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AN INTEGRATED REMOTE SENSING APPROACH FOR IDENTIFYING ECOLOGICAL RANGE SITES*

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ABSTRACT

A model approach for identifying ecological range sites has been applied to high elevation sagebrush-dominated rangelands on Parker Mountain, in south-central Utah. The approach utilizes map information derived from both high altitude color infrared photography and Landsat digital data, integrated with soils, geological, and precipitation maps. Identification of the ecological range site for a given area requires an evaluation of all relevant environmental factors which combine to give that site the potential to produce characteristic types and amounts of vegetation. A table is presented which allows the user to determine ecological range site based upon an integrated use of the maps which were prepared in this study. The advantages of identifying ecological range sites through an integrated photo interpretation/Landsat analysis are discussed.

INTRODUCTION

The ecological range site concept has become the most widely used foundation for range management in recent years. An ecological range site (hereinafter "range site") is a "distinctive kind of rangeland that differs from other kinds of rangeland in its ability to produce a characteristic natural plant community" (S.C.S. 1976). The natural plant community or climax community is that assembledge of plants that would eventually occupy a site in the absence of abnormal disturbances and physical site deterioration. Range sites are derived from the analysis of vegetation composition (by dry weight) from relict sites with similar soil, climatic, topographic, and geologic characteristics. Plant association tables are prepared and analyzed for significant differences in the kind of dominant species and species groups, proportionate make up of dominant species and species groups, and total annual production. Thus, definition of range site and designation of an area as being that range site, provides a single expression of all environmental factors responsible for the development of that range site. The range site concept has, therefore, become a key component in the use, development, and rehabilitation of rangelands. Although a given range site model may oversimplify the inherent variability in nature, it is

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nevertheless a valuable and adaptable tool for developing rangeland management plans.

If rangelands were in relict condition, one would merely need to map vegetation types to identify range sites. Since many rangelands have received intensive use, range site identification is achieved through an integrated analysis of vegetation (considered a temporal attribute) and spatial attributes.

The traditional approach to mapping range sites is field labor intensive, with reliance on large scale black and white aerial photography for vegetation and geomorphic analysis. Spatial attributes are also obtained from available soils, geologic, topographic, and precipitation maps. The objective of this study was to explore the utilization of high altitude color infrared ("CIR") photography and Landsat digital data as a means of achieving greater efficiency and accuracy in the identification of ecological range sites. This study is part of a comprehensive study to analyze and map rangeland resources of the Parker Mountain study area (described below) for the Utah Division of State Lands and Forestry (Jaynes 1982).

STUDY AREA

Efforts to identify range sites in this study were carried out on the Parker Mountain State Land Block in south-central Utah. The study area occupies over 45,000 acres of high elevation (8,600-9,800 ft.) rangeland on the western edge of the Awapa Plateau, an eastward sloping plateau covered with various types of volcanic flows and deposits. The Parker Mountain study area is characterized by rolling hills covered with mountain big sagebrush and islands of aspen forests on its western half, and, on the eastern half, black sagebrush with mountain big sagebrush areas in swales and on north and east facing slopes. The climate is characterized by cold, snowy winters and warm summers. The predominant use of Parker Mountain is cattle and sheep summer grazing. Numerous antelope, sage grouse, Utah prairie dogs, and other wildlife are found in the area.

METHODS

Aerial Photo Interpretation

The primary medium for preparing a 1:24,000 scale topographic map overlay of vegetation was high altitude CIR photography flown on July 1-2, 1975. Film positive transparencies at 1:31,680 nominal scale were utilized. Mapping units were identified by examining the following: the color, texture, and patterns on the photographs; hydrologic features; topography (from topographic maps and stereoscopic viewing as needed); and ecological context. Scale adjustments and photographic displacement corrections were accomplished primarily by reference to U.S.G.S. orthophoto quadrangles, in addition to the use of a K&E Kargl cartographic projector. Interpretations were augmented by the use of a map from Landsat digital data (described below).

Three short trips to the study area in the summer and fall of 1982 were considered adequate for calibrating photo and Landsat interpretations with ground characteristics.

