Multilevel Data Acquisition and Analysis for Wildlife Habitat Inventories

Brian T. Fine and Joel B. Dye[2]
John Bosworth[3]

Abstract.--Using state-of-the-art inventory techniques, a multipurpose inventory was conducted in the Denali Planning Unit, Alaska. This inventory provided a demonstration of this technnology (multilevel) and established a regional data base. As a result of the investment made in establishing the data base and using the multilevel technology, future resource description and analysis programs will be possible at a minimum cost for a given level of accuracy.

INTRODUCTION

Increasing population pressure and increasing awareness of the environment have prompted legislative, judicial, and executive action that requires much more precise and timely resource information for day-to-day resource management. Pressure from special interest groups ranging from environmentalists to cattlemen's associations have challenged resource managers' current information collection system in its timeliness and accuracy.

It is recognized, too, that resource information is but one component necessary in the management process, and therefore the collection of that information, to specified accuracy requirements, should be as timely and cost-efficient as possible. The resource manager needs the opportunity to both formulate and implement any management plans that are indicated based on current resource information. Inventory systems should not require so much time and effort as to restrict performance of those other management process components.

A number of sources of data can be utilized in collecting information to meet information requirements. They include Landsat hardcopy data, Landsat computer compatible tapes, high altitude photographic data, large scale aircraft data, ground data, and historical data. Each of these data sources needs to be evaluated in terms of its relative information content and its cost of acquisition.

Among the number of options available to the manager for the exploitation of the various data sources are direct measurement by manual methods, computer aided analysis techniques, sampling strategies, estimation procedures and pre- and post-processing procedures for image analysis.

The technical discussion presented in this paper is based on the results of the National Aeronautics and Space Administration Application System Verification Test (ASVT), Phase I-Alaska, on which ESL was the prime contractor (NAS9-15339). The objectives of this paper are to briefly outline the Phase I ASVT project and its significant results and to present a case study on advantages of using regional data bases in conducting special study projects.

The Phase I-Alaska-ASVT Program was designed to: 1) optimize the exploitation of Landsat data, aerial photography, ground data, and sampling inventory procedures; 2) provide technical training of Bureau of Land Management resource personnel; 3) generate cost data on the utilization of the technology; and 4) importantly, develop a regional data base on the vegetation and geology resources in the Denali Study Area. Future projects within the Denali area will be able to utilize this

[1]Paper presented at the PECORA IV Symposium on Multilevel Data Acquisition and Analysis for Wildlife Habitat Inventories, Sioux Falls, SD, October 12, 1978.

[2]ESL Incorporated, Sunnyvale, California.
[3]Bureau of Land Management, Anchorage District Office, Anchorage, Alaska.

established regional information data base to implement intensive inventory projects for specific requirements in a most cost-effective, timely and accurate way.

PHASE I-ALASKA-ASVT

The Phase I-Alaska technical approach (fig. 1) presented here is based on the detailed project specifications and requirements of the Bureau of Land Management.

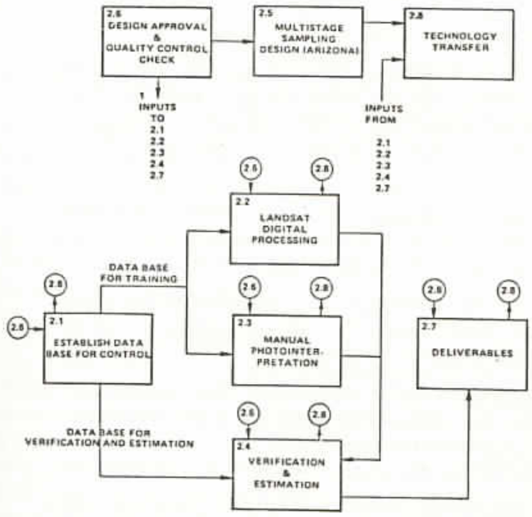


Figure 1.--Overview of technical approach

Objectives of Phase I

There are a number of distinct but interrelated objectives of the ASVT project. The first was to demonstrate the applications of multiple source data in inventory and mapping, using state-of-the-art analytical techniques and data types. The data types included: ground data, very large scale photography (1:1,200 and 1:10,000), medium scale aerial photography (1:30,000 and 1:120,000), very small scale photographic products (1:250,000 Landsat products), and Landsat digital data. Secondly, the project was to provide statistical and cost data to allow the Bureau of Land Management to evaluate the cost effectiveness of various analytical methods and data types at varying levels of detail. Third was the development of useful map and inventory products for use and evaluation by the BLM personnel in Alaska and establishment of a regional data base. A fourth, and distinctly different, objective was the planning of the data collection and data analysis efforts for Phase II on the Shivwits district in Arizona. Last was the transfer of the technical methodology, project planning and project management techniques to the BLM personnel.

Use of the Various Data Types

Ground Data

At each statistically selected ground plot, which was a subsample (double sample) of the selected and flown photo plots, detailed species composition, percentage of plot covered by each species, height information, stand condition and subjective classification were made. This data was used to determine the ability of the photo interpreter to identify species and also to provide a data base for planning of future projects.

Large Scale Aerial Photography

Approximately 5,600 large scale stereo pairs (photo plots) were acquired at a scale of 1:1,200. Of these, 4,500 photo plots were interpreted for four levels of ground cover: trees, tall shrubs, low shrubs, ground cover, and nonvegetation. Information on height, species, percent cover by species and drainage was recorded for each photo plot. This data provided the basis for making the quantitative descriptions of the map categories obtained from the manual photo interpretation and computer-aided analysis, and to provide confidence bounds with the descriptions.

Medium Scale Aerial Photography

1:30,000 scale and 1:120,000 scale color infrared aerial photographs were acquired by the RB-57 aircraft over nine intensive mapping areas selected by the BLM. These photos were interpreted for vegetation type, according to the classification framework provided by the BLM at mapping minimums ranging from five acres to 160 acres. Detailed cost information was maintained for each photo interpretation scale and mapping minimum. The large scale aerial photographs were then paired with the medium scale interpretation results to evaluate the interpretation and provide a quantitative description of the interpretation with confidence bounds.

Landsat Photographic Product

Three basic Landsat photographic products were interpreted at a scale of 1:250,000: 1) the standard EROS color product; 2) the EROS digitally enhanced (EDIES) product; and 3) a specially enhanced product for geologic interpretation. The standard EROS product and the EDIES product were interpreted at a 160-acre mapping minimum for vegetation according to the vegetation classification framework. All three of the above products were used in the interpretation for geologic features such as lineaments, geological hazards, and bedrock types. These interpretations provided general vegetation and geology maps of the Denali area and will be evaluated as to their cost effectiveness by the Bureau of Land Management.

Landsat Digital Data

Three separate Landsat scenes were classified using a mixed-mode, supervised/unsupervised classification training method, and a maximum likelihood algorithm, to produce the final computer-aided products. Each of the classified images was geometrically corrected to a 50-meter UTM grid using a nearest neighbor algorithm. In one of the areas the terrain data provided by the Bureau in a digital format was overlaid in the Landsat classification for each of the single date images. Three tables for each scene were developed to show the relationship between elevation and computer class, slope and computer class, and aspect and computer class. This data, along with the analysis data about each computer class, was then compiled for each computer class for each image to provide an easily readable, complete description of each computer class. Finally, the administrative boundaries and intensive mapping area boundaries were digitally overlaid to the UTM coordinate system and acreage summaries were generated for each, using the parameters from the analysis of variance (ANOVA) to estimate the acreage of each classification framework type down to the species level, where possible (table 1).

Many output products were generated from the Landsat digital analysis process. They include: 1:63,360 color coded maps of selected areas; 1:250,000 scale color products of the entire area for selected scenes; black and white separates of summary computer classes; gray scale maps at scale 1:63,360 of selected areas; line printer maps using printer symbols to indicate computer category; and computer plotter-generated polygons of summary computer classes at scale 1:63,360.

Summary of Significant Results

There are a number of very significant results from this program. The following is a partial list without regard to order of importance.

(1) The establishment of a regional data base for the Denali study area to provide for future analysis of sampling requirements for multistage and multiphase inventory projects in Alaska.

(2) The establishment of an initial data base that relates large scale photo interpretation results to ground conditions for this area.

(3) The establishment of a quantitative base on ground conditions for development of procedures in future programs.

(4) Development of a framework for defining inventory specifications at various levels: regional, planning unit, activity planning and high value/special interest planning.

(5) The incorporation of digital terrain data in the Landsat analysis to improve the utility of the final product.

(6) The acquisition of sufficient data to thoroughly evaluate and rank the relative cost effectiveness of Landsat digital processing results and photo interpretation data.

Table 1.--Example of area estimates and accuracy statements

AUGUST 1,1976 AREA A(CAP)			83045 HECTARES	207613 ACRES	ESTIMATES WITH 1 STD.DEV. ERROR BOUNDS				
SUMMARY CLASS # 1	57 PHOTO SAMP		1138 HECTARES	2845 ACRES					
CONIF	.11 PERCENT COVER	+/-	.060 PERCENT COVER	1 HA	+/-	1 HA	3 AC	+/-	2 AC
DECID	.26 PERCENT COVER	+/-	.264 PERCENT COVER	3 HA	+/-	3 HA	7 AC	+/-	7 AC
ALDER	12.75 PERCENT COVER	+/-	2.801 PERCENT COVER	145 HA	+/-	32 HA	363 AC	+/-	80 AC
WILLOW	24.00 PERCENT COVER	+/-	2.837 PERCENT COVER	273 HA	+/-	33 HA	683 AC	+/-	82 AC
DBIRCH	6.60 PERCENT COVER	+/-	1.457 PERCENT COVER	75 HA	+/-	17 HA	188 AC	+/-	41 AC
ML	51.20 PERCENT COVER	+/-	3.921 PERCENT COVER	583 HA	+/-	45 HA	1457 AC	+/-	112 AC
NONVEG	5.00 PERCENT COVER	+/-	1.113 PERCENT COVER	57 HA	+/-	13 HA	142 AC	+/-	32 AC
SUMMARY CLASS # 2	204 PHOTO SAMP		4196 HECTARES	10491 ACRES					
CONIF	.89 PERCENT COVER	+/-	.223 PERCENT COVER	37 HA	+/-	9 HA	93 AC	+/-	23 AC
DECID	.49 PERCENT COVER	+/-	.203 PERCENT COVER	21 HA	+/-	9 HA	51 AC	+/-	22 AC
ALDER	4.87 PERCENT COVER	+/-	.801 PERCENT COVER	204 HA	+/-	34 HA	511 AC	+/-	84 AC
WILLOW	28.20 PERCENT COVER	+/-	1.785 PERCENT COVER	1183 HA	+/-	75 HA	2959 AC	+/-	187 AC
DBIRCH	12.70 PERCENT COVER	+/-	1.057 PERCENT COVER	533 HA	+/-	44 HA	1332 AC	+/-	111 AC
ML	45.90 PERCENT COVER	+/-	2.079 PERCENT COVER	1926 HA	+/-	87 HA	4816 AC	+/-	218 AC
NONVEG	7.00 PERCENT COVER	+/-	.749 PERCENT COVER	294 HA	+/-	31 HA	734 AC	+/-	79 AC
SUMMARY CLASS # 3	327 PHOTO SAMP		4732 HECTARES	11830 ACRES					
CONIF	6.08 PERCENT COVER	+/-	.477 PERCENT COVER	288 HA	+/-	23 HA	719 AC	+/-	56 AC
DECID	.55 PERCENT COVER	+/-	.295 PERCENT COVER	26 HA	+/-	10 HA	65 AC	+/-	24 AC
ALDER	2.34 PERCENT COVER	+/-	.594 PERCENT COVER	111 HA	+/-	28 HA	277 AC	+/-	70 AC
WILLOW	20.40 PERCENT COVER	+/-	1.045 PERCENT COVER	965 HA	+/-	49 HA	2413 AC	+/-	124 AC
DBIRCH	25.10 PERCENT COVER	+/-	1.089 PERCENT COVER	1188 HA	+/-	52 HA	2969 AC	+/-	129 AC
ML	37.60 PERCENT COVER	+/-	1.167 PERCENT COVER	1779 HA	+/-	55 HA	4448 AC	+/-	138 AC
NONVEG	7.70 PERCENT COVER	+/-	.973 PERCENT COVER	364 HA	+/-	46 HA	911 AC	+/-	115 AC
SUMMARY CLASS # 4	12 PHOTO SAMP		246 HECTARES	615 ACRES					
CONIF	.00 PERCENT COVER	+/-	.000 PERCENT COVER	0 HA	+/-	0 HA	0 AC	+/-	0 AC
DECID	.00 PERCENT COVER	+/-	.000 PERCENT COVER	0 HA	+/-	0 HA	0 AC	+/-	0 AC
ALDER	.00 PERCENT COVER	+/-	.000 PERCENT COVER	0 HA	+/-	0 HA	0 AC	+/-	0 AC
WILLOW	2.80 PERCENT COVER	+/-	1.617 PERCENT COVER	7 HA	+/-	4 HA	17 AC	+/-	10 AC
DBIRCH	1.30 PERCENT COVER	+/-	1.241 PERCENT COVER	3 HA	+/-	3 HA	8 AC	+/-	8 AC
ML	6.80 PERCENT COVER	+/-	1.732 PERCENT COVER	17 HA	+/-	4 HA	42 AC	+/-	11 AC
NONVEG	89.20 PERCENT COVER	+/-	2.809 PERCENT COVER	220 HA	+/-	7 HA	549 AC	+/-	17 AC

(7) A large contribution is made to the geology data base for the area.

(8) The development of a significant data presentation format (menu) that summarizes the thousands of numerical analysis results in a readable format.

(9) The training of approximately ten BLM personnel from the basics through advanced techniques in remote sensing applications, sampling and numerical analysis.

DATA BASE CASE STUDY

"There is a wealth of resources on the lands we (the public agencies) administer and/or manage. Each resource specialist requires a set of information for management of the resource. Management must have accurate information in order to make intelligent decisions concerning the use, manipulation, etc., of those resources. Inventories collecting the data for these resource activities (such as forestry, range, wildlife) are often conducted separately.

While the management of each activity has individual information requirements, they also have much in common. Because management decisions are often based on evaluation of trade-offs between resources, a data base capitalizing on the commonality of information between resources is highly desirable, if not an absolute necessity. Such a data base may be built through multi-resource and multi-purpose inventories." (Lund 1978)

To illustrate the concept and advantages of using a data base for specific resource problems, the following case study is given. This case study will compare the procedures and relative costs required for two systems, both of which are designed to be an intensive in-place inventory for evaluation of winter moose ranges. The two comparative systems are (1) the "typical" techniques employed by large-game biologists which typically would not have a data base to draw upon, and (2) the multi-level techniques utilizing the established data base described above.

Winter moose range, according to wildlife biologists, seems to be characterized by shrub willow, willow/dwarf birch and willow/dwarf birch/conifer vegetation types. There is a variation in the usage of these vegetation types as winter moose range which could be weather dependent. The objective of such an in-place inventory would be to evaluate and describe the vegetation difference between the three various historical winter moose ranges (approximately .5 million acres). In order to reliably evaluate the difference, the accuracy level of the inventory would be set at making all vegetation description estimates at +10% at the .95 probability level.

Discussion

Procedure A

Assuming that 1:120,000 photography is available over the three areas, approximately 18 stereo pairs would have to be selected to cover the three areas. Using this photography, delineation of the different vegetation types at 100-acre mapping minimums would serve as a partitioning of the vegetation variability (stratification) and would eliminate cover classes of no concern. This stratification would be used in the selection of pilot samples and final samples.

In order to describe the vegetation in the three winter moose ranges to the level of accuracy required and without over-sampling, a measure of the vegetation variability is required. Because shrub willow appears to be a key indicator for this habitat, a pilot study to estimate willow variability would have to be conducted, if no estimate existed. Using the 1:120,000 photo stratification, five samples per willow strata would be randomly selected and plotted on field maps. Using a helicopter, percent cover of willow/dwarf birch/conifer would be estimated. All pilot plot data would be used to calculate the coefficient of variation (CV) for the percent cover of willow. Using this CV estimate the sampling intensity for the required accuracy level could be calculated.

Assuming the CV was estimated to be 70% per area, the sample size required would be determined using the following equation:

$$n = \frac{t^2 \cdot CV^2}{AE^2}$$

where

n = number of samples

t = student's t value for .95 probability (1.96)

CV = coefficient of variation (70%)

AE = allowable error (10%)

n = 189 plots/area (567 total plots).

With the sample size determined, selection of plots to visit on the ground would proceed in the same manner as the selection of pilot plot samples. The approximate project cost would be $230,000 (46¢/acre) and would require two years for the inventory, six two-man crews and one helicopter.

Multilevel Procedure

The major objectives of this in-place inventory are to describe and evaluate the differences between three winter moose ranges. As pointed out in the above procedure A discussion, to achieve these objectives in the most cost and time effective manner, a sampling scheme must be employed which, in turn, requires an estimate of the vegetation variability and a vegetation stratification. This data is then used to calculate a sampling intensity required to collect vegetation data at the level of accuracy needed to make the evaluations.

As pointed out above, the vegetation variability and the required accuracy level are the controlling factors in determining sampling intensity. Unlike procedure A, which did not have an initial estimate of vegetation variability, the multilevel procedure utilizing the previously established data base does. Using the existing data (% cover/species) over the three areas, CV could be calculated and thus eliminate the need for a pilot study. This CV calculation can be made for willow, dwarf birch and conifer, and subsequently, sampling intensity can be calculated. Because the willow cover type is key in this case study, sampling intensity has been calculated to ensure estimates of % cover willow ± 10 at .95 probability (see table 2).

Table 2.--CV and sample size determination using Denali data base

	Area 1(E)	Area 2(F)	Area 3(H)
CV Willow =	127%	116%	81%

$$\% \, CV = \frac{S}{\bar{X}} \times 100$$

$$n = \frac{t^2 \cdot CV^2}{AE^2}$$

where

n = number of photo plots

t = student's t value for .95 probability (1.96)

CV = coefficient of variation

AE = allowable error (10%)

# Samples/Area		Willow
n_1	=	620
n_2	=	517
n_3	=	252
	Σ =	1,389 photo plots

With the sample size determined, selection of plots to be used in the estimation of the vegetation cover would use the existing Landsat digital classification as the stratification in the same manner as procedure A would use its photo stratification (sample selection). Conducting a complete ground sample, as in procedure A, is very expensive. In order to minimize cost while maintaining the level of accuracy required, a clustered double sample could be used. This approach would employ the use of less expensive large scale photography (LSP) plots at a scale of 1:1,200 and a subsample of the LSP plots would be visited on the ground. The Denali data base shows a photo/ground correlation (R) for percent cover estimates of willow/dwarf birch to be no worse than .8. Taking this correlation into account and the relative costs of data collected from photos and from the ground, 155 out of the 1,389 photo plots should be visited on the ground to provide an accurate calibration of the photo estimates. The type of estimates made on both the LSP plots and the ground would be the same as those made using procedure A. This approach using large scale photography as a double sample with the ground and utilizing the data base would cost approximately $60,000 (12¢/acre) to collect vegetation descriptions for use in the evaluation of the three winter moose ranges. This approach would require one field season, one to two two-man crews, one helicopter and one photo interpreter.

CONCLUSIONS

With the increasing demand for timely and accurate resource data, the usage of the state-of-the-art technology for data collection and resource descriptions has shown that it does fulfill these requirements. Multilevel sampling techniques utilizing Landsat digital data, aerial photography and ground data to collect resource information on a regional basis can cost from 8¢ to 10¢ per acre, depending on the level of accuracy required. With this regional data base, effective planning and implementation of future projects can be done cost effectively and accurately, and can eliminate redundancy in some tasks.

To illustrate a benefit of a regional data base, two technical approaches were compared. One (procedure A) outlined the "conventional" ground data inventory techniques used in large game habitat evaluation; the other (multilevel) used the established Denali regional data base. The case study evaluated the approach, sampling requirements, cost and labor. The results of this case study show that:

(1) Estimated cost per acre for the multilevel approach is nearly one-fourth the "conventional" approach for the following reasons. Utilization of the established data base in the multilevel approach enables the estimate of vegetation variability and uses the existing Landsat stratification in sampling. Even if the Landsat stratification did not do as well partitioning the vegetation variability as does manual photo interpretation on aerial photography, a cost savings still is recognized due to the application of the established stratification in the multilevel approach. Even if a new Landsat stratification was generated, the cost per acre would only increase by approximately .5¢ per acre.

(2) As a result of many demonstration projects and as reflected in this case study, the partial replacement of ground work by use of large scale photography is a considerable cost and time savings.

In conclusion, it is safe to say that an initial capital investment of 8¢ to 10¢ per acre for the establishment of a regional data base through the use of multilevel techniques and subsequent usage of that data base employing multilevel techniques can reduce the costs of the overall data collection, resource description and management of our natural resources.

LITERATURE CITED

Lund, Gyde H. 1978. Inplace, Multiple Resource Inventories at Budget Prices. Resource Inventory Notes. BLM 13.

Environmental Monitoring for Remote Natural Areas Great Smoky Mountains National Park[1]

Raymond Herrmann, Daniel L. Stoneburner, Gary L. Larson, Raymond C. Mathews and Raymond E. Burge[2]

The concept for environmental monitoring of remote natural areas is developed and applied to Great Smoky Mountains National Park. In the simplest sense, this involves development of a set of integrated physical and biological measurements to detect and measure change. The resultant data increases our ability to understand the cause and effect relationships of "change" within the Park ecosystem.

INTRODUCTION

The Great Smoky Mountains National Park is 516,000 acres (209,000 hetares) of temperate deciduous and coniferous forest containing watersheds undisturbed by timber operations. The Park is a national resource and as a part of the Southern Appalachian Biosphere Reserve Cluster is proposed to serve as an important permanent reservoir of genetic material and a site where natural ecosystems can be preserved intact (Franklin 1977).

Current research focuses on broad-spectrum environmental monitoring under "natural" conditions and on exploring the impacts of anthropogenic factors on natural ecosystems. Recognition that preserves are not isolated units and reflect the effects of anthropogenic factors results in greater planning emphasis on long-term projects and permanent sampling regimes.

Franklin (1977) lists five kinds of research and monitoring activities for which the biosphere reserves are to be used. These include: 1) long-term baseline studies of environmental and biological features; 2) research to help develop management policies for the reserves; 3) experimental or manipulative, outside strictly preserved areas, particularly on the ecological effects of human activities; 4) environmental monitoring; 5) study sites for the various MAB research projects.

The remote monitoring project, designed also to meet the resource management needs of a national park embodies items one, two, four and five and is involved with development of a broad-based and cost-effective monitoring strategy that will have application across a spectrum of biosphere reserves and national parks.

MONITORING ACTIVITIES

For the purpose of solving complex resource management problems and providing for a better understanding of the functioning of natural ecosystems, specific data elements of otherwise independent research projects are incorporated into the overall monitoring program. Analysis of combined data sets has resulted in a better understanding of park resources.

Interactive monitoring activities now include: 1) pollutant input and cycling data, including precipitation analysis; 2) weather data; 3) serial collection of chemical and biological data; 4) permanent plot system for monitoring changes in major plant communities; 5) population monitoring of select terrestrial and aquatic species; 6) population censusing including endangered and exotic species.

Data has been collected in the park by National Park Service personnel, consultants, other Federal agency personnel, and university

---

[1]Paper presented at Pecora IV, Application of Remote Sensing Data to Wildlife Management, Sioux Falls, South Dakota, October 10-12, 1978.

[2]Respectively, Regional Chief Scientist, Atlanta, GA; Regional Ecologist, Athens, GA; Aquatic Ecologist, Gatlinburg, TN; Aquatic Biologist, Gatlinburg, TN; and Research Technician, Bay St. Louis, MS.

investigators (Herrmann et al. 1978). This project involves both the identification and evaluation of monitoring data required to test hypotheses and to answer resource management questions.

Methods of selecting monitoring parameters for measurement have inherent advantages and disadvantages (National Science Foundation 1977); however, our approach provides a promising means for development of a system to monitor long-term ecological change, while at the same time providing a structure within which to assist park management today.

The solution of complex resource management problems relating to anthropogenic influences and direct influences such as fire management, exotic species management or wildlife management is not independent of understanding how these systems function and precedes our ability to interpret the long-term meaning of biological changes. Interpretation of all of the interrelated data sets can not be completed at this time. However, in order to understand park ecosystems and their functions, each of these parameters must be evaluated individually and as a part of the overall system.

Assessing changes wrought by man and man's technology requires the intergration of our physical and biological data bases. Acid precipitation, pollutant, satellite, and other air, terrestrial and aquatic monitoring data, assessed relative to biological monitoring schemes, including permanent plots, and vegetation and aquatic surveys, leads ultimately to the problem assessment.

Pollutants

The complexity of pollutant monitoring relates to the detection of effects that may result from either a single short-term peak exposure, repeated short-term high level exposures, or multiple low-level, long-term exzosures. This picture is further complicated by the possibility of multiple pollutants acting synergistically or of a single pollutant causing or contributing to the aggravation of several different environmental effects. It is postulated that measurements of pollutant levels in remote areas will provide a least complicated clue of potential environmental effects. Thus, there exists the requirement for a better quantitative measurement of exposure of parks and biosphere reserves to background levels of biological, chemical, and physical agents as they relate to biological effects (Wiersma 1978).

The goal is to develop an accurate estimate of organism exposure to pollutants, including frequency, duration and intensity of exposure as related to other biological, physical and chemical parameters. This approach involves monitoring of levels, patterns, and trends of environmental pollutants or their metabolites in air, water, soil, and the biota. Annual sampling presently calls for the following: vegetation, 1,000 samples; air (particulates), 32 samples; air (organics), 16 samples; stream water (trace element), 80-100 samples; stream water organics, 10 samples; soil, 100 samples; litter, 100 samples; duff, 100 samples; samples of opportunity, 160 samples; and follows a block design based on the elevation aspect cutting history and type of forest. Samples are analyzed as appropriate by multiple techniques including gas chromatography - mass spectrometry, photon-induced x-ray fluorescense, inductively-coupled plasma emission spectrometry, spark source mass spectrometry, atomic absorption spectrometry, and scanning electron microscopy at two Environmental Protection Agency laboratories, Las Vegas, Nevada and Athens, Georgia and three university laboratories, University of Iowa, University of California at Los Angeles and Carnegie-Mellon University, Pittsburg.

Preliminary results to date indicate that sampling problems such as logistics and site access are not limiting. Laboratory limits of detection, employing the various techniques as appropriate for vegetation, soil and field techniques are adequate. They can be made adequate for trace elements in air and seem marginally adequate in water. Field sample variability, while high, can be accounted for by design (Wiersma 1978).

Finally, the data for the Great Smoky Mountains Biosphere Reserve site indicates there is already widespread lead residue contamination in the forest litter and possible contamination by other elements resulting from the long and short range transport (Wiersma 1978).

Acid Precipitation

Anthropogenic emissions of acid-causing pollutants increasingly are found to influence the pH of precipitation on local, regional, national, and international levels. Low pH of precipitation was identified as a problem in 1955-56 in the northeastern United States (Cogbill 1976). The problem, however, is not confined to the northeastern United States. In view of the potential impacts of the depressed pH of rainfall on soil and the success and survival of plants and animals, a program was established to monitor the pH of select streams in the Great Smoky Mountains National Park. In 1978, the program was expanded to include a limited number of rain and snow samples. The samples collected at the Uplands Field Research Laboratory near Gatlinburg, Tennessee, indicate that the pH of snow and rain was usually less than 5 and has been recorded as low as 3.3 for snowfall. However, the data are inconclusive at this time as to the cause and effect relationship of decreased pH and stressed aquatic ecosystems. Park aquatic habitats are comprised of streams having little buffering capacity which appear to be highly sensitive to acid precipitation and other atmospherically-derived substances. For this reason, long-term collection of water quality data and analysis of rain or snow collections for pH, conductivity, acidity, and alkalinity by standard method procedures will be continued.

Present data now suggest that considerable variation in the pH of precipitation exists. Some of this variability is ascribed to the direction (trajectory) of air masses, local topography, prevailing winds, seasonality, and whether precipitation is in the form of snow or rain. As an example, variation of pH of 1-day old snow with elevation was observed on February 2, 1978, along the Newfound Gap Road in the park, a north-south transect. These data indicate that pH change and elevation were positively correlated.

The expanded acid precipitation program, now being implemented, will be compatible with the North Central Project, NC-141, Atmospheric Deposition and includes weekly samples from a wet-dry deposition collector at the east, west, south and north edges of the park and near the highest elevation, about 6,000 feet (1,830 meters). Installation of these instruments will improve on present data and provide for long-term data analysis.

Photochemical Oxidants

Photochemical oxidants may exhibit elevated concentrations from reactions in sunlight between NO_x and various hydrocarbons and by-products of anthropogenic combustion of fossil fuels. The average annual concentration of photochemical oxidants in the United States is about .02 to .03 ppm (Talisayon 1972).

Recent studies by Skelly[3] et al. (1977) at several rural sites along the Blue Ridge in Virginia showed that the concentrations of photochemical oxidants were sometimes above the national ambient air quality standard of .08 ppm. They were able to correlate needle damage to white pine with the excessive oxidant concentrations and suggest that the oxidants were transported to the sites from midwestern urban areas.

A monitoring program for photochemical oxidants was established in the Great Smoky Mountains in 1978. A ground sampling site is located at the Uplands Field Research Laboratory; additional samples are taken during monthly aircraft flights over the park employing a Bendix monitor (chemiluminescence technique). The available data from the park are preliminary and causes cannot be ascribed. The average daily concentrations of ozone at the laboratory (Mast meter, model 724-2) are typically between .02 and .05 ppm. Hourly concentrations have occasionally approximated .07 ppm. Ozone concentrations recorded during the flights over the park typically range from .06 to .07 ppm. The ground monitoring program in the park will be expanded and is expected to include at least two Bendix monitoring instruments by fall, 1978.

Continuous Physical Monitoring

Long-term data collection includes water quality and weather data relayed from four Convertible Data Collection Platforms (CDCP) at three hour intervals by the Geostationary Operational Environmental Satellite System (GOES). The parameters transmitted are hydrogen ion concentration (pH), dissolved oxygen (D.O.), temperature, conductivity, oxidation-reduction potential (OPR) of water as well as wind direction, wind speed, surface barometric pressure, cumulative precipitation, air temperature and relative humidity. These data augment the monitors collecting continuous data on photo chemical oxidants and the nature of precipitation (acid, elemental constitutents, etc.). Compilation and analysis of these interactive and frequent data sets provides a comprehensive method for evaluating hypothesized complex changes in selected ecosystems.

---

[3]Skelly, J. M., Croghan, C. F. and Hayes, E. M., 1977. Oxidant Levels in Remote Mountainous Areas of Southeastern Virginia, and Their Effects on Native White Pine (Pinus strobus L.), 11 pp. (Unpublished)

Vegetation Survey

A relatively large amount of information is available on the park vegetation. A vascular species checklist has been published and a herbarium has been established for the park. Major alterations of the park flora, as previously stated, are occuring because of the activities of man, both directly and indirectly. Chestnut blight has removed almost all the mature chestnut trees, and replacement is by oak and other species. Much of the land that was disturbed for agriculture is now occupied by tulip poplar and pine. Burn scars and balds have grown in, and logged-over watersheds are supporting mature forests. Fire suppression has also altered to some unknown degree, vegetation patterns by changing the number and intensity of fires. Coves and high elevation stands remain unlogged, but much of the park has changed radically or is changing.

Changes following chestnut blight have been investigated by Woods and Shanks (1959) and changes due to wild boar invasion by Bratton (1974) and Howe and Bratton (1976). Changes related to disturbance, fire suppression, invasion by exotic species, anthropogenic and natural succession, require a great deal of further study and will rely upon monitoring data.

The survey plots and map data on a scale of 1:24,000, being developed as part of a 5 year program begun in 1977, serve as the record of park vegetation for future management and for interpretation of park flora. Monitoring insect outbreaks and plant diseases also relies upon this vegetation baseline. Presently both balsam woolly aphids and southern pine bark beetles are active in the park. The survey baseline data and permanent plot data will document the present occurrence and provide for analysis of future disturbances by these species.

Vegetation within Great Smoky Mountains National Park varies from the extremely heterogeneous deciduous forest to the very homogeneous coniferous forest. Plot size and spacing is somewhat arbitrary, given these conditions. However, reduction of sample variance is accomplished through consistent plot sizing (20 x 50 meters, about .25 acres) and high internal homogenenity, by establishment of subplots where necessary. Sampling intensity is presently sufficient to analyze variance and will be decreased as discernible patterns are detected and understood. At present approximately 300 plots have been established. In order to obtain the maximum amount of information about park communities and all the species contained therein, detailed and accurate sampling concentrates first in areas where the vegetation history is thought to be consistent.

Data obtained from permanent plot measurements, both physical and biological, provide insight into natural disturbance processes and provide a permanent record for monitoring change over a period of years. Successional changes influence the use of areas by wildlife and may change the importance of fire as a vegetation management tool. Successional change in the park will influence future management activities.

Other permanent vegetation plots are being employed to evaluate the impact of wild boars in different forest types. In conjunction with a series of hog exclosures (8 x 8 meters) in disturbed areas, they will also be used to evaluate vegetation recovery. Plots near trails, campsites and areas intensively used by visitors are being studied to quantify the effects of direct human impact such as trampling and firewood gathering.

Present data indicates that many sites exhibit rapid change because of the balsam woolly aphid (Hay et al. 1976) and human disturbance (Bratton et al. 1977), and by windfall (Becking and Olson 1977). Hypothesized climatic changes due to increasing carbon dioxide, or other changes owing to acid precipitation and various atmospheric pollutants also confound the monitoring design. If plots are to continue to serve the park as a long-term record of successional change in forest species composition, the ultimate network design must be determined not only by all of the preceeding management questions but at the same time it must account for detection required by anthropogenic and other subtle influences.

Aquatic Surveys

The remote areas of the Great Smoky Mountains are characterized by stream waters having little buffering capacity. Thus, exaggerated effects of non point source or atmospheric pollutants and the small scale changes generated by man and animal populations are of concern. The use of aquatic macroinvertebrates as indicators of water quality under these conditions requires a more complete understanding of the influence of other environmental factors.

In a series of preliminary observations, Stoneburner (1977) demonstrated that the aquatic macroinvertebrate community found at an altitude of 1020 meters was significantly different from that found at 640 meters. This finding indicates that standard methods employing diversity indices, are suspect where an altitudinal gradient is involved. Further data is required not only to isolate known anthropogenic effects and the effect of altitude but also the effect of distance from stream head waters. Thus, the inclusion of aquatic survey data, in addition to physical data as a part of the monitoring efforts, is providing a better understanding of the baseline condition of park aquatic ecosystems.

Investigations of the diatom and macroinvertebrate communities, designed to assess the changes in these communities through the various seasons, along altitudinal gradients and relative to distance from stream headwaters are currently underway. The analysis of the data collected is based on the taxonomic composition of the samples.

A significant problem encountered for park aquatic surveys is organism identification. Thus, altitudinal and longitudinal surveys and studies developing taxonomic keys will benefit from concurrent efforts to develop keys for organism identification and will for the first time provide for a biological "baseline" data set from remote areas of the park. Once the baseline is established, existing and new biological data can then be used to support detailed studies to assess changes through time. When these survey data, and the concurrently collected physical-chemical data have been accumulated in a large enough matrix, park managers will be able to determine, within a specified limit of confidence, the changes that occur in the water quality of remote streams, and assess the cause and effect relationships of changes in park streams.

Impacts from man's deliberate activities have been shown to result in water quality changes (Herrmann et al. 1976). Assessment of these changes is confounded by lack of knowledge about the natural resources and of other anthropogenic influences. Results of the present program indicate that "baseline" data from relatively undisturbed remote areas are also not free of man's unintentional influences.

CONCLUSION

Collection of coordinated physical, chemical, and biological data from remote natural watersheds within Great Smoky Mountains National Park establishes the "information base" for future comprehensive ecological studies. General survey sampling techniques as presented are combined with complex long-term monitoring data sets in order to establish "baseline" conditions, determine pollutant levels, forecast pollution trends and gauge the biotic responses caused by the introduction and fluctuation of small quantities of natural or exotic compounds. Man-induced phenomena, photo chemical oxidants, acid precipitation, increased sulfate levels and heavy metal burdens, are known to occur within the park. This project has established the rational and the capability for long-term monitoring of induced environmental changes within the park.

Advanced technological methods are being integrated into an environmental monitoring system involving interagency and interinstitutional cooperation in development of field surveys, permanent plot analyses, laboratory support systems and complex resources management research efforts. These efforts are expected to continue to produce timely environmental data which will benefit the decision-making process of natural resources management.

LITERATURE CITED

Becking, R. W., and Olson, J. S., 1978. Remeasurement of Permanent Vegetation Plots in the Great Smoky Mountains National Park, Tennessee, USA, and The Implications of Climatic Changes on Vegetation. Oak Ridge National Laboratory, Oak Ridge, Tennessee. RNL/TM-6083, Environmental Science Division, Publication No. 1111, 98 pp.

Bratton, S. P., 1974. The Effect of the European Wild Boar (Sus scrofa) on the High Elevation Vernal Flora in Great Smoky Mountains National Park. Bull. Torrey Bot. Club. 101: 198-206.

Bratton, S. P., Hickler, M. G. and Graves, J. H., 1977. Trail and Campsite Erosion Survey for Great Smoky Mountains National Park, Part I: Introduction and Methods, Management Report No. 16, National Park Service, Southeast Region, 61 pp.

Cogbill, C. V. 1976. The History and Character of Acid Preciptation in Eastern North America. Proc. of the International Symp. on Acid Precipitation and the Forest Ecosystem: 363-370.

Franklin, J. F., 1977. The Biosphere Reserve Program in the United States, Science, Vol. 195: 262-267.

Hay, R. L., Eagar, C. C. and Johnson, K. D., 1976. Status of the Balsam Woolley Aphid in Great Smoky Mountains National Park, Management Report No. 20, National Park Service, Southeast Region, 18 pp.

Herrmann, R. and Morgan, E. L., 1976. Aluminum Precipitation, Beech Flats and Walker's Prong Creeks, Great Smoky Mountains National Park. First Conference on Scientific Research in the National Parks, New Orleans, Louisiana. In press.

Herrmann, R. and Bratton, S. P., 1977. Great Smoky Mountains National Park as a Biosphere Reserve: A Research/Monitoring Perspective, Management Report No. 23, National Park Service, Southeast Region, 38 pp.

Howe, T. and Bratton, S. P., 1976. Winter rooting activity of the European Wild Boar in Great Smoky Mountains National Park. Castanea 41: 256-264.

National Science Foundation, 1977. Long-Term Ecological Measurements, Report of a Conference, Woods Hole Massachusetts, 26 pp.

Stoneburner, D. L., 1977. Preliminary Observations of the Aquatic Insects of the Great Smoky Mountains: Altitudinal Zonation in the Spring. Hydrobilogia, Vol. 56, 2: 137-143.

Talisayon, S. D., 1972. Low-level Air Pollution Effects on Experimental Animals: A Review. National Technical Information Service Paper No. 72-11, U. S. 40: 349-361.

Wiersma, G. B., Brown, K. W. and Crocett, A. B., 1978. Development of a Pollutant Monitoring System for Biosphere Reserves and Results of the Great Smoky Mountains Pilot Study. Fourth Joint Conference on Sensing of Environmental Pollutants, American Chemical Society: 451-156.

Woods, F. W. and Shanks, R. E., 1959. Natural Replacement of Chestnut by Other Species in the Great Smoky Mountains National Park. Ecology 40: 349-361.

Community Preference and Utilization Strategies of a Desert Herbivore[1]

Bobbi S. Low[2,3]

Abstract.--Using aerial photography, aerial census, and a variety of statistical analyses, the community use strategies and preferences of the red kangaroo (Megaleia rufa) were delineated. Despite the dramatic impact of rain in the central Australian desert, the occurrence of rain is very unpredictable, and it did not influence either density or dispersion of feeding red kangaroos. Both community type and season significantly ($p<.01$) influenced density; only community type ($p<.001$) significantly influenced feeding dispersion. Water availability appeared to have no effect on feeding dispersion.

INTRODUCTION

Like all heterotrophs, desert herbivores face the general problem of maximizing the net nutrient intake per unit of risk, energy, or search time (Cody, 1974; Schoener, 1969, 1971; MacArthur, 1972; MacArthur and Pianka, 1966; Levins, 1968; Emlen, 1966; Westoby, 1974); but they face additional problems because of the scarcity of rain in desert areas. This paper explores some of these problems for the red kangaroo (Megaleia rufa), a marsupial ranging from the 250-380 mm isohyet in the south to the 500 mm isohyet in the north of Australia.

The following questions are considered: How do the various aspects of rainfall (amount, variation, predictability), and concomitant changes in vegetation, affect the density and dispersion of feeding kangaroos? How do these effects interact with the effects of other parameters: vegetative composition of the community, season, available cover and free water?

[1]Paper presented at the Pecora IV Symposium, Sioux Falls, South Dakota, October 13, 1978.

[2]CSIRO Rangelands Research Unit, Alice Springs, N.T., Australia.

[3]Present address: School of Natural Resources, University of Michigan, Ann Arbor, MI 48109.

