in the three accompanying figures (Figures 6, 7 and 8). The photographs were obtained on two Apollo flights. Annotations include mapping symbols providing greater information than would be expected on ERTS-A imagery. The symbols convey information detail compatible with the interpretability of these examples of space photography. More or less interpretive detail can be extracted from other forms of space imagery depending primarily on resolution characteristics and the amount of time which can be allotted to the interpretation of each frame of imagery.

CONTINUING RESEARCH AND INVESTIGATION NEEDS

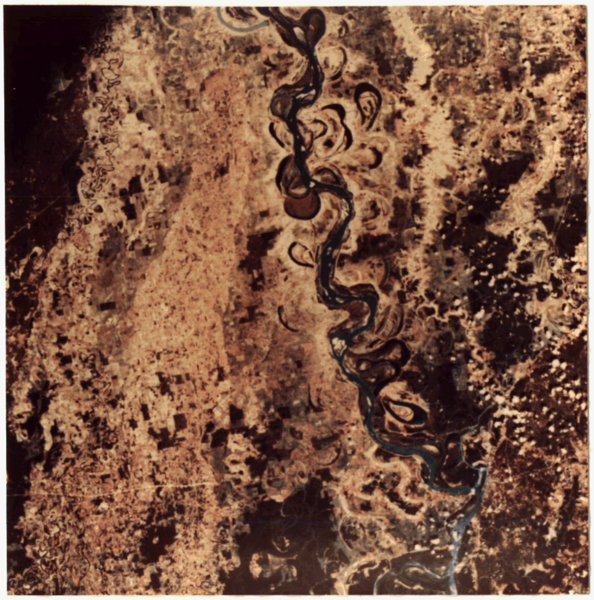
Legend Development

During the present year considerable attention has been given to the expansion of our legend concept to meet the requirements of different ecological regions. This work should be continued at least to the point of developing a system that would reasonably accommodate the broader hierarchical levels of vegetational resource classification throughout North America. Our research has already shown that at the specific hierarchical levels, classifications and legends will probably have to be developed on a regional basis. In the interest of a fully effective earth resource observational satellite system, some one group should develop and publish the framework for the broader hierarchical levels on



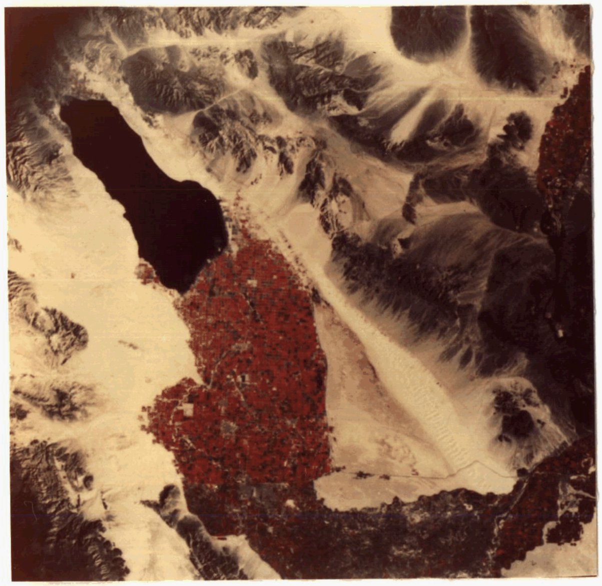
PRIMARY RESOURCE AND LAND USE		
Mapping Symbol	Key Word	Cover Class
100	Barren lands	5
330	Steppe	3
212	Lakes	2
261	Perennial ice and/or snow	1
MACRORELIEF		
1 and 2	Flat to rolling lands	4
4	Mountainous lands	5

Figure 6. Apollo 7 color frame AS-7-5-1617. Tibet, Naganglaring Tsho, near-vertical view.



PRIMARY RESOURCE AND LAND USE		
Mapping Symbol	Key Word	Cover Class
221	Rivers	1
360	Wooded and forested lands	2
400	Agriculture	6
500	Urban lands	1
MACRORELIEF		
1	Flat lands	6
2	Undulating to rolling lands	3
3	Hilly lands	1

Figure 7. Apollo 9 color infrared frame AS-9-26-3741. Mississippi, Vicksburg, Mississippi Valley, Greenville Bend.