Landsat Digital Data Analysis

The Landsat multispectral scanner ("MSS") records light reflectance values for four spectral bands: green, red, and two bands of near infrared light. MSS data represents light reflecting characteristics for the combined land cover and terrain features within each picture element or "pixel," which covers approximately 1.1 acres of ground area. See U.S.G.S. (1979) for additional information regarding MSS data. Landsat data used in this study were recorded July 28, 1979.

Landsat MSS data are analyzed statistically to detect light reflectance patterns which are sufficiently unique to make different ground cover types of interest consistently distinguishable (Hutchinson 1982). The analytical approach used in this study, often referred to as an unsupervised classification method, began by examining the recorded MSS reflectance values for each pixel in the entire study area. From this search of individual pixels, statistics were generated which characterize pixel groups with similar spectral features. Next, a maximum likelihood classification routine was used to associate each pixel in the study area with one of the 46 spectral groups generated.

The analysis next focused on detecting similarities and differences between spectral groups. A simple means of evaluating spectral characteristics is to plot each spectral group's mean reflectance value for the four MSS bands to form a diagnostic curve or "spectral signature." Since evaluating spectral signatures is often quite subjective, a more objective technique was also applied. First, a principal components analysis of the mean values for each signature's four MSS bands reduced such data to factor scores for two components. Next, the factor scores were used in a cluster analysis which grouped spectral signatures according to a similarity index. Finally, the factor scores and group clusters were used in a discriminant analysis of the signatures. The two-dimensional scatter plot produced in the discriminant analysis allows one to receive a graphical view of signature relationships. (See Merola, et al. 1983 for an example.) The use of discriminant analysis, based on MSS principal components and cluster analyses, in combination with examination of spectral signature plots and field experience has been a key element in achieving good results from the unsupervised classification approach to Landsat data analysis.

An additional and most vital dimension to the process of digital data analysis is calibrating spectral signatures with "ground truth." This is accomplished by assigning print symbols to each signature or signature group and printing maps which may then be registered to standard base maps or referenced to photographs and field study sites. In this study, a digital print map overlay was prepared to match the U.S.G.S. 7½-minute quadrangles (scale 1:24,000) mosaic of the study area. Calibration of spectral signatures with actual land cover types was accomplished primarily by use of the vegetation map prepared from photo interpretation, high altitude CIR photography, and field observations. The above-described process of interpreting and combining spectral signatures based upon signature curve similarity, discriminant analysis of the signatures and calibration of signature print symbols with photograph and ground observations is outlined in Ridd, et al.(1983).

The correspondence between Landsat spectral signatures and unique ground cover characteristics may be weak in some instances (Todd, et al. 1980). Landsat and pixel-analyzing computer algorithms perform robot-like functions and it is often necessary to introduce ancillary information to improve ground cover maps which are based solely on MSS data (Tom and Miller 1980). In this study, for example, the digital map calibration process indicated substantial spectral similarity, and therefore confusion, between sites dominated by a relatively low growth form of big sagebrush and black sagebrush. This spectral similarity is not surprising considering that both shrubs occupy similar ecological sites: generally on south and west facing slopes which are rocky and relatively dry. Such differences are also not evident on CIR photography, but must be ascertained in the field. However, black sagebrush appears to occupy this ecological site only on the western rim of the plateau and in areas to the east of a generalized 8,250 feet elevation contour. To improve the digital classification, the zone occupied by the short growth form of big sagebrush was digitized and an algorithm constructed to allow the detection of differences between sagebrush species. Basically, the algorithm assigned each pixel with spectral signatures common to both species to different classes depending upon the location of the pixel with respect to the digitized zone.

Other areas of spectral similarity were also addressed by the introduction of ancillary data. The surface geology of eastern half of the study area is predominantly older volcanic material in the north, and very recent volcanic flows in the south. The topography in the north is characterized by a series of smooth ridges running in a southeast direction, whereas the southern area has more of a plateau character with various exposures. The combination of surface geology and topography differences between the areas has resulted in the confusion of big sagebrush, which grows in swales and northeast exposures in the north, with the black sagebrush signature of the south; since the black sagebrush areas which occur on southwest slopes in the north are spectrally different from black sagebrush on the recent volcanic flows in the south, there is little confusion between this spectral class and big sagebrush classes. The recent flows were digitized as separate units within the study area and new Landsat spectral class numbers were assigned to the signatures causing the confusion.