MATERIALS AND METHODS

Study Area

The study area, Kunoth Paddock, is a 152 km^2 area on Hamilton Downs Pastoral Lease (23°35'S., 133°35-E.), 50 km northwest of Alice Springs, Northern Territory, near the center of the range of the red kangaroo. The mean annual rainfall is 28.2 ± 1.5 cm (data from World Weather Records). During the 2 1/2 year study period, local rain, measured by 20 rain gauges on the site, was 52% of the long-term mean (Millington and Winkworth, 1978). Although the area is fenced on three sides and bounded on the south by the MacDonnell Ranges, kangaroo movements are not restricted. One permanent and three semi-permanent water sources occur on the paddock, which comprises nine principal plant communities (Lendon and Ross, 1978). Plant community distribution is strongly correlated with soil type (Wright, 1978). Topographic relief is slight.

Survey Techniques

Large (75 cm sq) coded markers were placed over the entire paddock, forming a half-mile (0.8 km) grid system. The area was then flown at 1000 ft to obtain black-and-white, color, and color IR imagery from which photomosaics (W.A. Low et al., 1978) and detailed community maps were constructed.

Three weeks in every month, kangaroo feeding use of communities was determined by aerial surveys, made at dawn because this covered the middle of the major feeding period, and flight conditions were optimal. Surveys were flown in a Cessna 172 at 100 ft and 70 knots over east-west transects 1.6 km apart. The coded markers were called out by the pilot as the aircraft flew over, while three observers marked sightings of red kangaroos on detailed maps prepared from aerial photographs.

This system permitted accurate recording of the plant community in which sightings were made, and afforded an accuracy of about 0.2 km with regard to exact location. Rotation of observers provided a check of spotting accuracy, since on each flight two observers made duplicate observations. Differences in kangaroos seen were not due to differences in observers ($p<0.4$).

Detailed mapping allowed counts to be stratified by community type. Communities were classified as having open (<10 percent), moderate (10-60 percent), or heavy (>60 percent) cover. Spinifex, treeless floodplains, and gilgais were classed as open; calcareous shrubland, savannah woodland, and most mulga-shortgrass were classed as moderate cover; and mulga-perennial and one area of mulga-shortgrass were classed as heavy cover. In practice, there was no difficulty in distinguishing these communities from the air. Transect widths used were of 1300 m (open); 900 m (moderate); and 400 m (heavy cover).

Numbers, Density, and Community Preference

Population estimates for the entire paddock (fig. 1) were the summation of estimates for each community:

$$N_T = \sum_{x=1}^{X} N_X \frac{A_{xtot}}{A} \qquad (1)$$

where N_X = number of animals seen in community X, A_X = area of community X covered by flight path, and A_{Xtot} = total area of community X in study area. All communities were seen in the flight path, but communities did not occur in the flight path in the same proportion as they occurred in the entire study area. Equation (1) compensates for unequal community representation in the area sampled.

In addition to density in each community, the dispersion of kangaroos was obtained. Ecological and population studies are traditionally based only on estimates of population numbers or density; such estimates are most useful for assessing impact on a given community. Percent distributions, as contrasted with numerical distribution, show feeding distribution independent of density, permit valid comparisons of surveys during the times of different densities, and are useful in predicting community use under different climatological conditions.

Consideration of percent distributions also permits statistical comparison with an "expected" distribution based on the proportion of the area represented by each community, and thus some measure of preference for communities. The preference coefficient, C_p, is computed as:

$$C_{p_{ijx}} = \frac{N_{ijx}}{N_{ijt}} \cdot \frac{A_t}{A_{xtot}} \qquad (2)$$

where N = number observed, i = wetness, j = season, x = community, A_{xtot} = total area of community x, and A_t = total area.

Community (area km²)	SW	SI	SD	WW	WI	WD	B	Overall
Mulga Perennial (59.3)	1.13	0.86	0.78	0.36	0.93	1.24	1.61	0.97
Mulga Annual (26.6)	1.70	1.44	0.91	0.84	0.99	0.50	1.41	1.18
Savannah Woodland (26.8)	1.03	1.80	2.11	3.27	1.86	1.44	0.22	1.66
Floodplain (18.0)	0.74	0.67	0.97	0.86	0.82	0.66	0.15	0.66
Gilgai (8.9)	0.14	0.03	0.29	0.28	0.34	0.45	0.98	0.31
Calcareous Woodland (18)	3.83	1.25	2.83	0.75	1.67	2.17	4.75	2.33
Foothills (7.9)	0	0	0	0	0	0	0	0
Spinifex (1.7)	0 0	0	0	0	0	0	0	0
Riparian (1.3)	0	0	0	0	0	0	0	0

Table 1.--Community preference in different season and wetness conditions. SW = summer wet, SI = summer intermediate, SD = summer dry, WW = winter wet, WI = winter intermediate, WD = winter dry, B = biseasonal rains. For further discussion, see text.

A C_p relationship greater than one indicates a favored community, C_p = 1 denotes an "ordinary" community and $C_p < 1$, an avoided community. This relationship can be calculated for different seasonal conditions (C_{pij}) and used to predict densitites and differential use, or used as a measure of overall preference (C_p) in all conditions (table 1).

Once enough surveys have been made to allow the computation of community preference, the number of animals predicted to be feeding in any given community in any seasonal and wetness condition may be predicted:

$$n_{ijx} = N_t \cdot \frac{A_{xtot}}{A_t} \cdot C_{P_{ijx}} \qquad (3)$$

The total number predicted on an area of several communities n_t, is the sum of all n_{ijx}.

Two- and three-way Scheffe analyses of variance (ANOVAS) were performed for population density and percent distribution among communities using community type, wetness conditions, (wet, intermediate, and dry, defined by soil water balance [Keig and McAlpine, 1969]), and season as variables. When differences in preferences due to season or wetness are compared for the same community, or when communities are ranked by wetness, density figures show usage directly and are most useful when the impact on each community is of interest. Per cent figures, however, are most useful in showing community preference in any one season or climatic conditions regardless of the population size.

RESULTS AND DISCUSSION

The densities of kangaroos and their distribution in the communities during the study period are summarized in figure 1. Overall densities on the paddock fluctuated during the study from a mean of $.56 \pm .13$ kangaroos/km^2 (summer/intermediate) to a mean of 5.95 ± 2.59/km^2 (winter/wet).

Three-way ANOVAS show that season and community significantly affect the dispersion of feeding kangaroos ($p<.01$) while differences in wetness do not. Using a two-way ANOVA season/wetness and community effects are both significant ($p<0.01$) but the interaction term is not (Low, in press).

General Preferences

Even when all seasonal and growth conditions were combined some patterns of community preference were apparent ($p<.025$). Red kangaroos were never sighted feeding in the hills, foothill fans, or spinifex areas during the study. In two and one-half years only 13 kangaroos were sighted in the riparian areas; these were recorded as present in the larger community in which the riparian area occurred.

At almost all times of year the mulga-perennial community is used less than would be predicted from its area (table 1, fig. 1). Use is especially low during dry summer periods. In contrast, this community is strongly preferred during the "interseasonal wet" period. The mulga annual community is used less than predicted in winter wet and winter dry periods, as well as during the biseasonal rain period. Both mulga communities appeared to be used more extensively in summer than in winter. When usage is averaged over all season and rainfall conditions, both communities are utlized at about the predicted level (table 1): mulga perennial slightly less, mulga annual slightly more than predicted. Neither difference is statistically significant.

Savannah woodland is a preferred community under almost all conditions. It is used by kangaroos more than predicted during all seasons except during the period of interseasonal rain response (table 1), and the overall use is significantly higher ($p<.01$) than predicted. In general, this community sustains heavier use in the winter than the summer (fig. 1; table 1).

The floodplains show strong seasonality, being used much less in summer months (table 1). This may be attributable not only to heat and lack of cover, but also to the fact that the ground story is rich in forbs and favored ephemeral species that respond quickly even to light rains in winter.

Gilgais are used significantly only at two times: 1) after very light rains which yield growth response only in run-on areas such as gilgais; and 2) a period of some weeks, depending on the season and amount of rainfall, after general rains when vegetation in other communities is drying off, while the gilgais remain green. Overall, gilgais are used significantly ($p<.01$) less than predicted on the basis of area (table 1, figure 1)(Low, in press).

The calcareous woodland is favored, particularly during dry winter periods (table 1, fig. 1). Because this community comprised such a small proportion of the total paddock, however, its desirability had little effect on the density, distribution, or overall impact of kangaroos on the system.

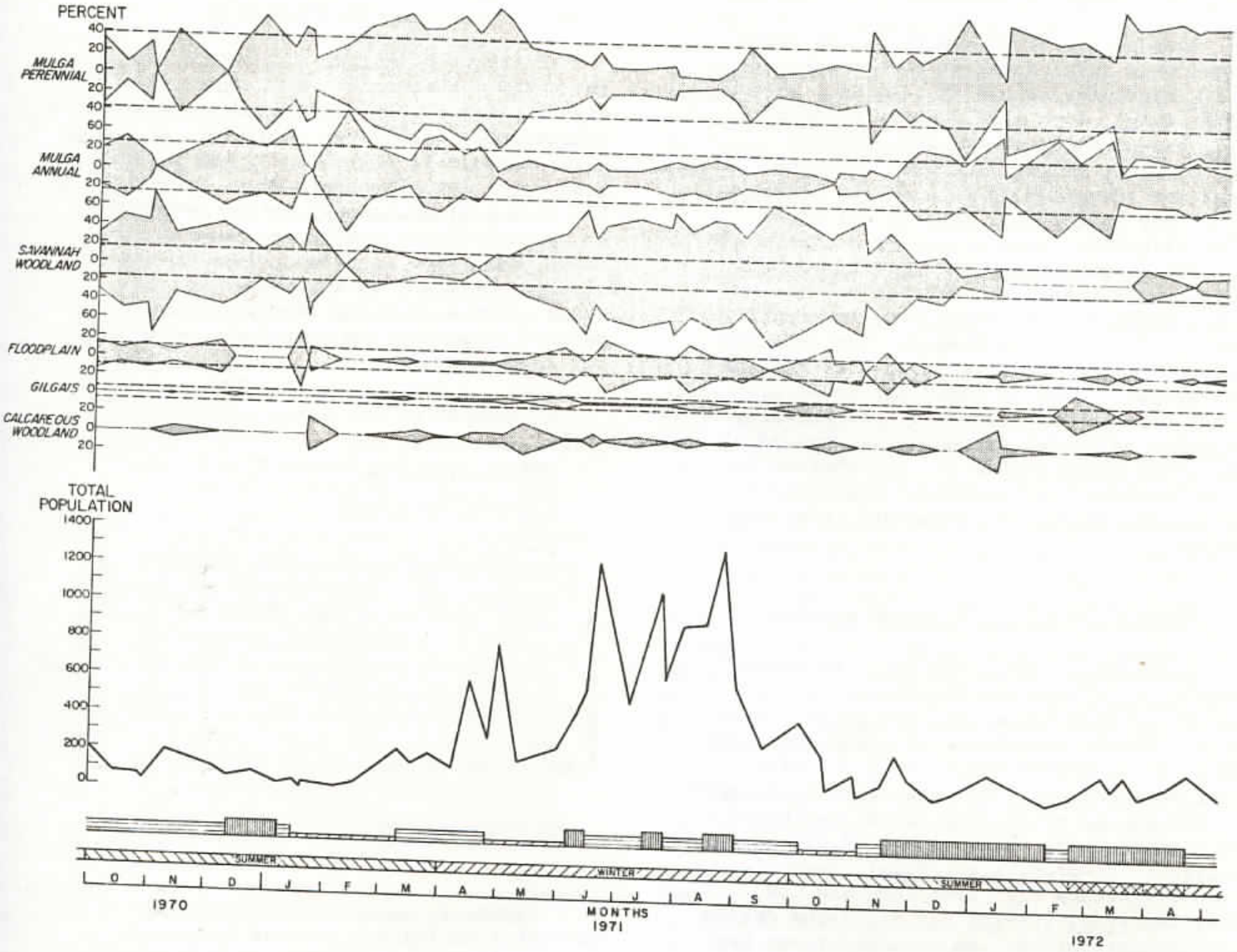


Figure 1.--Per cent distribution of red kangaroos feeding in different communities. Dotted lines show the expected distribution based on the area of each community. Total population numbers, season, and soil moisture condition are also shown. [wet symbol] = wet, [intermediate symbol] = intermediate, [dry symbol] = dry soil conditions.

Water

Although permanent or semi-permanent water is important to cattle (Low, 1972), and to kangaroos in other areas (Bailey, 1967; Ealey, 1967), it did not appear to influence feeding distribution during this study. Kangaroos were never sighted at the water holes; observed distributions did not center around the waters; kangaroos were never seen obviously moving to or from water, as cattle frequently are (Low, 1972); and only twice in two and one-half years were kangaroo signs found at a water hole on the study area.

Season

Population estimates for Kunoth showed a strong seasonality (fig. 1). Densities of kangaroos on the study area were greater in winter periods. Winter increases were due largely to movement into wooded communities, most strikingly the savannah woodland

and the floodplain. These effects exist because it was not practical to construct an entirely closed system which completely restricted kangaroo movements.

Seasonality of community use is accentuated when rains occur at interim periods--at the beginning or end of seasons. Late summer rains, from late January to April 1972, caused both summer- and winter-typical plant growth responses, and the kangaroos responded to this series of rains strikingly differently than to all other rains (fig. 1). When a two-way analysis of variance is performed comparing season and habitat only within the wet periods the season-habitat interaction term is significant ($p<.01$) (Low, in press). The relative frequency of potentially "interseasonal" or "biseasonal" rains is important in determining overall use patterns. For example, the mulga perennial community is avoided at most other times (table 1), and whether it is an "avoided" or "ordinary" community in any system depends on biseasonal rain frequency.

Rainfall and Soil Moisture Balance

Although rainfall was non-significant overall in influencing density or dispersion of feeding kangaroos, two effects were noted. Patchy occurrence of rains sometimes caused local shifts which could override other preferences. The most dramatic example of this was an artificial "rain" performed for another study on the area. A plot of woolybutt (Eragrostis eriopoda), normally a low-preference diet item (Low and Low, 1973; Low et al., 1973) was irrigated during a dry summer period. An electric fence kept cattle from grazing, but kangaroos consumed most of the plant biomass produced.

When widespread general rains occurred, the kangaroos frequently dispersed and used communities not represented in Kunoth. After certain rains, like those in late winter 1971, (fig. 1) density in the paddock fell sharply for a brief period. Aerial surveys showed concentrations of kangaroos feeding on gilgais in an area of Mitchell Grass (Astrebela pectinata) about 20 miles from the study area. Mitchell Grass plains, virtually monospecific stands, are not strongly represented in the Alice Springs District (300 km^2/144,000 km^2; Perry, 1960), and gilgais represent such a small proportion that Perry (1960) could not compute it. But these localized areas are intensely, if sporadically, used, and may therefore be important to kangaroo populations out of proportion to their actual commonness.

Cover and Group Size

Patterns of kangaroo distribution show two curious phenomena: a statistically significant ($p<.01$) preference for areas with considerable tree cover regardless of forage plants (table 1; figs. 1, 2), and a range in group size for all observations from one to 55, with a significantly larger ($p<.0001$) group size in all open areas (Low, in press). Since group size increases slightly but not significantly as density increases, only those surveys in which densities were comparable in wooded and open areas were used for comparison.

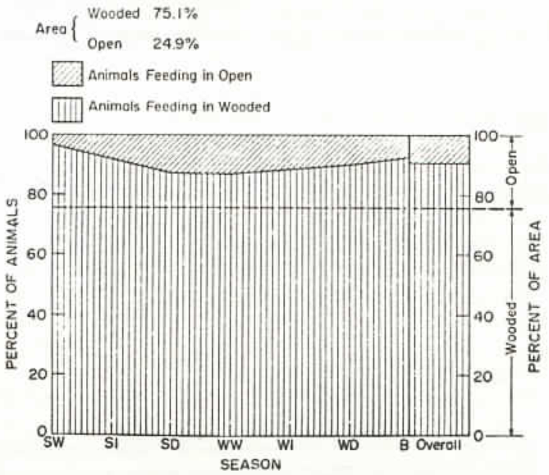


Figure 2.--Comparison of expected (--) and observed (—) per cent of kangaroos feeding in wooded (▥) and open (▨) communities. Seasonal abbreviations as in table 1.

Of all kangaroos sighted, 90.5% were in wooded areas that comprise only 75.1% of the study area (fig. 2). Wooded areas were preferred during all seasonal and rainfall conditions.

Hypotheses for patterns of preference between wooded and open areas appear to be reducible to three major types: 1) relief from temperature stress; 2) differences in desirability of forage species in different communities; and 3) selection pressure from predation, either current or in evolutionary history. These are not mutually exclusive, but each hypothesis provides testable predictions about distribution.

1) If temperatures were critical, kangaroos should seek cover when temperature in open areas reached some high level. This hypothesis predicts kangaroos would show higher preference for wooded areas (regardless of forage type) in hotter periods: summer days.

2) If forage desirability were paramount, distribution patterns would not necessarily be seasonally dependent, but preference might be expected to change with the occurrence of rains when preferred plant species are actively growing. A further prediction is that kangaroos should discriminate between different communities in wooded areas, if the forage species in those communities respond differently to rain. Although an overall preference for either wooded or open areas is conceivable, it seems unlikely that community preference would follow "open" and "wooded" categories since some major preferred grasses occur in both wooded and open areas. It seems likelier that preference would correlate with occurrence of preferred grasses.

3) If cover provided critical protection from predators two predictions would follow. First, kangaroos would seek cover more than predicted from random distribution at all times, regardless of temperature or forage distribution. Second, when feeding in open areas, kangaroos should tend to form larger groups -- in effect, using their conspecifics for cover in "selfish herd" strategy (Hamilton, 1971).

Another hypothesis sometimes proposed to explain the formation of groups is that of food distribution. Distribution of food alone appears to be sufficient to cause grouping (Lack, 1968; Horn, 1968) only when food is not only clumped, but when it is also more difficult for an individual to find than for a group of individuals to find (Alexander, 1974). Only in the gilgais does there appear to be any clumping of food resources in open areas. Kangaroos formed the largest aggregations in gilgais in times when all other communities were dry. This agrees with Newsome's (1965a) findings late in a severe eight-year drought, when the only green grasses were in gilgais. Except during drought, however, aggregation on the gilgais is an infrequent occurrence (fig. 2). Further, food in some wooded communities (e.g. mulga-perennial) is clumped, but group sizes are small. The feeding aggregation hypothesis is thus inadequate to explain the fact that groups are significantly larger in all open areas at all times, even when food in the open areas is not clumped, and smaller in all wooded areas even when food in the wooded areas is clumped.

The overall preference for wooded areas, and the difference in group size between wooded and open areas, suggest that predation may have played a stronger role than previously supposed in molding the social structure and feeding patterns of red kangaroos (see also Kaufmann, 1974). Temperature and forage composition have secondary effects on the level of preference for areas with cover.

The Extremeness and Predictability Of Rainfall

Because the effects of rain can be dramatic in arid lands it is not surprising that changes in feeding distributions are frequently attributed simply to rain (Newsome, 1965a).

Rain is one of the most impressive events in many deserts, both because of its immediate drama, and because of the greening of grass which follows. Desert rain is meager; less obviously it may also be unpredictable in timing and amount. Meagerness and unpredictability of rain present the herbivore with different problems, and the strategies appropriate in response to each seem to differ (Low, in press).

The mean is frequently used to describe the "usual" wetness or dryness of an area. In fact it is a poor predictor of life histories, since it is not clear that any organism reponds to the mean per se, but rather to the extremes encountered, and the predictability of timing of those extremes. Thus, a 13 cm rainfall area will have different characteristics from a 250 cm area because the extremes encountered are different; further, two areas with identical mean rainfalls may have very different life histories, if one is seasonal and the other not, or if one has little variance in amount of rain and the other has highly variable rain.

Measures like variance, standard deviation, standard error, and coefficient of variation reflect the extremes of wetness and dryness with which the organism must contend. Generally, when the variance of a parameter is very small, organisms may evolve to "tune" very closely to the parameter, even when it is extreme (for example, stenothermy in arctic fishes). As variance, and thus the extremeness of conditions encountered, increase, one expects to see three major types of strategies:

tolerance of extreme conditons (e.g., eurythermy in camels, dessication tolerance in desert amphibians); avoidance of extremes (nocturnal and burrowing habits of many desert dwellers); and modification of some portion of the environment by the organism to some less extreme condition (termite construction of mounds or slab nests in which temperature and humidity are more moderate and fluctuate less than in the external environment). In a variety of groups, adaptations to desert conditions specifically involve one of these three strategies.

Measures of rainfall predictability such as spectral analysis (Platt and Denman, 1975) and information theory (Colwell, 1974) reflect the degree to which organisms can evolve to depend on the occurrence of rain, as a function of its constancy (the degree to which conditions remain similar) and its contingency (the degree of association between rain and another parameter; e.g., seasonality). Predictability, constancy, and contingency can be defined mathematically (Colwell, 1974).

An organism's response to predictability is seen in the degree to which it relies on rainfall as a cue to initiate important activities. As predictability of rain increases due to contingency associated with seasons, for example, seasonality of response (breeding, change in feeding pattern, etc.) should increase. As predictability increases due to constancy, or as preditability decreases to zero, occurrence of rainfall gives less information about the suitability of the environment, and reliance on rainfall as a cue should decrease.

In the Alice Springs region rainfall predictability has low constancy, C, and contingency (e.g., seasonal changes), M (Colwell, 1974). Rainfall records for Alice Springs from 86 years from 1874-1960, (data from World Weather Records) show a predictability of $P = .111$ ($C = .069$, $M = .042$). There is thus a low probability of rain in any month, and no seasonal difference in probability of rain. Predictability of season ($P=1$, $M=1$) and community ($P=1$, $C=1$) are considerably higher. Since Colwell's (1974) indices may range from 0 to 1, this is a strong difference in predictability. On Hamilton Downs Newsome (1965a, b, c; 1971a, b) reported densities of $2.34/mi^2$ ($0.90/km^2$) during drought and of $5.02/mi^2$ $1.94/km^2$) after rains. However, the drought period he examined was in October, and the post-rain period was the following April and May; these times correspond to periods here termed summer dry and winter wet. Newsome made no surveys in dry winter periods or wet summer periods, and from his data it is impossible to distinguish effects of season versus rainfall. There is a difference in density of kangaroos on all communities studied on Hamilton Downs when season alone is retained as a variable (Low, in press). The effect of rainfall is nonsignificant. The effects of season, independent of any rainfall conditions, significant at the one percent level, may well explain the differences in density which Newsome (1965a) attributed to rain differences.

The red kangaroo's feeding dispersion thus appears to reflect the climatic uncertainty of central Australia. The basic community use pattern of this generalist species is set by the most predictable aspects of its environment, community and season. Rain, as the most uncertain parameter in the kangaroo's environment, sometimes causes momentary shifts in feeding dispersion, but is not responsible in any major way in determining the kangaroo's feeding density or dispersion. Feeding strategies are affected by the uncertainty of rainfall rather than by its scarcity.

ACKNOWLEDGEMENTS

I thank Ray Perry, W.A. Low, Colin Lendon, and Catherine Kemper of the CSIRO Rangelands Research Unit; Peter Hanisch, Laurie Corbett, John Calaby, and Alan Newsome of the CSIRO Wildlife Division; Don Abel and Warren Muller of the CSIRO Methematics and Statistics Division; and Richard D. Alexander, John Kadlec and Ed Morris of the University of Michigan. I am grateful to pilots Ossie Watts and Rob Horne of the Alice Springs Aero Club, and especially Bill Prior of Hamilton Downs, not only for permission to work and collect on the area, but for his interest and patience.

REFERENCES

Alexander, R.D. 1974. The evolution of social behavior. Ann. Rev. Ecol. Syst. 5: 325-383.

Bailey, P.T. 1967. The red kangaroo. M.Sc. thesis, Univ. Sydney.

Cody, M.L. 1974. Optimization in ecology. Science 183: 1156-1164.

Colwell, Robert K. 1974. Predictability, constancy and contingency of periodic phenomena. Ecology 55(5): 1148-1153.

Ealey, E.H.M. 1967. Ecology of the euro, Macropus robustus (Gould), in northwestern Australia. II. Behaviors, movements, and drinking patterns. CSIRO Wildl. Res. 12: 27-51.

Emlen, J.M. 1966. The role of time and energy in food preference. Amer. Nat. 110: 611-617.

Hamilton, W.D. 1971. Geometry for the selfish herd. J. Theoret. Biol. 31: 295-311.

Horn, H. 1968. The adaptive significance of colonial nesting in Brewer's Blackbirds. Ecology 49: 682-684.

Kaufmann, J.H. 1974. The ecology and evolution of social organization in the kangaroo family (Macropodidae). Amer. Zool. 14: 51-62.

Keig, Gael and McAlpine, J.R. 1969. WATBAL: A computer system for the estimation and analysis of soil moisture regimes from simple climatic data. CSIRO Div. Land Res. Tech. Bull. 69/9: 1-47.

Lack, D. 1968. Ecological adaptations for breeding in birds. Methuen, London. 408 p.

Leondon, C., and M. Ross. 1978. Vegetation. p. 66-90 In W.A. Low, et al., The physical and biological features of Kunoth Paddock in central Australia. CSIRO Div. Land Resources Mgmt. Techn. Pap. #4. 137 p.

Levins, R. 1968. Evolution in changing environments. Princeton Univ. Press, Princeton. 120 p.

Low, Bobbi S. in press. Rain in the desert: the herbivore's dilemma.

Low, B.S. and Low, W.A. 1973. Feeding interactions of red kangaroos and cattle in an arid ecosystem. p. 1(b)9-1(b)13. III World Conf. Animal Production, Melbourne, 1973.

Low, Bobbi S., E. Birk, C. Leondon, and W.A. Low. 1973. Community utilization by cattle and kangaroos in mulga near Alice Springs, N.T. Tropical Grasslands 7(1): 149-156.

Low, W.A. 1972. Community preference by free-ranging shorthorns in the Alice Springs District. Austr. Soc. Animal Production 9: 381-386.

Low, W.A., R.W. Millington, R.E. Winkworth, M.E. Sullivan, D. Johnson, M.J. Wright, C. Lendon, M. Ross, J.A.L. Watson, R.A. Barrett, P.J.M. Greenslade, Penelope Greenslade, and B.S. Low. 1978. The physical and biological features of Kunoth Paddock in central Australia. CSIRO Div. Land Resources Mgmt. Techn. Pap. #4. 137 p.

MacArthur, R.H. 1972. Geographical ecology. Harper & Row, New York. 269 p.

MacArthur, R.H. and Pianka, E.R. 1966. On optimal use of patchy environment. Amer. Nat. 100: 603-609.

Millington, R.W. and R.E. Winkworth. 1978. Climate. p. 16-22 In W.A. Low et al., The physical and biological features of Kunoth Paddock in central Australia. CSIRO Div. Land Resources Mgmt. Techn. Pap. #4. 137 p.

Newsome, A.E. 1965a. The abundance of red kangaroos, Megaleia rufa (Demarest), in central Australia. Austr. J. Zool., 13: 269-287.

Newsome, A.E. 1965b. The distribution of red kangaroos, Megaleia rufa (Desmarest), about sources of persistent food and water in central Australia. Austr. J. Zool. 13: 288-299.

Newsome, A.E. 1965c. Reproduction in natural populations of the red kangaroo, Megaleia rufa (Desmarest), in central Australia. Austr. J. Zool. 13: 735-759.

Newsome, A.E. 1971a. The ecology of red kangaroos. Austr. Zoologist 16(1): 32-50.

Newsome, A.E. 1971b. Competition between wildlife and domestic stock. Austr. Veterinary J. 47(12): 577-586.

Perry, R.A. 1960. Pasture lands of the Northern Territory, Australia. CSIRO Land Res. Serv. 5. 53 p. CSIRO, Melbourne, Australia.

Platt, T., and K.L. Denman. 1975. Spectral analysis in ecology. Ann. Rev. Ecol. Syst. 6: 189-210.

Schoener, T.W. 1969. Optimal size and specialization in constant and fluctuating environments: an energy-time approach. Brookhaven Symp. Biol. 22: 103-114.

Schoener, T.W. 1971. Theory of feeding strategies. Ann. Rev. Ecol. Syst. 2: 369-404.

Westoby, Mark. 1974. An analysis of diet selection by large generalist herbivores. Amer. Nat. 108: 290-304.

Wright, M.J. 1978. Soils. p. 34-61. In W.A. Low et al., The physical and biological features of Kunoth Paddock in central Australia. CSIRO Div. Land Resources Mgmt. Techn. Pap. #4. 137 p.

An Analysis of Vegetation Communities in the Lower Columbia River Basin[1]

John Grimson Lyon[2]

Abstract.--Natural vegetation communities were classified with LANDSAT data for 705,000 acres of the Lower Columbia River Basin. Both the IDIMS and Stansort digital processing systems were employed for a wetlands inventory, as well as a determination of the areal extent of riparian habitat and dredge spoils. The use of vegetation classifications for wildlife habitat assessment is addressed[3].

INTRODUCTION

Regional and site specific analyses of riparian, coastal, and estuarine vegetation communities were completed with multistage sampling of remote sensing data. Classified LANDSAT data, LANDSAT computer processed imagery, color infrared photography and extensive field work were employed to determine the extent of natural vegetation communities in the Basin. Species composition and growth form were described for each vegetation community with the UNESCO-Fosberg method of vegetation analysis. Aggregation of vegetation community information provides an estimate of available wildlife habitat.

Results of this study indicate the following. It is possible to use the UNESCO vegetation description system for assigning classifications to LANDSAT digital data. With this system, the computer classification accuracies ranged from 81-93%. Digital classifications can furnish supplementary information for environmental assessments.

The Study Area

The Columbia River wetlands support a large compliment of migratory, nesting and wintering bird species. Recent estimates indicate that the average daily wintering waterfowl count is in excess of 120,000 birds. The importance of the Basin for waterfowl is evident in the number of natural areas preserved for their use. The Sauvie Island Game Management Area in Oregon, and the Ridgefield National Wildlife Refuge (NWR) in Washington, are immediately downstream from Portland. Approximately 250 bird species have been identified in these areas. The estuarine islands between river miles 20 and 40 form the Lewis and Clark National Wildlife Refuge. It was created in 1972 to preserve habitat for the endangered Columbia White Tailed Deer.

A careful study of soil maps and environmental parameters preceded computer classification, and the study area was partitioned into four scenes with relatively homogeneous site conditions. Each scene was named after a major feature within the area. These include a coastal area (Astoria), a tidal island area (Upper Estuary), a forested river area (Puget Island), and an interior valley area near Portland (Sauvie Island)(see Figure 1).

---

[1]Paper presented at the Pecora IV Symposium, Sioux Falls, South Dakota, October 13, 1978.

[2]Research Assistant, The Remote Sensing Program, School of Natural Resources, University of Michigan, Ann Arbor, 48109.

[3]This work was made possible by the assistance of the NASA-Ames Research Associate Program, the University of Michigan Sea Grant Program, the National Wildlife Federation Fellowship Program, and the Remote Sensing Laboratory at Stanford University.

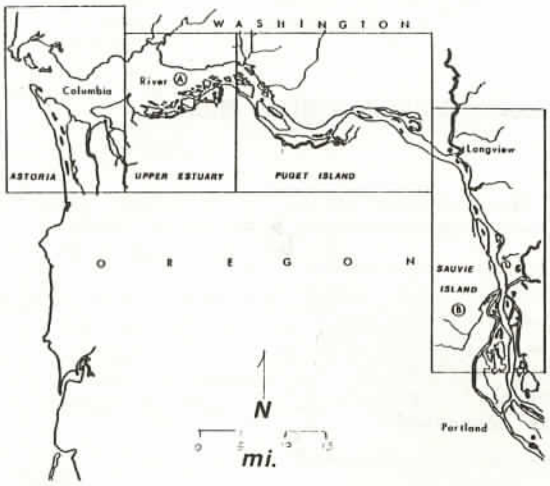


Figure 1.--A map of the lower Columbia River. Ⓐ indicates the location of the Lewis and Clark NWR. Ⓑ is the location of the Sauvie Island Game Management Area and Ridgefield NWR.

METHODOLOGY

Classification Approach

Site factors may modify the reflectance spectra of similar vegetation communities growing in different locations (Colwell, 1974). As a result, training sets composed of spectral signatures are valid for sites with similar conditions but cannot be extrapolated to areas with different topography, climate or soils (signature extension). This is a concern wherever a gradient of environmental conditions strongly selects for certain vegetation communities. The maritime climate, salinity intrusion and soils create important gradients in the Lower Columbia River Basin. Consequently, training sets were developed for each scene.

Within each scene, training areas representing the various cover types were selected from digital data products[4]. These were in the form of false color television projections and lineprinter dotprints, and products were created with the Stansort software at the Stanford University Remote Sensing Laboratory (Lyon et al, 1975). The Stansort dotprint images were overlayed on U.S.G.S. 1:24,000 scale quadrangles, and interpretation of the fourteen gray-levels allowed accurate delineation of training areas. The true scale of the dotprints is generally within one-percent of the nominal scale, and this proved satisfactory for feature location (Bellew and Lyon, 1977).

Figure 2 is a channels 7/5 dotprint of Sauvie Island and Ridgefield National Wildlife Refuge. The application of channel ratioing to enhance and accentuate environmental features is a useful technique. For vegetation studies the ratio of channels 7/5 provides a good indication of biomass, vegetation and shoreline Boundaries (Tucker, 1977). Using the 5/7 ratio for floodplain mapping, Harker and Rouse (1977) obtained a correlation coefficient of 0.94 with the one-hundred year floodplain mapped by the Corps of Engineers.

Once the training areas were located on computer data products, it was possible to create training sets with the IDIMS system (ESL, 1976). The training area coordinates were outlined on a color monitor with a trackball, and the data was processed through a self-clustering algorithm (TSSELECT). By selecting small areas to be "clustered", training sets with good statistics (as discussed below) were created. Training sets selected with this semi-supervised approach provide better classification accuracy than those selected by supervised or unsupervised methods.

It is possible to relate, a priori, the classification accuracy of measures of class separation. To obtain statistically-distinct training sets several subroutines were employed. The IDIMS subroutine DIVERGE will calculate the interclass separation in the four-dimensional parameter space created by the LANDSAT channels. By removing training sets below a threshold (1700/2000), statistical separability could be maintained and good classification accuracies achieved. The subroutine COMPARE graphically presents the clusters allowing visual comparison of any spectral overlap in the training sets.

After the a priori checks were completed, each section was classified with preliminary training sets and the individual class accuracies were evaluated with U-2 color infrared photography (NASA Missions 73-109 and 74-165). In addition, this classification program (CLASFY) provides a method of assessing the adequacy of the training sets. Classification likelihood values are calculated for each pixel by the IDIMS Bayesian decision rule.

---

[4] A July 25, 1975 LANDSAT-2 overpass, ID 2182-18204, was employed for vegetation classification.

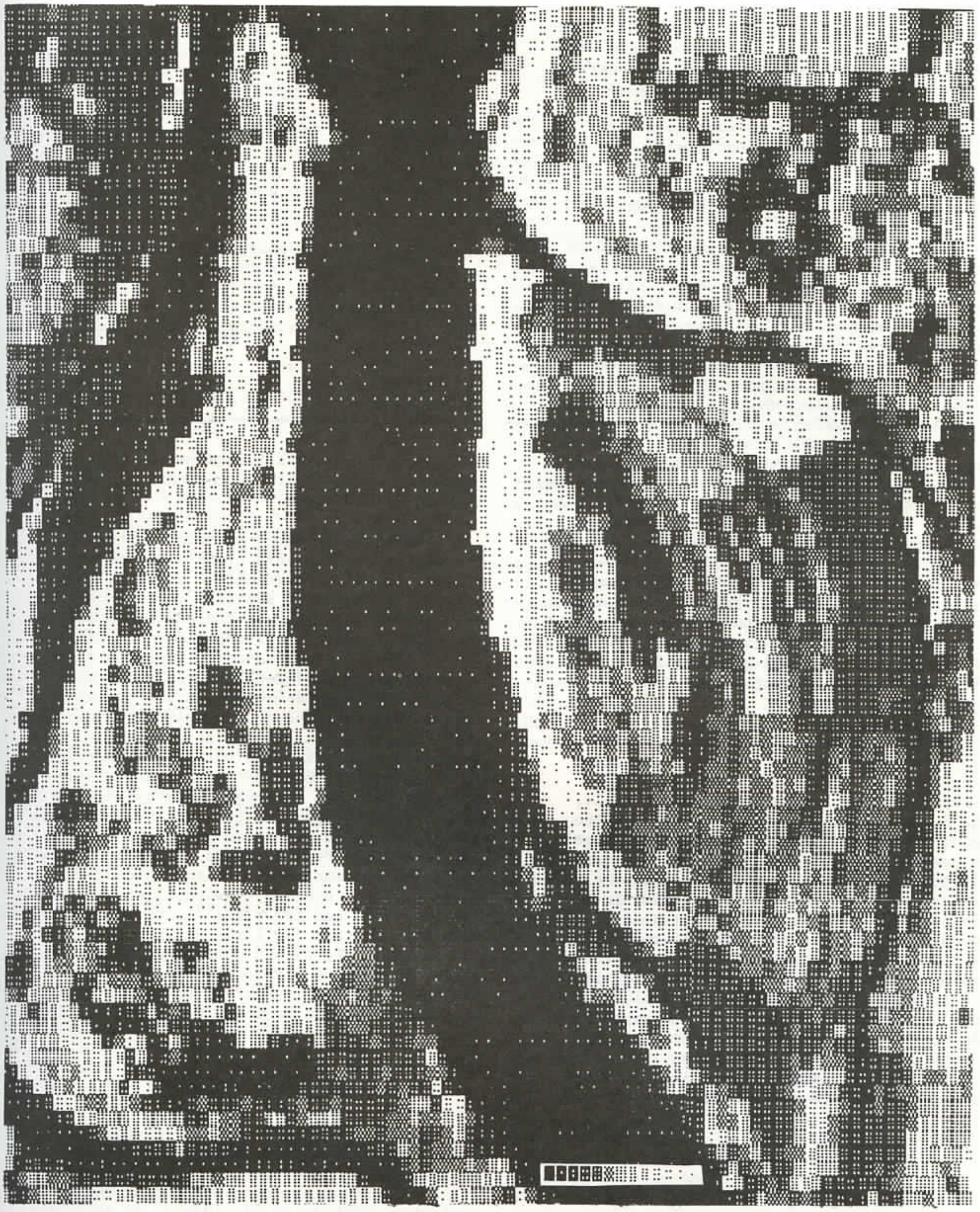


Figure 2.--Channesl 7/5 dotprint of Sauvie Island. White areas are Black Cottonwood and willow communities. Darker areas are fields, pastures and water. The original scale was 1:24,000, and the 14-member gray-scale is presented at the bottom.

These are displayed as a gray-level image, and the researcher can determine areas where additional training statistics should be generated to obtain a more accurate classification.

Final classifications were made after all the above tests were completed.

Vegetation Community Description

The species composition and physiognomy (vegetative growth form) of the training sets were described through field work. Each community strata or level was visually scored for species composition and cover-abundance. For these community training set descriptions, a slightly modified form of the UNESCO-Fosberg method of vegetation mapping was employed (UNESCO, 1973; Mueller-Dombois and Ellenburg, 1974; Anderson, 1976; Williams and Coiner, 1975). The United Nations Educational, Scientific and Cultural Organization developed this system over an eight-year period. This system, based on the physiognomy of the vegetation, is designed to provide a comprehensive framework for the preparation of vegetation maps of any part of the world at scales of 1:100,000 or less. The UNESCO approach classifies communities by the dominant growth-form of the uppermost strata. It is a useful system for remote sensing analyses as the canopy cover greatly influences the community light reflectance value, as well as the vegetation composition in the lower stratum.

Cover abundance estimations were made for one-acre areas and a value was assigned to each strata within the community. The system consists of a cover abundance scale, 1 to 5, in increments of 20% cover, and the symbol + for a lone example of a cover type. The upper three scale values (5,4,3) refer only to cover, which is understood as the vertical crown projection per species in the resolution cell. The lower three scale values are primarily estimates of abundance and cover. Abundance can be estimated for herb and shrub layer species with insignificant contribution to the community biomass. Table I presents an illustrative example of this method. Included are descriptions of a Sitka Spruce forest, dune areas, and swamps, from the Astoria scene. Dots appear between species to indicate codominance in the strata.

Sitka Spruce Forest	Spruce^{5} / Douglas Fir^{+}
Old Clearcut	Spruce^{3} / Alder^{2}
Lacustrine Swamp	Willow^{3} / dead Spruce^{1}
Estuarine Swamp	Spruce^{2} / Alder^{3} • Sedge^{1}
Dune	Beachgrass^{3} / Shorepine^{2}
Beach Swale	Alder^{1} • Pine^{2} / Salal^{2}

Table I.—Vegetation community type is presented on the left and the UNESCO description is on the right.