PRIMARY RESOURCE AND LAND USE		
Mapping Symbol	Key Word	Cover Class
120	Dune lands	1
240	Oceans and seas	1
320	Desert vegetation	5
400	Agriculture	3
500	Urban lands	1
MACRORELIEF		
1	Flat lands	5
2	Undulating to rollinglands	2
3	Hilly lands	3
4	Mountainous lands	1

Figure 8. Apollo 9 color infrared frame AS-9-26A-3799. California, Salton Sea, Imperial Valley; Mexico, Mexicali.

a continent-wide basis. The possibility exists that a successful system developed for one continent would be global in applicability or at least serve as a model for adaptation to other continents. In conjunction with legend development we have initiated legend keys to aid in both field identification and photo interpretation of legend units.

Regional legend development is continuing in the southern Arizona test sites, particularly Site 220. Field work during the past season, in addition to that completed earlier, will be sufficient to finalize vegetation classification and legend development in preparation of the high altitude photo mosaic (1:124,000) resource map. Additionally, detailed legend development at the plant community level is nearly complete for a selected 18 mile square area near Tombstone within Site 220. The original mapping will be done on black-and-white 1:35,000 scale photography to insure a record of greatest inventory detail. Several benefits are expected to be derived from this intensive study: (1) The suitability of mapping plant community level vegetation units on 1:35,000 photography will be compared to mapping on similar scale enlargements made from 1:124,000 high altitude photography. The nature and magnitude of interpretability difficulties will be determined. (2) Selected large acreage vegetation units mapped at the plant community level will be photo interpreted elsewhere in Site 220. Accuracy of interpretation for each subject at several legend levels will be determined. (3) Information from the plant community mapping at 1:35,000 may be of benefit in multi-stage sampling, particularly if success at (2) above is high.

Interpretation Testing

Consistent with the above, the currently available ground truth and existing imagery can provide the materials needed to prepare photo interpretation aids for the identification of legend units. This will lead to comprehensive photo interpretation tests to more adequately assess the accuracy, extent and nature of photo interpretation errors in the interpretation of earth resources and land uses from available imagery. These tests conducted on Apollo photography would form an excellent base for the evaluation of ERTS suitability.

Steady progress is being made in photo interpretation testing using Apollo 6 photography in Test Site 220. As with the photo interpretation testing reported herein for the Phoenix high altitude mosaic, interpretation testing investigations on space photography are concentrating on macrorelief-landform identification and mapping interpretations. The importance of accurately interpreting landforms, specifically macrorelief, will become ever more important as more landform-vegetation correlations are determined. The first of these tests, including results, rationale and ground data map, were published earlier (Poulton, et al., 1970). Since then, interpretation testing procedures have been standardized and are more easily understood. Several groups of interpreters, with and without a photo interpretation or remote sensing background, have participated in recent testing utilizing both stereo and non-stereo viewing. The impact of the various backgrounds on interpretation accuracy as well as stereoscopic assistance will be assessed. Methods are being examined for extracting and analyzing the data from the interpreted landform maps.

Several attempts have been made to handle the data from the maps with current procedures appearing successful.

Development of Base Maps

Based on a photo interpretation accuracy check done during the past field season, the high altitude and space resource maps of Test Site 29 will be updated and corrected where necessary. Vegetation data gathered during the past season on Site 220 will contribute to the data store which is being used to produce a similar high altitude resource photo map of this latter site. Throughout the history of this project, data have been gathered at more than 550 ground locations. This represents considerably more information than was compiled for Site 29, but has been necessary because of the greater variety of vegetation present. A complete and accurate ground truth map is required for planned multistage sampling experiments and for evaluation of the effects that plant phenologies have on multidate photographic images.

Using the photo maps as ground truth bases, the information provided thereon will prove invaluable for evaluation of ERTS-A and subsequent satellite imagery. Considering that the diversity of natural vegetation and landforms from both test sites occurs in similar and overlapping ecological regions, a strong possibility exists that interpretations from ERTS-A may be accurate at some acceptable level over a geographic range extending between and beyond the two test sites.

Multistage Sampling

An operational procedure needs to be worked out and tested for the multistage probability sampling to be used in the mapping, identification and statistical analysis of naturally vegetated landscapes using a sub-sampling combination of space, high altitude and intermediate scale aircraft photography. The multistage concept has important implications in the identification of ecosystems and in the derivation of statistics on the amounts and distribution of natural landscape features. These applications, however, present some unique procedural and statistical problems that are not inherently solved by drawing on established approaches for measuring timber volumes and related characteristics. Some unique developmental research is called for in the application of the multistage subsampling concept to ecological resource analysis problems. The necessary photography and ground truth data records are now available for serious examination of the problem. If successful, plans call for a comparative evaluation of Gemini, Apollo and ERTS-A imagery for suitability as the first stage in a multistage sampling scheme for vegetation classification and inventory.