Spectral similarity was also encountered in areas which are primarily bottomland loamy soils with mountain silver sagebrush or wetland vegetation cover. The majority of bottomland soils were digitized from an available S.C.S. soils map and spectral signatures not normally associated with mountain silver sagebrush and wetlands were reassigned class numbers to avoid confusion.

RESULTS AND DISCUSSION

CIR Photo Interpretation

High altitude CIR photography proved to be an ideal photographic medium for the task of mapping rangeland resources; it provides high resolution prints with more information and less displacement than low altitude photographs, and is relatively unaffected by atmospheric haze which significantly scatters blue light. In addition, contrasts between different vegetation types such as aspen and sagebrush are extremely vivid, whereas black and white photography often obscures such boundaries. CIR photography also generally produces greater discrimination between vegetation types than natural color photography because infrared light reflectance is highly sensitive to plant leaf shape and cell differences, as well as plant vigor.

Despite the advantages offered by the CIR photography in this study, field observations and ecological interpretations were vital in completing the mapping process. Generally, different ground cover types were found to be associated with distinct patterns of color, tone, and texture on the CIR photographs. A few circumstances led to confusion in interpreting the photos. For example, reddish-brown rocks on recent basalt flows often form a dominant feature which tends to produce similar CIR photo color-tone patterns, making black sagebrush areas indistinguishable from areas dominated by big sagebrush. Field observations and the map from Landsat digital data helped to sort out the confusion.

In a number of instances, the ability to reference the Landsat digital print map significantly aided in the task of mapping rangeland cover from CIR photographs; the digital print map often flagged areas which might otherwise have gone unnoticed because of subtle visual differences. Available geologic, soils, precipitation, and topographic maps were also quite helpful. The rangeland cover types delineated from these procedures follow: black sagebrush; mountain big sagebrush, short growth form (dry, rocky sites); mountain big sagebrush, tall growth form (mesic sites); mountain silver sagebrush; wetland (rush/sedge); aspen; Douglas fir; pinyon-juniper.

Landsat Digital Data Analysis

The methods applied in the analysis of Landsat data initially expanded the number of spectral signatures before reducing the number of classes mapped to 20. As noted above, a total of 46 signatures were developed from statistically searching the study area for representative signatures. Partitioning the study area based upon elevation, geology, and soils, as described previously, led to the creation of more than 10 additional classes. The final selection of 20 classes of rangeland cover represents a compromise between the goals of map simplification and preservation of meaningful (or potentially meaningful) detail. Further feedback from digital print map users will determine whether the number of classes mapped should be expanded or reduced. It is estimated that the Landsat map accuracy was increased by 25% through the efforts to partition the study area based upon ancillary information.

Landsat map accuracy was assessed by randomly placing a grid, with vertices at ten-pixel row and column intervals, over the Landsat map and photo interpreting the nearest group of 4-10 pixels of a given class. A total of 830 pixel groups (average group size was approximately 6) were examined, which represents a sample size of approximately 12% of all pixels. Table 1 presents an error matrix for six levels of vegetation cover interpretation. Overall map accuracy is 89%, with the greatest amount of confusion associated with short growth form big sagebrush. Map verification by examining pixel groups probably produces a positive bias over verification of individual pixels because it leads to the checking of areas on photos which are relatively homogeneous spectrally. However, simply looking at single pixels probably produces an opposite bias as a result of difficulty in achieving close registration between the Landsat map and photos. Sampling small groups of pixels is believed to be a good compromise, especially since pixels tend to occur as groups rather than as scattered individuals.

Table 1. Landsat map error matrix with verification for six levels of vegetation cover intrepretations.

	VERIFIED CLASSES*								
Landsat Classes	Asper	Big sage, tall form	Big sage, short form	Black sagebrush	Silver sagebrush	Wetland	Total	Percent Correct	Percent Commission
Ø,Ɵ,Ø,θ,0,Ø	115	2					117	98	2
V,U,T		210	20				230	91	9
S,R,+,-		39	106	14			159	67	33
~,',·,Blank		6	3	257			266	97	3
♦,#		4	3		48		55	87	13
W						3	3	100	0
Total	115	261	132	271	48	3	830		
Percent Omission	0	20	20	5	0	0	Overall Accuracy:	89%	

*Verification of Landsat classes is based upon photo interpretation and field observation for regularly spaced pixel groups of 4-10 pixels each.