Some have objected to this method on the grounds that it appears crude and does not utilize actual measurements. However, quantitative measures of species composition are of little value, because the LANDSAT multispectral scanner integrates the reflectance of all the hetergeneous cover types in a 1.1 acre picture element. Here, the emphasis is placed on many semiquantitative estimates, rather than a few vegetation samples containing exact measurements of species quantities. This approach reveals spatial variation important to a regional vegetation survey, and allows for a timely analysis of large study areas. The UNESCO-Fosberg approach to vegetation description (as applied here) can be easily adapted to the new National Wetlands Inventory System, providing wetland species information for the classification process (Cowardin, et al, 1977). The 1:100,000 mapping scale for this inventory requires a method for large area vegetation assessment. The UNESCO system can be used to record vegetation information in the field, and provide ground truth for assigning classifications from the National Wetlands Inventory System.

Accuracy Assessment

When conducting a resource inventory, ground data should be collected at random so that unbiased estimates can be obtained and confidence statements made about these estimates (Nichols et al, 1976). As satellite data collection can be viewed as a stochastic process, areas for detailed photointerpretation and field checking were randomly chosen. This was accomplished by selecting four sections in each 1:24,000-scale quadrangle with a random number generator function (n=25). Within each section, a sixty-six pixel area was examined and scored for vegetation types and anthrogenetic features (Poulton, 1975). The same procedure and survey form were employed for both training set description and accuracy assessment.

The coefficient of variation or overall mapping accuracy is a common, easily understood measure of variability, and is expressed as a per cent of the population average. The scene classification accuracies are:

Astoria	86%
Upper Estuary	83%
Puget Island	81%
Sauvie Island	93%

Commission errors were associated with similar spectral signatures of rural, residential, and agricultural land use. Ommission errors occurred in some areas of heterogeneous cover types. The greater accuracy in the Sauvie Island scene resulted from a forty training set classification, as opposed to twenty-two training sets in the other scenes. The larger number provides a better representation of scene heterogeneity. However, the amount of digital processing, photointerpretation, and field work is greatly increased.

To obtain an estimate of the quantity and distribution of wetlands, the community classifications were aggregated for all four scenes. From Table II, it is apparent that 12,900 acres of marsh and 86,700 acres of swamp are present in the classified area.

The Utility of Computer Classified Data

It is desirable to know the extent of spoils deposited on riparian areas vis a vis. the extent of remaining natural shoreline. The quantity is uncertain, and no values were reported in the environmental impact statements for future dredging (U.S. Army, 1975 and 1976). This provides a good example of the utility of computer classified data for habitat assessment, as the available riparian habitat can provide a potential index of productivity.

From the classified data it was determined that 82% of both shorelines of the Columbia River from Portland to Longview (32 river, or 64 shoreline miles) are covered with dredge spoils or revetments. To arrive at this value, the picture elements for riparian areas were separated into two classes, natural and man-influenced shorelands, and aggregated by hand. The computer classifications were compared with U-2 CIR photography to insure accuracy. Spoil distribution maps were somewhat helpful (U.S. Army, 1975), and measuring the extent of mapped spoils provided a conservative estimate of 72% altered shoreline.

	ASTORIA	UPPER ESTUARY	PUGET ISLAND	SAUVIE ISLAND	TOTAL	% TOTAL
DUNE	1511	-	-	-	1511	0.2
MARSH	2074	2560	4231	3986	12861	1.8
SWAMP	17542	2935	22525	43742	86734	12.3
GRASS	3200	5840	4200	28760	42000	6.0
SHRUB / GRASS	12200	16134	37653	12748	78735	11.2
ALDER	8717	2478	2899	7382	21477	3.0
DECIDUOUS / CONIFER	29993	24645	66690	52828	174156	24.6
DOUGLAS FIR	-	12595	53567	24624	90786	12.8
STIKA SPRUCE	29954	17790			47744	6.8
FIELDS	11961	6824	23104	15347	57236	8.1
PASTURE	12665	6070	22072	9683	50490	7.2
RESIDENTAL	9529	3060	5025	6423	24037	3.4
URBAN	457	500	763	2990	4710	0.7
DREDGE SPOILS	8163	505	2101	2367	13136	1.9
	147967	101936	244830	210880	705632	100.0%

Table II.--A general aggregation of vegetation community classifications for all four scenes.

DISCUSSION

Vegetation community classifications can be employed as a surrogate for wildlife habitat assessment. The data forms a sampling grid of vegetation community information. When habitat needs of an animal species are defined in terms of vegetation communities, maps of these communities can be used to determine the areal extent and juxtaposition of essential and desired habitat types which are indicative of habitat quality. By developing a habitat model based on life history and weighting the importance of model parameters, data from this classification system can be employed in assessing habitat quality. While the LANDSAT resolution cell and spectral windows do not optimize detection of some resource characteristics, a field sampling program and a model of resource characteristics can be employed with regression techniques to obtain the desired information (Colwell et al, 1978).

Carter and Schubert (1974) report that streamside productivity is approximately twice that of inland areas. Higher marine productivity is believed to be typical of areas with very convoluted shorelines. The length of the shoreline per unit area of water is one index which might be considered in estimating shrimp production for estuary systems, or for fish productivity in shallow lakes. These indices are seldom used because of the difficulty of obtaining measurements of shoreline length and composition. Because remote sensing information can be digital, parameters such as acreage and shoreline length can be quickly and accurately determined. Both the monitoring of the vegetation types, and the areal extent of shoreline provide desirable types of resource information.

While important Columbia River wildlife areas have been preserved, much of the remaining estuarine and riparian habitat is no longer productive. Dredge spoils, revetments and levees isolate the river from its floodplain. The Columbia River has been dredged since 1877, and these activities are continuing to insure a channel depth of forty-feet. The destruction of riparian habitat is a serious problem on the Columbia. Only twenty-two miles of shoreline from Bonneville Dam (near Portland) to the Canadian Border are not involved in a dam or its impounded waters. Below Bonneville Dam, 65 percent of the floodplain is protected by levees (U.S. Army, 1975). Floodplain areas contribute nutrients in the form of detritus from leaf-drop and through flooding. The detritus and benthic forms which process the matter are an important nutrient source for fish in the Columbia Estuary (Lyon, 1977).

The Lower Columbia River has a sand bottom throughout much of its reach. As a result, planktonic and benthic organisms are not abundant, and those found in the Estuary are transported by the River from upstream sources. Where disposal material is dredged and placed along vegetated shorelines, the plant and benthic community that inhabits the river bottom and near-shore margins is extensively disrupted. Also, there is a loss of unique fish habitat found close to beach and island shorelines; sturgeon, smelt and shad use such areas for spawning and feeding. The shore plants also protect some of the important food organisms, and juvenile fish from predators. Dredge spoil areas take years to revegetate. Black Cottonwood and some willow species can vegetatively regenerate under three feet of spoil, but most plants experience poor germination in the clean, fine sand that makes up 99 percent of the spoil material (U.S. Army, 1975). This effectively eliminates leaf-drop as nutrient source for the relatively nutrient-poor River system.

The quantitative habitat information provided by digital remote sensing data can present an important argument against further destruction. In the next few years, the Corps of Engineers plan to bury an additional 5.2 miles of shoreline under spoil, and revet a further two miles. They may seem like a small request, but it represents a decrease in available riparian habitat from, 18 to 7 percent.

An understanding of ecosystem dynamics depends upon an understanding of the vegetation communities which provide for the basic transfer of sunlight energy into chemical energy for consumer species. Light reflectance is a measurable parameter that provides information on the dynamic nature of vegetation communities both in terms of monitoring succession and in monitoring the effects of human and natural disturbances.

Regional assessment of habitat with remote sensing techniques provides such planning information and can be employed for many different applications. The difficulty of gathering this data for wetland areas makes remote sensing a particularly beneficial information source. The utility of this approach is evident from the example of riparian habitat assessment.

CONCLUSIONS

The results and discussion appear to justify the following conclusions.

It is possible to use the UNESCO system for assigning vegetation classifications to digital data.

The accuracy achieved ranged from 81-93%, and leads me to believe the UNESCO system is probably adequate for many habitat description requirements.

Digital classifications can provide supplementary input to environmental assessment projects.

BIBLIOGRAPHY

Anderson, J., 1976. On Vegetation Mapping In Alaska Using LANDSAT Imagery. Instit. of Arctic Biology, UN. of AK, Fairbanks, 220 p.

Ballew, G. and R.J.P. Lyon, 1977. The Display of LANDSAT Data At Large Scale By Matrix Printer. Photo. Eng. Remote Sensing 43: 1147.

Carter, V. and J. Schuber, 1974. Coastal Wetlands Analysis From ERTS MSS Digital Data and Field Spectral Measurements. In Proc. of the 9th INT. Sym. on Remote Sensing of Environ., ERIM, Ann Arbor, MI, p. 1241.

Colwell, J., 1974. Grass Canopy Bidirectional Spectral Reflectance. In Proc. of the 9th INT. Sym. on Remote Sensing of Environ., ERIM, Ann Arbor, MI, p. 1061.

Colwell, J., D. Gilmer, E. Work, D. Rebel, and N. Roller, 1978. Use of LANDSAT Data to Assess Waterfowl Habitat Quality. Environ. Res. Instit. of Mich., Ann Arbor, MI, 83 pp.

Cowardin, L., F. Golet, and E. LaRoe, 1977. Classification of Wetlands and Deep-Water Habitats of the United States. J. Sather, Ed., USDA Fish and Wildlife Service, Office of Biological Sciences, Washington, D.C.

Electromagnetic Systems Laboratory, 1976. IDIMS Users Handbook. Mountainview, CA.

Harker, G. and J. Rouse, 1977. Floodplain Delineation Using Multispectral Data Analysis. Photo. Eng. Remote Sensing 43: 81-88.

Lyon, J., 1977. Outerspace: A Remote Sensing Analysis of Vegetation Communities on the Lower Columbia River and Estuary. B.A. Thesis, Dept. of Biology, Reed College, Portland, Oregon, 220 pp.

Lyon, R.J.P., 1975. Evaluation of ERTS Multispectral Signature in Relation to Ground Control Signatures Using a Nested Sampling Approach, Vol. I-III. Remote Sensing Laboratories, Stanford Univ., Palo Alto, CA.

Mueller-Dombois, D. and H. Ellenburg, 1974. Aims and Methods of Vegetation Ecology. John Wiley and Son, N.Y.

Nichols, J., R. Harding, R. Scott, and J. Edwards, 1976. Forest Inventory of Western Washington By Satellite Multi-Stage Sampling. In Proc. of Fall Sym. of ASP, Seattle, WA.

Poulton, C., 1975. A Comparative Interregional Analysis of Selected Data From LANDSAT-1 and EREP For the Inventory and Monitoring of Natural Ecosystems. In Vol. A of NASA Earth Resources Survey Symposium, Houston, TX, p. 507.

Williams, D. and J. Coiner, 1975. Utilization of LANDSAT Imagery for Mapping Vegetation on the Millionth Scale. In Vol. I-A of NASA Earth Resources Survey Symposium, Houston, TX, p. 53.

Tucker, C., 1977. Use of Near Infrared/Red Radiance Ratios for Estimating Vegetation Biomass and Physiological Status. NASA-GSFC X-923-77-183, 41 pp.

UNESCO, 1973. International Classification and Mapping of Vegetation. Paris: UNESCO, 93 pp.

U.S. Army, 1975. Columbia and Lower Willamete River Maintenance and Completion of the 40-Foot Navigation Channel Downstream of Vancouver, WA and Portland, OR. Corps of Engineers, Portland Distric, 250 pp.

U.S. Army, 1976. Lower Columbia Bank Protection Project. Draft EIS, Corps of Engineers, Portland District, 150 pp.

Remote Sensing of Fish Habitat Areas

Paper presented at the Pecora IV Symposium
on the Application of Remote Sensing Data to Wildlife Management
at Sioux Falls, South Dakota, Oct. 10-12, 1978.

H.F. Olsen
Estuarine Management Officer, Queensland Fisheries Service
Brisbane, Queensland, Australia.

ABSTRACT: The Queensland Fisheries Service is engaged in an inventory of the estuarine areas of the State of Queensland, Australia. Base-line data on estuarine conformation and fish habitat areas is prepared by the utilization of remote-sensing to supplement ground surveys. Methods of survey, assessment of habitat areas and preparation of estuarine management plans are outlined and discussed.

INTRODUCTION

The responsibility for management of the marine and freshwater fisheries of the State of Queensland rests with the Queensland Fisheries Service. Along with the regulation of actual fishing operations the Service also has a concern for the control and protection of the aquatic environment in terms of physical disturbance or alteration of habitat areas deemed to be of value to fisheries.

BACKGROUND INFORMATION

The State of Queensland is the second largest State of Australia and comprises almost a quarter of the continent's land-mass; it is approximately twice the size of Texas, U.S.A. It is situated in the north-eastern sector of the country and has some 3,250 miles of coast-line, stretching between the 10th and 29th parallels of south latitude.

Physiography and Climate

The main Dividing Range is situated on the eastern rim of the State with a maximum elevation of the order of 5,000 feet in the Atherton Tableland region in North Queensland; most of the Divide has an elevation of around 1,000 to 2,000 ft. It is the dominating feature of Queensland's drainage pattern; the State falls broadly into four areas of surface drainage. Two of these drain south and west towards the interior of the continent; the remaining two areas constitute the East Coastal and the Gulf Coastal drainage systems.

Rainfall is strongly seasonal in the northern half of the State's coastal zone with a pronounced Summer "wet" and a dry Winter-Spring period. Summer rain in the coastal strip varies from about 40" in the South to 80" in the vicinity of the northern ranges.

Tidal range within Queensland varies from 7 feet Spring range at Brisbane in the southern part of the State to 26 feet in central Queensland. At the extreme north of the State in Torres Strait the Spring range is 11 ft. East coast tides are semi-diurnal; tides at the head of the Gulf of Carpentaria are mostly diurnal with a maximum range of about 18 feet.

Estuarine Conformation

The south-eastern estuaries are typified by sea-grass communities and associated mangrove communities within bar-built estuaries, with offshore islands or coastal dune formations. The coast-line is exposed to the open sea (Pacific Ocean).

The coast-line embracing the central and northern east coast estuaries is protected from the Pacific Ocean by the coral formations of the Great Barrier Reef. These estuaries fall into two categories: (a) a meandering flood plain system with deltaic mangrove islands or (b) short rivers usually containing limited areas of mangrove forests in sheltered embayments. Sea-grass meadows are not a conspicuous feature of these systems.

The braided Gulf streams meander across extensive coastal plains and are generally fringed by narrow bands of mangroves. The coastal plains are low-lying and are seasonally flooded in the "wet" season for upwards of 15 miles inland from the High Water line.

RATIONALE

Fisheries management in Queensland, like that in many countries throughout the world, has traditionally relied on limitations on fishing effort. These limitations were imposed by restricting entry to a particular fishery, restrictions on size and type of fishing gear, seasonal or permanent closure of fishing grounds or protection of specific fish stocks by total prohibition on capture.

However, in the 1960-1970 period there was a growing awareness that management or protection of fish stocks served little purpose if fish habitat areas were destroyed, Olsen (1977)[1]. The present estuarine inventory programme arose from this concern at the evident conflict of use occurring in the more densely populated regions of the State; initial action was taken in January 1969 by declaration of a number of Fish Habitat Reserves under Queensland government legislation. Disturbance of sub-strate or vegetated areas (e.g. mangroves, sea-grass) is prohibited within such Reserves although all legal forms of commercial and recreational fishing are permitted. The provision of funds by the Federal government in 1974 enabled extension of this approach to cover a review of the whole of the State's estuaries and their management.

Because of the varying climatic, geographic and estuarine conditions encountered within the State, a system of estuarine appraisal was required by the Service which would allow some consistent form of comparative evaluation. The extensive coast-line and the virtual inaccessibility of many regions prevented detailed biological studies of each estuarine complex. To enable completion of a State-wide inventory in a reasonable time period it was evident that basic data input could best take the form of an evaluation of a conservation rating of habitat areas with later appraisal of particular areas on a site-specific basis.

A priority ranking of the 'conservation' value of fish habitat areas is therefore used by the Service. Features in each estuary are assessed independently and incorporated in an additive and multiplicative scoring of disturbance likely to affect habitat value. The system essentially consists of a "Use-Interference" model which attempts to evaluate Present Use - Expected Interference - Future Value.

There has been a considerable volume of work carried out in relation to evaluation of terrestrial areas for conservation purposes, particularly that of Gehlbach (1975), Goldsmith (1975), Ratcliffe (1971), and Tans (1974). Kuchler (1973) reviewed the problems in classifying and mapping vegetation and a number of workers have elaborated on land-use and agricultural land capability, e.g. Rosser et al (1974). In dealing with the Moreton region of south-east Queensland Martin (1974) established criteria for the evaluation of habitat suitability for fauna.

Adamus and Clough (1978) similarly set down criteria for evaluation of species for protection in natural areas, whilst Wright (1977) discussed the criteria commonly used for the survey of mainly terrestrial nature reserves and score systems for their evaluation. The Service approach, like that of Wright, attaches much importance to the need for a method that is systematic and is capable of storage in a data bank or card index system. The method used by the Service attempts to integrate estuarine management zones with regional and town planning needs. Criteria have been previously outlined by the author (Olsen, 1977)[2] but are briefly mentioned in the present paper in relation to specific survey methods and the results achieved.

METHOD

The sequence of activities followed by the Service can be summarised under three principle headings -

(i) Collection and analysis of data;

(ii) Preparation of a Use-Interference model for each estuary;

(iii) Determination of a Strategy Plan and Policy Plan for each Region or watershed.

Initial appraisal consists of a review of existing topographic and cadastral mapping and available aerial photography. The State Air Photography programme is intended to suit the needs of mapping agencies, hence available photography is usually 9" x 9" format, black and white, at a photo-scale of 1:25,000. This appraisal enables interim planning of field study programmes, definition of the limits of the particular study area, and broad determination of watersheds, vegetation groupings, and estuarine features. Howard (1970) has pointed out the limitations of the use of black and white photography of this scale for photo-ecological work. Field trials by Service personnel have confirmed the general observations of Howard, although considerable benefit is derived from the initial analysis of mapping and photography in relation to coastal geomorphology as indicated by Verstappen (1977). Table I sets out the guidelines and procedures adopted by the Service -

TABLE I - Photo-Interpretation

(a) Habitat Assessment using Photo-Interpretation

1. Photo-interpretation provides information at two levels -

   (i) Policy Level; photo-scale 1:30,000

   (ii) Management Interpretation; photo-scale 1:8,000 - 1:12,000.

2. Photo-interpretation data comprises -

   (i) Mangrove, sea-grass, samphire and clay-pan areas;

   (ii) Community classification of mangroves, wetland vegetation;

   (iii) Foliage cover/height as an index of of available leaf-litter;

   (iv) Terrain classification; land-form and features as habitat zones;

   (v) Tidal scour, siltation patterns as estuary characterics.

(b) Common Diagnostics for Photo-interpretation.

   (i) Shape: conformation of estuarine features;

   (ii) Shadow: density and height of vegetation;

   (iii) Tone: reflectance varies with species composition and soil moisture;

   (iv) Pattern: both for mangrove occurrence and for past man-made disturbance;

   (v) Texture: related to luxuriance, species in canopy and density of vegetation;

   (vi) Colour: both false colour infra-red, normal colour photography and enhanced imagery can be interpreted in relation to ground truth data on colour differences;

   (vii) Site: for mangroves, sea-grass and samphire, "site" related to species/soil type/drainage patterns.

Having defined the watersheds to be included in the study area, use is made of photographically enhanced Landsat imagery to illustrate regional land-use, vegetated and agricultural areas, turbidity patterns in estuarine and near-shore waters and overall estuarine conformation.

Experience under Queensland conditions has shown that, where detailed investigations and management decisions are necessary, the use of stereo colour photography (9" x 9" format) and low level oblique photography (35 mm at 1,000 ft. flying height) are the preferred options. Colour photography at photo scale 1:12,000 in 9" x 9" format is flown by private air-survey companies under contract to the State mapping authority; the low-level 35 mm photography using both normal colour and false-colour infra-red film is flown by Fisheries Service personnel. In more remote locations, this flight serves a dual purpose; it provides interpretive photography and also enables the study team to assess land and sea access routes.

The advantages of this multiple analysis of the study area can be stated as -

(i) Landsat imagery provides a regional overview of major environmental factors; as an example of this approach, imagery of Moreton Bay, near Brisbane, identified more vigorous algal and mangrove growth adjacent to three sewerage outlets and enabled rapid delineation of the affected areas;

(ii) Stereo colour photography at 1:12,000 provides ease of interpretation and enables detail base map preparation at photo-scale for field studies;

(iii) False colour infra-red photography of specific sites enables identification of growth patterns within communities, i.e. Spotted mangrove (*Rhizophora stylosa*) communities can be separated into two sections -

(a) the higher levels of sub-strate with mangroves of reduced growth habit: these provide a dull purple-red film colour response; and

(b) the lower levels subject to more frequent tidal inundation, hence less "woodiness" in the canopy; these mangroves give a bright rose-red colour response.

Trials by Service personnel have served to demonstrate the feasibility of this type of detailed analysis of estuarine areas by remote sensing techniques under the field conditions encountered in Queensland. It would be useful to have total stereoscopic coverage of the estuaries in infra-red false colour. Difficulty in maintaining a supply of film in remote areas and fund allocation to the particular project serve to place a constraint on this approach. It is considered that the use of Landsat imagery and estuarine project photography in conjuction with low-level flights by Service personnel provide an acceptable and economic alternative to total 9" x 9" photo coverage.

Vegetation Mapping

From subsequent analysis of photography, field sites are selected to enable collection of ground truth data. Data collected in the field follows the procedure adopted by Walker et al (1973).

In the preparation of vegetation descriptions and the accompanying mapping project a modification of the classification proposed by Specht (1970) is used. Personnel from the Botany Branch, Dept. of Primary Industries (State Herbarium) undertake this section of the work as a co-operative effort. Data collected at each field site includes a description of the plant community in terms of structure, species present and projective foliage cover. In addition to the selected field sites, transects are made on foot and boat throughout the study area to confirm the detailed photo-interpretation and cartographic presentation.

Analysis

On completion of the field work and cartography each estuarine habitat zone is subject to analysis on a grid basis either on a 1 km x 1 km unit or an aggregate cell of 4 km x 4 km (16 units). This vegetation and estuarine habitat information is eventually incorporated in the ranking procedure for the total estuary and a comparative evaluation obtained. This procedure identifies the several types of zoning adopted by the Service, viz. -

Suitable for (i) reservation as a Fish Habitat Reserve or Marine Park proposal;

(ii) multiple use as an Ecological Buffer zone; and

(iii) zoning as Development Node i.e. sites of lower ecological value which may be reclaimed, dredged, etc without appreciable loss of fisheries resource areas.

The habitat zones defined in accordance with the above three ranking values are then subject to discussion with local and State agencies. Legislative action is then taken as an integrated planning proposal for estuarine management. In this fashion the Service endeavours to foster the concept of coastal zone management as -

(a) a Regional Strategic plan for use of the State's resources;

(b) a Policy plan for determination of management zones within each estuary; and

(c) a fisheries Management plan for each individual reserve or zone within an estuary.

Table III lists the "ranking value" for one estuary, and indicates the management option available for that estuary; in this case, the estuary falls within the ranking of a "protected" zone. Because of the existence in the region of a commercial fishery, such management zone desirably should be a Fish Habitat Reserve. Declaration of such a Reserve would allow the continuance of the existing fishery; Marine Park legislation under the Queensland Fisheries Act prohibits commercial fishing and declaration of a Marine Park, whilst possibly the most effective conservation measure, would curtail the existing commercial use of the area.

The features used to arrive at a ranking of the conservation value of an estuary are assembled (Table II) under the basic headings of the Use-Interference model - Present Value : Interference : Future Use. Within the range of the numerical values assigned to each unit of the assessment, a further simplification is made by assembling the ratings as units within a decile grouping. Conservation value from a fisheries viewpoint is the inverse of the "disturbance" value; areas showing a Below Average to Very much below Average ranking are those considered suitable for reservation as Fish Habitat Reserves or similar management zoning. (Table III).

TABLE II - Present Value - Jenny Lind Creek

Feature	Rating	Multiplier	Units
Intrinsic Value	1	1	1
Common-ness	2	2	4
Diversity	1	3	3
Use-Value	1	4	4
TOTAL			12

- Interference (Projected Impact)

Feature	Rating	Multiplier	Units
Estuarine Development	1	5	5
Hinterland Development	2	5	10
Availability	1	5	5
TOTAL			20

DISCUSSION

Present Use

Under the heading of Present Use the several items listed comprise -

1. Intrinsic Value. This item incorporates a rating of the features -

(a) Present degree of disturbance;

(b) Size;

(c) Compactness and configuration;

(d) Surrounding Land Use;

(e) Fauna Suitability;

(f) Detrital Input.

To enable assessment of these feature, it was previously necessary to obtain a considerable number of 9" x 9" air photographs and assemble a temporary mosaic to enable an assessment to be made on a regional or watershed basis. The use of photographically enhanced Landsat imagery has enabled a much improved procedure for this work. The combination of low-level air photography and inspection (1500 ft. flying height) and overall estuarine landsat imagery meets the needs of the features listed as (a), (b), (c) and (d). Items (e) Fauna suitability and (f) require field study although Detrital input is estimated by utilizing photo-interpretation in association with field analysis of plant communities in line with Dowling (1978). The assumption is made that closed forest has a greater direct input of detritus for fisheries resources than open heath land, given the same degree of tidal flushing for each community;

2. Common-ness is rated as the common-ness within a region of a plant community, habitat zone or feature of ecological value to fisheries. Photo-identifiable features enable remote-sensing techniques to be directly applied to this assessment;

3. Diversity as an item for rating relates not simply to diversity of species but rather both to the range of features or communities present in the study area and also to the range of life-forms dependent on a feature. This is best exemplified by an extensive sea-grass meadow. In itself the meadow is a single feature, and hence rates of "low" diversity; however the range of marine animals directly and indirectly dependent on the meadow forms a significant feature of the estuary, and therefore enhances its value to fisheries.

In most instances, photo-identifiable features can be verified by ground truth data with a considerably more effective use of actual field time.

4. Use-value of each site to fisheries. Unlike the previous features, remote-sensing can provide very little if any input to this rating. Conventional methods continue to form the basis of this assessment, i.e. field work by Service personnel, commercial catch returns, recreational fishing census, etc.

Interference

This rating item can also be stated as a measure of expected future human impact on the system. The Service differentiates between two impacts (a) development within the estuary where development can directly affect or destroy habitat zones and (b) future hinterland use. Table III illustrates the grouping of the features to arrive at Future Use of the area as a Management Option.

Table III - Jenny Lind Creek

As From Table II	Comparative Value		Decile Group	Indicated Management
	75, 70		V. much above Av.	Development Node
	65		Much above	
	60		Above Av.	
Present Value: 12 Inter-ference: 20	55, 50, 45, 40		Average	Multiple Use or Buffer Zone
	35		Below Av.	Protected Zone
	30	32	Much below	
	25		V. much below Av.	

Both impacts require evaluation of regional and local planning schemes, port and industrial activities and potential changes in the water-shed.

The range of involvement of the Service is in consequence widened beyond the powers and responsibilities delegated to it in relation to the sectional interests of fisheries. Such involvement is partly met by the use of a matrix as a "check-list" of proposed actions against environmental conditions applicable to fisheries. Problems are not solved by this technique; however it is used in order to highlight areas of use-conflict. In this fashion the Service is able to co-ordinate and plan management strategies requiring opposition to or modification of development works in sensitive ecological sites. The planning of particular reserves is also facilitated by this exercise either as ecological buffer zones or as Reserves behaving as biogeographic islands, as postulated by Diamond (1975).

CONCLUSIONS

The need to prepare an estuarine inventory for 3,250 miles of coastline and formulate management strategies capable of integration with local and regional planning was met principally by the use of remote sensing techniques. A previous localized survey of Moreton Bay, using conventional transect and field survey methods required of the order of 10 times the man-hours for completion compared to recent surveys using air photography and satellite imagery. A major benefit ensues from the analysis of mangrove vegetation by the State Herbarium using air-photo interpretation and structural formation of vegetation as an index of detrital input. Satellite imagery enables a graphic and rapid appreciation of regional land-use and estuarine conformation which was not previously possible.

Unlike terrestrial animals, fish and marine animals generally are more difficult to assess in short term field surveys. This section of the work remains a major problem in estimating the capability of an area to support a significant assemblage of animals. Some 50% of the State's estuaries are currently only lightly fished on either a commercial or amateur basis - primarily due to difficulty of access, distance from market outlets or processors, market preference for particular fish or fishing effort is expended on alternative high unit-value fisheries, e.g. prawns, scallops. As a result, the present inventory relies heavily on presentation of base-line data on estuarine conformation and the presence /absence of a range of habitat features. On this basis the use of remote-sensing has proved to be the most suitable means of achieving a comparative evaluation of the State's estuarine zones; input on fauna suitability is taken as a function of the range of available habitat features present in each estuary.

ACKNOWLEDGEMENTS

Acknowledgement and thanks are due to Mr. T.J. McDonald, Supervising Scientist and R. Dowling, Botanist, of the Dept. of Primary Industries, Queensland whose ready assistance in both field studies and analysis of results has been essential for the preparation of the Estuarine Inventory.

Acknowledgement is also due to D. Bateman and D. Mayer, Cartographers of the Fisheries Service who co-ordinated ground-truth collection with map preparation to form the basis of the geographic data base on which the assessment procedure depends.

BIBLIOGRAPHY

Adamus, P.R. & Clough, G.C. 1978. Evaluating species for protection in natural areas. Biol. Conserv. 13 : 165-178.

Cowardin, L.M. & Myers, V.I. 1974. Remote Sensing for identification and classification of wetland vegetation. J. Wildl. Manage. 38(2) : 308-314.

Diamond, J.M. 1975. The island dilemma : Lessons of modern biogeographic studies for the design of natural reserves. Biol. Conserv. 7 : 129-146.

Dowling, R.M. 1978. The mangrove vegetation : Tannum Sands to Round Hill Head (In press: Qld. Fish. Serv.).

Gehlbach, F.R. 1975. Investigation, evaluation, and priority ranking of natural areas. Biol. Conserv. 8(2): 79-88.

Goldsmith, F.B. 1975. The evaluation of ecological resources in the countryside for conservation purposes. Biol. Conserv. 8(2): 89-95.

Howard, J.A. 1970 Aerial Photo-Ecology. Faber and Faber Ltd, London, England, pp 325.

Kuchler, A.W. 1973. Problems in classifying and mapping vegetation for ecological regionalization. Ecology. 54(3): 512-523.

Martin. J. 1974. Land suitability for fauna. Moreton region, non-urban land suitability study. Dept. of Primary Industries, Q. Aust. Tech. Bull. 11: 4.1-4.2.

Olsen, H.F. 1977 [1] Great Sandy Strait Fisheries Habitat Reserves. Occ. Pap in Anthrop; Uni. of Q. 8, 231-236.

Olsen, H.F. 1977 [2] Estuarine Management Areas. Mar. Res. in Indonesia 19, 7-20

Ratcliffe, D.A. 1971. Criteria for the selection of nature reserves. Advmt. Sci. London. 27: 294-296.

Rosser, J., Swartz, G.L., Dawson, N.M. and Briggs, H.S. 1974. A land capability classification for agricultural purposes. Dept. of Primary Industries. Q. Aust. Tech. Bull. 14, 4 pp.

Specht, R.L. 1970. Vegetation in the Australian environment. (F.W. Leeper, Ed.) C.S.I.R.O. (Aust) and Melb. Uni. Press, Melbourne. 44-67.

Tans, W. 1974. Priority ranking of biotic natural areas. The Michigan Botanist. 13: 31-39.

Verstappen, H. Th. 1977. Remote sensing in geomorphology. Elsevier Sci. Pub. Co., Amsterdam, The Netherlands. pp 214.

Walker, J., Ross, D.R., & Beeston, G.R. (1973) The collection and retrieval of plant ecological data. Woodland Ecology Unit. C.S.I.R.O., Pub. No. 1.

Wright, D.F. 1977. A site evaluation scheme for use in the assessment of potential nature reserves. Biol. Conserv. 11: 293-305.

Quantitative Wildlife Habitat Evaluation Using High-Altitude Color Infrared Aerial Photographs[1]

Lawrence R. Pettinger[2]

Adrian Farmer[3]

Mel Schamberger[4]

Abstract.--The habitat value for elk and sage grouse of two proposed phosphate strip mine sites was determined using habitat parameter measurements from high-altitude color infrared aerial photographs. Habitat suitability was assessed using the Habitat Evaluation Procedures being developed by the U.S. Fish and Wildlife Service. Similar results were obtained from two approaches--a remote-sensing-only-approach and a mix of measurements from photo interpretation and conventional field surveys.

OBJECTIVE

The objective of this study was to determine if high-altitude color infrared aerial photographs might be used effectively as a rapid assessment technique for implementing the Habitat Evaluation Procedures (HEP) being developed by the U.S. Fish and Wildlife Service (FWS). Two approaches were taken. First, selected habitat parameters were measured on high-altitude color infrared aerial photographs and used with estimates of other parameters to calculate the habitat suitability for two representative wildlife species, elk (Cervus elaphus), and sage grouse (Centrocercus urophasianus). For the second approach, the remote sensing-derived parameters were combined with field measurements of the remaining parameters to calculate habitat suitability for the same project areas.

These two assessments were compared to determine whether data from remote sensing analysis alone were sensitive enough to provide a measure of habitat value. Comparisons were carried out for two proposed phosphate strip mine sites in Caribou County, Idaho.

HEP OVERVIEW

Historical Background

In 1970, a task force recommended that the FWS begin to develop procedures to quantify fish and wildlife habitat and to estimate the degree to which such habitat would be altered by proposed changes in land use. A number of systems were evaluated for such use and a system used in Missouri (Daniels and Lemaire 1974) was selected for further refinement and adoption.

The Habitat Evaluation Procedures were developed by the FWS in cooperation with other agencies for use in project planning and impact assessment. Moreover, the procedures were developed in response to Federal legislation and concerns of conservationists that fish and

---

[1]Paper presented at Pecora IV Symposium, Application of Remote Sensing Data to Wildlife Management, Sioux Falls, South Dakota, October 10-12, 1978.

[2]Applications Scientist, Technicolor Graphic Services, Inc.,† USGS - EROS Data Center, Sioux Falls, South Dakota.

[3]Terrestrial Ecologist, Project Impact Evaluation team, U.S. Fish and Wildlife Service, Ft. Collins, Colorado.

[4]National Coordinator, Project Impact Evaluation team, U.S. Fish and Wildlife Service, Ft. Collins, Colorado.

† Work done under U.S. Geological Survey Contract No. 14-08-0001-16439.

wildlife resources were needlessly being sacrificed in many projects, and that little or no mitigation was being implemented to offset those losses. Recent Federal legislation has been enacted which addresses these concerns. The Fish and Wildlife Coordination Act of 1934 (48 Stat. 401 as amended; 16 U.S.C. 661-667) requires that the FWS and State conservation agencies be consulted concerning impacts to fish and wildlife resources that result from federally funded or licensed water resource projects. The National Environmental Policy Act of 1969 (42 U.S.C. 4321-4347) requires the preparation of statements in which the possible environmental impacts of the proposed action and all reasonable alternative actions must be considered. The adoption of the Principles and Standards for Planning Water and Related Land Resources (Water Resources Council 1973) requires planning for environmental quality as well as for national economic development. Other environmental legislation, including various permit and licensing programs and the Endangered Species Act of 1973 (16 U.S.C. 1531-1543), has provided a strong legal mandate for environmental planning and impact assessment.

The Habitat Evaluation Procedures fulfill a number of needs in the area of resource development planning and environmental impact assessment. The objectives were to:

1. Develop methodologies to quantitatively assess baseline habitat conditions for fish and wildlife;

2. Provide a uniform system for predicting impacts on fish and wildlife resources;

3. Display and compare the beneficial and adverse impacts of project alternatives on fish and wildlife resources;

4. Provide a basis for recommending alterations to compensate for or mitigate adverse effects on fish and wildlife resources; and

5. Provide data to decision makers and the public from which sound resource management decisions can be made.

Methodology

HEP promotes a community approach to habitat evaluations and assumes that the suitability of habitat for wildlife can be ascertained from measurements of physical characteristics of the landscape. The procedures are designed to assess three parameters: 1) baseline habitat quality; 2) habitat quantity; and 3) temporal changes in habitat quality and/or quantity.

The basic unit of analysis, the vegetative cover type, is defined in terms of vegetative structure and plant species composition. Vegetative cover types are selected so that physical and/or chemical attributes are homogeneous throughout the habitat type.

Another assumption is that the suitability of a vegetative cover type for selected animal species can be numerically characterized by determining the degree to which life requisites (food, cover, water, reproductive, etc.) are provided. The numerical value, termed the Habitat Suitability Index (HSI; range, 0.0-1.0), is computed for each wildlife species from measurements made at each sample site. Species HSI scores are averaged for all sites within a vegetative type.

The HSI score is a quality per unit area measure. HSI relationships are determined through a three-step process:

1. Determine the characteristics of the habitat that are important for the survival and well-being of the wildland species being evaluated;

2. Rate each appropriate habitat characteristic against optimum conditions for each species; and

3. Determine a site Habitat Suitability Index for each species that integrates the index rating for all habitat characteristics.

The HSI value is assumed to be directly proportional to the productivity potential per unit area of habitat. An HSI value of 1.0 corresponds to the maximum attainable productivity potential for the specified unit area. The product of habitat quality (HSI) and habitat quantity (area) yields the total number of Habitat Units (HU) for the area evaluated and wildlife species considered:

$$HSI \times area = HU$$

These relationships provide a rapidly applicable method for comparing the impacts of alternative land use actions and determining management efforts required to offset negative land use impacts. Project alternatives are compared numerically on the basis of average annual change in HU's.

Probable impacts on fish or wildlife species and habitats are extrapolated into the future by making projections for with and without project futures. The difference in habitat units between the future with project conditions and the future without project conditions is the primary measure of the net project effects on each species in each vegetative type.

STUDY AREA DESCRIPTION

Site Characteristics

The Diamond Creek and Caldwell Canyon phosphate strip mine sites are located in the east-central and central portions of the Blackfoot River watershed in southeastern Idaho, figure 1. The watershed consists of a

Figure 1.--Index map of Idaho showing the Blackfoot River Watershed located northeast of Soda Springs.

series of northwest/southeast-trending ridges and valleys. Upland ridges average 7,700 feet in altitude and contain the phosphate-bearing rock. These ridges support coniferous forests, deciduous forest (aspen), and evergreen scrub (sagebrush, perennial grasses), and are administered by the U.S. Forest Service, Bureau of Land Management, and State of Idaho Lands Department. Lowland areas average 6,250 feet in altitude. A large part of the lowlands is privately owned and has been converted from shrubland to grassland to improve grazing forage production. Average annual precipitation in the area is 20 to 25 inches, with 50 to 60 percent falling as snow. The watershed is sparsely settled; developments include a few ranches and five phosphate strip mines. Hunting, fishing, camping, and other types of outdoor recreation bring numerous visitors to the area.

Terrestrial wildlife--including elk, mule deer, moose, coyote, beaver, sage grouse, and large raptors--are common within the study area. Ducks, geese and greater sandhill cranes occupy the area during spring, summer, and fall. The mountain meadows and wetlands in the study area provide nesting sites and feeding areas for these birds.

The Diamond Creek site is located about 28 miles northeast of Soda Springs. The phosphate-bearing rock formation crops out in a series of low hills at the base of the Webster Range, slightly above the floor of southern Upper Valley. Major vegetation cover types include aspen, conifer (mainly Douglas-fir and lodgepole pine), and evergreen scrub. Riparian hardwoods dominate the major stream bottoms that cross the site.

The Caldwell Canyon site is located about 14 miles northeast of Soda Springs. Evergreen scrub cover dominates the site. Aspen stands are found on the protected north- and east-facing slopes, and riparian cover occurs along the bottom of Caldwell Canyon.

Impact of Phosphate Mining

The phosphate deposits in the Blackfoot River watershed comprise about 35 percent of the U.S. reserves (U.S. Geological Survey 1976). Increasing demands for phosphate have led to the proposal of 15 new phosphate mines in the watershed. Mining activities consist of the open pits and waste dumps at the mine site, but also include on-site processing plants, equipment storage and maintenance areas, and offices. Transporation facilities include haul roads as well as railroads and power lines. Environmental impacts in this relatively undeveloped area take many forms, including growing population in the neighboring communities, air and water pollution, alteration of the native vegetation, and possible effects on the diverse terrestrial and aquatic wildlife species in the area.

IMPACT ANALYSIS

Selection of Aerial Photographs

Most photo interpreters who use aerial photographs for vegetation mapping and habitat evaluation prefer to use aerial photographs at scales of 1:15,000 to 1:30,000. Although black-and-white photographs are suitable for many applications, natural color or color infrared films are preferred because of the additional information they provide regarding vegetation composition, density, and phenology.