Plant Phenologies and Sequential Photography

Work needs to continue in the evaluation and development of procedures to fully exploit the multidate concept as it relates to vegetational feature discrimination. Because of the consistent seasonal developmental patterns (phenologies) of vegetation and contrasts between vegetation types in this regard, the multidate concept appears to have highly significant potential for the improvement of vegetation identification and refinement of mapping delineations. Accomplishments in this area have suffered considerable delay because of breaks in the photographic sequence at critical seasons. Enough imagery is available, however, for partial attainment of the objectives. With completion of a full annual sequence of multidate imagery in Test Site 220 either from additional RB-57 flights or from the NASA-Ames ERTS simulation over the Arizona Regional Ecological Test Site, this investigation can make substantial progress.

Through the cooperation of the United States Air Force and personnel of Luke Air Force Base, natural vegetation changes are being similarly monitored with a spectroradiometer. The initial helicopter mission to gather radiometric data was conducted over selected vegetation units in Test Site 220. The helicopter provided a stable platform necessary to utilize a Forestry Remote Sensing Laboratory spectroradiometer at 500-1000 feet above terrain. Tentative plans have been made to repeat the flights at other seasons to garner an understanding of how the signatures may change, in a quantitative manner, with phenological development. These data will be collected on appropriate dates so that they can be used as a standard against which to compare data acquired by high altitude aircraft and the ERTS satellite.

SUMMARY FOR FISCAL YEAR 1971

Introduction

Substantial progress has been made during the year in demonstrating the value of small scale, high altitude photography for inventory and display of natural vegetation and related features of the landscape. As a prerequisite for display of natural vegetation resources, however, the vegetation must be classified into ecologically meaningful units. Exercises of this sort are academic unless (1) the units as described are understood by potential users, (2) all resource features are displayed in a readily intelligible common legend system, and (3) each unit is related, through a descriptive legend, to land use potentials and limitations. Our work to this time has concentrated heavily on the tasks of identifying, classifying and developing a legend for natural vegetation and related features. In fostering the philosophy that research of this nature is meaningless unless the research is applied in a utilitarian manner we have also made a concerted effort to take our resource analysis concepts and examples of results to potential users.

High Altitude Photography Report

The high altitude photography report (Pettinger, et al., 1970) emphasized the primary work accomplished during the first portion of the fiscal year. In it was shown a natural vegetation/landform, agricultural and land use resource map produced on a high altitude photo mosaic. The values of such a map were alluded to in that report. Considerable ground checking and legend development were necessary in order to produce the photo map. Of importance was the successful combining of three legend systems into a comprehensive single system. Natural vegetation, agriculture and land use are the components of the combined legend. In addition to mapping and describing vegetation-soil systems in Maricopa County, a comparison was made of broad scale soil mapping to a segment of our vegetation mapping.

Another section of that report summarized a pilot test of our legend and interpretation techniques in southeastern California. This effort, which successfully demonstrated the regional applicability of the legend, was conducted as part of the Bureau of Land Management's California Desert project.

Continuing Research

Substantial quantities of field research and laboratory effort have gone toward update and expansion of the legend system. Test Site 220 (Ft. Huachuca) is the region where detailed legend work is continuing in an effort to produce a more complete and meaningful classification of natural vegetation. The broader hierarchical categories of the legend are being expanded and refined for the continental United States. It is anticipated that both the regional and continental portions of the legend will have applicability for ERTS and subsequent space imagery.

In Test Sites 29 and 220, photo interpretation testing is continuing for features discernible on Apollo and NASA high altitude photography. On space photography, macrorelief landform testing is receiving the greatest emphasis concurrent with an evaluation of vegetation-landform relationships. Similar emphasis is being given to interpretation testing of high altitude photography (1:125,000) along with a comparative evaluation of the high altitude photography vs. a more conventional scale of photography (1:35,000).

The northern Maricopa County resource map (Test Site 29) which was produced on high altitude photography (Pettinger, et al., 1970) is being updated. That map, together with the one being produced in Test Site 220, will provide the ground truth base for upcoming experiments. Among them will be multistage sampling experiments comparing ERTS to Apollo photography when used at the first stage. The base maps additionally will prove valuable as continued efforts are made to utilize sequential photography as an aid in vegetational feature and macrorelief discrimination. Recently initiated efforts have been made to utilize a helicopter-borne spectroradiometer to monitor phenological development. If successful, such data will provide a standard for comparing imagery from high altitude aircraft and the ERTS satellite.

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