Table 2 illustrates that the Landsat map, based on available field information and photo interpretation, contains fair to good accuracy for most of the 20 spectral classes. The overall accuracy is 74%, with 21% average omission error and 23% average comission error. Table 2 also provides a brief description of the rangeland cover associated with the 20 classes.

Integration of Photo Interpretation and Landsat Maps

The availability of two different maps of rangeland cover could lead map users to feel obligated to select the more accurate of the two approaches. However, there is no need to make such a choice when the fundamental differences between both mapping procedures are examined. Both mapping techniques have trade-offs in terms of spatial and interpretive accuracies which makes direct comparison of maps difficult: relative map accuracies must be judged by reference to available ground truth and in light of the particular spatial and interpretive accuracy specifications of each mapping project.

Table 2. Landsat map error matrix with verification for twenty levels of vegetation cover interpretations.

		VERIFIED CLASSES*																						
Class No.	Landsat Symbol	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Percent Correct	Percent Commission
1	▮	19	4	1																		24	79	21
2	▮	6	34	6																		46	74	26
3	●		4	14	1																	19	74	26
4	θ		1	4	10					2												17	59	41
5	O					6																6	100	0
6	θ						5															5	100	0
7	V							42	17	3	3											65	65	35
8	U							13	39	7	2											61	64	36
9	T							3	8	78	10	5										104	75	25
10	S							3	2	8	22	4										39	56	44
11	R							4	3	4	1	25	1	2		1	10	1				52	48	52
12	+									7			30									37	81	19
13	-									8		1		20			2					31	65	35
14	⌢									6		2			72	16						96	75	25
15	,														14	38	1					53	72	28
16	·											1					22	5				28	79	21
17	Blank																2	87				89	98	2
18	♦																		20			20	100	0
19	#								4					3						28		35	80	20
20	W																				3	3	100	0
Total		25	43	25	11	6	5	65	73	123	38	38	31	25	86	55	37	93	20	28	3	830		
Percent Omission		24	21	44	9	0	0	35	47	37	42	34	3	20	16	31	41	6	0	0	0	Overall Accuracy: 74%		

*Verification of Landsat classes is based upon photo interpretation and field observations. Class interpretations corresponding to the numbers for verified classes (columns) and Landsat classes (rows) follow:

Aspen

1. closed canopy, good health
2. open canopy, good health
3. patchy or edges, fair-good health
4. patchy mix with big sage, fair-good health
5. open canopy/patchy, poor-fair health
6. mix with conifers, edges, north slopes

Mtn. big sagebrush: tall growth form

7. moist loamy bottoms, grassy understory
8. loamy north slopes, significant grass
9. rocky, north slopes in east, various aspects in west

Mtn. big sagebrush: short growth form

10. western half of area, south slopes
11. eastern half, mixes with black sagebrush
12. western half, south slopes
13. western half, south slopes

Black sagebrush

14. basalt flows
15. basalt flows, mixes with big sage
16. breccia areas, southwest slopes, mixes with big sage
17. breccia areas, southwest slopes

Mtn. silver sagebrush

18. very moist bottoms
19. drainage bottoms

Wetland

20. wet soil, rush/sedge

Photo interpretation forces the mapper to generalize spatially to avoid creating map polygons which are too numerous and/or too small. Selecting minimum mapping unit sizes and simplifying the map legend are necessary in preparing a visually interpretable map where patterns may be detected. Landsat mapping includes numerous cells, which are equivalent to, but generally much smaller than, the photo interpreter's line-drawn polygons, thus offering the potential for increased spatial mapping detail. However, information obtained for each pixel by the Landsat scanner is already spatially generalized (ca. one acre pixel size), which offsets this advantage somewhat. Of course, the digital map format offers the advantages of automated area calculations, editing, updating, etc.

Interpretive generalizing and error occurs with photo interpretation since vegetation boundaries are not always distinct but, as a practical matter, lines must be drawn to complete map polygons. Generally speaking, the areal polygons mapped may be considered to have relatively homogeneous land cover. However, subtle but significant vegetation mixing may occur within some map polygons which is either undetected by the interpreter or overlooked to avoid additional lines and labeling of polygons which would clutter up the map. Landsat data is quantitative, and analysis of spectral signatures is generally more objective than photo interpretation. The Landsat spectral bands cover a narrower spectral range than most photographic emulsions and permit the analysis of single or multiple bards: aspects which often serve to simplify the process of associating light reflectance with ground cover. Error and generalizing in interpretation of classes occurs when the combinations of physical factors, which determine multispectral reflectance for different land cover types, produce similar spectral responses. Unless such situations can be corrected by the use of ancillary data to digitize boundaries which avoid the confusion, misclassification of pixels will occur.