The only recent aerial photographs available for the study area were acquired by the National Aeronautics and Space Administration (NASA) with color infrared film from high-altitude aircraft. The photographs were acquired on August 26, 1975[5]--during the part of the growing season when most vegetative cover types were fully developed phenologically. Scale of the original film is approximately 1:120,000. However, enlargements of these photographs to 1:60,000 and 1:24,000 had been used earlier to successfully map vegetation types and certain sensitive wildlife habitat (Carneggie and Holm 1977). It was concluded that these photographs were suitable for assessing some of the habitat parameters which had been identified for elk and sage grouse. Although the higher resolution of medium scale (1:15,000 to 1:30,000) aerial photographs might facilitate more precise measurement of certain vegetation parameters (for example, percent forest canopy cover and tree height), this study was intended to demonstrate the degree to which relatively low resolution aerial photographs could be used for habitat assessment. Should these high-altitude photographs prove suitable, then one could conclude that aerial photographs of larger scale would be of the same or greater utility.

The portion of two overlapping aerial photographs which covers the Diamond Creek mine site was enlarged to a scale of about 1:24,000. When the same ground area from overlapping photographs was enlarged, the study area could be viewed stereoscopically with a pocket or mirror stereoscope. The same procedure was repeated for the Caldwell Canyon site.

Wildlife Species

Two wildlife species, sage grouse and elk, were selected to demonstrate the application of HEP using a combination of field inventories and air-photo interpretation. Table 1 lists those habitat parameters that can be related to the survival and well being of sage grouse and elk. The quantitative relationship between the habitat characteristics and habitat suitability for sage grouse and elk in the three vegetative types is displayed in figures 2, 3, and 4.

Photo Interpretation Methodology

Standard photo interpretation techniques and equipment were used to measure habitat parameters on the enlarged aerial photographs. Vegetative type mapping was performed through stereoscopic analysis with a mirror stereoscope and a 2x - 4x pocket stereoscope. Delineations were made directly onto acetate overlays placed over the photographs (figs. 5 and 6). A three-acre minimum map unit was used, although smaller map units could have been delineated.

The three vegetative communities used in this study exhibited distinctive image characteristics on color infrared film: coniferous forest (coarse texture; magenta to reddish purple color), deciduous forest (medium texture; bright reddish-pink color), and evergreen scrub (medium to smooth texture; pink, blue, or white color, depending on vegetation density).

Distance measurements were made using the known average photo scale, 1:24,000. Since the relief within each mine site was not great (approximately 500 ft.) in comparison to the height above terrain of the aircraft taking the photographs (approximately 53,000 ft.), changes in scale due to altitude differences were not significant, and compensation was not made for measurements made of areas of different altitudes.

Estimates of stand area were made directly from the vegetative type maps using a dot grid (dot grid density = 100 dots per sq. in.). Canopy cover (percent) was visually estimated for the forest types through stereoscopic viewing of each stand. Stereo viewing was useful for distinguishing ground cover from overstory vegetative cover. Height measurements were made using a parallax bar and standard height measurement techniques (Avery 1968, p. 53-61). The average of three independent measurements was recorded for each selected stand.

Resolution of the high-altitude photographs could potentially affect the accuracy with which only two parameters--tree height and canopy cover--were measured. Since the resolution of the photographs used was lower than that of conventional-scale photographs (in terms of fine tree crown and surface feature detail), canopy cover and tree height estimates have greater variability than if they were measured on conventional-scale photographs. Although no measure of this variability was made, we believe that canopy cover and tree height were measured with sufficient precision to be usable in data analysis. This conclusion was based on a comparison of field estimates of stand height and canopy cover with the corresponding photo estimates.

Habitat Analysis

A three-acre grid was superimposed over aerial photographs of the two proposed mine sites, and grid cells were selected randomly for use as field sampling plots. The number of cells selected in each vegetative type was

---

[5] Source of aerial photography: USGS - EROS Data Center, Sioux Falls, SD, 57198. Photo ID: 5750022007ROLL, frames 6498-6499 (Caldwell Canyon), frames 6526-6527 (Diamond Creek).

Table 1.--List of habitat parameters for elk and sage grouse

Parameter	Method of Measurement[1/]	Species	
		Sage Grouse	Elk
Ground cover of forbs (%)	G	ES[2/]	
Diversity of forbs (#)	G	ES	
Sagebrush canopy cover (%)	G	ES	
Av. sagebrush height (in)	G	ES	
Distance to strutting grounds (mi)	G	ES	
Distance to water (mi)	A	ES	ES, CF[2/], UD[2/]
Composition of understory	G		CF, UD
Distance to opening (ft)	A		CF, UD
Perceived sight distance (ft)	G		CF, UD
Av. stand width (ft)	A		CF, UD
Av. tree height (ft)	A-G		CF, UD
Tree canopy closure (%)	A-G		CF, UD
Size of stand (acres)	A		CF, UD
Distance to road (mi)	A		ES, CF, UD
Distance to forest cover (ft)	A		ES
Herbaceous ground cover (%)	G		ES, CF, UD

1/ A = aerial photographs; G = ground measurements.

2/ Cover type for which parameter measurement is made: ES = evergreen scrub, CF = coniferous forest, UD = upland deciduous forest.

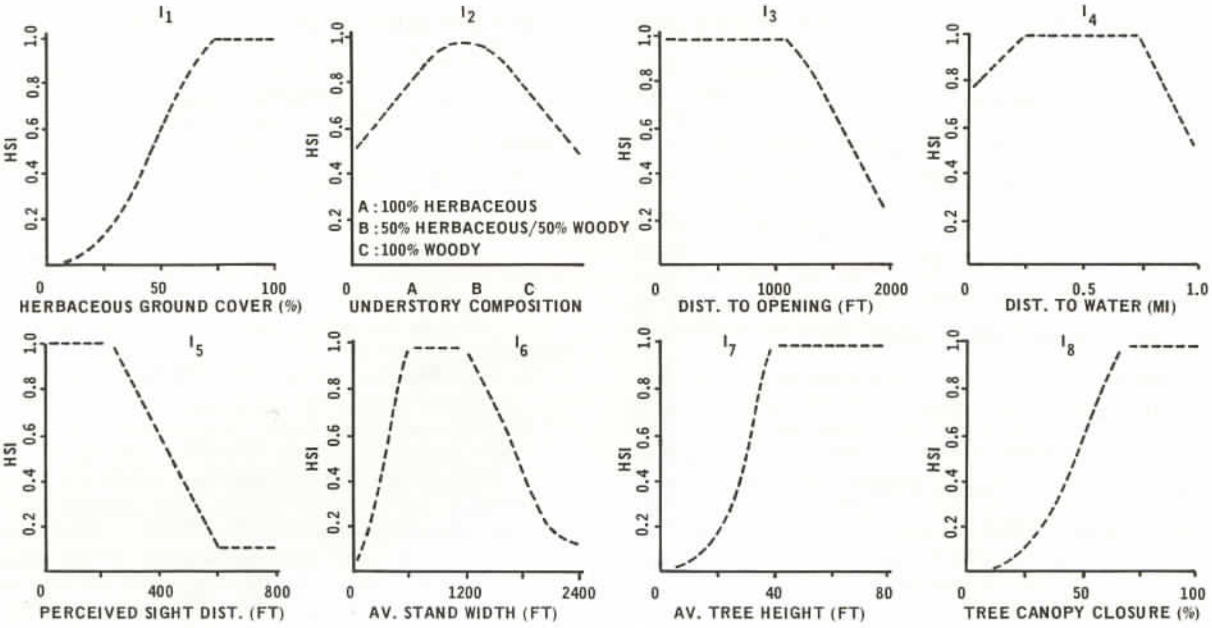
proportional to the abundance of the vegetative type in the proposed mine site. At least three plots were selected in the least common type. The specified characteristics were measured at each sample plot, and an HSI score was obtained from the graphical parameter-HSI relationships[6] (figs. 2, 3, and 4). The process of converting raw field measurements to HSI scores proceeds as follows:

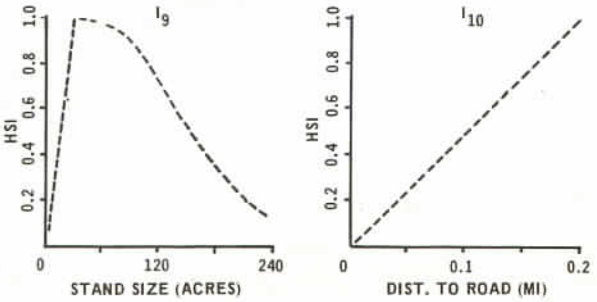
1. Each parameter measurement is converted to an HSI value using the graphical relationship provided for that parameter. The raw measurement of the parameter is found on the X-axis, then projected upward to the curve and then horizontally to the Y-axis to obtain the scaled HSI value.
2. The scaled scores for characteristics are used in the life requisite equations to obtain HSI scores for each life requisite provided by that vegetative cover type.
3. The lowest of the life requisite HSI values for a sample plot is used as the single HSI value for that sample plot.

Each vegetative cover type is scored for only those life requisites that it can reasonably be expected to provide. If a given vegetative type does not provide all life requisites for a particular wildlife species, then a stand of that type must occur within a certain proximity of other vegetative types providing the missing life requisites in order to receive a positive score. For example, an evergreen scrub plot may provide abundant food for elk (food value HSI = 1.0) but may not occur within a home range diameter of forested cover. This plot would receive an HSI value of 0.0 because it does not provide usable food for elk. These plot scores are averaged to obtain an average HSI value for each vegetative type for each wildlife species.

---

6 The habitat suitability curves in figures 2, 3, and 4 are from an unpublished manuscript "Terrestrial habitat evaluation criteria--ecoregion M313," prepared by the Project Impact Evaluation Team, U.S. Fish and Wildlife Service, Fort Collins, Colorado.





LIFE REQUISITE EQUATIONS

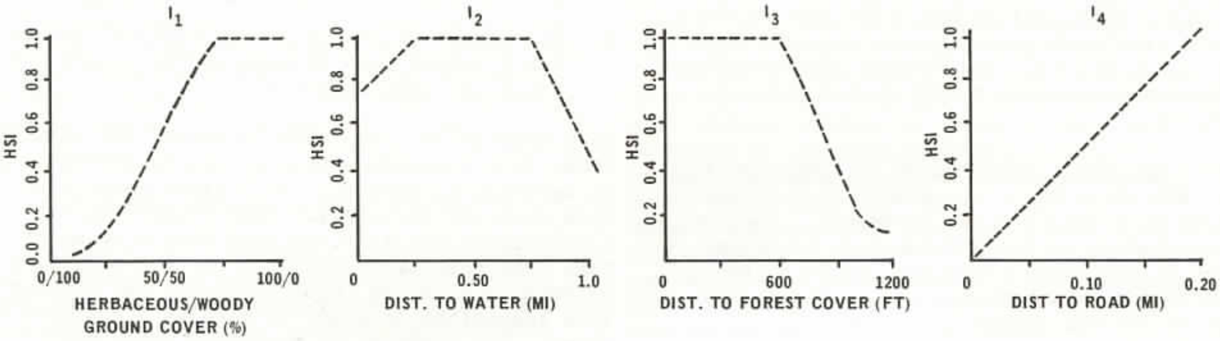
FOOD VALUE (X_1) $= \frac{2(I_1) + (I_2) + 3(I_3)}{6}$

WATER VALUE (X_2) $= I_4$

COVER VALUE (X_3) $= \left[(I_5 \times I_6)^{1/2} \times (I_7 \times I_8 \times I_9)^{1/2}\right]^{1/2}$

SPECIAL CONSIDERATIONS VALUE (X_4) $= I_{10}$

Figure 2.--Quantitative relationships of habitat characteristics to Habitat Suitability Index (HSI) for elk in coniferous and upland deciduous forests. Life requisite equations are also given.



LIFE REQUISITE EQUATIONS

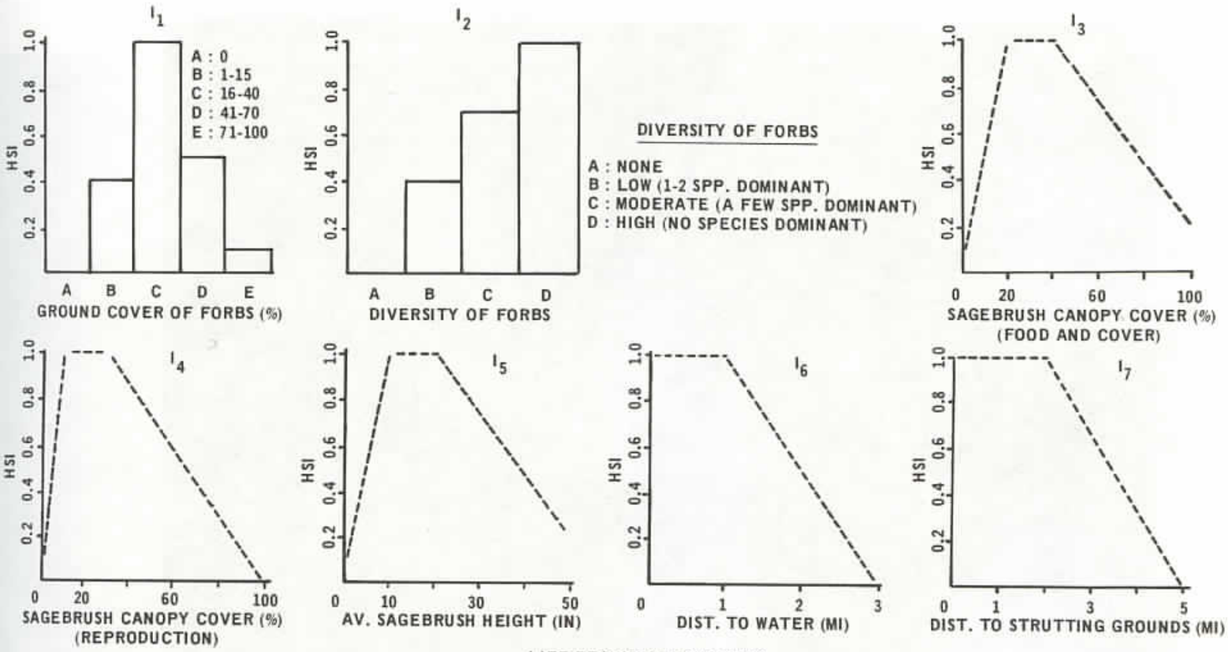
FOOD VALUE (X_1) $= I_1$

WATER VALUE (X_2) $= I_2$

COVER VALUE (X_3) $= I_3$

SPECIAL CONSIDERATIONS VALUE (X_4) $= I_4$

Figure 3.--Quantitative relationships of habitat characteristics to Habitat Suitability Index (HSI) for elk in evergreen scrub. Life requisite equations are also given.



LIFE REQUISITE EQUATIONS

$$\text{FOOD VALUE } (X_1) = \left[\frac{(I_1 + I_2)}{2} + I_3\right]^{1/2}$$

$$\text{WATER VALUE } (X_2) = I_6$$

$$\text{COVER VALUE } (X_3) = \frac{2(I_3) + I_5}{3}$$

$$\text{REPRODUCTIVE VALUE } (X_4) = (I_4 \times I_5 \times I_7)^{1/3}$$

Figure 4.--Quantitative relationships of habitat characteristics to Habitat Suitability Index (HSI) for sage grouse in evergreen scrub. Life requisite equations are also given.

These scores represent a baseline condition for the proposed mine sites. These HSI scores, multiplied by the area of the corresponding vegetative types within the mine site, provide a quantitative measure of the total habitat available (number of Habitat Units) for each wildlife species within the site.

Analysis of project impacts on wildlife habitat proceeds through the same steps. The investigator estimates the degree to which habitat characteristics would be modified by the proposed project. Then he determines another set of HSI values for each wildlife species based on these assumptions. The probable changes in the availability (surface area) of each cover type must also be estimated. The product of the expected HSI and corresponding area provides a quantitative measure of the available pre-project habitat.

For many projects, changes in habitat conditions may occur throughout the life of the project and therefore are not limited to one fixed set of conditions. The above process still applies, however. The investigator merely estimates habitat conditions for various target years throughout the life of the project and calculates an "average annual HSI" for each species in each vegetative type.

The difference between the baseline HU values and the HU's expected to be available with the project in future years provides a measure of project impacts. This is a gross value. In order to obtain a net impact value, a similar analysis must be performed for the project site for future without project conditions. This analysis provides an estimate of average annual habitat conditions expected to occur with specific land use change and/or vegetation successional trends within the site, without project influences. The difference

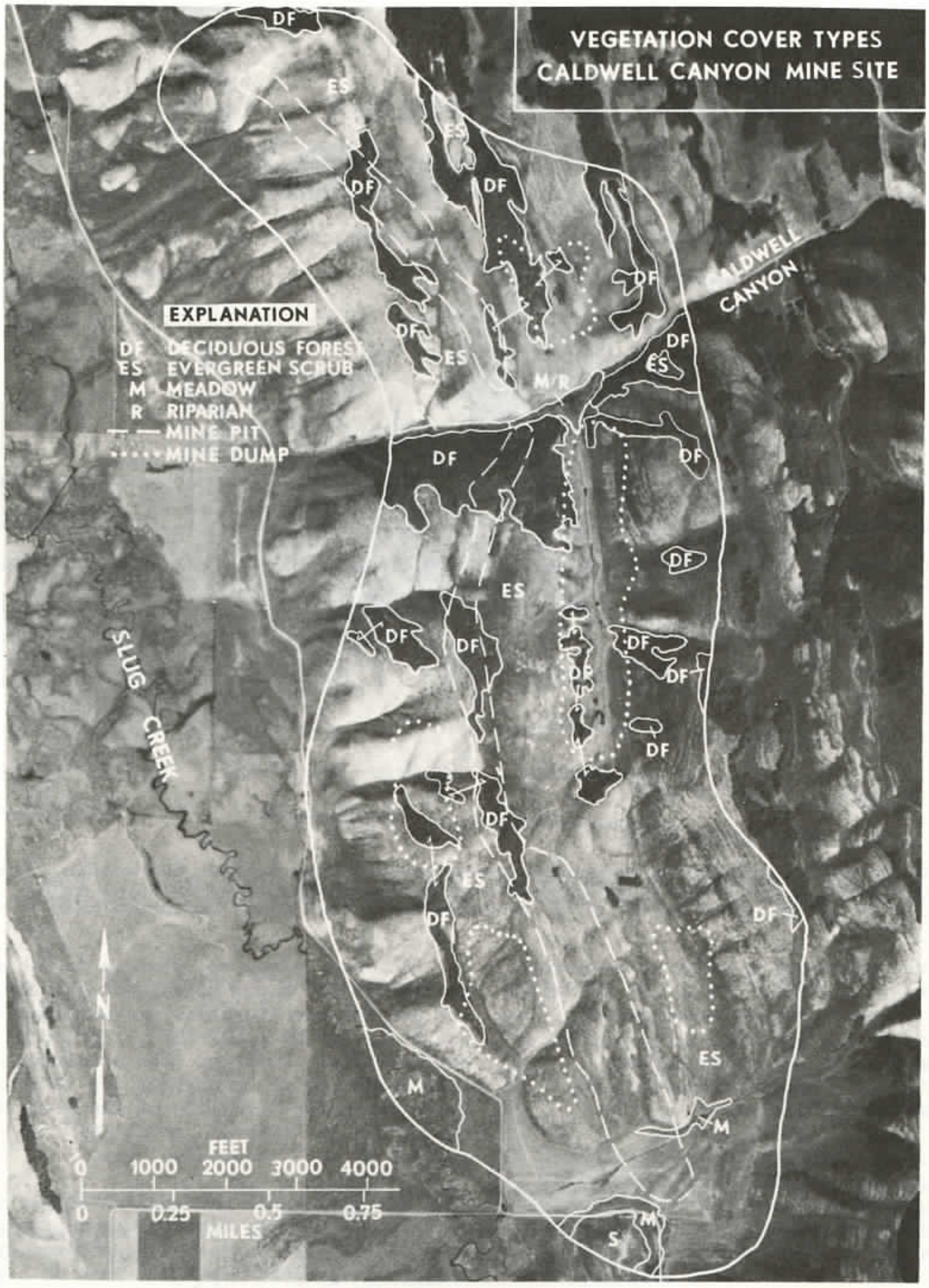


Figure 5.--Black-and-white copy of enlarged NASA high-altitude color infrared aerial photograph showing vegetative cover map of the proposed Caldwell Canyon phosphate strip mine. Location of proposed mine pits and mine dumps is also shown.

Figure 6.--Black-and-white copy of enlarged NASA high-altitude color infrared aerial photograph showing vegetative cover map of the proposed Diamond Creek phosphate strip mine. Location of proposed mine pit, mine dumps, and a railroad line is also shown.

between future with project and future without project habitat conditions is the true measure of project impacts.

Comparison of Mining Alternatives

Baseline habitat suitabilities were calculated for both elk and sage grouse at both proposed mine sites according to the above procedures. Two separate analyses were performed for each mine site: one using either remote sensing or field measurements of all habitat parameters and the other using remote sensing measurements of certain parameters combined with estimates of the remaining parameters.

For the total inventory analysis, (table 2), all characteristics listed in table 1 were measured. Characteristics requiring ground measurements (labeled "G" in table 1) were measured in the field. For those characteristics measurable either by photo interpretation or on the ground (labeled "A-G" in table 1) the ground measurement was used. Characteristics more suited to photo interpretation (labeled "A" in table 1) were measured on the aerial photographs.

For the remote-sensing-only analysis, (table 2), six parameters were measured from the aerial photographs (stand size and width, and four distance measurements). Those characteristics measurable by either technique (average tree height and percent canopy closure) were measured on the aerial photographs, whereas those characteristics requiring ground measurement were estimated. Otherwise, the HSI equations would have had to be restructured include only those parameters that were measurable from aerial photographs. It was concluded that this is a valid approach since the field investigator will normally have some knowledge of local conditions or access to a previous data base of vegetative measurements.

For this study the mean value for ground measurements made in the total inventory analysis was used for the estimated values of ground-dependent characteristics. This procedure introduces a bias since the objective was to compare a total inventory and remote-sensing-only analysis. In order to minimize the bias, mean values were derived using data from both mine sites and the same mean values were applied to the separate analysis of each mine alternative. It was hoped that values derived in this fashion would help maintain the comparability of alternatives and also be more representative of estimates that would be made in practice.

Results

For both total and remote-sensing-only data sets, the two alternative mine sites were ranked in the same order for elk habitat quality (HSI) and ranked inconsistently for sage grouse habitat quality (table 2). One reason for inconsistent ranking of sage grouse habitat was that only one of six characteristics

Table 2.--Baseline habitat conditions for elk and sage grouse as determined by total inventory (remote sensing and field measurements) and remote sensing measurements only

Proposed Mine	Vegetative Cover Type	Area of Cover Type (acres)1/	Species	Total Inventory		Remote Sensing Only	
				HSI2/	HU3/	HSI2/	HU3/
Diamond Creek	Coniferous Forest	20	Elk	0.57	11.4	0.56	11.2
	Deciduous Forest	115	Elk	0.74	85.1	0.66	75.9
	Evergreen Scrub	630	Elk	0.2	126	0.3	189
			Sage grouse	0.41	258	0.82	516
Caldwell Canyon	Deciduous Forest	125	Elk	0.42	52.5	0.48	60
	Evergreen Scrub	325	Elk	0.51	166	0.3	98
			Sage grouse	0.60	195	0.82	266

1/ Area to be disturbed by mining activities.

2/ HSI = Habitat Suitability Index, per acre.

3/ HU = Habitat Units = HSI x area of cover type.

relating to HSI of evergreen scrub for sage grouse was measurable from the remote sensing information used in the study. The number of habitat units (HSI x area) for each wildlife species and vegetative type is also presented in table 2. Table 3 contains a summary of HU's for both species in all vegetative types. When the quantity of habitat is taken into account by calculating Habitat Units, the sites are ranked in the same order by both analyses.

The final steps in the comparison of alternatives would be to calculate the number of habitat units expected to be available with mining in progress and to determine the gross change in habitat units as measured from baseline conditions for each site. A net change in habitat units for each site would be calculated by analyzing the expected future without-mining condition and obtaining the difference between future with- and future without-mining conditions. In practice, this measure of net change would be used to rank the two alternatives according to wildlife impacts. For testing the objectives of this study, it was assumed that the mine sites would be completely destroyed and the future without-mining habitat conditions would be the same as the baseline conditions. The impact of the mining proposals is therefore expressed as the number of baseline habitat units.

SUMMARY

This study demonstrated that, in the absence of extensive ground based inventories, the use of photo interpretation measurements appears to be a viable means of performing elk and sage grouse habitat analyses. In applying this technique, the HEP user should remain alert to the fact that analyses for some wildlife species require mostly ground based assessments and remote-sensing-only approaches may not perform adequately. Although very large scale aerial photographs were not used in this study, their use could extend the list of habitat characteristics that are measurable from remote sensing data.

For HEP applications to early planning for development projects, remote sensing provides a cost-effective approach to wildlife assessment. If the planner has limited funds available for field studies, some of the characteristics can be measured from good quality aerial photographs and a rough estimate of habitat suitability can be made. If adequate funding is available, particularly later in planning, then extensive field measurements can be made at numerous sites. Regardless, there are certain characteristics (i.e., distance, area, and some vegetative cover measurements) that can almost always be measured with remote sensing techniques.

LITERATURE CITED

Avery, T. Eugene. 1968. Interpretation of aerial photographs. Burgess Publishing Co., Minneapolis, Minn. 324 p.

Carneggie, David M., and Christopher S. Holm. 1977. Remote sensing techniques for monitoring impacts of phosphate mining in southeastern Idaho. Proceedings, 2nd William T. Pecora Memorial Symposium, p. 251-272. American Society of Photogrammetry, Falls Church, Va.

Daniels, C. S., and R. J. Lemaire. 1974. Evaluating effects of water resource developments on wildlife habitat. Wildlife Society Bull. 2(3):114-118.

U.S. Geological Survey. 1976. Draft environmental impact statement--development of phosphate resources in southeastern Idaho. U.S. Geological Survey, Reston, Va. Vol. 1, 665 p.

Water Resources Council. 1973. Principles and standards for planning water and related land resources. Federal Register 38(174), September 10, 1973.

Table 3.--Total baseline habitat availability (Habitat Units) for sage grouse and elk, determined by summing HU values for all vegetative cover types

Proposed Mine	Species	Habitat Units (Total Inventory)	Habitat Units (Remote Sensing Only)
Diamond Creek	Elk	222.5	276.1
	Sage grouse	258.0	516.0
Caldwell Canyon	Elk	218.5	158.0
	Sage grouse	195.0	266.0

Inventory of Wildlife Habitat: An Approach and Case Study [1]

Anthony M. B. Rekas[2]

Abstract.--An approach to evaluating a geographic area to determine its potential as habitat for a particular animal species is described. The approach was used to identify potential black-tailed prairie dog (*Cynomys ludovicianus*) habitat on the Fort Carson, Colorado, military installation. The hypothesis tested was that the habitat in which a species currently exists would be identified as "potential habitat" using the habitat inventorying procedures. Results show that 93 percent of existing prairie dog towns were found to be located entirely within the areas designated as potential prairie dog habitat.

INTRODUCTION

Background

Management of the natural resources of an Army installation is a complex process that involves the reconciliation of two primary objectives. One objective is the need to use the area for the purposes for which it was intended, including weapons firing, vehicle maneuvering, troop bivouacking, and other military activities. If these purposes are to be fulfilled, men and machines must move across or live on the landscape for varying periods of time, thus imposing certain inevitable pressures on that landscape; i.e., plant and animal populations are disturbed and topographic and hydrologic conditions are altered. The second objective is the desire to maintain the installation's natural resources in as natural a state as possible, or at least in a state aesthetically pleasing and ecologically viable. Many military reservations contain within their boundaries some of the finest wildlife and native conservation areas in their regions. Nevertheless, increased use of some areas and the desire to prevent the mistakes of the past have led to a requirement for far more skillful management practices than have previously been needed.

Army Regulation (AR) 200-1 entitled "Environmental Protection and Enhancement," dated 7 December 1973, implements Department of Defense Directive 5100.50 and provides general Department of the Army policy on environmental protection and enhancement of the natural resources of all Army installations in the United States and overseas. The long-term planning and management objectives outlined in AR 200-1 require that design, construction, operation, and maintenance activities on an installation must be conducted with minimum environmental impact on the natural resources of the installation.

Since 1971, the U. S. Army Engineer Waterways Experiment Station (WES) has been conducting research designed to develop procedures and methodology for acquiring on-site environmental baseline data that could be used by Army facilities engineers to manage the natural resources of their installations.[3]

In 1977, the WES completed a study[4] on Fort Carson, Colorado, (a 554.4 km^2 Army installation located seven miles south of Colorado Springs, Colorado) that was designed to provide direct support to Fort Carson in the generation of information and environmental baseline data needed to develop and implement a

---

[1] Paper presented at the PECORA IV Symposium on Application of Remote Sensing Data to Wildlife Management, Sioux Falls, South Dakota, Oct. 10-12, 1978.

[2] Zoologist, Environmental Laboratory, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

[3] Research sponsored by Directorate of Military Construction, Office, Chief of Engineers, U. S. Army under Department of the Army Project 4A162121A896, Task 01, Work Unit 006.

[4] Research sponsored by Directorate of Facilities and Engineering, Fort Carson, Colorado.

natural resources management program. The study resulted in a series of reports in which WES provided baseline data for use in the wildlife management (Rekas 1977), water-quality control (West and Floyd 1977), rangeland conservation and restoration (Rekas and Kirk 1978), erosion control (Keown and West 1978), and land management (Dardeau and Zappi 1977) portions of a natural resources management program.

Purpose

The purpose of the present paper is to describe an approach that was used to evaluate the Fort Carson installation to determine its potential as habitat for the black-tailed prairie dog (*Cynomys ludovicianus*). The details of the procedural steps and their adequacy to delineate habitats of the prairie dog are discussed in the following paragraphs.

Rationale

The actual occurrence of an animal species, within its range, is limited by its abiotic and biotic requirements to a specific and aerally restricted environmental that constitutes its habitat.[5] The hypothesis tested in the case study described below was that the habitat in which a species currently exists would be identified as potential habitat using the habitat inventorying procedures.

HABITAT INVENTORYING PROCEDURE

The objective approach developed by the WES to evaluate a geographic area to determine its potential as habitat for a particular animal species involves the following steps:

- Identify the habitat requirements of the species. Habitat requirements are those minimal environmental factors that a species requires to survive and reproduce viable offspring.
- Locate the required factors in the geographic area of interest. Remote-sensing techniques developed by WES (Link and Shamburger 1974), augmented by ground-truth data, are used to map these factors.
- Prepare map overlays showing the extent of each factor in the geographic area. West (1973) described this procedure.
- Prepare composite map. Those geographic areas where all critical factors occur are potential habitats for the species. Potential habitats are those areas that contain all the minimal habitat requirements of a species.
- Verify map.

[5] In this paper the term "habitat" is considered to denote a spatial environment in which an animal species lives and all elements of that environment, including land and water area, physical structure and topography, flora, fauna, climate, human activity, and the quality and chemical content of soil, water, and air.

INVENTORY OF POTENTIAL BLACK-TAILED PRAIRIE DOG HABITATS

Identification of Habitat Requirements

Several authors have indicated that certain selected environmental factors of the black-tailed prairie dog's habitat appear to limit the actual occurrence of the species within its range (Armstrong 1972, Kelso 1939, Koford 1958, Sheets et al. 1971, Smith 1967, Soper 1938). According to the literature, the important factors for the black-tailed prairie dog are topographic elevation and slope, vegetation species, plant height, percent ground cover, and soil type. These factors within the Colorado habitat areas were reported as:

Elevation: < 2800 m

Slope: 0 to 0.175 radians

Vegetation type: short- and mixed-grass prairie species

Vegetation height: < 30 cm

Vegetation cover: 5 to 50 percent

Soil type: deep cohesive soils (loam, silty loam, clay, clay loam, and sandy loam)

Since all the values for the six environmental factors were obtained from literature that reported the results of black-tailed prairie dog studies performed outside of Fort Carson, the WES conducted a short field sampling program (Rekas 1977) of seven prairie dog towns on Fort Carson that confirmed that the literature-reported values for the six factors were applicable to Fort Carson. However, since all elevations on Fort Carson were less than 2800 m and the vegetation height and cover in the plant communities on Fort Carson containing short- and mixed-grass prairie species were predominately within the less than 30 and 5 to

50 percent limits for those factors respectively, the elevation, vegetation height, and vegetation cover factors were not considered for separate mapping. Minimum soil depth in the seven WES-surveyed prairie dog towns was determined to be 76.2 cm from data furnished by the U. S. Department of Agriculture (USDA), Soil Conservation Service (SCS) at Colorado Springs, Colorado.

Locating and Mapping the Environmental Factors

With the above habitat requirements in mind, the next problem was the determination of where these factors occur on Fort Carson. Thus, it was first necessary to map the environmental factors for the complete reservation at a sufficient level of detail to permit a reliable assessment of potential habitat areas. The data on vegetation, soils, and slope were mapped at a scale of 1:50,000 for the reservation The following tabulation presents the factor classes and factor class ranges that were established for the mapping:

Environmental Factor	Factor Class	Factor Class Range
Slope	1	0.088 radians
	2	0.088-0.175 radians
	3	>0.175 radians
Soil	1	Loam and silty loam[1]
	2	Clay and clay loam[1]
	3	Sandy loam[1]
	4	Other[2]
Vegetation	1	Short- and mixed-grass prairie species
	2	Forest

[1]Depths $\geq$ 76.2 cm.

[2]Exposed rocks, cobbles, gravels, and sands, silts, loams, and clays < 76.2 cm in depth.

The methods used to map the environmental factors are discussed below.

The slope data were obtained manually[6] with a clear acetate slope-class template and a 1:50,000-scale topographic map of the installation. The slope template was printed with circles with diameters that were scaled to slope class based on the map scale and contour interval of the Fort Carson map. The slope class of the terrain between any two contour lines was determined by putting the template on the map and selecting the set of circles that bracketed the separation between the two contour lines. This process was repeated many times over the entire topographic map until the slope conditions of the terrain on Fort Carson had been classed into the three slope-factor classes (0-0.088, 0.088-0.175, and >0.175 radians). The boundaries of the factor classes were then transferred from the 1:50,000-scale map to transparent drafting film.

The soils data were abstracted from the SCS photomosaics and soils survey interpretations for all SCS mapping units. The locations of the SCS mapping units were first transferred to a 1:50,000-scale Fort Carson map; then the USDA Textural Soil Classifications and soil depths were determined for each mapping unit. Boundaries were drawn that enclosed soils mapping units having the same soil factor class. The boundaries were then transferred from the map to transparent drafting film.

The vegetation data was interpreted from 1:20,000-scale black-and-white aerial photography flown in 1974. The boundaries enclosing each vegetation factor class were drawn on a 1:50,000-scale Fort Carson map and then transferred to transparent drafting film.

Identification of Potential Habitat

After the three environmental factors (slope, soil, and vegetation) had been mapped at 1:50,000 scale, they were combined into a landscape composite map by superimposing each of the individual transparent maps on a common base map (Figure 1). The terrain patches on the landscape map that contained slope classes 1 or 2, vegetation class 1, and soil classes 1, 2, and 3 were considered to be potential habitat areas for the black-tailed prairie dog. This landscape map was then used to produce a final potential habitat map (Figure 2) of the Fort Carson Reservation. The total area of the potential habitats is 283.3 km^2 (51 percent of Fort Carson). The unmapped areas on this potential habitat map include the cantonment area, the ammunition supply point, Butts Airfield, and the main impact area. Of these, only the main impact area may have additional potential habitat areas for the prairie dog; however, the intensive use of that area for artillery, mortar, tank, and rocket fire would probably discourage the establishment of prairie dog towns.

[6]Although a manual procedure was used for determining slope for the Fort Carson project, the WES has developed an automated procedure for calculating slope direction and magnitude and for constructing slope maps. This automated procedure is discussed in detail by Struve (1977).

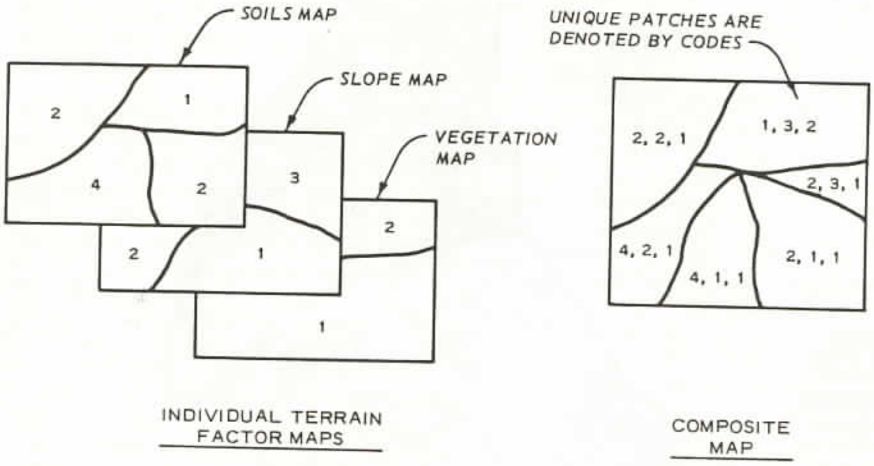


Figure 1. Compilation of individual terrain factors maps to form composition map

Verification of Potential Habitat Map

Since the prairie dogs are social animals that live in colonies (prairie dog towns), the existing prairie dog habitats on Fort Carson were those areas where prairie dog towns occurred. Therefore, the verification procedure was to locate and map the locations of the existing prairie dog towns and compare their locations to the areas identified as potential habitats. If the habitats (town locations) were located in the mapped potential habitat areas, this would tend to support the hypothesis that the application of the five procedural steps resulted in a realistic map of the prairie dog's potential habitat.

The locations and sizes of prairie dog towns were determined by air-photo interpretation techniques and ground reconnaissance. Aerial photography of the Fort Carson Reservation at several different scales was available for use as follows:

Type of Imagery	Scale	Date Flown
Black-and-white	1:20,000	August 1962
Black-and-white	1:80,000	June 1972
Black-and-white	1:20,000	September 1974
Black-and-white	1:20,000	August 1974 (partial coverage)
Color-infrared	1:5,000	August 1974 (partial coverage)
Color	1:5,000	August 1974 (partical coverage)
Black-and-white	1:20,000	August 1975

The interpretation of the locations of the prairie dog towns consisted of a stereoscopic examination of overlapping prints. The various photographic terrain patterns of the prairie dog towns were identified according to their tone, texture, and topographic settings. The small (≈2- to 3-m-diam) circular soil mounds of the prairie dogs could be readily identified on the 1:5,000 and 1:20,000 photography but not very easily on the 1:80,000. The polka-dot type pattern of the burrows within the towns was the key to identifying the towns. In some regions of the reservation, it was difficult to distinguish the prairie dog burrows from the mounds that had been constructed by harvester ants (*Pogonomyrmox sp.*). Therefore, all the towns located on the aerial photography were field checked.

After all the prairie dog towns had been outlined on the air photos, their boundaries were checked by ground reconnaissance, which revealed that some of the towns had expanded since the air photos had been made. The field reconnaissance also showed that three of the photo-interpreted towns contained no live animals. The final boundaries of the prairie dog towns, as determined from the air photos and as field checked by ground surveys, were transferred to a 1:50,000-scale topographic map overlay of the Fort Carson Reservation. The overlay is shown superimposed on the potential habitat map (Figure 2). It depicts 40 existing towns (containing live black-tailed prairie dogs) and 3 abandoned towns. The amount of land occupied by the 40 active black-tailed prairie dog towns on the Fort Carson Reservation was calculated to be approximately 20.2 km^2, i.e., about 7 percent of the potential habitat areas were occupied.

EVALUATION OF RESULTS

The locations of the existing and abandoned towns were compared to the locations of the areas identified as potential habitats (Figure 2).