Consequently, although Landsat analysis and CIR photo interpretations are both forms of remote sensing, comparing the products produced by both methods is similar to judging the difference between an apple and an orange. In addition, it can generally be assumed that ground truth is rarely available in such abundance as to permit good comparisons of the mapping approaches; Landsat maps are typically evaluated largely by reference to air photo interpretations, which leads to errors through misregistration or misinterpretation and bias that may inflate the apparent accuracy of maps from photo interpretation.

The vegetation map produced in this study from photo interpretation offers the advantages of allowing a user to easily detect general patterns and locate most vegetation boundaries with a high degree of accuracy. The main weakness of the photo interpreted map is that only six major vegetation classes were able to be mapped, and that environmental variations within map polygons are often generalized. The Landsat map overlay in large part compensates for these weaknesses in the hand-drawn map with its 20 cover classes and nearly one acre polygon size.

Identification of Ecological Range Sites

The delineation of the vegetation cover types noted above provides an indication of present forage composition, but, more importantly, it provides a primary means of identifying range sites. The plant community occupying a given site is a "synthometer" of the total environment of that site. The biotic and abiotic components have, over time, led to the dominance of the existing vegetation. Since Parker Mountain has not recently had any widespread major disturbances, it may be assumed that the vegetation types mapped from CIR photography and Landsat data are the best single indicator of distinct sites for which management prescriptions may be developed. This is especially the case where available information regarding spatial environmental variables such as soils, geology, precipitation, and topography have been integrated in both land cover mapping approaches.

Range sites are mapped from an analysis of physical indicators which are associated with the range site. In this study, ecological conditions encountered on Parker Mountain suggest that twelve major range sites are present in the study area. These ecological sites have not been mapped per se, but may be identified for any portion of the study area by reference to Table 3, and available maps of vegetation, soils, and geology.

Table 3. Ecological range sites in study area, and associated photo interpreted land cover, geology, soils, and Landsat map symbols.

	Associated Map Characteristics			
Ecological Range Sites	Land Cover*	Geology	Soils	Landsat Map Symbol(s)
high mountain loam	"a" aspen, and "f/a" conifer/aspen	breccias (rarely basalt)	Faim	Various "0"
high mtn. stony loam	" " "	breccias & basalt	Parkay	Various "0"
high mtn. shallow loam	" " "	basalt flow	Parkay	Various "0"
semi-wet meadows	"c" mtn. silver sage	breccias	Foy	#, #
wet meadows	"w" wetland	breccias	Foy	W
mountain loam	"t" mtn. big sagebrush, tall growth form	breccias (rarely basalt)	Faim	V, U
mountain stony loam	" " " "	breccias (some basalt)	Parkay	T
mountain stony loam	"s" mtn. big sagebrush, short growth form	breccias & basalt	Parkay (some Forsey)	R, S, +, -
mountain shallow loam	" " " "	basalt flow	Parkay (some Forsey)	+, -
upland stony loam	"n" black sagebrush	basalt, breccias and sediments	Forsey (some Parkay)	Blank, `, ', ^
upland shallow loam	" " "	basalt flow	Forsey	^, '
upland stony loam (juniper)	"p" pinyon-juniper	landslide debris	Parkay (some Forsey)	Various

* Photo interpreted map.

CONCLUSION

This project has permitted a close evaluation of the relative merits of mapping rangeland resources from CIR photo interpretation and from MSS digital data. Best results are obtained when both approaches are used in tandem; each approach has certain inherent disadvantages which are to a large extent corrected by utilizing the other approach.

Combined with soils and geology maps, the vegetation maps permit an accurate means of identifying ecological range sites. At a cost of approximately $0.15/acre, this approach produces significant improvements in accuracy and efficiency over labor-intensive alternatives. The maps and other information generated as part of this study are presently being used by Parker Mountain range managers to select range condition/trend monitoring sites and plan range improvements.

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