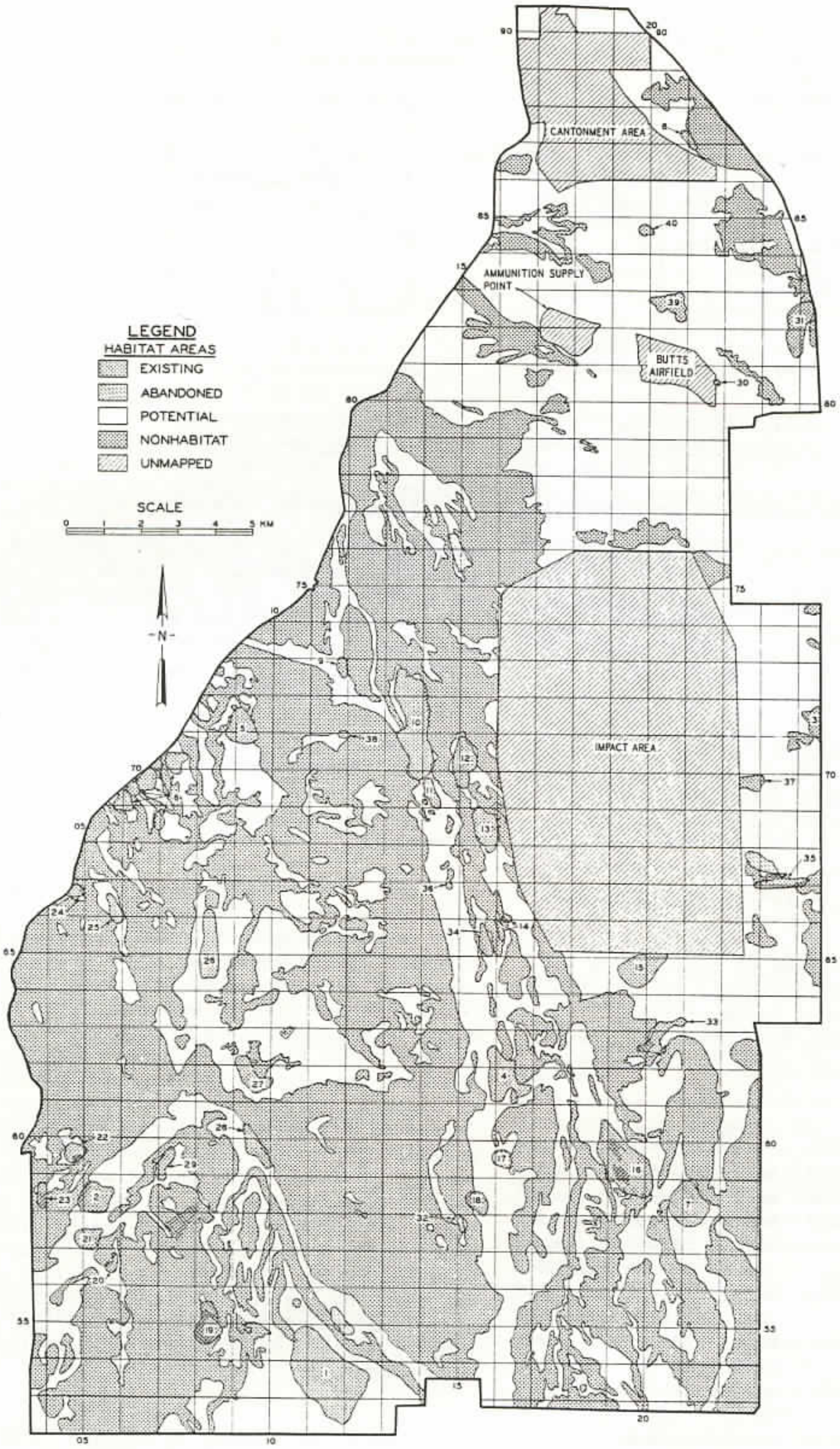


Figure 2. Map of existing and abandoned towns superimposed on potential habitat areas for the black-tailed prairie dog

If 95 percent or more of each town area was located within an area identified as potential habitat, the town was considered to be within the potential habitat.

Of the 40 existing and 3 abandoned towns, 37 existing towns and all 3 abandoned towns (93 percent) were found to be located within the area identified as potential habitat for the prairie dog. Although this accuracy is considered adequate for delineation of potential habitat areas for wildlife management purposes, the WES desired to determine why from 18 to 50 percent of the area of three of the existing towns (16, 19, and 23) were located in areas that were not identified as potential habitat. A review of the soils mapping data indicated that portions of the three towns existed on soils that were shallower than the soil-depth criterion (76.2 cm) used to map the potential habitats. The WES did not consider changing the mapping criterion to the shallowest depth (30.5 cm) in the three towns since 93 percent of the towns were correctly identified using the 76.2-cm-depth criterion.

CONCLUSIONS

The five-step habitat mapping procedure that was developed during this study was applied successfully to identify potential habitat of the black-tailed prairie dog on Fort Carson. The habitat requirements listed in the literature proved to be adequate for mapping potential habitats of the prairie dog. Specific findings of this study indicate that:

Photography at a scale at least as large as 1:20,000 is required to identify prairie dog towns.

There were 40 active and 3 abandoned prairie dog towns on Fort Carson. The active towns cover 20.2 km^2 of Fort Carson.

The potential habitat for the prairie dog on Fort Carson covers 283.3 km^2 or 51 percent of Fort Carson.

LITERATURE CITED

Armstrong, D. M. 1972. Distribution of mammals in Colorado. Monograph of the museum of natural history. The University of Kansas. No. 3. pp 135-137.

Dardeau, E. A., Jr., and M. A. Zappi. 1972. Environmental baseline description for use in the management of Fort Carson natural resources. Report 5. General geology and seismicity. Technical Report M-77-4. U. S. Army Engineer Waterways Experiment Station. CE. Vicksburg, Miss.

Kelso, L. H. 1939. Food habits of prairie dogs. U. S. Department of Agriculture. Circular No. 529. pp 1-15.

Keown, M. P., and H. W. West. 1978. Environmental baseline descriptions for use in the management of Fort Carson natural resources. Report 4. Analysis and assessment of soil erosion in selected watersheds. Technical Report M-77-4. U. S. Army Engineer Waterways Experiment Station. CE. Vicksburg, Miss.

Koford, C. B. 1958. Prairie dogs, whitefaces, and blue grama. Wildlife monographs. No. 3. 78 pp.

Link, L. E., Jr., and J. H. Shamburger. 1974. Application of remote sensors to Army facility management. Technical Report M-74-2. U. S. Army Engineer Waterways Experiment Station. CE. Vicksburg, Miss.

Rekas, A. M. B. 1977. Environmental baseline descriptions for use in the management of Fort Carson natural resources. Report 1. Development and use of wildlife and wildife habitat data. Technical Report M-77-4. U. S. Army Engineer Waterways Experiment Station. CE. Vicksburg, Miss.

Rekas, A. M. B., and W. L. Kirk. 1978. Environmental baseline descriptions for use in the management of Fort Carson natural resources. Report 3. Inventory and assessment of current methods for rangeland conservation and restoration. Technical Report M-77-4. U. S. Army Engineer Waterways Experiment Station. CE. Vicksburg, Miss.

Sheets, R. G., R. L. Linder, and R. B. Dahlgren. 1971. Burrow systems of prairie dogs in South Dakota. J. Mammal. 52:451-453.

Smith, R. E. 1967. Natural history of the prairie dog in Kansas. Museum of Natural History and State Biological Survey of Kansas. Univ. of Kansas. Misc. Paper No. 49. pp 1-39. (Reprinted from Misc. Paper No. 16. pp 1-36. 1958).

Soper, J. D. 1938. Discovery, habitat and distribution of the black-tailed prairie dog in Western Canada. J. Mammal. 19(3): 29-300.

Struve, H. 1977. An automated procedure for slope map construction; description and instructions for use of the automated procedure. Technical Report M-77-3. Vol 1. U. S. Army Engineer Waterways Experiment Station. CE. Vicksburg, Miss.

West, H. W. 1973. Effects of environment on microseismic wave propagation characteristics in support of SID testing at Fort Bragg, N.C.; Dry-season conditions. Technical Report M-73-2, Report 1. U. S. Army Engineer Waterways Experiment Station. CE. Vicksburg, Miss.

West, H. W., and H. M. Floyd. 1977. Environmental baseline descriptions for use in the management of Fort Carson natural resources. Report 2. Water quality, meteorologic, and hydrologic data collected with automated field stations. Technical Report M-77-4. U. S. Army Engineer Waterways Experiment Station. CE. Vicksburg, Miss.

Riparian Wildlife Habitat Analysis in the Arid Southwestern United States

Jon E. Rodiek and Michael M. McCarthy[1]

Abstract.--The Boghole waterfowl project came into reality in 1974 with the construction of a 49 acre foot water impoundment. The reservoir was created to form the base facility for a migratory waterfowl habitat. Oblique and vertical photography was used to analyze the site's capability of supporting aquatic vegetation for wildlife habitat needs. Wildlife habitat planning requires the identification of information in three related areas: (1) habitat potential; (2) habitat requirement needs of a given wildlife population; and (3) species behavior as it is influenced by the habitat.

INTRODUCTION

The Boghole waterfowl project came into reality in 1974 with the construction of a 49 acre foot water impoundment. The reservoir was created to form the base facility for a migratory waterfowl habitat. Funds were derived from the Pitman-Robertson Act for Federal Aid in Wildlife Restoration and the Dingall-Johnson Act for Federal Aid in Fisheries. The water impoundment, once vegetatively stabilized, will provide specific habitat needs for the waterfowl and nongame fish native to this area.

The Boghole is located on the Coronado National Forest just north of the San Raphael Valley in Santa Cruz County, Arizona. The project consists of a 198 acre cattle exclosure on a high plains grassland ecosystem. This region is unique to Arizona and the southwest United States by virtue of its high elevation (5000 feet above sea level) and rainfall accumulation (17 inches per year). The wildlife species consist of a mixture of high plains range land mammals, including pronghorn antelope (Antilocarpa americana), mule deer (Odocoileus hemionus), white tail deer (Odocoileus virginianus), red wolf (Canis niger) and a variety of birdlife. Fish populations are represented by relic species from an earlier "watered environment" era. The birdlife includes hawks, eagles and a migratory waterfowl population, including shorebirds, diving ducks, puddle ducks, and the Mexican black duck (Anas diazi).

[1]School of Renewable Natural Resources
University of Arizona
Tucson, Arizona 85703

The project was initially designed to provide three additional impoundments within the exclosure at some future date. Public concern for the project required the Arizona Game and Fish Department and the U.S. Forest Service to reassess the feasibility of creating additional water impoundments with only surface water supplies. The landscape architecture department at the University of Arizona undertook the task of providing these agencies with supportive technical information that would clarify some of these questions. The objectives of this endeavor were to: 1. Determine the adequacy of the existing facility for migratory waterfowl, shorebirds, and nongame fish. This was accomplished by analyzing the physical characteristics of the land-water edge of the impoundment, the morphology of the impoundment bottom, and the upstream and downstream channels. 2. Aquatic plant species were carefully researched for use within each of the habitat types proposed. Vegetation provides the primary food, cover, and reproduction requirements for these wildlife species. It was therefore critically important to select the plant species that would best survive within this unique environment. 3. Landscape treatment prototypes needed to be developed for the habitat requirements presented by the various wildlife species to be housed there.

HABITAT ANALYSIS

The primary objective of this project was to put the water impoundment facility into a regional context so that public and private interest groups might see clearly how decisions were made regarding the location, availability of water and the ultimate form of the habitat area. A major concern of these groups interested in the project was just where the water was coming from and what impacts the facility would have on the grazing operations adjacent to the project. It was apparent that a continuum of different dated imagery would be required to meet the objectives of this study. Remote sensing data collection began with a series of photo missions over the Boghole site. A two camera bank with 35 mm normal color and color infrared film was initially used. These oblique photographs served to identify the optimum time and the most useful scale for professional vertical photography.

Vertical photography was completed on April 17, 1978 using Kodak aerochrome infrared film #2443 (1/500 f 5.6 RC10 wild with 6 inch Avigon lens). Nine by nine inch transparencies were shot at a scale of 1:12,000 or one inch = 1000 feet. Future flights are planned to assist in monitoring changes that occur over time on the site. A landscape analysis was conducted over a regional watershed boundary of approximately 25 square miles.

Topographic, vegetational and surface water conditions were individually analyzed, then combined to define regional functional landscapes (Rodiek 1978). A functional landscape is a three dimensional unit of land possessing dominant patterns of vegetation, surface water, and topographic configuration, as well as patterns of land use ranging from the most natural conditions to the most man-made. While many man-made features (buildings, roads, etc.) and natural elements are common to all functional landscapes, the amount and pattern of distribution differs significantly between them. Similarly, many of the human activities (recreational, residential, grazing, etc.) carried on are common to all, but differ tremendously in terms of specific location and intensity. A landscape analysis assesses the end products of our natural and cultural systems. The procedure standardizes the products of these two systems into three dimensional units or functional landscapes (Figure 1).

VEGETATION SELECTION

The task of selecting those aquatic plant species to be used in the habitat treatment scheme was accomplished through a two phase process. In phase one it was necessary to determine those plant species that provide food value to puddle ducks throughout the western region. The ducks found in the project area migrate here from points north and west. The plants native to their summer range may not be suitable for the growing conditions found in the Boghole impoundment. In phase two, this plant material list was narrowed down to a select few species that met the following criteria:

1. The plants had to be of primary food value to ducks.

2. The plants must be able to survive under the specific growing conditions found at the Boghole. The limiting factors for growth were seen to be the high alkalinity found in the water and the fluctuating conditions created by high evapotranspiration rates particular to the area.

3. The plant species must have specific functional and structural characteristics needed to produce habitat cover.

4. The plant species must be available from nursery stock.

Phase One

Forty-four plant species and some insects and animal fiber were found in the gizzards of 909 ducks sampled on some forty-five locations in the western United States. The plant species, identified in a report entitled "Food of Game Ducks in the United States and Canada," were reduced to twenty key species based on the volumetric proportion of those plants found in the ducks sampled (Martin and Uhler 1939).

Phase Two

The functional aspects (food value, regeneration mechanisms, total biomass accumulation per year) and the structural aspects (growth form, foliage density and life form -- submergent, floating or emergent) were considered for each of the twenty plant species.

Ten plant species were finally selected for inclusion in a habitat treatment master plan (Figure 2).

HABITAT REQUIREMENTS

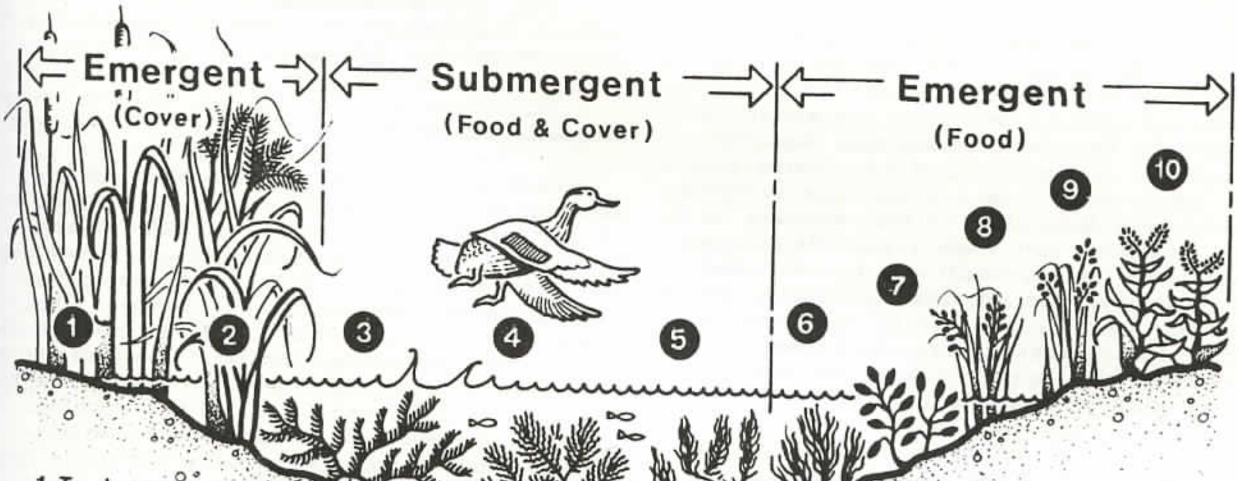
Three general types of wildlife were to be provided with varying degrees of habitat improvement treatments. Theoretically, the five essential ingredients of wildlife habitat are food, water, shelter or cover, adequate territory, and arrangement. Each of these

Functional Landscape 1.

Riparian Channel (Steep Bank)
49 Linear Miles in Study Area
45% in Steep Bank (27 Miles)

Functional Landscape	% of Area
2. Riparian Channel (Flood Plain)	55% of Strms. 22 Miles
3. Impoundments	1.5% of Reg. 95
4. Flat Grassland	49% of Reg.
5. Rolling Grassland	21.7% of Reg.
6. Woodland (Evergreen Oaks)	27.8% of Reg.

FIG. 1 Landscape Analysis – Functional Landscapes



1-Typha sp
2-Echinochloa crusgalli
3-Ceratophyllm demersum
4-Najas flexilis 5-Chara sp 6-Potamogeton pectinatus
7-Potamogeton americanus
8-Scirpus acutus
9-Scirpus americanus
10-Polyganum pensylvanicum

FIG. 2 Aquatic Plant Species

components varies according to the species being planned for and the geographical area in which the habitat is to be located.

Migratory waterfowl, particularly the puddle feeding ducks (not diving ducks), were of primary importance. Nongame fish, including the rare desert pupfish (Cyprinodon macularis), and resident shorebirds, including the great blue heron (Ardea herodias), green heron (Butorides striatus), and belted kingfisher (Megaceryle alcyon alcyon), complete the list. Migratory waterfowl frequent the Boghole area from late October through April of the following year. These ducks, as best as can be determined from state game and fish tagging studies, migrate from northern Utah and western Idaho located in the northwestern portion of the western United States (Fleming 1959). The ducks migrate along a southern route down the Pacific and Rocky Mountain flyways and then disperse over a wide area in southern Arizona, New Mexico, and portions of northern Mexico.

Food, cover, and reproduction areas in southern Arizona are very different from the summer feeding grounds to the north. A sample survey within the study area involving some 225 square miles identified an average water body size of 1.67 acres with a density of 1.05 water bodies per square mile. These figures represent a relatively low density of water in the region. However, this region is one of the more densely watered areas in the southwestern United States. The aquatic habitats that do exist are predominately man-made stock tanks, irrigation ditch systems, and canals. Therefore, the migratory waterfowl are becoming more and more dependent upon man-made systems designed for grazing and agricultural uses. It was for this reason that state and federal officials decided to create a facility that would derive its source of water from surface runoff not directly used by agricultural and grazing interests. The impoundment facility was located in a remote area of the country where disturbance to surrounding land uses and from incidental visitors would be minimal.

Duck Habitat

The Boghole impoundment will serve as a winter home for some twelve species of duck common to the area during the winter months. One of these, the Mexican duck (Anas diazi), will serve as a representative example. The Mexican duck's breeding grounds in the United States has been greatly reduced due to habitat loss. The species' natural habitat is found in the wetland areas, especially lakes, ponds, and potholes. Its survival can be attributed to its ability to adapt to the man-made situations that have displaced more natural areas. The critical components of its habitat are: vegetative cover, water stability, and impoundment configuration. In general, Mexican duck habitat is a set of complex relationships between water depth, water quality, size of wetland area, amount of human disturbance, vegetation density, and species composition of the vegetation. There is some evidence that an insufficiency in any one factor might be compensated for by the high quality of another factor (Swarbrick 1975).

To better understand the habitat requirements of the Mexican duck, a time line profile of the species was generated from the existing literature (O'Brien 1975; Swarbrick 1975; and others). The following is a synopsis of those findings.

Prenesting

The number of water bodies used by prenesting ducks in the late November through early December period is greater than at any other time. Flocks roam over large areas foraging for remnant seeds and other vegetative food parts wherever they may be available. Vegetation densities that provide cover are less important due to the absence of flightless adults and young. The ducks select mere expansive water sites for the purposes of courtship and group security; therefore, habitat requirements for pairs or individuals is not as critical during this period.

Courtship and Mating

Courtship begins in December and is usually well established by January. Pairing is completed by late February. The flock breaks up slowly as the pair bonds are formed. This breakup continues into March and April during which time breeding begins. The gregariousness of the flock is replaced by an increasing intolerance of pairs for others of their own kind. This behavior serves to define spacing needs within the nesting habitats and prepare the pairbonds for egg laying and brood rearing activities. Generally speaking, breeding requirements related to habitat conditions are triggered by: temperature thresholds above 32 °F; the availability of residual winter vegetation cover; and the germination of aquatic food plants.

Nesting and Brood Rearing

The nesting season (first egg laying to

last hatch) extends from late March to mid-June, whereas brood rearing spans the period between late April to mid-September. Egg laying and incubation requires approximately 34 days, after which brood rearing begins. Chicks will range in numbers from one to thirteen with an average of five per clutch surviving to maturity. Optimum nesting habitat requirements, while not clearly established, are more strongly related to cover requirements (nesting, travel, and escape) provided by vegetation densities than to the presence of any one particular species. Observations carried out in existing Mexican duck nesting areas suggest that a maximum amount of shoreline (water vegetated land edge) promotes a maximum number of breeding duck territories (Figure 3).

Nongame Fish Habitat

Nongame fish, namely the small plant and insect feeders such as the desert pupfish (Cyprinodon macularis), were to be included in the habitat improvement treatment plans for several reasons. The species selected for inclusion -- gila topminnow (Poeciliopsis occidentalis occidentalis) and Longfin dace (Agosia chrysogater) -- represent some of the remnant fish species formerly found in this area when water was more abundant. Their inclusion represents an effort to reestablish fish species that are now approaching extinction in this area of the country. These fish are not a game fish and therefore do not constitute a consumptive recreational potential. Finally and most importantly, these species will fill a vacant niche space. They will serve the purpose of controlling aquatic insect populations as well as providing a vital link in the food chain conversion scheme as energy is transformed from photosynthetic to plant and animal protein. Shorebirds such as the heron and kingfisher are dependent upon amphibian, insect, and fish populations to sustain their dietary needs. Wihout these nongame fish, a vital component of the riparian habitat will be absent from the Boghole project.

The desert pupfish will serve as the representative example for planning nongame fish habitat requirements. Presently the pupfish is found only in Quitobaquito Springs, Organ Pipe Cactus National Monument, and portions of the Sonoita River Basin in northern Mexico. Pupfish characteristically inhabit springs, marshes, flowing streams, backwaters and other complex lateral habitats of large rivers. They can tolerate great extremes in environmental conditions within desert climatic regimes. They have been known to endure salinities of almost three times that of sea water and have temperature tolerances ranging from 2 to 44 °C. They can tolerate extremely low levels of dissolved oxygen (0.13 mg/l). Pupfish are active only during daytime hours, occupying the warmer levels in the upper strata of the pond.

Water is the life zone for fish species. It defines the boundaries of their mobility and carries food and oxygen necessary for their survival. Habitat treatments designed to improve breeding behavior and winter survival are centered on three environmental factors: water depth, water temperature, and substrate type.

Optimal breeding conditions relative to water temperature range around 24 °C (75 °F). According to Kynard (1976), breeding behavior begins when water temperature consistently exceeds the 26 °C level. Habitat preference experiments conducted by Kynard suggest that males will selectively breed in shallow water 15 to 20 cm (6 to 8 inches) deep, where open water (no vegetation) provides good visibility and good nesting opportunity (sand bottoms). Kynard's data indicates that while pool or pond deepening may afford more secure water levels the critical breeding habitats occur in the upper 15 cm of water along pool edges (Figure 4).

CONCLUSIONS

The Boghole water impoundment does possess a satisfactory amount of surface runoff area to supply water needs for the existing facility. Furthermore, shoreline configuration and bottom slope are very well engineered so as to maintain optimal land-water edge characteristics regardless of water drawdown due to low rainfall or high evapotranspiration rates. The upstream and downstream channels can significantly add needed food and cover habitat to the project.

Oblique and vertical photography, when timed to capture color signature characteristics during "leafout" and plant rejuvenation periods, provided valuable information regarding the food and cover potentialities on the site. Over time, duck and fish reproduction may become established, given the successful development of aquatic plant materials. The aquatic plants selected for planting should, according to existing literature, perform well in the Boghole.

Habitat prototype recommendations must stand the test of time before any further conclusions can be made as to their effectiveness. Theoretically, the five essential components of wildlife habitat are

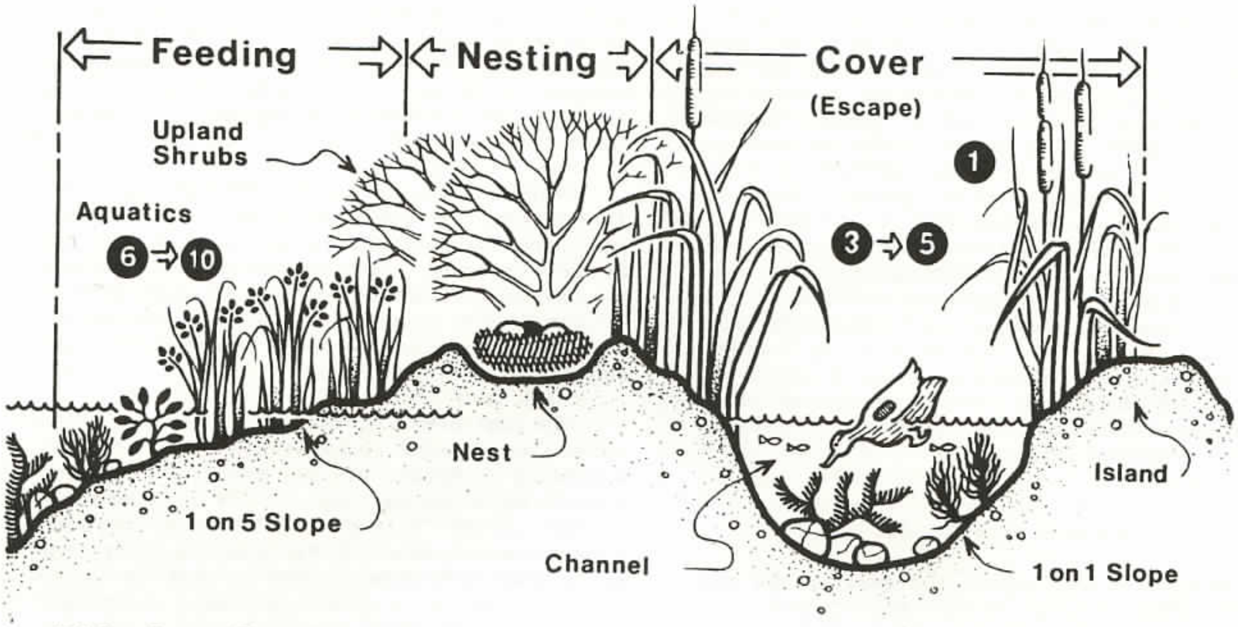


FIG. 3 Duck Nesting Habitat – Island Component

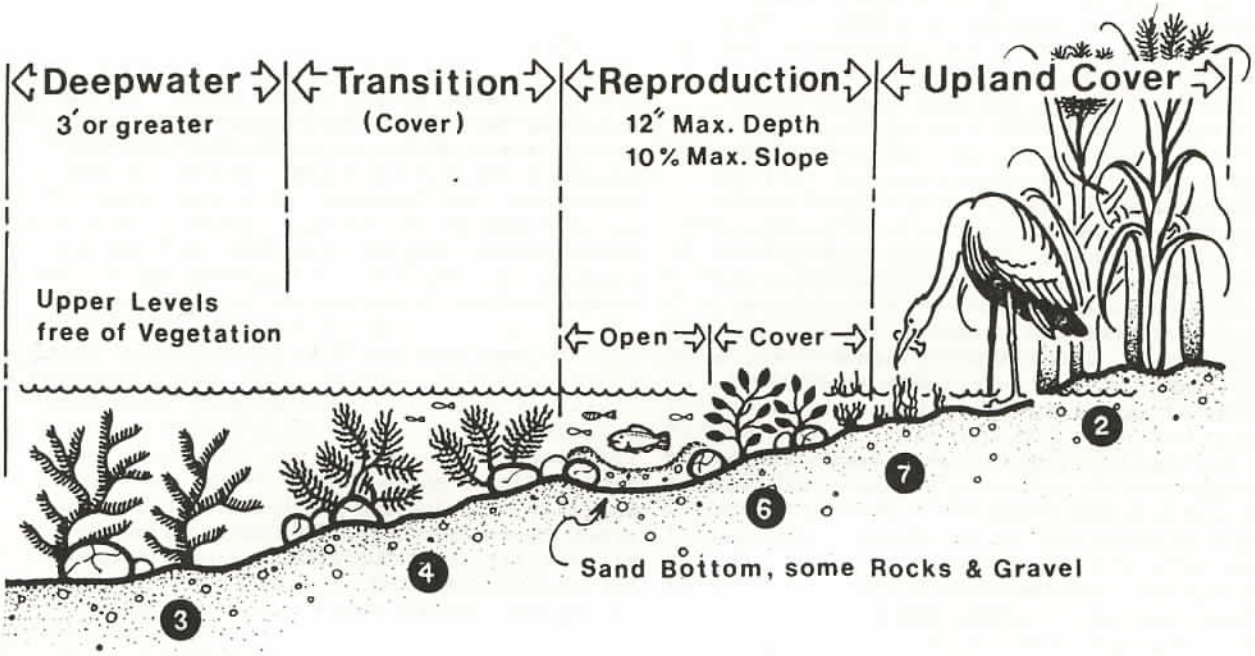


FIG. 4 Desert Pupfish Reproduction Area

well known. The habitat prototypes were modeled after the best technical information available. Whether or not these recommendations, once implemented, will be used by the intended species is a function of species recognition, behavior, and adaptation. Success of this project is dependent not only on the appropriate arrangement of habitat components on the Boghole but the status of the surrounding habitats in southeastern Arizona and the summer ranges to the north.

LITERATURE CITED

Davis, C. A, and V. W. Bevill. 1970. Effects of restoration and management of the San Simon March on its utilization by Mexican ducks. New Mexico State University, Las Cruces, New Mexico.

Fleming, W. B. 1959. Migratory waterfowl in Arizona: A management study. State of Arizona Game and Fish Department, Phoenix, Arizona. 74 pp.

Kynard, B. 1976. Reproductive ecology of the Quitobaquito pupfish from Organ Pipe National Monument, Arizona. First National Conference on Scientific Research in National Parks, New Orleans, Louisiana.

Lindsey, A. A. 1946. The nesting of the New Mexican duck. Auk 63(4):483-492.

Martin, A. C. and F. M. Uttler. 1939. Food of game ducks in the United States and Canada. U.S.D.A. Tech. Bul. #634. G.P.O., Washington.

O'Brien, G. P. 1975. A study of the Mexican duck (Anas diazi) in southeastern Arizona. Special Report No. 5, Arizona Game and Fish Department. 45 pp.

Rodiek, J. E. 1978. Landscape analysis -- A technique for ecosystem assessment and land use planning. Landscape Planning 5:27-44.

Swarbrick, B. M. 1975. Ecology of the Mexican duck in the Sulphur Springs Valley of Arizona. Master's thesis, University of Arizona, Tucson.

Image Processing Applications to Western Wildlife Habitat Inventory [1]

Craig Tom[2]

Abstract.--Thirteen ancillary landscape variables were spatially overlaid onto 20 Landsat spectral bands and tested for significance in mapping fifteen vegetation cover classes. Single-date summer and fall image training set classification results were virtually identical at 58 percent average accuracy. A small improvement was made with an eight-channel summer/fall multidate classification at 61 percent accuracy. Fourteen additional band ratios provided a 63 percent accuracy. Spatial filtering and multidate classification provided only marginal improvement. Ancillary data added to Landsat bands achieved a 69 percent accuracy. A ten-variable subset was identified by stepwise linear discriminant analysis to cost-effectively cover map the USGS quadrangle test site. Total direct cost was estimated at either $10.25 per square mile or $534.22 per 7½-minute USGS quadrangle. The flexibility of both remote sensing and map inputs and analyses indicated considerable potential and cost-effectiveness together in a geographic information system.

INTRODUCTION

Large tracts of strip-mineable coal underlie the rolling grass/shrub steppes of the Northern Great Plains. The disturbance of these surface vegetative communities threatens populations of numerous large and small mammal, bird, fish, and reptile species. Wildlife managers are currently handicapped by a lack of knowledge regarding the structure and distribution of important habitat components.

Habitat inventory data is an essential prerequisite to address rapidly evolving issues of coal/soil shale/geothermal energy development, water allocation and diversion, rural community development, and strip-mine reclamation.

The Western Energy and Land Use Team (WELUT) was formed in 1975 by the U. S. Fish and Wildlife Service's Office of Biological Services to specifically identify and evaluate alternatives for the development of potential energy resource lands throughout the western states. Both aircraft and Landsat Imagery are utilized by WELUT in research and operational modes.

Vegetation cover mapping is an initial step in habitat inventory, and is a primary function of remote sensing endeavors. The use of aerial photography, particularly color infrared, allows photointerpreters to recognize different vegetation cover types and their patterns through contextual and inferential clues (Table 1). Problems arise, however, in terms of aircraft data acquisition and human interpretation factors involving large, regional-sized areas.

It was hypothesized that the application of statistical pattern recognition techniques to Landsat multispectral scanner (MSS) data, combined with overlays of map-derived ancillary landscape data, would offer particular promise for regional vegetation cover mapping. Some advantages of Landsat as a remote sensing platform include its regional (100 by 100 n mi) coverage, repetitive overflights (every nine days), and both digital/photographic formats for processing/interpretation flexibility.

---

[1]Paper presented at The Fourth William T. Pecora Memorial Symposium, Sioux Falls, South Dakota, October 10-12, 1978.

[2]Senior Environmental Analyst, Energy and Natural Resource Systems, HRB-Singer, Inc., Fort Collins, Colorado 80526.

TABLE 1.--HIERARCHICAL LAND COVER CLASSIFICATION SCHEME USED FOR AERIAL PHOTOINTERPRETATION AND MACHINE CLASSIFICATION. This three-level standardized classification was created by WELUT for 1:31,500-scale, single-date summer color infrared airphoto interpretation, and subsequently used for machine processing. Land cover classes not found on the test site are indicated by an *.

Digital Codes	First-Order Land Cover	Second-Order Land Cover	Third-Order Land Cover
1	URBAN OR BUILT-UP LANDS		
11*		Industrial and Commerical	
12*		Residential	
13*		Transportation, Communications, and Utilities	
2	AGRICULTURAL AND RECLAIMED LANDS		
21*		Irrigated Croplands	
22		Nonirrigated Croplands	
23*		Orchards, Groves, Nurseries	
24*		Feed Lots	
25*		Other Agricultural Land	
26*		Reclaimed Mine Lands	
27*		Other Reclaimed Lands	
3	WATER		
31*		Perennial Streams	
32*		Intermittent Streams	
33*		Irrigation Canals	
34*		Natural Lakes	
35*		Reservoirs	
36*		Other Water (ponds, springs)	
4	BARREN LANDS		
41*		Dry Salt Flats (playas)	
42*		Beaches	
43*		Bare Exposed Rock	
44*		Cliffs, Buttes, and Spires	
45*		Mine Lands (strip mines, quarries, and gravel pits)	
5	SPECIAL FEATURES		
51		Prairie Dog Town	
511*			Positive Prairie Dogs
512*			Suspected Prairie Dogs
52*		Other Cultural Features	
6	NATIVE VEGETATION		
61		Closed Forest (trees 80 pct. canopy cover or greater)	
611			Closed Ponderosa Pine Forest
612*			Closed Juniper Forest
613*			Closed Ponderosa Pine/Juniper Forest
614*			Closed Aspen Forest
615*			Closed Riparian Deciduous Forest
616*			Closed Upland Deciduous Forest
62		Open Forest/Shrubs (trees 20-80 pct., shrubs greater than 20 pct., and herbs less than 20 pct.)	
621*			Open Ponderosa Pine Forest/Sagebrush
622			Open Ponderosa Pine Forest/Mixed Upland Shrub
62		Open Forest/Shrubs (Cont.)	
623*			Open Juniper Forest/Sagebrush
624*			Open Juniper Forest/Upland Mixed Shrub
625			Open Ponderosa Pine-Juniper Forest/Sagebrush
626			Open Ponderosa Pine-Juniper Forest/Upland Mixed Shrub
627			Open Riparian Deciduous Forest/Riparian Deciduous Shrub
63		Open Forest/Herbaceous (trees 20-80 pct., shrubs less than 20 pct., and herbs greater than 20 pct.)	
631			Open Ponderosa Pine Forest/Herbaceous
632*			Open Juniper Forest/Herbaceous
633*			Open Ponderosa Pine-Juniper Forest/Herbaceous
634*			Open Riparian Deciduous Forest/Herbaceous
64		Open Shrubs/Trees (shrubs 20-80 pct., trees 2-20 pct., and herbs less than 20 pct.)	
641			Open Sagebrush/Scattered Ponderosa Pine
642*			Open Sagebrush/Scattered Juniper
643*			Open Sagebrush/Scattered Ponderosa Pine-Juniper
644			Open Upland Mixed Shrub/Scattered Ponderosa Pine
645*			Open Upland Mixed Shrub/Scattered Juniper
646			Open Upland Mixed Shrub/Scattered Ponderosa Pine-Juniper
647			Open Riparian Deciduous Shrub/Scattered Riparian Deciduous Trees
65		Open Herbaceous/Trees (herbs 20-80 pct., trees 2-20 pct., and shrubs less than 20 pct.)	
651*			Open Herbaceous/Scattered Ponderosa Pine
652*			Open Herbaceous/Scattered Juniper
653*			Open Herbaceous/Scattered Ponderosa Pine-Juniper
654*			Open Herbaceous/Scattered Riparian Deciduous Trees

TABLE 1.--HIERARACHICAL LAND COVER CLASSIFICATION SCHEME USED FOR AERIAL PHOTOINTERPRETATION AND MACHINE CLASSIFICATION (Cont.).

Digital Codes	First-Order Land Cover / Second-Order Land Cover / Third-Order Land Cover
6	NATIVE VEGETATION (Cont.)
66	Closed Shrubs (shrubs greater than 80 pct., herbs less than 20 pct., and trees less than 2 pct.)
661*	Closed Sagebrush Shrub
662*	Closed Upland Mixed Shrub
663*	Closed Riparian Deciduous Shrub
664*	Closed Halophytic Shrub
67	Open Shrubs/Herbaceous (shrubs 20-80 pct., herbs greater than 20 pct., and trees less than 2 pct.)
671	Open Sagebrush Shrub/ Herbaceous
672	Open Upland Mixed Shrub/Herbaceous
673*	Open Riparian Deciduous Shrub/Herbaceous
674*	Open Halophytic Shrub/ Herbaceous

Digital Codes	First-Order Land Cover / Second-Order Land Cover / Third-Order Land Cover
6	NATIVE VEGETATION (Cont.)
68	Closed Herbaceous (herbs greater than 80 pct., shrubs less than 20 pct., and trees less than 2 pct.)
681*	Closed Upland Herbaceous
682*	Closed Riparian Herbaceous
69	Open Herbaceous/Scattered Shrubs (herbs 20-80 pct., shrubs less than 20 pct., and trees less than 2 pct.)
691	Open Upland Herbaceous/ Scattered Sagebrush
692*	Open Upland Herbaceous/ Scattered Upland Mixed Shrub
693*	Open Riparian Herbaceous/ Scattered Riparian Deciduous Shrub

OBJECTIVES

The objectives of this research were to overlay ancillary map data onto a Landsat multispectral data base, and to map vegetation cover types on a test quadrangle area. Specific objectives included the following:

- Development of a digital terrain model with elevation, slope, aspect, and insolation components;
- Overlaying of the Landsat images onto the digital terrain model;
- Optimization of the Landsat image classification algorithm when used with landscape or ancillary variables;
- Optimal vegetation cover mapping of the study area using Landsat and landscape variables;
- Verification of the machine-produced map;
- Testing various preprocessing and feature extraction techniques;
- Tabulation of computer, labor, and material costs/times for the vegetation cover map; and
- Testing various color infrared photographic analysis techniques.

STUDY SITE

The Beaver Creek School 7½-minute USGS topographic map quadrangle was designated as the study area of the vegetation cover mapping effort. The site is located in southeastern Montana approximately 64 miles (103 km) southeast of Miles City (Figure 1). The study area is rectangular in shape, with dimensions of 6 miles (9.7 km) east-west and 8.6 miles (13.9 km) north-south, and an area of approximately 52.1 square miles (134.8 square km). An abundance of landforms and vegetation types occur within the quadrangle test site.

APPROACH

Single-date, medium-scale (1:31,500) summer color infrared photography was manually interpreted by the preceding scheme, and compiled on the 1:24,000-scale Beaver Creek School quadrangle sheet. This cover map was subsequently entered into a geographic information system (GIS) as digitized polygons, and accessed for "ground-truth" comparisons later. Other image processing techniques applied to the color infrared imagery were analog density analysis and digital multispectral classification.

The 25 Jul 1974 and 17 Sep 1974 Landsat-1 scenes were geometrically rectified and resampled to yield 138 rows and 97 columns of 2½-acre

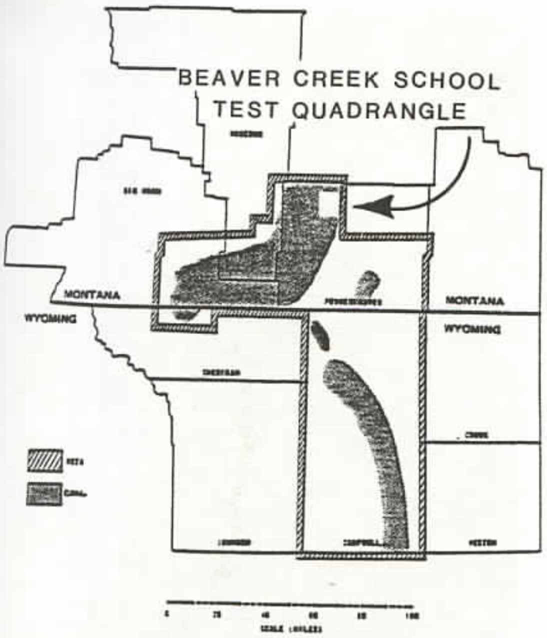


FIGURE 1.--MAP OF THE WELUT REGIONAL ENVIRONMENTAL TEST AREA (RETA). The Beaver Creek School quadrangle is located in the north-central portion of the RETA. Display scale approximately 1:4,770,635.

(1.01 ha) square pixels covering the Beaver Creek School quadrangle. A nearest-neighbor algorithm with earth rotation, scanline skew, nonlinear mirror velocity, frame rotation, and pixel resampling without ground control points was used to generate the multidate summer (Figure 2) and fall (Figure 3) subscenes. This geometric rectification allowed the spatial registration of Landsat spectral data with ancillary elevation, slope, and aspect data. Landsat multidate image insolation was calculated from the elevation, slope, and aspect variables to yield the incident solar radiation on the terrain at the time of the two summer and fall overflights (Figure 4). Additional MSS band ratios and MSS band/image insolation ratios were formed for a total of 33 image and ancillary mapping variables (Table 2). A spatial filtering transformation was then applied to the initial data set to form a second multidate summer (Figure 5) and fall (Figure 6) data set for comparative testing.

RESULTS

Stepwise linear discriminant analysis was applied to the rectified only and rectified/filtered data sets with a new, systematic grid-sampled training set approach to test the statistical utility of each image/ancillary map variable. Analytical results were recompiled to reflect aggregative changes to the original terrestrial wildlife habitat characterization (Table 1).

The four summer rectified Landsat MSS bands gave an average training set accuracy of 58.98 percent (Table 3), while the rectified/filtered summer bands produced a 58.40 percent average accuracy (Table 4). The four fall rectified Landsat MSS bands yielded an average training set accuracy of 56.93 percent (Table 5), while the rectified/filtered fall bands improved the accuracy somewaht to an average of 57.91 percent (Table 6).

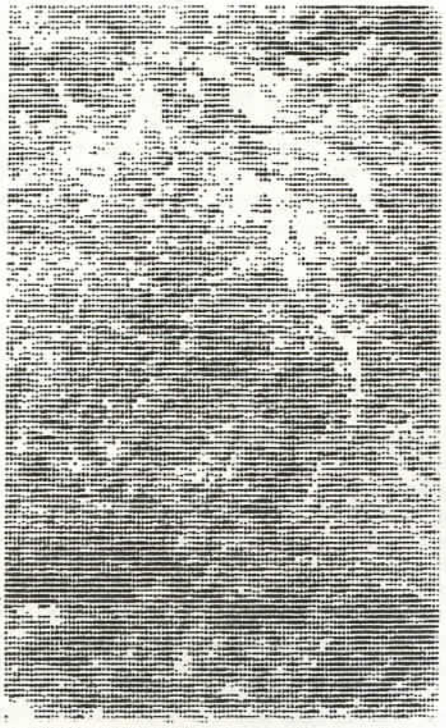
Thirteen ancillary map variables reclassified the grid training set at a 62.70 percent average accuracy (Table 7). Topographic elevation, slope, and aspect constituted valuable nonimage data to remove terrain effects from Landsat digital data in variable topography. These topographic variables were used to model the Landsat-viewed insolation at the time of the summer and fall overflights, but are also highly useful for land planning activities by themselves.

The multidate original MSS bands were almost identical for the rectified only (Table 8) and rectified/filtered (Table 9) data sets at 61 percent average accuracy. The addition of 14 band ratios raised the average accuracies for rectified only (Table 10) and rectified/filtered (Table 11) image training sets to 62.99 and 63.77 percent, respectively.

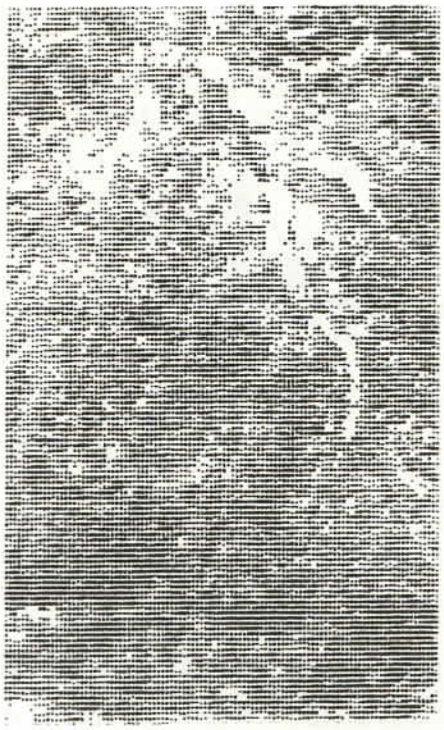
The combined use of all 33 ancillary/image variables yielded average accuracies of 67.29 and 68.75 percent, respectively, for rectified only (Table 12) and rectified/filtered (Table 13) training sets. Topographic elevation, slope, and aspect ranked high in both analyses.

An optimum ten-variable subset was selected from the rectified/filtered entry order (Table 14) with an average training set accuracy of 62.89 percent. A 79.28 percent training set accuracy was realized with a conventional rectangular training field approach to feature extraction on the rectified/filtered data set (Table 15). The entire Beaver Creek School quadrangle was classified using the ten-variable mean/covariance matrices derived from the grid-sampled point and rectangular field analyses to compare these feature extraction techniques.

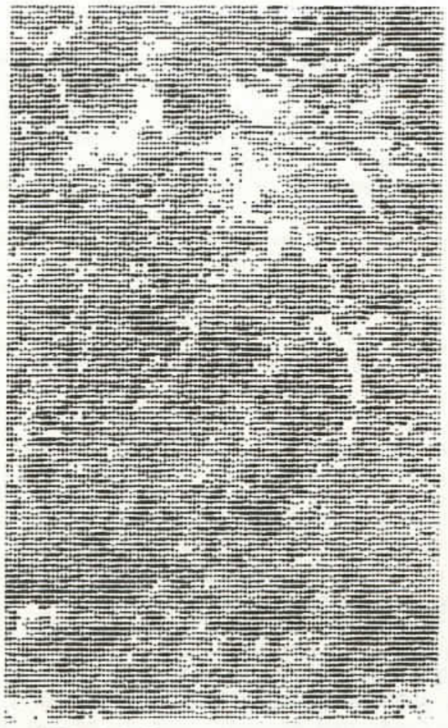
The digitized vegetation cover map in the GIS was converted from polygons to 2½-acre cells for verification of the grid point and rectangular training set-derived quadrangle cover map classifications. The grid-sampled statistics predicted a 62.89 percent average accuracy; the final verified quad accuracy was 65.62 percent. While a rectangular training set accuracy of 79.28 percent was predicted, only an average accuracy of 54.23 percent was achieved on the full quad. Thus, the systematically distributed grid point training set represented an unbiased



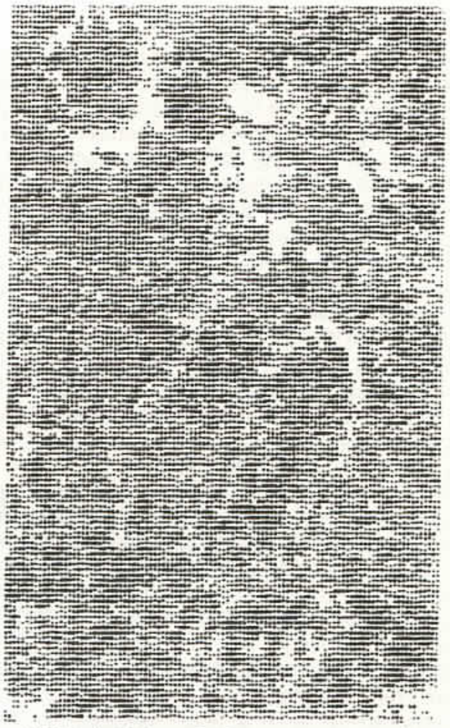
(a) Rectified Visible Green Image (Summer)
(MSS Band 4 = 0.5 to 0.6 μm)



(b) Rectified Visible Red Image (Summer)
(MSS Band 5 = 0.6 to 0.7 μm)

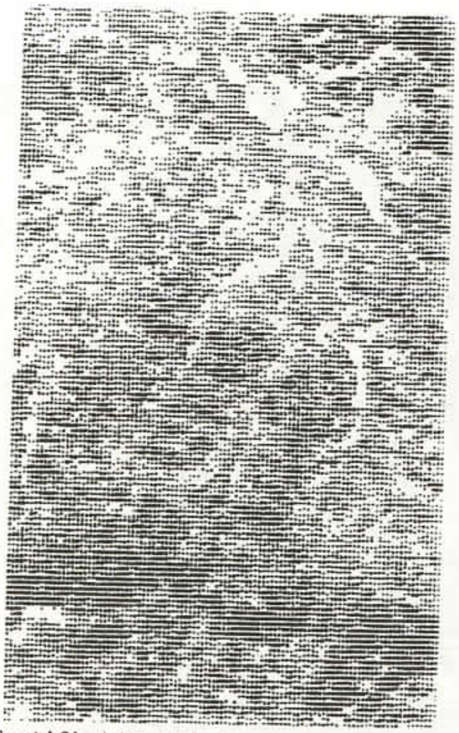


(c) Rectified Solar Infrared1 Image (Summer)
(MSS Band 6 = 0.7 to 0.8 μm)

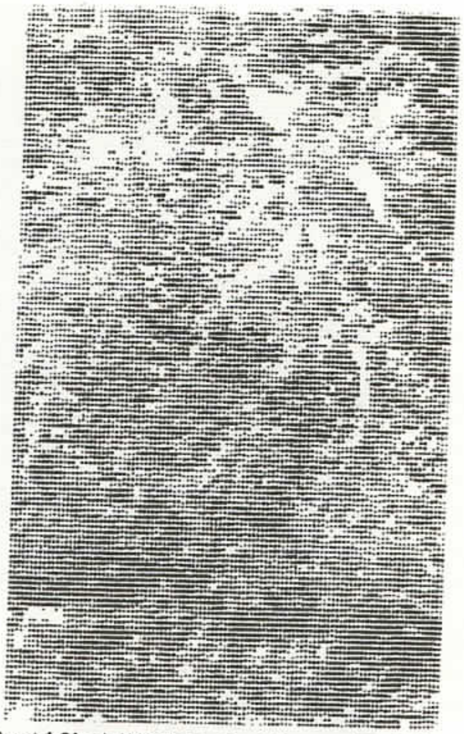


(d) Rectified Solar Infrared2 Image (Summer)
(MSS Band 7 = 0.8 to 1.1 μm)

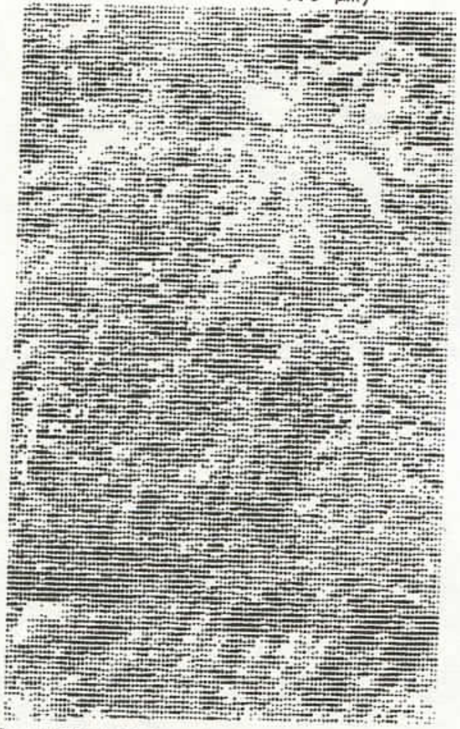
FIGURE 2.--DISPLAY OF BEAVER CREEK SCHOOL QUADRANGLE RECTIFIED/RESAMPLED MULTISPECTRAL LANDSAT-1 IMAGERY EMPHASIZING LOWEST BAND SPECTROREFLECTANCE (in black). The original picture elements were 192- by 259-foot inclined rectangles rectified and resampled to 330-foot north-south squares to overlay 2½-acre ancillary map data. Image taken 25 Jul 1974. Display scale nominally 1:170,000.



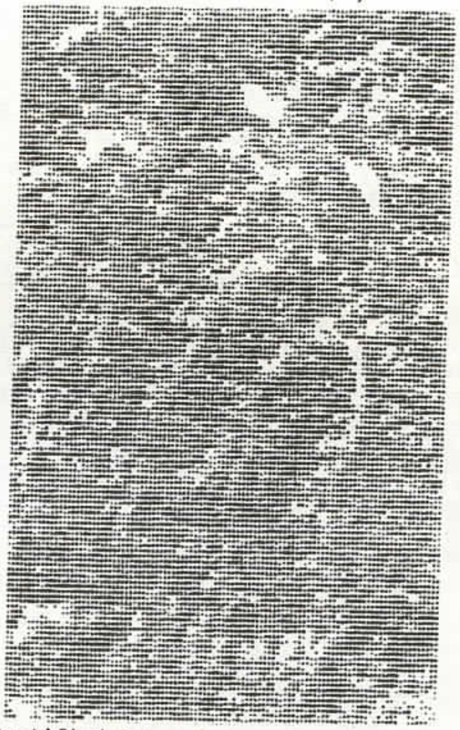
(a) Rectified Visible Green Image (Fall)
(MSS Band 4 = 0.5 to 0.6 μm)



(b) Rectified Visible Red Image (Fall)
(MSS Band 5 = 0.6 to 0.7 μm)

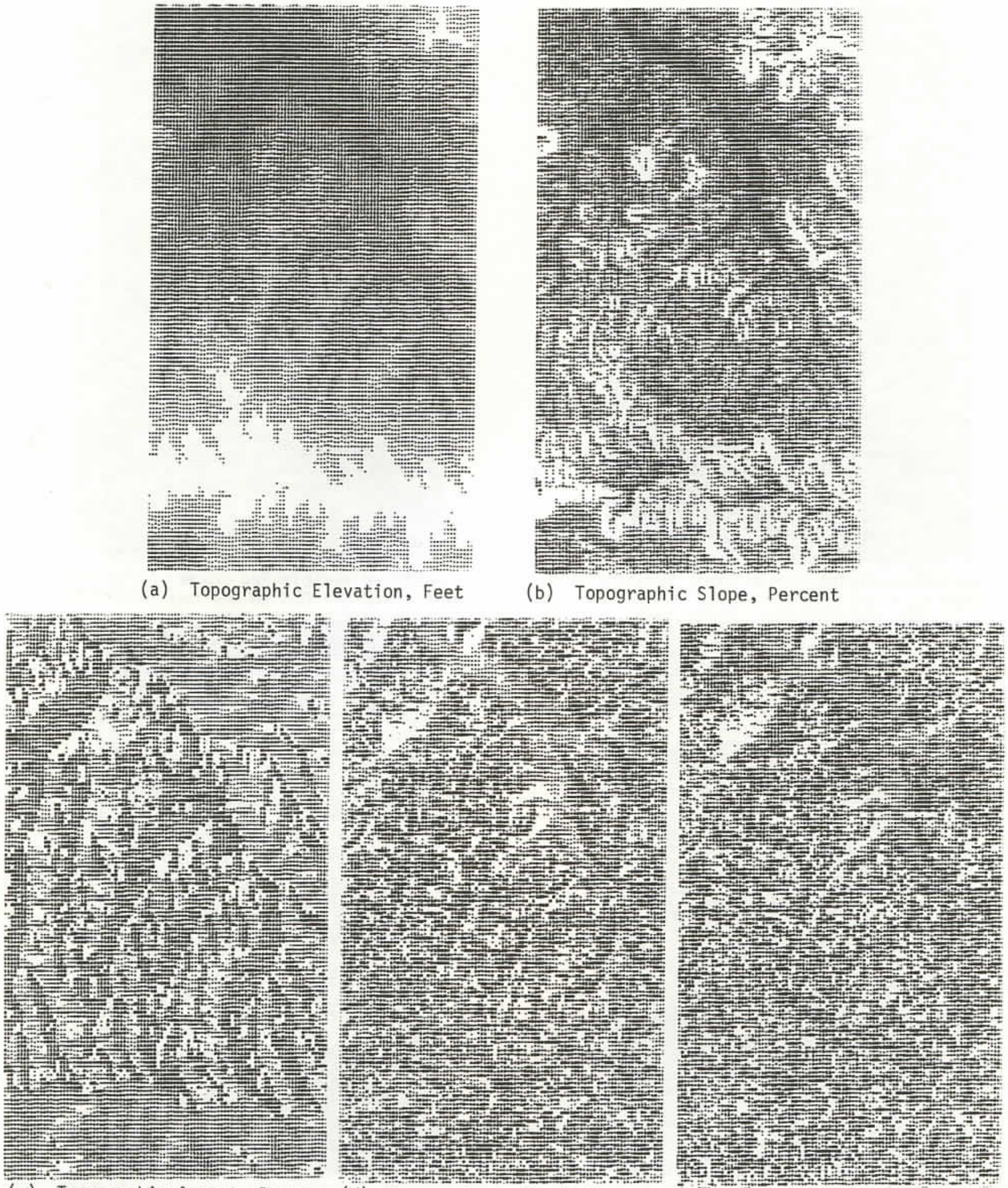


(c) Rectified Solar Infrared1 Image (Fall)
(MSS Band 6 = 0.7 to 0.8 μm)



(d) Rectified Solar Infrared2 Image (Fall)
(MSS Band 7 = 0.8 to 1.1 μm)

FIGURE 3.--DISPLAY OF BEAVER CREEK SCHOOL QUADRANGLE RECTIFIED/RESAMPLED MULTISPECTRAL LANDSAT-1 IMAGERY EMPHASIZING LOWEST BAND SPECTROREFLECTANCE (in black). The original picture elements were 192- by 259-foot inclined rectangles rectified and resampled to 330-foot north-south squares to overlay 2½-acre ancillary map data. Image taken 17 Sep 1974. Display scale nominally 1:170,000.



(a) Topographic Elevation, Feet (b) Topographic Slope, Percent

(c) Topographic Aspect, Degrees (d) Summer Image Insolation (e) Fall Image Insolation

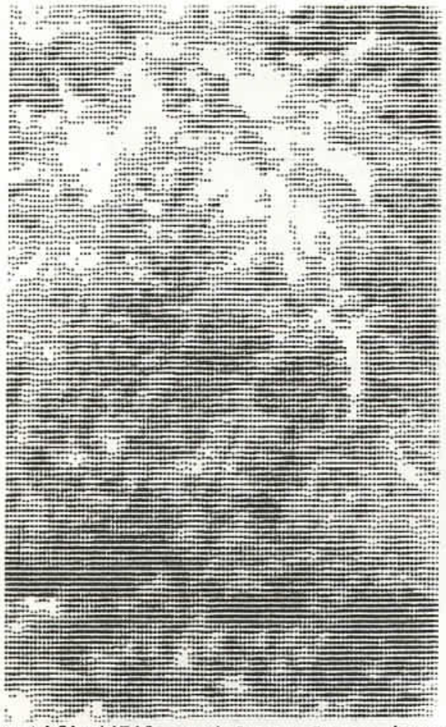
FIGURE 4.--DISPLAY OF BEAVER CREEK SCHOOL QUADRANGLE ANCILLARY MAP DATA EMPHASIZING LOWEST ELEVATION, SLOPE, NORTHEAST ASPECT, SUMMER INSOLATION, AND FALL INSOLATION (in black). Elevation data was manually coded from the USGS quadrangle. Slope and aspect were computed from the digital terrain model. Insolation was computed for the summer and fall Landsat overflights. Display scale nominally 1:170,000.

TABLE 2.--LIST OF LANDSAT SPECTRAL AND ANCILLARY LANDSCAPE VARIABLES USED FOR VEGETATION COVER MAPPING. Various linear combinations of these twenty image and thirteen map variables were examined through linear discriminant analysis, and the stepwise contribution of each variable to mapping accuracy was quantified. Summer = 25 Jul 1974, and Fall = 17 Sep 1974.

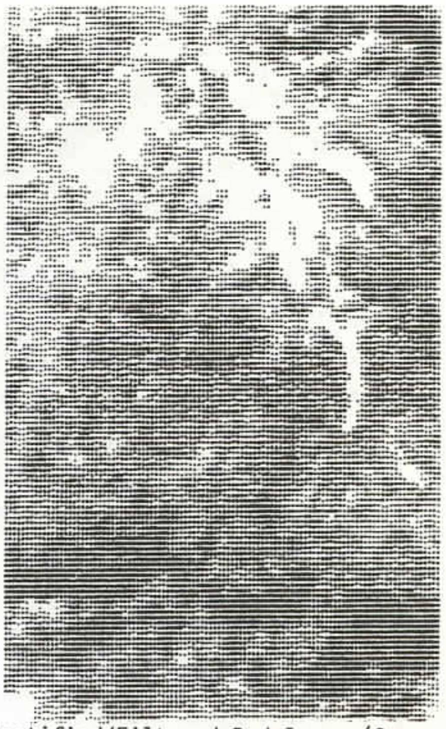
Symbol	Variable	Unit of Measurement
X_1	Landsat-1 MSS-4 (visible green)/Summer	watts cm^{-2} μ^{-1} sr^{-1}
X_2	Landsat-1 MSS-5 (visible red)/Summer	watts cm^{-2} μ^{-1} sr^{-1}
X_3	Landsat-1 MSS-6 (solar infrared1)/Summer	watts cm^{-2} μ^{-1} sr^{-1}
X_4	Landsat-1 MSS-7 (solar infrared2)/Summer	watts cm^{-2} μ^{-1} sr^{-1}
X_5	Landsat-1 MSS-4 (visible green)/Fall	watts cm^{-2} μ^{-1} sr^{-1}
X_6	Landsat-1 MSS-5 (visible red)/Fall	watts cm^{-2} μ^{-1} sr^{-1}
X_7	Landsat-1 MSS-6 (solar infrared1)/Fall	watts cm^{-2} μ^{-1} sr^{-1}
X_8	Landsat-1 MSS-7 (solar infrared2)/Fall	watts cm^{-2} μ^{-1} sr^{-1}
X_9	Topographic Elevation	feet above sea level
X_{10}	Topographic Slope	slope, percent
X_{11}	Topographic Aspect	azimuth, degrees
X_{12}	Landsat-1 Summer Image Insolation	centilangleys $minute^{-1}$
X_{13}	Landsat-1 Fall Image Insolation	centilangleys $minute^{-1}$
X_{14}	MSS-5/MSS-4 Summer Band Ratio	number
X_{15}	MSS-6/MSS-4 Summer Band Ratio	number
X_{16}	MSS-7/MSS-4 Summer Band Ratio	number
X_{17}	MSS-5/MSS-6 Summer Band Ratio	number
X_{18}	MSS-7/MSS-5 Summer Band Ratio	number
X_{19}	MSS-7/MSS-6 Summer Band Ratio	number
X_{20}	MSS-4/Summer Insolation Ratio	number
X_{21}	MSS-5/Summer Insolation Ratio	number
X_{22}	MSS-6/Summer Insolation Ratio	number
X_{23}	MSS-7/Summer Insolation Ratio	number
X_{24}	MSS-5/MSS-4 Fall Band Ratio	number
X_{25}	MSS-6/MSS-4 Fall Band Ratio	number
X_{26}	MSS-7/MSS-4 Fall Band Ratio	number
X_{27}	MSS-5/MSS-6 Fall Band Ratio	number
X_{28}	MSS-7/MSS-5 Fall Band Ratio	number
X_{29}	MSS-7/MSS-6 Fall Band Ratio	number
X_{30}	MSS-4/Fall Insolation Ratio	number
X_{31}	MSS-5/Fall Insolation Ratio	number
X_{32}	MSS-6/Fall Insolation Ratio	number
X_{33}	MSS-7/Fall Insolation Ratio	number

sampling of the important mapping attributes. The rectangular training fields, by virtue of sample point clustering, failed to obtain representative mean and covariance vectors for the entire Beaver Creek School quadrangle. Hence, the resulting poor classification results.

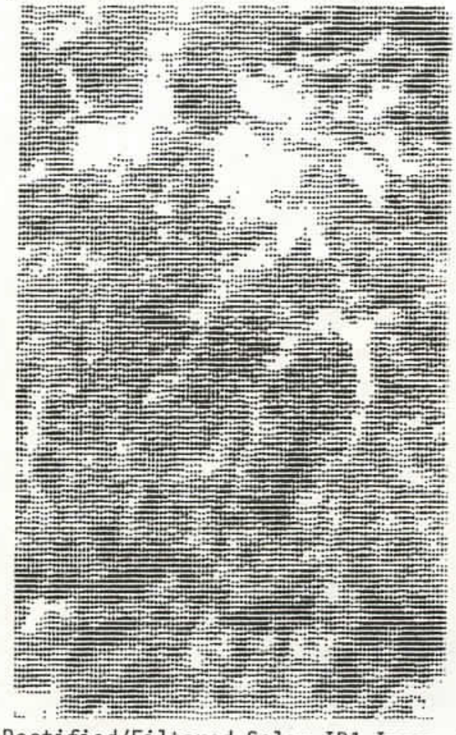
Computer, labor, and material times/costs were tabulated for the multidate ten-variable vegetation cover mapping effort (Table 16). The average direct cost was either \$10.25 per square mile or \$534.22 per 7½-minute quadrangle.



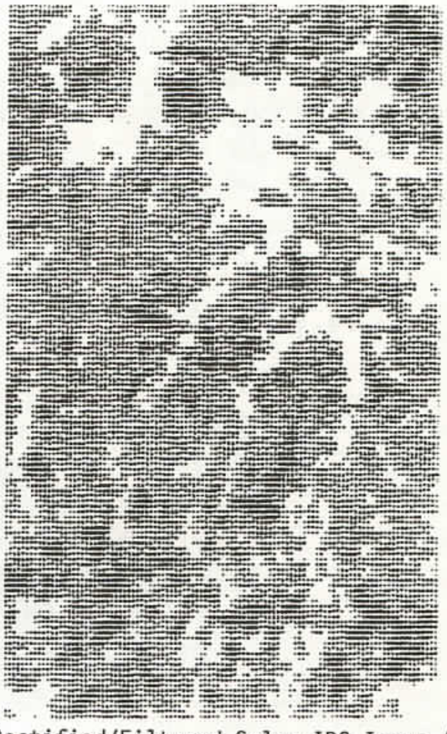
(a) Rectified/Filtered Green Image (Summer)
(MSS Band 4 = 0.5 to 0.6 μm)



(b) Rectified/Filtered Red Image (Summer)
(MSS Band 5 = 0.6 to 0.7 μm)

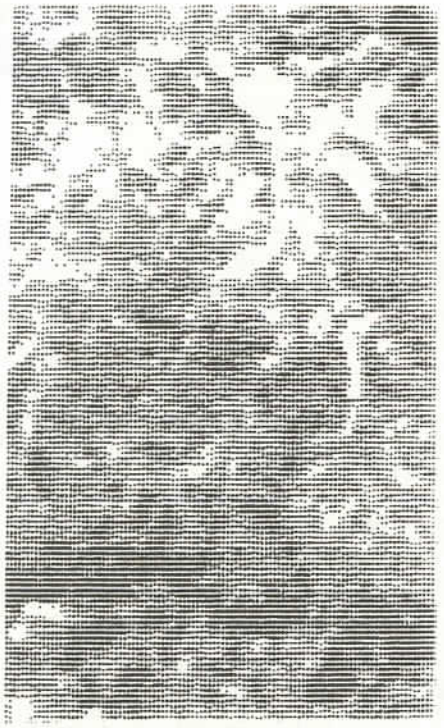


(c) Rectified/Filtered Solar IR1 Image (Summer)
(MSS Band 6 = 0.7 to 0.8 μm)

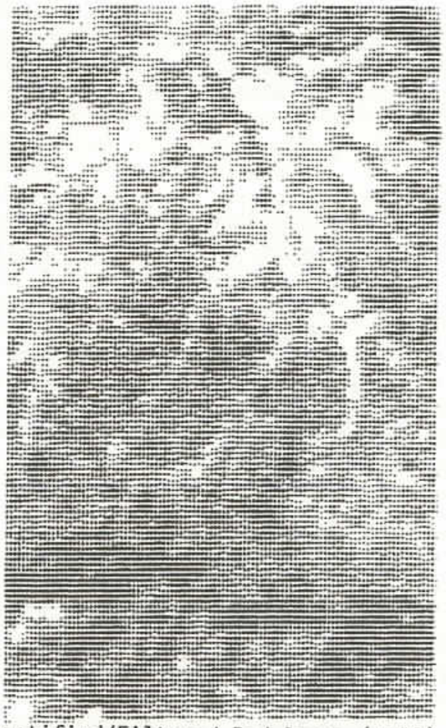


(d) Rectified/Filtered Solar IR2 Image (Summer)
(MSS Band 7 = 0.8 to 1.1 μm)

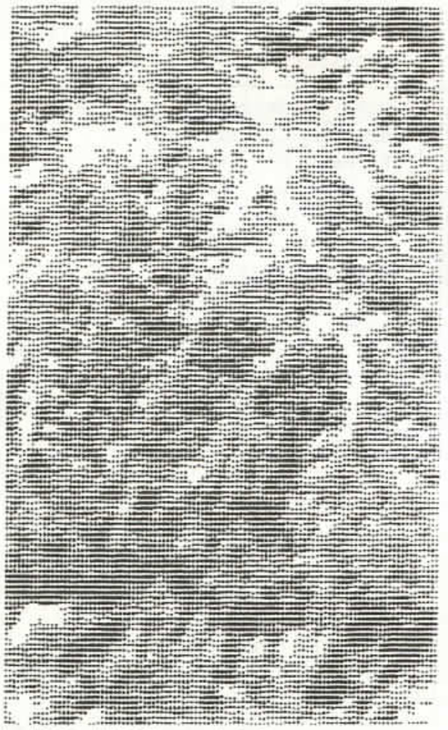
FIGURE 5.--DISPLAY OF BEAVER CREEK SCHOOL QUADRANGLE RECTIFIED/FILTERED MULTISPECTRAL LANDSAT-1 IMAGERY emphasizing lowest band spectroreflectance (in black). A spatial filtering transformation was applied to the 2½-acre rectified pixels as an image smoothing operation. Image taken 25 Jul 1974. Display scale nominally 1:170,000.



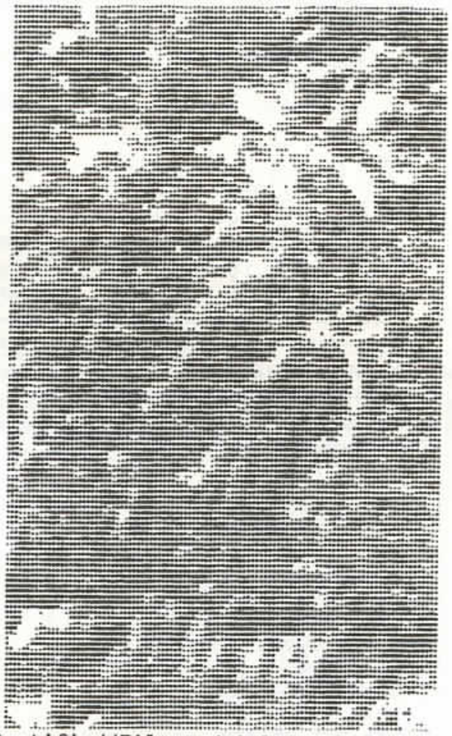
(a) Rectified/Filtered Green Image (Fall)
(MSS Band 4 = 0.5 to 0.6 μm)



(b) Rectified/Filtered Red Image (Fall)
(MSS Band 5 = 0.6 to 0.7 μm)



(c) Rectified/Filtered Solar IR1 Image (Fall)
(MSS Band 6 = 0.7 to 0.8 μm)



(d) Rectified/Filtered Solar IR2 Image (Fall)
(MSS Band 7 = 0.8 to 1.1 μm)

FIGURE 6.-- DISPLAY OF BEAVER CREEK SCHOOL QUADRANGLE RECTIFIED/FILTERED MULTISPECTRAL LANDSAT-1 IMAGERY EMPHASIZING LOWEST BAND SPECTROREFLECTANCE (in black). A spatial filtering transformation was applied to the 2½-acre rectified pixels as an image smoothing operation. Image taken 17 Sep 1974. Display scale nominally 1:170,000.

TABLE 3.--SINGLE-DATE SUMMER RECTIFIED TRAINING SET ACCURACY. Six hundred and four 2½-acre training set points were correctly reclassified into fifteen vegetation cover classes for a 58.98 percent figure-of-merit. The Landsat image variables were added in a free stepwise fashion and classified using linear discriminant analysis. C-P = Central-Processor.

Step Number	Variable Entered	Training Set Classification Total Right	Percent Right	Step C-P Time, Secs.	Step Correct Pts Per C-P Sec	Average Correct Pts Per C-P Sec	F-Value To Enter
1	MSS-5 (visible red)	595	58.11	2.15	276.74	276.74	41.54
2	MSS-7 (solar IR2)	595	58.11	2.33	255.36	265.63	5.73
3	MSS-4 (visible green)	604	58.98	2.54	237.80	255.56	5.71
4	MSS-6 (solar IR1)	604	58.98	2.68	225.37	247.22	0.78

TABLE 4.--SINGLE-DATE SUMMER RECTIFIED/FILTERED TRAINING SET ACCURACY. Five hundred ninety eight 2½-acre training set points were correctly reclassified into fifteen vegetation cover classes for a 58.40 percent figure-of-merit. The Landsat image variables were added in a free stepwise fashion and classified using linear discriminant analysis. C-P = Central-Processor.

Step Number	Variable Entered	Training Set Classification Total Right	Percent Right	Step C-P Time, Secs.	Step Correct Pts Per C-P Sec	Average Correct Pts Per C-P Sec	F-Value To Enter
1	MSS-5 (visible red)	594	58.00	2.15	276.28	276.28	44.58
2	MSS-4 (visible green)	607	59.28	2.30	263.91	269.89	8.53
3	MSS-7 (solar IR2)	607	59.28	2.49	243.78	260.52	5.76
4	MSS-6 (solar IR1)	598	58.40	2.71	220.66	249.33	2.50

TABLE 5.--SINGLE-DATE FALL RECTIFIED TRAINING SET ACCURACY. Five hundred eighty three 2½-acre training set points were correctly reclassified into fifteen vegetation cover classes for a 56.93 percent figure-of-merit. The Landsat image variables were added in a free stepwise fashion and classified using linear discriminant analysis. C-P = Central-Processor.

Step Number	Variable Entered	Training Set Classification Total Right	Percent Right	Step C-P Time, Secs.	Step Correct Pts Per C-P Sec	Average Correct Pts Per C-P Sec	F-Value To Enter
1	MSS-5 (visible red)	573	55.96	2.24	255.80	255.80	26.75
2	MSS-6 (solar IR1)	584	57.03	2.35	248.51	252.07	4.28
3	MSS-4 (visible green)	588	57.42	2.55	230.59	244.40	1.77
4	MSS-7 (solar IR2)	583	56.93	2.75	212.00	235.39	1.46

TABLE 6.--SINGLE-DATE FALL RECTIFIED/FILTERED TRAINING SET ACCURACY. Five hundred ninety three 2½-acre training set points were correctly reclassified into fifteen vegetation cover classes for a 57.91 percent figure-of-merit. The Landsat image variables were added in a free stepwise fashion and classified using linear discriminant analysis. C-P = Central-Processor.

Step Number	Variable Entered	Training Set Classification Total Right	Percent Right	Step C-P Time, Secs.	Step Correct Pts Per C-P Sec	Average Correct Pts Per C-P Sec	F-Value To Enter
1	MSS-5 (visible red)	589	57.52	2.22	265.32	265.32	46.18
2	MSS-7 (solar IR2)	594	58.01	2.39	248.54	256.62	6.75
3	MSS-6 (solar IR1)	596	58.20	2.52	236.51	249.51	2.52
4	MSS-4 (visible green)	593	57.91	2.71	218.82	241.06	1.69

A separate but related study analyzed photointerpretation, image density analysis, and multispectral analysis of color infrared transparencies at the most generalized classification (level I) and the next most detailed classification (level II).

Manual photointerpretation on seven frames of imagery showed 64 percent accuracy at level I, and 22 percent accuracy at level II (Bernath, Kramer, and Smith, 1978). Analog density slicing on five frames was somewhat superior to manual photointerpretation with average

TABLE 7.--THIRTEEN ANCILLARY LANDSCAPE VARIABLE TRAINING SET ACCURACY. Six hundred forty two 2½-acre training set points were correctly reclassified into fifteen vegetation cover types for a 62.70 percent figure-of-merit. The nonimage map variables were added in a free stepwise fashion and classified using linear discriminant analysis. C-P = Central-Processor. Summer = 25 Jul 1974, and Fall = 17 Sep 1974.

Step Number	Variable Entered	Training Set Classification Total Right	Percent Right	Step C-P Time, Secs.	Step Correct Pts Per C-P Sec	Average Correct Pts Per C-P Sec	F-Value To Enter
1	Topographic Elevation	547	53.42	3.49	156.73	156.73	43.55
2	Topographic Slope	565	55.18	3.65	154.79	155.74	4.69
3	MSS-5/Summer Insol	562	54.88	3.84	146.35	152.46	4.08
4	MSS-4/Summer Insol	600	58.59	4.05	148.15	151.30	4.05
5	Topographic Aspect	602	58.79	4.19	143.68	149.64	3.20
6	MSS-7/Summer Insol	615	60.06	4.36	141.06	148.05	3.09
7	MSS-5/Fall Insolation	622	60.74	4.55	136.70	146.21	2.50
8	MSS-4/Fall Insolation	634	61.91	4.77	132.91	144.29	4.91
9	MSS-7/Fall Insolation	638	62.30	4.94	129.15	142.31	1.79
10	Fall Image Insolation	638	62.30	5.11	124.85	140.23	1.56
11	Summer Image Insol	638	62.30	5.32	119.92	137.99	1.47
12	MSS-6/Summer Insol	642	62.70	5.45	117.80	135.95	0.82
13	MSS-6/Fall Insolation	642	62.70	5.70	112.63	133.71	0.95

TABLE 8.--MULTIDATE ORIGINAL MSS RECTIFIED TRAINING SET ACCURACY. Six hundred twenty four 2½-acre training set points were correctly reclassified into fifteen vegetation cover types for a 60.94 percent figure-of-merit. The Landsat image variables were added in a free stepwise fashion and classified using linear discriminant analysis. C-P = Central-Processor. Summer = 25 Jul 1974, and Fall = 17 Sep 1974.

Step Number	Variable Entered	Training Set Classification Total Right	Percent Right	Step C-P Time, Secs.	Step Correct Pts Per C-P Sec	Average Correct Pts Per C-P Sec	F-Value To Enter
1	MSS-5 (red)/Summer	595	58.11	2.66	223.68	223.68	41.54
2	MSS-5 (red)/Fall	616	60.16	2.83	217.67	220.58	8.33
3	MSS-7 (IR2)/Summer	614	59.96	3.02	203.31	214.45	5.71
4	MSS-4 (green)/Summer	613	59.86	3.20	191.56	208.20	4.76
5	MSS-7 (IR2)/Fall	620	60.55	3.36	184.52	202.92	3.71
6	MSS-4 (green)/Fall	617	60.25	3.55	173.80	197.37	1.77
7	MSS-6 (IR1)/Fall	622	60.74	3.72	167.20	192.35	1.39
8	MSS-6 (IR1)/Summer	624	60.94	3.90	160.00	187.54	0.69

TABLE 9.--MULTIDATE ORIGINAL MSS RECTIFIED/FILTERED TRAINING SET ACCURACY. Six hundred twenty seven 2½-acre training set points were correctly reclassified into fifteen vegetation cover types for a 61.23 percent figure-of-merit. The Landsat image variables were added in a free stepwise fashion and classified using linear discriminant analysis. C-P = Central-Processor. Summer = 25 Jul 1974, and Fall = 17 Sep 1974.

Step Number	Variable Entered	Training Set Classification Total Right	Percent Right	Step C-P Time, Secs.	Step Correct Pts Per C-P Sec	Average Correct Pts Per C-P Sec	F-Value To Enter
1	MSS-5 (red)/Fall	589	57.52	2.67	220.60	220.60	46.18
2	MSS-5 (red)/Summer	621	60.64	2.83	219.43	220.00	15.12
3	MSS-7 (IR2)/Fall	626	61.13	3.01	207.97	215.75	6.87
4	MSS-4 (green)/Summer	627	61.23	3.17	197.79	210.87	6.25
5	MSS-7 (IR2)/Summer	617	60.25	3.35	184.18	204.92	3.56
6	MSS-6 (IR1)/Fall	626	61.13	3.56	175.84	199.35	3.03
7	MSS-4 (green)/Fall	624	60.94	3.84	162.50	193.05	2.06
8	MSS-6 (IR1)/Summer	627	61.23	3.91	160.36	188.19	1.52

TABLE 10.--MULTIDATE ORIGINAL MSS/BAND RATIO RECTIFIED TRAINING SET ACCURACY. Six hundred forty five 2½-acre training set points were correctly reclassified into fifteen vegetation cover types for a 62.99 percent figure-of-merit. The Landsat image variables were added in a free stepwise fashion and classified using linear discriminant analysis. C-P = Central-Processor. Summer = 25 Jul 1974, and Fall = 17 Sep 1974.

Step Number	Variable Entered	Training Set Classification Total Right	Training Set Classification Percent Right	Step C-P Time, Secs.	Step Correct Pts Per C-P Sec	Average Correct Pts Per C-P Sec	F-Value To Enter
1	MSS-5 (red)/Summer	595	58.11	4.33	137.41	137.41	41.54
2	5/6 Fall Ratio	611	59.67	4.57	133.70	135.51	11.05
3	MSS-7 (IR2)/Fall	611	59.67	4.78	127.82	132.82	6.51
4	7/5 Summer Ratio	605	59.08	4.90	123.47	130.36	7.97
5	MSS-4 (green)/Summer	626	61.13	5.08	123.23	128.83	3.44
6	7/4 Fall Ratio	625	61.04	5.32	117.48	126.74	3.12
7	5/4 Summer Ratio	624	60.94	5.59	111.63	124.30	2.86
8	5/6 Summer Ratio	632	61.32	6.01	105.16	121.46	2.37
9	MSS-6 (IR1)/Summer	632	61.72	6.11	103.44	119.10	6.71
10	7/5 Fall Ratio	632	61.72	6.30	100.32	116.87	2.12
11	7/6 Fall Ratio	637	62.21	6.47	98.45	114.87	2.80
12	5/4 Fall Ratio	640	62.50	6.75	94.81	112.82	2.13
13	MSS-4 (green)/Fall	642	62.27	6.84	93.86	111.05	1.18
14	MSS-5 (red)/Fall	643	62.78	7.00	91.86	109.37	3.34
15	MSS-7 (IR2)/Fall	645	62.99	7.17	89.96	107.77	1.20
16	MSS-6 (IR1)/Fall	645	62.99	7.34	87.87	106.23	1.74
17	7/4 Summer Ratio	645	62.99	7.52	85.77	104.72	1.11
18	6/4 Fall Ratio	645	62.99	7.70	83.77	103.25	0.93
19	7/5 Fall Ratio	645	62.99	7.87	81.96	101.83	0.85
20	6/4 Summer Ratio	645	62.99	8.18	78.85	100.33	0.76

TABLE 11.--MULTIDATE ORIGINAL MSS/BAND RATIO RECTIFIED/FILTERED TRAINING SET ACCURACY. Six hundred fifty three 2½-acre training set points were correctly reclassified into fifteen vegetation cover types for a 63.77 percent figure-of-merit. The Landsat image variables were added in a free stepwise fashion and classified using linear discriminant analysis. C-P = Central-Processor. Summer = 25 Jul 1974, and Fall = 17 Sep 1974.

Step Number	Variable Entered	Training Set Classification Total Right	Training Set Classification Percent Right	Step C-P Time, Secs.	Step Correct Pts Per C-P Sec	Average Correct Pts Per C-P Sec	F-Value To Enter
1	MSS-5 (red)/Fall	589	57.52	4.37	134.78	134.78	46.16
2	5/4 Summer Ratio	620	60.55	4.57	135.67	135.23	16.80
3	7/5 Fall Ratio	627	61.23	4.71	133.12	134.51	10.52
4	MSS-7 (IR2)/Fall	633	61.82	4.91	128.92	133.03	5.66
5	7/5 Summer Ratio	631	61.62	5.08	124.21	131.13	4.83
6	5/6 Summer Ratio	640	62.50	5.38	118.96	128.88	4.21
7	6/4 Summer Ratio	649	63.38	5.43	119.52	127.40	3.51
8	7/4 Summer Ratio	642	62.70	5.58	115.05	125.68	2.56
9	MSS-7 (IR2)/Summer	648	63.28	5.79	111.92	123.94	2.47
10	MSS-4 (green)/Summer	649	63.38	6.13	105.87	121.81	4.32
11	MSS-5 (red)/Summer	657	64.16	6.28	104.62	119.96	2.91
12	5/6 Fall Ratio	648	63.28	6.47	100.15	117.98	2.36
13	MSS-6 (IR1)/Fall	648	63.28	6.65	97.44	116.06	2.99
14	7/6 Fall Ratio	646	63.09	6.84	94.44	114.17	2.22
15	MSS-4 (green)/Fall	648	63.28	6.88	94.19	112.55	1.77
16	5/4 Fall Ratio	646	63.09	7.19	89.85	110.78	2.24
17	MSS-6 (IR1)/Summer	651	63.57	7.40	87.97	109.09	1.49
18	7/4 Fall Ratio	648	63.28	7.58	85.49	107.42	1.20
19	6/4 Fall Ratio	651	63.57	7.83	83.14	105.77	1.02
20	7/6 Summer Ratio	653	63.77	8.01	81.52	104.19	0.26

TABLE 12.--COMBINED ANCILLARY/LANDSAT RECTIFIED TRAINING SET ACCURACY. Six hundred and eighty nine 2½-acre training set points were correctly reclassified into fifteen vegetation cover classes for a 67.29 percent figure-of-merit. The ancillary landscape and Landsat image variables were added in a free stepwise fashion and classified using linear discriminant analysis. C-P = Central-Processor. Summer = 25 Jul 1974, and Fall = 17 Sep 1974.

Step Number	Variable Entered	Training Set Classification Total Right	Percent Right	Step C-P Time, Secs.	Step Correct Pts Per C-P Sec	Average Correct Pts Per C-P Sec	F-Value To Enter
1	Topographic Elevation	547	53.42	5.97	91.62	91.62	66.32
2	MSS-5 (red)/Summer	602	58.79	6.13	98.21	94.96	25.35
3	7/4 Fall Ratio	638	62.30	6.32	100.95	97.01	8.76
4	7/4 Summer Ratio	635	62.01	6.49	97.84	97.23	7.32
5	MSS-7 (IR2)/Summer	649	63.38	6.61	98.18	97.43	5.21
6	Topographic Slope	651	63.57	6.88	94.62	96.93	4.64
7	7/5 Fall Ratio	654	63.87	7.07	92.50	96.24	3.76
8	7/5 Summer Ratio	650	63.48	7.23	89.90	95.37	3.29
9	Topographic Aspect	653	63.77	7.38	88.48	94.52	2.92
10	7/4 Fall Ratio	647	63.18	7.59	85.24	93.48	2.74
11	MSS-4 (green)/Summer	654	63.87	7.75	84.39	92.55	2.42
12	5/4 Summer Ratio	653	63.77	7.93	82.35	91.58	1.73
13	Fall Image Insolation	655	63.96	8.12	80.67	90.61	1.45
14	MSS-7/Summer Insol	653	63.77	8.33	78.39	89.59	1.79
15	Summer Image Insol	651	63.57	8.45	77.04	88.61	1.85
16	MSS-5/Fall Insolation	654	63.87	8.63	75.78	87.66	1.60
17	MSS-7 (IR2)/Fall	652	63.97	8.81	74.01	86.71	1.26
18	MSS-4 (green)/Fall	651	63.57	9.01	72.25	85.74	1.78
19	MSS-5 (red)/Fall	657	64.16	9.17	71.65	84.84	2.20
20	5/6 Summer Ratio	663	64.75	9.45	70.16	83.94	1.31
21	MSS-6 (IR1)/Summer	659	64.36	9.73	67.73	82.97	4.99
22	7/6 Fall Ratio	643	62.79	9.67	66.49	82.05	1.18
23	MSS-6 (IR1)/Fall	647	63.18	9.82	65.89	81.18	2.11
24	5/6 Fall Ratio	652	63.67	9.98	65.33	80.36	1.35
25	MSS-4/Summer Insol	655	63.96	10.07	65.04	79.59	0.97
26	MSS-6/Summer Insol	651	63.57	10.30	63.20	78.80	0.87
27	7/6 Summer Ratio	675	65.92	10.47	64.47	78.13	0.89
28	MSS-5/Summer Insol	679	66.31	10.95	62.01	77.38	0.87
29	6/4 Fall Ratio	677	66.11	10.99	61.60	76.67	0.83
30	6/4 Summer Ratio	686	66.99	10.94	62.71	76.07	0.73
31	MSS-7/Fall Insolation	691	67.48	11.16	61.92	75.48	0.60
32	MSS-4/Fall Insolation	686	66.99	11.32	60.60	74.88	0.96
33	MSS-6/Fall Insolation	689	67.29	11.65	59.14	74.25	0.80

accuracies of 63 and 46 percent, respectively, for level I and II classes (Bernath and Smith, 1978). Machine classification of digitized photographs, however, was the most useful at 91 and 81 percent average accuracies at level I and II, respectively (Bernath, Kramer, and Smith, 1978).

FUTURE RESEARCH AND NEW OPPORTUNITIES

Several conclusions were derived from the experience and results of this study. These conclusions are summarized as follows.

• TOPOGRAPHIC ELEVATION DATA DIGITIZATION. Elevation, together with its derivative slope, aspect, and insolation data, is an essential element of vegetation cover mapping. Alternative elevation data sources need to be developed to replace the hand cellularizing used in this study and the generalized Defense Mapping Agency terrain tapes. The proposed STEREOSAT, with a 17-m pixel, appears promising for terrain relief, slope, strike, and dip studies (Doyle, 1978; Henderson and Ondrejka, 1978).

• MULTIDATE/MULTITEMPORAL LANDSAT DATA ANALYSIS. Point congruence through image rectification allows multiple scenes to be processed. The cost-effectiveness of exploiting the temporal dimension needs to be more fully addressed; however, the value of the summer/fall multidate classification was in change detection, and not in enhanced classification results.

• ADDITIONAL ANCILLARY MAP DATA INPUTS. The most obvious landscape variables (elevation, slope, aspect, and insolation) have been examined, but other possibilities exist as well. Soil survey data, for example, might prove highly useful.

TABLE 13.--COMBINED ANCILLARY/LANDSAT RECTIFIED/FILTERED TRAINING SET ACCURACY. Seven hundred and four 2½-acre training set points were correctly reclassified into fifteen vegetation cover classes for a 68.75 percent figure-of-merit. The ancillary landscape and Landsat image variables were added in a free stepwise fashion and classified using linear discriminant analysis. C-P = Central-Processor. Summer = 25 Jul 1974, and Fall = 17 Sep 1974.

Step Number	Variable Entered	Training Set Classification Total Right	Training Set Classification Percent Right	Step C-P Time, Secs.	Step Correct Pts Per C-P Sec	Average Correct Pts Per C-P Sec	F-Value To Enter
1	Topographic Elevation	547	53.42	6.06	90.26	90.26	66.32
2	MSS-5 (red)/Fall	616	60.16	6.27	98.25	94.32	23.83
3	5/4 Summer Ratio	653	63.77	6.44	101.40	96.75	14.52
4	7/5 Fall Ratio	649	63.38	6.59	98.48	97.20	9.02
5	MSS-7 (IR2)/Fall	643	62.79	6.80	94.56	96.64	5.64
6	7/5 Summer Ratio	651	63.57	6.99	93.13	96.02	5.08
7	Topographic Slope	657	64.16	7.12	92.28	95.44	4.11
8	Topographic Aspect	654	63.87	7.29	89.71	94.66	2.81
9	MSS-4 (green)/Summer	648	63.28	7.38	87.80	93.83	2.20
10	MSS-5 (red)/Summer	644	62.89	7.67	83.96	92.73	2.39
11	7/4 Summer Ratio	650	63.48	7.87	82.59	91.68	2.27
12	7/6 Fall Ratio	649	63.38	8.09	80.22	90.59	1.85
13	MSS-6 (IR1)/Fall	643	62.79	8.17	78.70	89.54	2.76
14	5/6 Fall Ratio	645	62.99	8.36	77.15	88.52	2.35
15	5/6 Summer Ratio	653	63.77	8.77	74.46	87.39	1.65
16	MSS-6 (IR1)/Summer	666	65.04	8.89	74.92	86.46	6.76
17	Fall Image Insolation	672	65.63	8.99	74.75	85.64	1.61
18	MSS-7/Summer Insol	677	66.11	9.01	75.14	84.94	1.76
19	Summer Image Insol	676	66.02	9.23	73.24	84.20	1.70
20	5/4 Fall Ratio	682	66.60	9.52	71.64	83.44	1.40
21	MSS-4 (green)/Fall	678	66.21	9.80	69.18	82.59	2.03
22	MSS-5/Fall Insolation	660	64.45	9.74	67.76	81.77	1.37
23	MSS-4/Summer Insol	668	65.23	9.89	67.54	81.00	1.30
24	7/4 Fall Ratio	672	65.63	10.05	66.87	80.28	1.11
25	6/4 Fall Ratio	674	65.82	10.15	66.40	79.59	0.97
26	MSS-6/Summer Insol	672	65.63	10.38	64.74	78.87	0.95
27	MSS-7/Fall Insolation	685	66.89	10.55	64.92	78.22	0.95
28	MSS-6/Fall Insolation	696	67.97	11.03	63.10	77.52	3.04
29	MSS-4/Fall Insolation	693	67.68	11.08	62.55	76.85	0.88
30	MSS-5/Summer Insol	701	68.46	11.03	63.55	76.29	0.89
31	6/4 Summer Ratio	706	68.95	11.25	62.76	75.72	0.77
32	MSS-7 (IR2)/Summer	702	68.55	11.41	61.53	75.15	0.82
33	7/6 Summer Ratio	704	68.75	11.75	59.91	74.54	0.30

TABLE 14.--OPTIMUM TEN-CHANNEL RECTIFIED/FILTERED GRID TRAINING SET ACCURACY. This is the best ten-variable subset as found in Table 13. The training set points were systematically distributed over the entire mapping area, as in all the preceding cases. Six hundred forty four 2½-acre training set points were correctly reclassified into fifteen vegetation cover classes for a 62.89 percent figure-of-merit. The ancillary landscape and Landsat image variables were added in a free stepwise fashion and classified using linear discriminant analysis. C-P = Central-Processor. Summer = 25 Jul 1974, and Fall = 17 Sep 1974.

Step Number	Variable Entered	Training Set Classification Total Right	Training Set Classification Percent Right	Step C-P Time, Secs.	Step Correct Pts Per C-P Sec	Average Correct Pts Per C-P Sec	F-Value To Enter
1	Topographic Elevation	547	53.42	3.11	175.88	175.88	66.32
2	MSS-5 (red)/Fall	616	60.16	3.28	187.80	182.00	23.83
3	5/4 Summer Ratio	653	63.77	3.44	189.83	184.74	14.72
4	7/5 Fall Ratio	649	63.38	3.62	179.28	183.27	9.02
5	MSS-7 (IR2)/Fall	643	62.79	3.87	166.15	179.45	5.64
6	7/5 Summer Ratio	651	63.57	4.01	162.34	176.23	5.08
7	Topographic Slope	657	64.16	4.16	157.93	173.24	4.11
8	Topographic Aspect	654	63.87	4.34	150.69	169.96	2.81
9	MSS-4 (green)/Summer	652	63.67	4.65	140.22	165.95	2.20
10	MSS-5 (red)/Summer	644	62.89	4.88	131.97	161.74	2.39

TABLE 15.--OPTIMUM TEN-CHANNEL RECTIFIED/FILTERED RECTANGULAR TRAINING SET ACCURACY. Conventional rectangular training fields were selected from the rectified/filtered data set. However, just 666 total points were used to represent the same fifteen cover classes previously sampled by 1,024 grid-sampled points. Five hundred twenty eight (of 666) 2½-acre training set points were correctly reclassified into fifteen vegetation cover classes for a 79.28 percent figure-of-merit. The ancillary map and Landsat image variables were added in a free stepwise fashion and classified using linear discriminant analysis. C-P = Central-Processor. Summer = 25 Jul 1974, and Fall = 17 Sep 1974.

Step Number	Variable Entered	Training Set Classification Total Right	Percent Right	Step C-P Time, Secs.	Step Correct Pts Per C-P Sec	Average Correct Pts Per C-P Sec	F-Value To Enter
1	MSS-5 (red)/Fall	470	70.57	2.04	230.39	230.39	203.86
2	Topographic Elevation	479	71.92	2.17	220.74	225.42	48.06
3	MSS-5 (red)/Summer	491	73.72	2.29	214.41	221.54	24.86
4	MSS-6)IR1)/Summer	497	74.62	2.41	206.22	217.40	14.65
5	7/5 Fall Ratio	503	75.53	2.48	202.82	214.22	15.82
6	MSS-7 (IR2)/Fall	516	77.48	2.68	192.54	210.09	16.19
7	MSS-4 (green)/Summer	508	76.28	2.79	182.08	205.46	9.69
8	6/4 Summer Ratio	518	77.78	2.92	177.40	201.31	8.43
9	5/4 Summer Ratio	516	77.48	2.99	172.58	197.54	7.69
10	5/6 Fall Ratio	528	79.28	3.11	169.77	194.20	5.68

TABLE 16.--COST/TIME TABULATION FOR TWO-DATE, TEN-VARIABLE LANDSAT/ANCILLARY MAP VARIABLE CLASSIFICATION FOR THE BEAVER CREEK SCHOOL QUADRANGLE, MONTANA. Quoted figures represented only direct computer, labor, and material costs/times. They accounted for only the one-time costs and did not represent redoing anything over. Only the steps which would actually be employed in an operational mode were costed. SRU = System Resource Unit ($0.075 per SRU).

Task Description	Time	Cost
1.0 Landscape Modeling		
1.1 Topographic Elevation Coding	78.4 man-hrs	$392.00
1.2 Slope/Aspect Computations	327.5 SRUs	24.56
1.3 Image Insolation Modeling	102.7 SRUs	7.70
1.4 Map File Merging	36.2 SRUs	2.72
		$426.98
2.0 Image Preprocessing		
2.1 Data Reformatting	28.2 SRUs	$ 2.12
2.2 Image File Merging	53.8 SRUs	4.04
2.3 Image Rectification/Resampling	466.6 SRUs	35.00
2.4 Image File Trimming	40.5 SRUs	3.04
2.5 MSS Channel Transformations	322.7 SRUs	24.20
		$ 68.40
3.0 Feature Extraction		
3.1 Graymapping	65.2 SRUs	$ 4.89
3.2 Training Set Classification	68.6 SRUs	5.15
		$ 10.04
4.0 Image Classification		
4.1 Composite File Creation	135.3 SRUs	$ 10.15
4.2 File Classification	248.7 SRUs	18.65
		$ 28.80
	Grand Total	$534.22

• FURTHER INFORMATION SYSTEMS DEVELOPMENT. The synergistic combination of Landsat image and ancillary map data strongly suggests additional information systems development to provide complete, objective, and consistent information and analyses. The versatility of a unified, multivariate data base can be used to address a wide spectrum of management, planning, and research problems.It was apparent from the early phases of this study that the merging of geographic map data and Landsat spectral data into a composite format would provide a realistic and dynamic information base for integrated land planning purposes.

ACKNOWLEDGEMENTS

The author extends his appreciation to

Robert L. Riggs (HRB-Singer) for providing the Landsat computer-compatible tapes and image processing software, Carl N. Reed (U. S. Fish & Wildlife Service) for GIS data retrieval, and Timothy O. Tomlin (Colorado State University) for topographic map coding. Dr. Gearold R. Johnson, Associate Director of the Colorado State University Computer Center, provided computing resources.

LITERATURE CITED

Bernath, S. C., J. E. Kramer, and J. A. Smith. 1978. *Evaluation of Color Infrared Aerial Photography for Regional Wildlife Habitat and Land Use Inventory and Analysis. Vol. I: Comparison of Photo Interpretation and Image Density Analysis to Ground Truth.* Phase I Final Report, HRB-Singer, Inc., contract no. 14-16-0008-2161. Dep't of Earth Resources, Colorado State Univ., Ft. Collins. 26 pp., plus appendices, illus.

____________, and J. A. Smith. 1978. *Evaluation of Color Infrared Aerial Photography Data for Regional Wildlife Habitat and Land Use Inventory and Analysis. Vol. II: Procedures and Evaluation of Image Density Analysis.* Phase I Final Report, HRB-Singer, Inc., contract no. 14-16-008-2161. Dep't of Earth Resources, Colorado State Univ., Ft. Collins. 26 pp., plus appendices, illus.

Doyle, Frederick J. 1978. "The Next Decade of Satellite Remote Sensing." *Photogram. Eng. and Remote Sensing* 44(2): 155-164.

Henderson, F. B., and R. J. Ondrejka. 1978. "GEOSAT: Geological Industry Recommendations on Remote Sensing from Space." *Photogram. Eng. and Remote Sensing* 44(2): 165-169.

Ranson, K. J., and J. A. Smith. *Evaluation of Color Infrared Aerial Photography Data for Regional Wildlife Habitat and Land Use Inventory and Analysis. Vol. III: Procedures and Evaluation of Multispectral Analysis of Digitized Color Infrared Transparencies.* Phase I Final Report, HRB-Singer, Inc., contract no. 14-16-0008-2161. Dep't of Earth Resources, Colorado State Univ., Ft. Collins. 45 pp., plus appendices, illus.

Wildlife Habitat Mapping from Color Aerial Photography in Central Arizona

-AN INTERIM REPORT-[1]

B. Dean Treadwell[2]

Abstract.--A multistage remote sensing design is being used to map wildlife habitat in a 300 square mile research area in Central Arizona. High altitude photography was used to identify general land-resource systems. 1:24,000 color infrared photography is being used to delineate plant associations within desert scrub, chaparral, woodland and forest vegetation types as well as other habitat features. Large scale (~1:2,000) 35mm photographs taken from low flying aircraft, and ground surveys are being used to determine distributions of key plant species used by javelina, black bear and desert mule deer.

INTRODUCTION

A map of wildlife habitats should emphasize features (both biotic and abiotic) which are known to be particularly important for each animal of interest. The first section of this paper describes a study area where research conducted by the Arizona Game & Fish Department has yielded sufficient information to define many of the habitat features important for javelina, black bear and desert mule deer. The methodology section describes a remote sensing based inventory designed to delineate these features and other general information. The results of this ongoing work reported in this paper center on the development of an appropriate classification system and the definition of the photographic characteristics of the different classification categories.

Project Area

The Three-Bar Wildlife Area in central Arizona has been the center of both big and small game research activities conducted by the Arizona Game & Fish Department for many years. The area lies about 50 miles northeast of Phoenix in the Mazatzal Mountains. This region is part of the transition zone between the Sonoran Desert communities of the basin and range geographical province found in Southern Arizona, and the great basin desert scrub of the Colorado Plateau to the northeast. The transition zone itself is an abrupt uplift supporting the largest contiguous belt of pinyon-juniper woodland and ponderosa pine forest in the state. It is not surprising, therefore, that the study area, situated in this ecotonal environment, exhibits a diverse flora and fauna with numerous geographical and climatic affinities. Elevations range from 2,300 to 7,600 feet and general vegetation types include desert scrub, chaparral and coniferous forest.

Research activities in the Three-Bar Area have centered on desert mule deer (Odocoileus hemionus), javelina (Pecari tajacu), black bear (Euarctos americanus) and quail (Lophortyx gambelii). Studies have included various aspects of wildlife ecology such as foraging strategies, population dynamics, and home range patterns, as well as addressing certain wildlife management problems such as supplemental water development and the effects of hunting pressures. A one square mile predator proof enclosure has been constructed which provides a known population of deer and javelina for certain investigations. Radio-telemetry has also been used extensively.

---

[1]Paper presented at the Pecora IV Symposium, Sioux Falls, South Dakota, Oct. 10-12, 1978.

[2]Research Assistant, The Applied Remote Sensing Program, Office of Arid Lands Studies, University of Arizona, Tucson, 85719.

Objectives and Background

The Research Division of the Arizona Game & Fish Department, under the auspices of the state Game & Fish Commission, has contracted with the Applied Remote Sensing Program, Office of Arid Lands Studies at the University of Arizona (Tucson) to produce a detailed wildlife habitat map of the Three-Bar Area and vicinity (nearly 300 square miles). The map scale will be 1:24,000. This map will be used to correlate and analyze the data from many of the department's ongoing investigations.

Although vegetation types at the fifth and sixth levels of detail are the primary consideration, other features of the landscape such as slope angle and aspect, parent material, soil characteristics and surface water are also being incorporated. These additional parameters serve a twofold purpose. First, they aid in mapping natural plant communities by providing correlative information about their physical setting. Second, they contribute to wildlife habitat definition by adding a physical dimension to the biological components of the habitats as expressed by the plant communities.

Many vegetation maps used in wildlife research and management depict plant communities defined by plant ecologists and subsequently interpreted by wildlife biologists into animal habitat types. In contrast, this mapping effort emphasizes habitat components as seen from the animal's perspective. The significance of this approach is analogous to the differences between a range vegetation cover map and a map depicting range condition and productivity. A cover map provides general information useful for large area suitability classification. Range condition and productivity maps consider the abundance and health of key forage species and can be used to determine carrying capacities and for site specific management planning. The initial procedural requisite for wildlife habitat mapping, then, is to define key species and other habitat parameters of significance to the animals of interest.

Information Requirements

In the Three-Bar Area, years of wildlife investigations and observations have contributed a significant amount of information towards defining many of the habitat parameters important to javelina and black bear. Extensive radio-telemetry work has yielded data on areas preferred for feeding and resting, and on home ranges. In addition it aided in locating the animals for direct observations. Although radio-telemetry has not been used as much with mule deer, numerous studies both in the Three-Bar Area and in similar areas elsewhere in the state have contributed considerable information on habitat requirements. Based on these investigations, the research division has indicated specific information to be included on the habitat maps. This is summarized below for each animal being considered.

Javelina.--The vast majority of observations of javelina feeding activities occur in areas having moderate to dense stands of prickly pear cactus and/or staghorn cholla (Opunta spp.). Fecal analysis further indicates that these cacti are key food plants. The biologist conducting these studies believes that home range sizes and shapes, as well as potential population densities would correlate well with the distribution of these food sources. Field observations, however, reveal that these cacti are not always associated with particular plant communities. Rather, their distribution appears somewhat independent: often overlapping into parts of adjacent vegetation types or occurring as small inclusions where the microhabitat is apparently favorable. It is also known that some of these small 1- or 2-acre inclusions are important feeding grounds. Another important food source, and bedding ground area, is defined by dense stands of mesquite (Prosopis juliflora) and jojoba (Simmondsia chinensis). These species correlate better with general vegetation types although density varies considerably with local conditions. Poor javelina habitat is represented by creosotebush (Larrea tridentata) which is often found in relatively pure stands, and by chain-fruit cholla (Opuntia fulgida) an invader species. It becomes apparent, then, that optimal javelina habitat mapping must consider distributions of particular species, as well as general vegetation associations.

Black Bear.--Black bear inhabit the chaparral, woodland, forest and riparian vegetation types. In the Three-Bar Area, there are at least two subtypes of chaparral characterized by different dominant plants and elevational ranges. There are also some distinct transitional chaparral types. Many of the plants in these chaparral types provide food for bears. These include all of the oaks (Quercus spp.), and manzanita (Arctostaphylos spp.). These food sources can be correlated with basic plant communities. Superimposed over these natural climax types of chaparral, woodland and forest, however, is an intricate pattern of wildfire disclimax successions. Many of these burn areas result in significant changes in bear habitat. For example, a common disclimax in burned woodlands is dominated by manzanita, a preferred seasonal bear food. Riparian types and seeps are very important components of bear habitat. Although the broadleaf riparian areas are rather apparent and easy to delineate, this is not always the case with the numerous seeps. Many of the seeps only occupy a few hundred square feet, yet apparently provide sufficient reason for a bear to move from one canyon to another in the course of a day. One other feature identified as an important component of bear habitat are thickets of gambel's oak (Quercus gambellii). Even though some of these thickets only contain a few trees and occupy a very small area, bears have been observed to bed down in them for the day. Optimal mapping of black bear habitat, accordingly, should consider general plant associations, distributions of burned areas, point sources of water and related vegetation, and the distribution of at least one individual species, the gambel's oak.

Mule Deer.--In addition to providing information for some of the very specific deer studies conducted on the Three-Bar, habitat typing in this study area will have wide application throughout the desert regions of the state for better mule deer management. Several vegetation parameters are of particular interest. Studies of fawn mortality indicate a very high correlation between abundant green spring forage and fawn survival. It appears that forbs are more important than grasses or browse in this respect. Accordingly, there seems to be a need for delineating areas which produce an abundance of herbaceous growth. Another interest centers on the distribution of key species such as jojoba, prickly pear cactus, mesquite, shrub live oak (Quercus turbinella) and fairy duster (Calliandra eriophylla). Some of these species correspond to general vegetation types, while others are more ubiquitous. Finally, there is an interest in delineating such vegetation types as the chaparral which provides an abundance of food from many of these species, as well as escape and resting cover.

Uses of the Habitat Maps

It is important to know what specific information is required for particular studies in order to define the data which should be collected for inclusion on the map. It is also important to know how the map will be used in order to select the best format for presentation of the data. Decisions concerning scale, separate overlays or composite maps, and legend format are critical if optimal understanding and utility of the product are to be realized.

The primary purpose for this project is to provide a base map of habitat information on which to superimpose radio-telemetry locations and other field observations on feeding and bedding activities, den sites, etc. There already exists sufficient data to define home ranges, daily and seasonal movements, major activity areas and other spatial information. These habitat maps will serve to verify the activity patterns inferred from the field work (for example, are all prickly pear concentrations utilized by pigs? Are gambel's oak thickets favorite resting places for bears? Are areas with abundant herbaceous productivity conducive to fawn survival?).

Another use of the habitat maps will be to correlate the spatial distributions of habitat features (both biotic and abiotic) with the known distributions and den sites of the animals. Such habitat attributes as sizes and shapes of certain features, total acreages of particular types, distances between critical elements, and interspersion relationships are virtually impossible to determine without the perspective provided by a map.

Finally, habitat maps are the vehicle for transferring research results into management practices. Habitat features are easier to delineate in new areas than are wildlife population estimates. Since it is reasonable to assume that similar habitats have a similar potential for supporting wildlife, maps can facilitate the inital assessment of wildlife suitabilities in new areas.

METHODOLOGY

Now that the importance of planning a habitat map based on the requirements of the target species has been illustrated by the preceding examples, the practicality of this approach must be considered. Each of the animals previously discussed exhibits affinities for particular plant species as well as at least one general vegetation type. Further, it is well known that most mobile animals select important habitat elements from numerous natural communities. Finally, it is often easier to map general vegetation types than to map the distributions of individual plant species. It appears, therefore, that the most suitable approach is to combine both efforts. The basic delineations on the map will be natural vegetation types mapped at the association level (Daubenmire , 1968). Particular attention will be placed on the key species, however, both in gathering field data and when preparing the map. Many of the distributions of these species may be indicated on the maps as "point types" or inclusions within the more general mapping units. This approach is particularly useful when more than one wildlife species is being considered. By producing a general map of all available habitat elements which emphasizes those particular elements known to be important, one has the capability for extracting a complete habitat map for each animal from the single base map. Another advantage of the base map approach is that information will be available to explain some of the unexpected results of the animal distributions. If a map of javelina habitat showed only prickly pear cactus distribution, a cluster of telemetry locations outside a prickly pear area would necessitate a repetition of the entire effort; this time for a new habitat element.

The methodology used to produce these habitat maps includes the acquisition of appropriate color aerial photography, a multistage sampling design, incorporation of existing corollary information, and concurrent photointerpretation and ground data collection activities.

Imagery Assessment and Acquisition

There were three sources of existing aerial photography available for the study area. Several NASA high altitude reconnaissance flights (1:120,000) covered all or part of the area. Although these missions were not used for detailed mapping because the scale was considered too small for the detail required, plans have been made to evaluate their utility compared to the final map products. If adequate information can be extracted from these missions, it would greatly facilitate habitat assessment throughout the state because of availability of photo coverage. A preliminary analysis of color-infrared positive transparencies was promising, at least for the higher elevation plant communities, riparian vegetation, and seeps.

Another source of photography was a 1:31,680 scale natural color overflight flown for the USDA Tonto National Forest. In addition to poor color balance and resolution, a field evaluation of this photography proved that it was inadequate for the objectives of this project. Even some of the rather obvious riparian areas were not readily discernable on the photos.

The last source of available photography for the entire area was 1:20,000 black and white photography flown for the Forest Service in 1946. Although this photography might aid in documenting certain changes in the area, it was also judged inadequate for the primary project objectives.

Based on the preliminary field work and evaluation of existing photography, it was decided to subcontract for 1:24,000 contact scale color infrared photography. This was flown in August when warm season grasses and summer herbs were at peak development and prior to the leaf drop of deciduous trees and shrubs. This design would certainly provide a maximum of information for vegetation types and plant species exhibiting at least a moderate canopy, and it was hoped suitable information would also be available for interpretation of the desert vegetation types. A nine-inch film format aerial mapping camera was used to provide maximum resolution. The availability of the 1:31,680 natural color photography, although not of preferred quality, was also considered for desert vegetation mapping had the color-infrared proved inadequate. Treadwell and Mouat (1977) have found natural color photography to be more useful for mapping areas with sparse vegetative cover. The cost of the infrared overflight of approximately 300 square miles, with two sets of prints, was $2,100.

Proper color balance for infrared film is extremely important. The user should work closely with the film printer to insure this. Reviewing samples of different color balances for a single frame prior to printing the entire roll is essential.

Multi-Stage Sampling

Multi-stage sampling involves the use of progressively larger scale imagery to ascertain more detail about representative sites delineated on previously interpreted smaller scale imagery. Because of the detailed information required by this project (e.g., distribution of individual key species; distribution of herbaceous vegetation) a multistage sampling design was considered, and preliminary field work supported its utility. Higher elevation vegetation types (chaparral, woodland, forest) and riparian types were readily identifiable on the 1:24,000 scale color infrared photography. Desert types and species presented more of a problem.

Field work revealed that both plant types and species changed throughout the desert areas, reflecting differences in microhabitat. Differences in parent materials, elevation, and fire were interacting to provide similar (even if seemingly different) micohabitats within the physiological tolerance limits of the various plant species. It was found that by delineating broad "land resource systems" on small scale photography (1:120,000 high altitude imagery), a degree of uniformity of plant responses was observed on the ground within each delineation. The primary characteristic used for these separations was erosion patterns. This consituted the first stage of the multi-stage design.

The second stage entailed combined photointerpretation and ground data collection based on the 1:24,000 scale photography. The purpose at this stage was to delineate mappable units, define plant-terrain-image relationships and achieve a satisfactory level of predictability in the patterns observed.

The final stage of the multi-stage design will address the distributions of key species. This will be achieved by exposing 35 and/or 70mm film from low flying aircraft. Photo scales of 1:2,000 have provided sufficient resolution to discriminate different types of columnar cacti in another project conducted by the Applied Remote Sensing Program. The problem of locating these large scale sample areas will be mitigated by exposing a continuous strip along carefully planned flight lines selected to represent the various mapping units delineated on the 1:24,000 scale photos.

Corollary Information

Any relevant supplemental information can only improve the final product. For the Three-Bar Project several additional information sources were available.

Arizona Game & Fish Research Personnel

Much of the information concerning habitat requirements and diagnostic elements has been presented previously. The importance of continuous interaction with the intended product users, however, can not be overstated. In addition, the Three-Bar biologists supplied information on particular areas and often knew "what was on the other side of that hill." Even recommendations on road and trail access were extremely useful.

USGS Topographic Quadrangles

These maps (7½' series) provided slope angle information for inaccessible areas, elevations and information on road and trail networks.

Orthophotoquads (1:24,000)

These rectified aerial photographs are available for virtually all of Arizona. Although the image quality is not suitable for photointerpretation commensurate with the scale, orthophotoquads do facilitate the visual transfer of information from other aerial photography to a planimetrically accurate base map.

Soil Maps

A soil resource inventory of the Tonto National Forest has been conducted by the U. S. Forest Service. The maps are scaled at 1:20,000. Information includes profile descriptions, physical setting and capabilities and limitations for various uses.

Fire Maps

The Forest Service has also provided 1:20,000 scale maps depicting burn areas and dates. These maps will be invaluable for identifying fire disclimax vegetation types and hopefully for developing a succession chronology.

Other Aerial Photography

Even though the available aerial photography described previously was considered unsuitable for the objectives of this project, it will certainly provide some information. High-altitude photography provides an overall perspective; the color photography is useful primarily in the desert areas; the older black and white photos is useful in determining fire effects.

Photointerpretation and Ground Data Collection

Photointerpretation and ground data collection were essentially concurrent activities in this project. At the onset of the field work vegetation associations were defined and their corresponding photographic characteristics were ascertained. Data were also collected on the distributions of the key species. This was accomplished by several traverses of vegetational gradients. All accessible vegetation types were included.

Each time the vegetation structure changed, or a key species was encountered, the area was marked on the photograph and notations recorded. Data included plant species ranked according to abundance in each stratum and physiographic information such as slope angle and aspect, landform and parent material. Ground level photographs were taken at each of these locations. Special attention was given to determing if a reliable indicator species occurred in the type.

Photointerpretation entailed the careful stereoscopic analysis of each data location to determine if the type could be defined by inherent photographic characteristics. Color was particularly important. The brightness and shades of red on the infrared prints were often diagnostic for different species. Tonal variations in the blue corresponded to changes in the substrate. Tree shadows were another useful characteristic. The texture of an area was used to distinguish between grassland and shrubland, and sometimes to suggest different densities of shrubs. The relative position of vegetation types related to physiographic features determined from stereoscopic viewing was also a diagnostic criteria. These characteristics were defined for each category of the classification. Some examples are presented in the Results section of this paper. The major emphasis of the photointerpretation process was to achieve a degree of predictability for designating a plant community in an unknown area, and then verifying the identification with subsequent field work. This predictability is one key to successful application of remote sensing techniques to wildland vegetation mapping.

Corollary information was also incorporated during this phase of analysis. Once the general types were initially defined, and subject-image relationships established, substrate data and topographic information could be examined for additional refinement. The increased photographic resolution from the 35 mm sampling camera was also utilized in this refinement phase.

The final phase of this process is verification of the delineations in the field. Assuming ground data collection sites are accurately mapped and identified, verification entails spot-checks of areas where mapping was based primarily on photointerpretation. Game and Fish Department personnel are assisting in this final phase.

RESULTS

Classification System Criteria and Format

As previously indicated, the primary emphasis of the habitat maps is on plant associations, with particular attention directed towards key species and significant abiotic components. The classification is hierarchical. The flexability of a hierarchical format readily accomodates within the same classification framework both the generalized information derived from aerial photo interpretation, and the increased detail afforded by on-site observations.

The more general levels of the classification are based on the physiognomy (growth form) of the communities. Major categories include forest, woodland, chaparral, desert scrub and grassland types. More detailed levels are defined by floristics. The dominant species in each strata (canopy, understory and ground cover) are indicated. Key species (important to animals), indicator species (exhibiting a high fidelity for the type) or other diagnostic plants serve as criteria for the most detailed levels. The classification categories are derived from intensive field observations of the plant communities in the study area.

Because vegetation types are the primary emphasis of the habitat maps, abiotic parameters are not directly addressed in the hierarchical classification. A general assumption was made that most vegetative communities represent an integrated expression of the abiotic factors operating at that site. Indeed, such factors are often used to define the plant types and are included in a written description of each classification category. When locally significant abiotic components are encountered (limestone outcrops, salt deposits, recent burns, etc.), they are referenced as mapping unit modifiers in the denominator of a fractional composite map symbol (see Figure 1). Unlike most composite mapping efforts which compromise on boundaries, the vegetation types are always used as the primary determinant for a mapping unit. The abiotic components provide additional information for a particular area.

There are other localized characteristics of vegetation which are often significant to wildlife habitat. Some of these include plant density or coverage, utilization and disturbance. Although systematic inclusion of these characteristics was beyond the scope of this study, data was noted for areas visited in the field and additional data will be collected in the future by Game and Fish Department personnel. Accordingly, provisions were made in the fractional map symbol to accomodate these characteristics as vegetation type modifiers whereever the information was available.

The habitat map classification system has four parts: 1) the map symbol, 2) a technical description, 3) a narrative legend, and 4) an interpretive legend.

The Map Symbol

The map symbol is an alphanumeric designator used to label each mapping unit, and to reference the written descriptions contained in the other three parts of the classification. Strongly contrasting or particularly significant localized vegetation features (inclusions in other mapping units) are called "point types" and are indicated with a dot preceeding the map symbol. Examples include small seeps or gambel's oak thickets occupying only a few hundred square feet. The format of the map symbol is presented in Figure 1.

A vegetation complex is defined as two or more distinct types which can not be separated due to areal limitations imposed by the mapping scale. These complexes are delineated as a single mapping unit, but labelled with the map symbols for each vegetation type included.

vegetation type (acreage)

substrate % slope / cover-util.-disturb.

Figure 1.--Map symbol format.

The Technical Description

The technical description references the dominant plant species for each strata. Botanical acronyms are used to abbreviate the scientific names.

The Narrative Legend

The narrative legend states the definitive features of the classification type. The entire scientific name of the dominant plants abbreviated in the technical description are provided. Any true indicator plants are indicated. Other associated species are listed by strata, and significant local variations are mentioned. The physical setting is also described, including elevational ranges and aspect relationships; predominant slope angles, soil types and parent materials, and any other diagnostic abiotic features. A representative ground level photograph is included as well as a reference to the location of field verification site(s). Information presented in the narrative legend is restricted to "facts". Subjective information is included in the Interpretive Legend.

The Interpretive Legend

The interpretive legend contains the following information: Key forage and cover plants are listed for each animal considered. Geographic affinities and climatic relationships are inferred. Potential vegetation and known successional stages are identified. Suitability evaluations and management recommendations are also included.

There was an effort in this project to separate objective from subjective information. Vegetation was mapped "as it appeared", and corollary data was included where available. Classification decisions based on current conditions are more consistent and repeatable than are those based on personal interpretations, yet the opportunity for independent interpretations concerning site potential still exists. Further, wildlife in the area are interacting with the current conditions rather than with some pristine environment.

Examples of Classification Categories and CIR Photographic Characteristics

Chaparral plant communities are used to exemplify the information presented in the narrative legend. Photographic characteristics of the color infrared prints are described for general forest, woodland, chaparral, grassland and desert scrub vegetation types.

Preliminary Classification of the Chaparral

There are three major chaparral types in the study area, and each has several sub-types. In addition, there is a definite transitional type between the chaparral and desert scrub. This type is not a complex, rather, it is a distinct and predictable type having both chaparral and desert scrub species as co-dominants. Because of its definitive characteristics and sizable area occupied, this transition type is considered as a separate plant association in the classification.

High Chaparral.--Co-dominants are typically Arctostapylos pungens and Quercus turbinella. These and other associated shrubs comprise the combined canopy and understory strata. Cover often exceeds 60%. Ground cover species, when present, are usually perennial grasses. Arizona white oak (Quercus arizonica) is an indicator species. Associated species include Ceanothus greggii, Garrya wrightii, and Yucca spp.

The high chaparral occurs above 5000 feet and is only influenced by aspect at the lower end of its range. Substrate is either exposed granitic bedrock, steep colluvial slopes, or very gravelly loam, sandy loam or clay loam, non-calcareous soils.

Virtually the entire type exhibits some stage of fire disclimax. Tree size white oaks were apparently prevalent in the climax type.

There are at least two sub-types. Locally, almost pure stands of A. pungens occur. A woodland variation of the chaparral type having a moderate component of pinyon and juniper trees is another sub-type.

Mid-Chaparral.--The mid-chaparral is an ecotonal type. Although the dominant plants are variable, the type is defined by having co-dominants from both the high and low chaparral types. These species can include Arctostaphylos spp., G. wrightii, Q. arizonica and turbinella, C. greggii and Cercocarpus breviflorus. Other species from the low chaparral are also associated.

Low Chaparral.--Co-dominants are Q. turbinella and C. breviflorus. Rhus ovata is an indicator plant. Sub-types are related to slope aspect. Other associated species include Celtis pallida, Berberis fremontii and C. greggii on the mesic slopes and Acacia greggii on the xeric slopes. A distinct understory is usually present and includes one or more of the following half shrubs: Calliandra eriophylla, Haplopappus laricifolius, Gutierrezia sarothrae and Eriogonum wrightii. Ground cover is predominantly annuals, including Euphorbia spp. and Bromus rubens.

The low chaparral is generally below 4200 feet on soils of granitic origin. Slopes are usually less steep than those associated with the high chaparral. Old burns are still evident.

Photographic Characteristics on CIR Prints

Forest Communities

Ponderosa pine forests appear strongly textured with a dark red and black mottled color (trees and their shadows) and a minimum of blue colors showing (substrate). The tall, rounded top trees and their distinct shadows are apparent under stereo viewing.

Woodland Communities

Thickets of Gambel's oak appear as finely textured, almost smooth, small, bright red areas. Cover is virtually solid (little blue showing) and shadows are not evident. The color and pattern contrast strongly with the adjacent forest and chaparral types.

Chaparral Communities

In general, chaparral types appear as medium textured, densely stippled patterns of distinct red dots on a smooth blue background. Elevations provide one clue to separating the sub-types, but careful scrutiny under high magnification allows the identification of certain diagnostic species. High chaparral types can be distinguished by the tall, scattered conifer and white oak trees with their distinct shadows. Low and mid chaparral types are characterized by varying amounts and aspect locations of Rhus ovata, which appears as a bright red dot with a rounded black shadow. Q. turbinella is more clumped at the lower elevations, appears flat-topped, and has no shadow.

Grassland Communities

Both high elevation and desert grasslands appear as smooth textured, bluish areas with scattered light red or dark blue dots representing shrubs. Elevations and adjacent plant communities can be used to infer some of the herbaceous species.

Desert Scrub Communities

Typically, desert scrub communities are difficult to separate on aerial photography due to their sparse vegetative cover. Mapping is usually accomplished by establishing terrain feature-plant relationships. The large scale 35mm aerial photography is used in this project to provide some additional spatial resolution for selected areas. On 1:24,000 color infrared prints, desert scrub communities are characterized by their moderate texture and bluish tones (open canopy and exposed substrate). Trees and large shrubs appear as dark blue, bluish-red or marroon dots which tend to blend into a rather indistinct shadow.

LITERATURE CITED

Daubenmire, Rexford. 1968. Plant communities: a textbook of plant synecology. Harper and Row Publishers. New York.

Treadwell, B. Dean and David A. Mouat. 1977. Applications of high and medium altitude color aerial photography for vegetation mapping in Arizona. Proc. 6th Biennial Workshop on Aerial Color Photography in the Plant Sciences. Colorado State Univ., Fort Collins.

A Computerized Wildlife Habitat Information System[1]

James F. Williamson, Jr.[2]

James B. Whelan[3]

Roy A. Mead[4]

Abstract.--A computerized system for determining the qualitative status of wildlife habitat on a single or multi-species basis is presented. System input includes remotely sensed land classification data from which isoplethic maps are produced by computer line printer. Current or predicted wildlife potential may be estimated by using time event simulation to predict future vegetative characteristics.

INTRODUCTION

Effective wildlife management demands abundant and reliable information. However, much of wildlife management is still an art, and frequently managers are forced to make decisions based on intuition as well as on experience and training. A primary reason for this type of decision making is not necessarily a lack of information; often volumes of assorted information may exist. Rather, it is the lack of a source of readily available and usable information that results in sub-optimal decisions.

In an attempt to integrate various existing, but diverse, information sources into a meaningful data base for wildlife managers, a computerized wildlife habitat information system is being developed within the Department of Fisheries and Wildlife Sciences at Virginia Polytechnic Institute and State University. The system will be capable of evaluating wildlife habitat and displaying qualitative differences for selected species in the form of computer generated isoplethic maps. With the system, information on the status of wildlife habitat may be presented for the current situation, or at some time in the future. This is accomplished by utilizing two interrelated sub-systems, a habitat evaluation system and a vegetative characteristic prediction system.

The study area chosen for the project was the lower one-third of Shenandoah National Park, Virginia (hereafter referred to as SNP).

We would like to acknowledge the National Park Service and the personnel of SNP for their cooperation. Our appreciation is extended to the National Wildlife Federation and the U.S. Forest Service for their financial support. The School of Forestry and Wildlife Resources at Virginia Polytechnic Institute and State University provided computer facilities and funds for data analysis.

HABITAT EVALUATION SYSTEM

Habitat evaluation is the process of assigning a qualitative rating to a given area, based on how well that area meets the requirements of the wildlife species under consideration. While various types of models exist for evaluation, a linear additive model was used.

The major habitat factors (e.g. food availability, cover, nesting sites, etc.) for a given species are defined and are ranked in relative importance on a scale from 1 (least important) to a 10 (most important). Levels, or intensities, of individual habitat factors are then stratified into a maximum of 10 categories and assigned values ranging from

[1]Paper presented at the PECORA IV Symposium: Applications of Remote Sensing to Wildlife Management, Sioux Falls, South Dakota, Oct. 10-12, 1978.

[2]Graduate Research Assistant, Department of Fisheries and Wildlife Sciences, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

[3]Assistant Unit Leader, Virginia Cooperative Research Unit, Department of Fisheries and Wildlife Sciences, Virginia Polytechnic and State University, Blacksburg, Virginia.

[4]Assistant Professor, Department of Forestry and Forest Products, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

1 (least intense) to 10 (most intense). For example, in the case of evaluating squirrel habitat, food availability would be an important habitat factor, while mast production would be a measure of that factor's intensity. Importance values are derived from available literature and expert opinion.

Levels of each habitat factor are assigned in a linear fashion, as are relative importance values. This permits the derivation of a qualitative habitat rating for any specific site, which can be expressed in the form of an equation:

$$V = \sum_{i=1}^{n} b_i X_i,$$

where V = habitat value,

b_i = relative importance of the i^{th} habitat factor,

X_i = relative intensity of the i^{th} habitat factor,

$i = 1, 2, 3, \ldots\ldots, n.$

Separate "overlay" maps are encoded into a computer mapping program, CMSII (Federation of Rocky Mountain States 1977), for each habitat factor selected. The coded computer maps consist of a cellular matrix with appropriate values assigned to each element, or cell. Each map covers the area represented by a USGS 7½" quadrangle and are standardized to the appropriate quadrangle map. Maps may be digitized, or coded manually using a grid overlay of rectangular cells, each 1/120th of map width and 1/120th of the length of the map. Software is used to convert digitized input into the required cellular format for the mapping and evaluation programs.

The CMSII mapping system was selected as the core program for the habitat evaluation system because of the capability of that system to use the above algorithm iteratively to generate composite matrices in the form of maps. Using the CMSII system, matrix cell values can be categorized and displayed as one of 10 distinct grey-tone symbols. Final output is in the form of a line printer generated map, a maximum of 120 characters wide and 120 characters long.

Input data sources are varied. However, emphasis is placed on using available information rather than on acquiring new baseline data. Data sources include USGS topographic maps, classification maps of SNP derived from topographic base maps, and vegetation maps compiled from LANDSAT imagery and/or aerial photography. Specifics regarding aerial photography are left to the discretion of the user. However, it should be noted that the more accurate vegetation type maps, based on superior aerial photography, will likely result in a more valid habitat evaluation.

While the basic procedure described above could be used to evaluate habitat potential for a variety of wildlife species, a prototype was developed for evaluating black bear (*Ursus americanus*) habitat on the study area. Habitat potential for other wildlife species may be evaluated at a later date, depending upon needs for wildlife information within SNP. Factors encoded for bear habitat evaluation include hunting pressure, panhandling potential, remoteness from human disturbance, and a forest type preference index (Beeman 1975:94). Data for these factors were gathered either directly from USGS quad sheets, or from vegetation maps prepared from aerial photography.

VEGETATIVE PREDICTION SYSTEM

In an effort to alleviate the problem of the inherently time specific nature of the habitat evaluation/information system, a time event simulation is being developed to predict vegetational characteristics at times in the future. Output from this program can be used for estimating habitat potential at future times.

A predictive algorithm was developed, based on the assumption that forest stands maintain integrity and permanence. (A stand is defined here as an area relatively homogeneous in vegetational and/or ecological characteristics.) Stands were assumed to respond uniformly as a unit; that is, a common fate befalls all cells occurring within a stand. A portion of a stand cannot be considered independently (unless that portion is re-defined as a separate stand).

The algorithm used in the predictive process is simplistic. Initially, an inclusive set of all vegetational stages occurring in SNP was compiled. Next, the probability of migrating from any one stage to any other stage within any given year was derived from the literature and SNP records. A Markov transition matrix (Shamblin and Stevens 1974:55) was then constructed from these probabilities. In the transition matrix, the top row header represents the destination condition while the original condition is represented by the left row header. The path of migration (i.e. succession) is downward and to the right.

In the predictive system, each stand which represents a specific stage, is considered individually. A Monte Carlo type simulation is used to predict the fate of each stand. Tag numbers for the simulation are the elements of the appropriate row from the transition matrix. By iterating the simulation for a pre-determined number of years, the fate of each stand can be approximated. The final output of the prediction is a vegetation map of the area showing vegetational characteristics at specific times in the future. Major habitat factors (e.g. food and cover) are directly related to vegetation cover. Therefore, these new habitat factor maps can be produced and used to predict future habitat conditions for many wildlife species.

APPLICATIONS

The system described has promise of wide utility and can be used in evaluating habitat for a variety of wildlife species. It is capable of evaluating and displaying qualtitative differences in habitat potential for virtually any wildlife species with definable and mappable diagnostic habitat requirements. The system may be used on a multi-species basis by inputting the final composite evaluation maps for a number of wildlife species into the evaluation system. The system can then be used to delineate those areas most valuable to the set of selected species.

The system has the potential for non-wildlife and wildlife related applications. For example, those areas of SNP most desirable to hikers could be delineated for Park managers once the diagnostic parameters have been identified. Likewise, areas where hikers are most likely to encounter bears, or other selected wildlife species, could also be identified.

LITERATURE CITED

Beeman, L. E. 1975. Population characteristics, movements, and activities of the black bear (Ursus americanus) in the Great Smoky Mountains National Park. Ph.D. Dissertation. The University of Tennessee, 218pp.

Federation of Rocky Mountain States. 1977. Composite Mapping System II users's guide. Federation of Rocky Mountain States, Inc., Denver, Colo. 209pp.

Shamblin, J. E. and G. T. Stevens. 1974. Operations research: a fundamental approach. McGraw-Hill Book Company, New York. 404pp.

Technology and Decision Making

Robert L. Herbst

Our planet is in trouble. The task facing managers of its natural resources is becoming increasingly complex and increasingly difficult. The resources we have left to manage are dwindling, yet the competing demands for them are growing.

Reconciling the biological and esthetic values of wildlife with the need for economic development and the pressure on habitat from an expanding human population becomes daily more challenging, and daily more critical.

Some of the major resource management issues facing this country in the next few years are the preservation of wetlands, protection of the barrier islands, attention to all of our rivers--not just those in the Wild and Scenic Rivers System--and perpetuation of non-game wildlife species.

All of these tasks call for major management decisions--decisions that must be based on the soundest data available, including the vital information that is coming back to us from remote sensing sources.

Before we talk about remote sensing data and what managers can and should expect from it, let me explain a little about decision-making--that difficult and sometimes exotic process that combines science and politics in an effort to best serve the public interest.

The best example in recent times of how this process works--of how the competing economic, social, environmental and political factors are intermeshed and balanced--is the monumental effort that went into planning for the management of the Alaska d-2 lands.

The Alaska package that even now is being debated in the final hours of this session of Congress is one of the broadest-scale, largest and most complex resource management packages ever put together. It has been more than six years in the making, and on its enactment hang the hopes of America to redeem its lost frontier.

The U.S. Fish and Wildlife Service, the National Park Service, and what was then the Bureau of Outdoor Recreation put together the first Alaska planning teams in Washington in 1971, shortly after passage by the Congress of the Alaska Native Claims Settlement Act. This was the Act that provided that the so-called d-2 lands (named for their section of the Act) could be used as national parks, wildlife refuges, rivers, trails, and forests.

The three Services deployed field teams to Anchorage in the spring of 1972. What followed was five years of the most intense data gathering and evaluation ever devoted to such a large chunk of real estate in advance of any development. This outpouring of expert effort built on a base of more than 70 years of biological data collected in Alaska by the U.S. Fish and Wildlife Service, and almost 50 years of similar work in Alaska by the National Park Service.

Some of the new data were gathered through research contracts with the University of Alaska and other institutions of higher learning. Some were collected on the ground by the personnel of the three Services. Teams including experts from many disciplines and from all three bureaus, for example, engaged in joint research on almost 50 rivers.

Some data--on nesting densities, for example--came through visual reconnaissance from light aircraft. And some--like the physiographic mapping of the State and data on overall vegetative patterns--came from satellite imagery and aerial photography.

It was to the aerial photographers that scientists turned in their attempts to estimate the size of the Porcupine caribou herd. A combination of aerial reconnaissance and sampling produced studies of the Yukon Delta analyzing the habitat of Canada geese and other marine birds.

The Evergreen College study of the Alaska peninsula used satellite imagery and lower level aerial photography and produced a vegetative map that was extremely valuable in determining mammal and migratory bird distributions.

And what happened to all this information?

Last summer the National Park Service, the Fish and Wildlife Service, and the now reconstituted Heritage Conservation and Recreation Service, made comprensive recommendations to A/S Herbst on the Alaska d-2 package, including proposals for parks, refuges, forests, wilderness areas, trails and wild and scenic rivers.

There were, predictably, some cases of competing recommendations for certain units of land.

After extensive consultations with his staff and deputies, A/S Herbst made an initial decision on the d-2 package that consisted of 93 million acres and 33 wild and scenic rivers. This proposal was presented to Secretary Andrus and subsequently to the other Assistant Secretaries for their evaluation and comments.

At that point, there were conflicting conclusions--questions of mineral development versus parks, of mineral exploration versus mineral extraction, of the advisability of taking easements on some state or native lands.

Secretary Andrus, after thorough consultation with all of his Assistant Secretaries, made his decision to adopt and submit to the Office of Management and Budget substantially the package Herbst had recommended to him.

In turn, the Office of Management and Budget submitted Interior's d-2 proposal to all the other Departments of the Federal Government. Departments like Defense, Transportation, Energy--all had substantial interests. Again there were conflicting recommendations. At one point in the decision-making process Herbst was required to stand up and defend Interior's proposal against the varying reactions from other Departments.

After OMB had evaluated Interior's recommendations, it presented alternatives to the President for his consideration. The d-2 bill finally sent to the Congress was based on a personal decision made by the President.

In the process of developing these recommendations, Herbst went to Alaska himself. Secretary Andrus went. So did Assistant Secretaries Guy Martin and Joan Davenport.

The House of Representatives held extensive public hearings in Alaska and heard testimony from the Governor, from the State Legislature, from the Native Corporations, from businessmen and from environmentalists.

The positions were largely predictable. Business interests favored almost unbridled developments; environmentalists favored extensive protection; the State wanted to take off in its own growth directions, and the Natives on the whole saw themselves as partners with the Federal Government in managing the resources on which they depend for their subsistence.

Taking all these factors into account, the House voted overwhelmingly for a d-2 package that incorporated most of what Interior and the Administration had recommended.

At that point, one would suppose that only the happy ending need be added. But life is no fairy story, and in the Senate the special interests finally had their way. The d-2 withdrawal authorization at this moment seems fated to die when the current session closes on October 14.

Of course it isn't completely dead. There are ways to hook the body up to respirators and keep it breathing until we assemble another legislative gathering, and this we intend to do. One alternative is to wait until next year, relying on the protection of the d-1 section of the Alaska Native Claims Settlement Act, and try again for a comprehensive package that will give us a chance, as managers, to conserve Alaska's superb heritage. However, some of the experts in this sort of thing don't believe the d-1 authorization will be adequate to stave off the pressures that are after the lands we seek to protect.

Another alternative is to withdraw substantial areas for emergency wilderness protection or for wilderness study under the authority vested in the Secretary of the Interior by the Federal Land Protection and Management Act.

A third alternative is for the President to declare many of the lands in our package to be National Monuments. Those that were proposed as parks in our d-2 proposal would then be managed by the National Park Service; those proposed as refuges would be managed by the Fish and Wildlife Service.

If the President and the Secretary take any of these actions--or if the Congress passes a d-2 package--the Services must be prepared to start protecting and managing these resources as soon as possible.

To this end, all three Services have had implementation teams analyzing the amounts of money and manpower it will take to manage the Alaska lands effectively. Already, they have made recommendations on such details as pre-fabricated housing, support vehicles, and schooling for dependents of Interior employees who would be sent to Alaska.

What all of this suggests, I think, is that the process by which natural resource management decisions are made and implemented is extraordinarily complex and sometimes equally cumbersome, but it must be so if it is to provide the kind of interest-balancing and public participation that our society quite properly demands.

The process can be more or less lengthy and more or less complicated depending on the scope of the decision. But in few cases will the processes tend toward less complexity, because the worldwide resource crunch has no place to go but upwards. And in any event, the quality of the decisions are going to continue to be dependent on the quality of the information we base them on.

That information must be timely and it must be accurate. In addition, it must be delivered within a time frame that matches the decision-making schedules. And finally, all this must be accomplished against a fiscal background where real budgets are declining, and when possible increases in personnel are questionable.

Remote sening technology offers an attractive alternative to traditional, labor-intensive data gathering and information analysis; however, there are certain problems that remain to be resolved.

For example, there is the problem of timeliness of data products. LANDSAT continues to be a NASA program and therefore it is still classified as experimental. Because it is an experimental system, NASA never has felt it necessary to provide LANDSAT data products in a real-time or even a quasi-real-time environment. In contrast, data from operational meteorological satellites are available in many cases to the user community within 15 minutes of satellite acquisition.

It seems an anachronism that the data from a space age system such as LANDSAT is taken in micro-seconds by a receiving station, put on computer tape, and then sent--BY U.S. MAIL--to processing and distribution centers.

If you have wondered about the delay in delivery of LANDSAT data, it presently falls into the same pattern as the one that brings you your Christmas cards just in time for Easter. However, after the first of the year this situation will vastly improve. Space-age technology will be brought fully to bear on the LANDSAT System. Antennae to link LANDSAT receiving stations to the EROS Data Center using the Domestic Communications Satellite will be installed. With this improvement data cannot only be received from LANDSAT in micro-seconds, but relayed from the receiving stations to the processing center in comparable time.

Another problem is data continuity. The nature of LANDSAT as an experimental system has not provided the user community with confidence that a standard, recognizable product will continue to be available. It is understandable that users have not been willing to commit themselves to data which, although of potentially high benefit, are very expensive and whose continued availability is in constant question. The risk is perceived as too high.

What we have here is a classic case of the chicken and the egg. On one hand, users are unwilling to commit personnel and resources to an experimental data source; on the other hand, it is difficult to make an Earth Resources Information System truly operational before the uses and the users have been documented and the calculated benefits show a substantial positive value.

Experience seems to indicate that a commitment to provide the data on a continuing basis must come first--before use and investment can be expected to follow.

In fact, Dr. John Townsend, former Associate Administrator of the National Oceanographic and Atmospheric Administration, recently noted that "NOAA would not have an operational meteorological satellite program today if we had been forced to undergo the same cost/benefit analysis as the LANDSAT program before obtaining operational status."

Similarly, standard products from airdraft imagery programs are not available. Only recently has a concerted effort been made to organize an effective continuing High Altitude Photography program designed to provide users with a product of known format and a defined period of availability.

Once data continuity is assured, long-range plans for continued monitoring and for the up-dating of data can reasonably be devised.

The National Park Service and the Fish and Wildlife Service, for instance, support the High Altitude Photography concept, even though the benefits to be derived are not yet fully documented. The Park Service uses remote sensing of various types for various jobs. In the Everglades--a park that covers 1.4 million acres of southernmost Florida--satellite platforms broadcast information on water levels and air temperature to LANDSAT I and II. Satellite imagery, coupled with field studies, enable park scientists to construct a moving picture of the water as it flows overland from Lake Okeechobee through the conservation districts of Florida and its canals, and into the park.

Vital questions in the management of the Everglades are concerned with how the water enters the park, how it spreads out, and how it dries down. The Big Cypress Swamp north and west of the park is a vital link in the water chain. The Cross-Glades highway known as the Tamiami Trail interrupts the historic sheet flow. Remote sensing is a proper tool for studying these vital but far-flung linkages.

Archeology is another proper sphere. The Cultural Resources Management Bulletin of the Park Service recently carried an article by Dr. Thomas Lyons of the Service's Remote Sensing Division in Albuquerque. He announced that a systematic study, now in its ninth year of progressively more sophisticated remote-sensing applications and techniques, has resulted in a methodology he calls "non-destructive archeology."

The non-destructive approach, Dr. Lyons writes, "emphasizes the acquisition and sophisticated analysis of a variety of remotely sensed imagery and data as the primary tools of exploration, discovery and recording."

He likens the advances in remote sensing to developments in optical physics, and calls their potential for discovery and analysis "as great now as the new eyes on the universe provided by the optics of the telescope and the microscope."

Those of us who are managers and decision-makers too, must be aware of the role of remote sensing in information systems. Greater attention must be paid to the questions being asked by resource managers and to the appropriate format for information responding to those questions.

The tendency has been to develop remote sensing systems in the most technologically rewarding direction, with little attention to the role that resulting data will play in the decision process.

Similarly, the technology often has been compromised, to satisfy the largest possible community of users. The result has been that none of the users is entirely satisfied. To put it another way, the new systems have been designed with the broadest possible application in order to appear cost-effective at the outset. The final result however, often is that inappropriate or marginally appropriate information is forced into the decision process.

If it is not possible to satisfy everyone, perhaps we must learn to accept the high cost of satisfying a smaller community of high-priority users. We also must be more realistic about our decisions on data sources. Everyone has a tendency to look to a spectacular new technology as a panacea for the problems of the decision-makers.

I think we must realize that there are no such panaceas, and that remote sensing should not have to shoulder such expectations as an additional burden.

We must develop a sharper sense of when remote sensing is our best choice for data gathering and when it is not. The use of satellite data by the Fish and Wildlife Service to analyze ice conditions in Arctic goose nesting grounds, for example, strikes me as a legitimate use of remote sensing technology--one in which the data cannot be gathered at acceptable cost by any other means.

On the other hand, there still are many situations in which a handful of wet, cold, miserable biologists in hip boots are still the best--the most appropriate--means for gathering data.

It would seem that the techniques are proven; it remains to construct the optimum utilization patterns and delivery systems. Resource managers and decision-makers must learn how best to use this new tool and their decisions must be predicated in part on the economic factor as well as on such considerations as response time and information format.

These are challenges that we must face together--as remote sensing experts, as field managers of wildlife and wildlife habitat, and as policy-makers.

I am convinced that if we work at it, remote sensing technology can become an increasingly valuable part of the resource management picture, a part that can allow us to conserve more efficiently and perfectly our nation's heritage of wild lands and wild life.

Remarks of the Honorable Robert L. Herbst, Assistant Secretary of the Interior for Fish and Wildlife and Parks at the Pecora IV Seminar on the Application of Remote Sensing Data to Wildlife Management at Sioux Falls, South Dakota, October 12, 1978.

A Perspective on Remote Sensing for Wildlife Management: The Pecora IV Symposium[1]

D. M. Carneggie[2]

A. Marmelstein[3]

INTRODUCTION

The Pecora IV Symposium (Applications of Remote Sensing Data to Wildlife Management) conducted October 10-12, 1978, in Sioux Falls, S.D., provided a perspective on the uses of remote sensing techniques for wildlife management. The task of summarizing the Symposium, which is the objective of this paper, is not simple because of the diversity of opinions presented regarding (a) the magnitude of the wildlife management problems, and (b) the uses of remotely sensed data to address these problems. Factors which contributed to the diversity of opinions presented include: varying degrees of experience with wildlife management problems, differences in experience with remote sensing applications, and level of responsibility within the management decision-making process.

Approximately one quarter of the Symposium participants were remote sensing technologists; that is, persons engaged in developing remote sensing techniques to address wildlife management problems. Another quarter of the participants were resource managers currently using remote sensing tools to make their wildlife management job more efficient. The remaining one-half of the participants were resource managers who were aware of remote sensing, but who had little or no experience from which to assess its utility. It was to the latter two groups that the Review of Remote Sensing Terminology, Systems, Data, and Applications presented on the first day of the Symposium, was addressed. This half-day review provided the opportunity to refresh and elevate participants' knowledge of remote sensing in order to prepare them to better understand and evaluate the techniques and applications being addressed by the remote sensing technologists.

The Symposium also provided a setting for the technologists and the resource managers to talk informally to one another. As a result, the remote sensing technologists learned that remote sensing tools have value only when directed toward gathering needed information as defined by the wildlife resource managers. At the same time, the resource managers were exposed to innumerable new applications of remote sensing techniques, both operational and experimental, a distinction often overlooked by those not experienced with remote sensing but which is important in providing perspective to the current and future role of remote sensing for wildlife management.

WILDLIFE MANAGEMENT PERSPECTIVE

Many different perspectives of the wildlife management problem were presented. Dr. Robert Cook, Assistant Director, U.S. Fish and Wildlife Service, implied that "our planet is in trouble" because "the resources (wildlife) left to manage are dwindling . . . while demand for them is growing (see paper in these proceedings)." Dr. Les Pengally, Professor of Wildlife Management, University of Montana, presented a historic perspective of the dwindling wildlife resources on the North American continent resulting from man's continuous efforts to expand, settle, and develop wildland areas. South Dakota's Governor, Harvey Wollman, attributed the dwindling pheasant population in South Dakota to expanded agricultural cropping. Many of the wildlife specialists presenting papers addressed the problems of wildlife whose habitat was threatened by a variety of interrelated development projects such as reservoirs, pipelines, mining, or new roads.

The general outlook for wildlife management initially was pessimistic. Too frequently, issues involving a trade-off between the

---

[1]Paper presented at Pecora IV Symposium, Application of Remote Sensing Data to Wildlife Management, Sioux Falls, South Dakota, October 10-12, 1978.

[2]Applications Scientist, USGS - EROS Data Center, Sioux Falls, South Dakota.

[3]Remote Sensing Coordinator, U.S. Fish & Wildlife Service, Office of Biological Services, Washington, D.C.

environment and development are decided in favor of development and at the expense of wildlife and their habitat.

However, an optimistic note about improving animal populations and habitat through wildlife management was sounded by Dr. Russell Peterson, Director of the Office of Technology Assessment, U.S. Congress, Dr. Noel Hinners, Associate Administrator for NASA's Office of Space Science, and a few wildlife specialists. The examples cited, however, were generally restricted to small areas and did little to assuage the feeling that when man and wildlife are in conflict . . . the wildlife lose!

Thus, the general tenor of the Symposium with respect to the wildlife management problem was one of acknowledging (a) the importance of wildlife in our lives; (b) that our wildlife resources have dwindled substantially in direct proportion to the rate of cultural development; (c) that management efforts are best directed towards sustaining existing wildlife populations and that, without strong legislation, existing management efforts cannot hope to attain this modest goal; and (d) the need and the legislative requirement to document the size and extent of animal populations and their associated habitats that are threatened by man's development. The acknowledgement of this need for such resource inventories provided the incentive and the setting for examining remote sensing technology as one of the tools for collecting information about the wildlife resource. However, the kind, amount, and level of detail of information required was viewed differently by the participants depending upon their level of management responsibility and the habitat and species they were investigating.

REMOTE SENSING PERSPECTIVE

Applications

By design, the Symposium addressed wildlife management problems from the perspective of remote sensing. As such, it did not emphasize conventional ground techniques currently used for gathering resource data, although they are important to verify the validity of remote sensing analysis and to provide supplementary information not attainable through analysis of remotely sensed data.

The Symposium emphasized three primary application areas: (a) habitat analysis; (b) animal census; and (c) integrated analysis of wildlife in relation to other resources or resource uses. A total of 57 papers (9 invited and 48 poster session papers), were presented in the technical program of the Symposium. Approximately 80 percent of these studies utilized remotely sensed data for wildlife habitat information, and the remaining 20 percent utilized remotely sensed data for animal census and tracking (see table 1). Of those papers which analyzed habitat, 58 percent addressed habitat mapping, 12 percent addressed analysis of habitat in relation to some other resource or use, 14 percent addressed quantification of a parameter of the habitat, and 4 percent addressed the use of information systems for describing habitat.

Although one must be cautious about extrapolating these figures to the wildlife management community in general, it is apparent that mapping components of the habitat, for example, vegetation, moisture, drainage, water bodies, is the most common use of remote sensing data. Two applications also of considerable interest include the use of remotely sensed data for monitoring changes in habitat and for quantifying habitat parameters used to assess suitability of the habitat for the specific wildlife species. As wildlife resource managers become more familiar with remote sensing tools, there will be greater usage of the tools for these last two applications. For example, Dr. Glen Adams, Canadian Wildlife Service, reports (these Proceedings) that 30 percent of the applications of remotely sensed data for habitat analysis in Canada involve monitoring changes in the habitat.

Although a smaller proportion of the Symposium papers dealt with animal census and tracking, it was apparent, nevertheless, that remote sensing is playing an important role in increasing our understanding of where animals are located within their environment. The telemetry papers in particular, which comprised a little less than half those dealing directly with animals, revealed a growing technology, not only in terms of developments in radio tracking technology, but also in terms of its acceptance as a tool for gathering information about the location and behavior of animals in their habitat. Whereas most of the radio tracking papers relied upon ground-to-ground transmissions, the use of aircraft or satellites represents the next generation of technological development for the radio tracking of large animals.

Table 2 lists the kinds of wildlife that were discussed (direct census and habitat evaluation) in the papers given in the Symposium. It is not too surprising that most are either larger animals or game species. Three of the papers, however, addressed endangered species.

Table 1.--Remotely sensed data types analyzed for wildlife management applications in 57 Symposium papers

APPLICATIONS	Visual Survey	Large Scale Panchromatic	Large Scale Color	Large Scale Color IR	Conventional Panchromatic	Conventional Color	Conventional Color IR	High Altitude Color IR	Multispectral Panchromatic/Near IR	Multispectral Scanner (Visible/Near IR)	Thermal IR	Radar (Imaging)	Landsat Imagery	Landsat CCT's	Telemetry	Radar	Number of Papers*
	REMOTE SENSING DATA																
General Habitat Mapping			1	4	3	2	5	5	1	2			7	7			16
Wetland Mapping					1		1	1						1			4
Waterbody Mapping							1			1			1	1			2
Stream Habitat Mapping			1	1			1										3
Winter Habitat													1				1
Monitoring Change In Habitat					5		2	1				1					5
Integrated Resource Analysis					1		1	1					2				5
Quantity Habitat Parameters					2		2	1					1	1			7
Geographic Information Systems							1						1				2
Animal Census	1	1			2	1					4					1	7
Animal Tracking	1														5		5
Totals	2	1	2	5	14	3	14	9	1	3	4	1	13	10	5	1	57 / 88
		Photographs (49)								Non Photographic (8)			Manual	Digital			
	Aircraft (59)												Landsat (23)				

* Many of the papers used several data types to demonstrate an application, or presented several applications using one or more data types.

Table 2.--Wildlife types either directly or indirectly analyzed in papers in the Pecora Symposium that described remote sensing techniques

General Wildlife		13
Birds:		21
Waterfowl	9	
Upland Game	7	
Nongame	5	
Big Game Mammals		11
Ocean Mammals		2
Marsupials		2
Game Fish		3
Rodents		3

Remote Sensing Data

Of the 57 papers presented, nearly half (49 percent) analyzed only remotely sensed data acquired by aircraft, 21 percent analyzed only Landsat imagery, 19 percent analyzed both Landsat and aircraft data, and the remaining 11 percent discussed the use of telemetry or radar to track animals. Because many of the papers addressed a variety of applications in which several sources of remotely sensed data were used, it is difficult to obtain an accurate measure of the frequency of use of specific data collection platforms (aircraft or spacecraft). Moreover, some papers used various types of remotely sensed data in an "experimental mode," further confounding the problem of identifying the extent to which certain data types are used operationally to address wildlife problems.

However, 40 percent of the papers described the use of Landsat data for specific wildlife applications (primarily imagery; two papers discussed the use of Landsat for telemetry), whereas 49 percent described the use of aircraft data alone. An additional 19 percent of the papers also described the use of aircraft data to support the analysis of Landsat data. These percentages indicate a much larger usage of Landsat data for wildlife management problems than is currently being used operationally. Table 1 also provides a more detailed accounting of the data types analyzed in the various applications contained in the 57 papers presented at the Symposium. Here only 26 percent (23 out of 88) of the data uses involve Landsat imagery. In the opinion of the authors this is a more realistic indicator of the current and potential use of Landsat data for providing resource information to wildlife managers. Table 1 also provides some other indicators relative to the usage of remotely sensed data. For example, (1) aerial photographs were still the most important data type: 56 percent (49 out of 88) of all data uses involved aerial photographs; (2) color-infrared film was the preferred film type: 57 percent (28 out of 49) of the photographic data products analyzed were color-infrared; (3) panchromatic aerial photographs, because of their availability, were a valuable remote sensing data type for wildlife habitat assessment and census: 16 out of 49 (33 percent) photographic uses involved panchromatic film, nearly half of which was used to monitor changes in habitat over time; (4) conventional photographic scales (1:15,000 to 1:40,000) were employed in more than half the aerial photographic studies, while the remainder were split between large scale (1:500 - 1:2,000) and small scale (1:60,000 - 1:120,000) photographs. What is not clear in this analysis of the types of images used, is what proportion was serendipitous and what was conscious selection. Therefore, this summary of data (images) used by investigators may not reflect the actual value of various remote sensor platforms (aircraft or spacecraft) or film types (color, color-infrared, panchromatic) to the discipline, but does indicate interesting trends.

Remote Sensing Analysis

Manual (visual) and digital analysis techniques were applied to both aircraft and Landsat imagery, although only one example of digital analysis of aircraft data was presented. In this one example, density slicing was used to define and estimate the area of water surfaces associated with prairie potholes. Twenty-three papers were presented which discussed the analysis of Landsat imagery, of which thirteen used a manual approach for delineating cover types, and ten used Landsat computer compatible tapes and a computer-driven analysis system to automate the classification of cover types. For the most part, these ten studies using computer analysis relied upon aerial photographs to define and identify training areas and to verify the results of the digital classification of cover types.

DISCUSSION

The Pecora IV Symposium papers provide a sample of the wildlife management applications being addressed by remote sensing. Land cover mapping using panchromatic and color-infrared aerial photographs is currently the most common use of remotely sensed data. Although panchromatic photographs of medium scale (1:15,000 to

1:40,000) have long been readily available for land cover mapping, the trend presently is toward greater use of color-infrared photographs. Likewise, there is a trend toward increased use of panchromatic and color-infrared aerial photographs for monitoring changes in wildlife habitat.

An application area in which aerial photographs are likely to be utilized more frequently in the future is "habitat evaluation," whereby certain parameters of the habitat are measured to determine wildlife suitability. Not all habitat parameters contributing to wildlife species suitability can be measured or interpreted directly from aerial photographs; but for those that can be (for example, distance to water or to cultural developments; size of openings and edge; minimum width of critical cover types), the use of aerial photographs provides a more accurate and efficient method than ground measurement.

The use of do-it-yourself, small format, oblique aerial photographs is on the rise, and provides an inexpensive method for recording habitat conditions within small areas. Both color and color-infrared 35-mm film are popular for this type of reconnaissance and for providing greater detail about habitat characteristics.

High-altitude color-infrared and Landsat imagery have been analyzed separately and together, primarily for purposes of regional land cover mapping. The advantage of interpreting large areas, however, is offset by lower image resolution, which reduces classification accuracy and map detail. For applications where high resolution is not a requirement, Landsat imagery offers much potential. For example, assessing the suitability of nesting sites for waterfowl, inventorying surface water as it relates to waterfowl populations, and determining the amount and distribution of agricultural land that provides feeding grounds for migrating waterfowl are among the practical applications for Landsat data. Despite these practical applications, nevertheless, much of the analysis of Landsat data for wildlife management purposes is still considered "experimental." For example, it remains to be demonstrated that Landsat data can be utilized to accurately map detailed upland and wetland habitats or to determine juxtaposition and edge. However, for many wildlife species that range over large areas and diverse habitats, detailed habitat maps may not be as important as general use patterns. In this case the synoptic view provided by Landsat imagery is well suited for evaluation of habitat condition and change, and Landsat data will continue to be an increasingly important tool.

The use of aerial photographs for recording animal numbers has been and will continue to be an important application. Many wildlife species, such as deer, game birds, raptors, and grizzlies, however, are difficult to enumerate using imaging remote sensors. Radio tracking, a form of remote sensing, has been shown to be a valuable technique for determining animal location, distribution and movement, and physiology and animal behavior. Recent developments in miniaturization of circuitry and longevity of power cells has contributed to an increased utilization of telemetry for gathering vital information regarding the presence or absence and distribution of wildlife within their habitats.

THE FUTURE

The Symposium has afforded a look at present and potential applications, and it has caused us to reflect on the future trends of remote sensing applications.

One application that undoubtedly will receive greater attention is the use of medium scale color-infrared photographs for quantifying habitat parameters. Many of the variables contributing directly to indices of habitat suitability for individual wildlife species can be measured or observed more efficiently and accurately from medium scale photographs than from Landsat imagery.

We expect an increase in the number of wildlife studies that combine habitat analysis (for example, vegetation mapping and edge measurement) with telemetry data in an effort to refine our impressions of what constitutes suitable wildlife habitat and why. There should soon be greater utilization of satellites for relay of signals from animals carrying radio transmittors.

We will see an increase in the use of Landsat data for regional wildlife analysis and especially in integrated resource approaches to resolving conflicting resource uses. The assured continuity of Landsat data will stimulate new uses and a continuation of existing practical applications. Future satellites undoubtedly will provide new opportunities for studying wildlife and habitat. Radar and thermal-infrared equipped satellites, for example, offer promise for assessing sea, ocean, and ice conditions that will increase our understanding of fish and other marine life. Improved resolution from space will expand the potential uses of this imagery. Declassification of imagery acquired by the military may also offer a new source of high-resolution remotely sensed data to improve our wildlife management perspective.

As wildlife managers, we must assume the responsibility for gathering the most timely and accurate information available about wildlife and their habitat. Moreover, it is our responsibility to carefully consider all the tools at our disposal for collecting needed information and their wise use. Using a tool properly requires acknowledging both its validity and its limitations. Where relatively new technologies, such as remote sensing, are involved, we must acquire the proper training to understand and apply the tools. Accepting remote sensing is half the battle. Care must also be taken to select the proper film or sensor type, season of year, and scale to assure that the information extracted is responsive to and consistent with intended application objectives. The Pecora IV Symposium has provided a valuable discussion of the wide variety of remote sensing applications to wildlife management. These proceedings provide a clearer perspective of who is currently using remote sensing, how and where it is being used, and for what purposes. It is now up to us to take advantage of all available tools to increase both our own and the general public's knowledge, awareness, and perception of our wildlife resources.