Defining Biophysical Land Units for Resource Management

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ABSTRACT: El Malpais National Conservation Area in New Mexico has been selected by the Rio Puerco Resource Area of the Bureau of Land Management as a prototype for new methodologies of resource management on public lands. The landscapes are being described by delineating biophysical land units (BLUs) using an image-based geographic information system (GIS). One strength of the BLU approach is that the GIS data for each unit can include unique themes, as well as those generic to the entire Conservation Area. This is an important concern to managers because there are several types of administrative units within El Malpais, each having different management criteria, while occupying or overlapping some of the same BLU.

The aim of this paper is to present conceptual arguments for adopting the BLU as a management tool and to illustrate and describe the results of its adoption in the Conservation Area.

INTRODUCTION

IN 1987, CONGRESS ESTABLISHED El Malpais National Monument and the El Malpais National Conservation Area (NCA)) in west-central New Mexico (Public Law 100-225). Administratively, the area is parceled into the El Malpais National Monument (under the jurisdiction of the National Park Service) and the surrounding National Conservation Area (under the Bureau of Land Management, BLM) (Figure 1). BLM's responsibilities cover seven noncontiguous land units patchworked around the Chain of Craters *Wilderness Study Area*, the West Malpais *Wilderness Area*, and the Cebolla *Wilderness Area* (Bureau of Land Management Planning Team, 1990). All of these have different resource attributes and legislated (or policy driven) management requirements; and these, in turn, are different from the management strategies and requirements followed by the National Park Service for the Monument. When administrative boundaries are superimposed on current land ownership, a complex management environment is revealed that is further exacerbated by the variety of biophysical attributes in the area. The problem is to find a technique that will display these many attributes in a systematic and quantifiable way so that, as changes occur, management strategies can be adjusted appropriately.

The Bureau's overall management philosophy for El Malpais hinges on conservation and preservation (the principles of multiple use and sustained yield), but there are unique objectives for each administrative unit. The two Wilderness Areas in Figure 1 are to be managed to preserve their wilderness character for recreational, scenic, scientific, educational, conservation, and historical uses. The Wilderness Study Area is to be managed to maintain its present "potential" as a Wilderness Area. The remainder of the NCA is to be protected for the benefit and enjoyment of future generations in all of its physical, cultural, and scientific uniqueness. The problem is that natural landscapes do not conform to the management boundaries shown in Figure 1. Rather, they range across zones that are stable enough to depict patterns, but are by no means fixed (Taylor, 1988; Jensen, 1983; Bailey, 1988). Landscape ecologists recognize that ecological processes vary in their effects at different spatial and temporal scales; that biogeographic processes may be unimportant in determining local patterns; that individual plant and animal species operate at different scales of reference, such that what appears to be a homogeneous patch to one may be extremely patchy to another; and that all of these perspectives are defined by the objectives of a particular management question (Franklin, 1987; Risser, 1987). Thus, it is necessary to adopt a land analysis system that is sensitive to both the shared biophysical attributes of landscapes and their unique (patchy) attributes. The biophysical land unit (BLU) offers this capability in ways that are superior to earlier land systems.

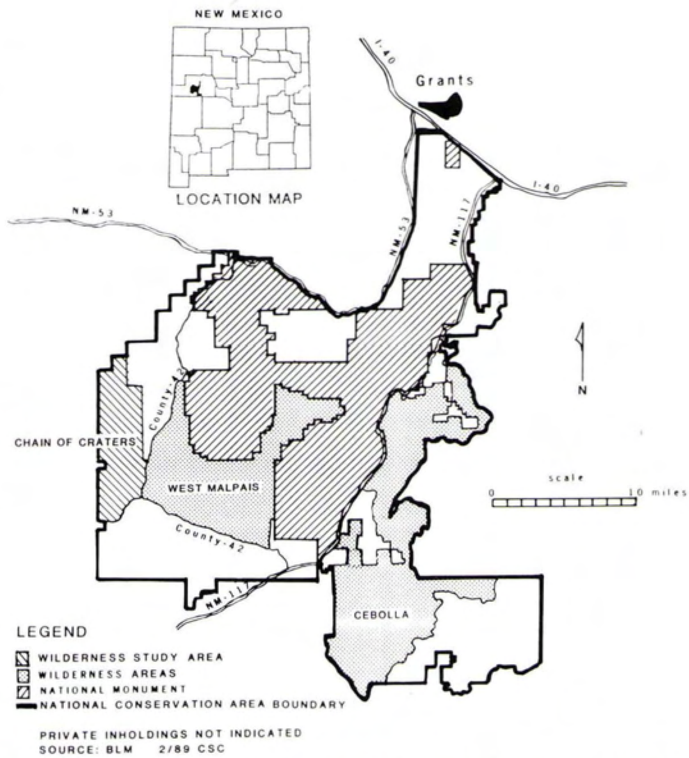

FIG. 1. General location and administrative units of El Malpais National Monument and National Conservation Area.

THE STUDY AREA

El Malpais consists of the lava flows and surrounding sandstone badlands south of Grants, New Mexico. Repeated extrusions of lava in past millennia have resulted in today's diversity

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of ecological, geological, and biological phenomena. In addition, prehistoric Anasazi cultures have left numerous sites throughout the area, and descendants of these cultures attach deep religious significance to their remains. Subsequent cultures have also left their imprints, and all have contributed to a setting that combines natural beauty, history, and spiritualism to a remote part of New Mexico.

The total management area is some 375,000 acres (150,000ha). At its greatest extent, it stretches 30 miles east-to-west by 40 miles north-to-south. Approximately 50,000 acres (20,000ha) of exposed and variously vegetated lava are present. Roughly equal acreages (95,000 acres or 20,000ha each) are covered by grass/shrub, shrub/conifer, and mixed conifer vegetation and their gradations, while much smaller areas are occupied by ponderosa parkland and deciduous woodland (2000 acres or 800ha each). Pinyon/juniper woodland (the regional vegetational formation) and sparsely vegetated areas represent another 34,000 acres (13,500ha). Elevations range from 7250 ft (2196 metres) to 8400 ft. (2546 metres). Although located in the desert Southwest, the elevation of El Malpais places it in the microthermal mixed broad-leaved deciduous and coniferous vegetational formation.

THE BLU CONCEPT

Biophysical land units are defined on the basis of their biogeochemical attributes as manifested in lithology, surface drainage, soil types, geomorphology, microclimates and vegetational cover; and by their cultural attributes as inherited from past and present human occupation (Walmsley, 1976; Stoddart, 1986). Because units exhibit strong uniformity in physical and biological attributes, they are expected to respond similarly to given intensities of human use and management strategies. More importantly, BLUs have internally consistent potentials and capabilities, and are therefore expected to have predictable response curves to changes in management strategy (BLM Planning Team, 1990).

The BLU is similar to, but not synonymous with, "bio-physical land classification" (Hills, 1976), the "land system" of Australia as described by Christian and Stewart (1968), the study units of "landscape ecology" articulated by Risser (1987), and the "integrated terrain unit" described by Dangermond *et al*. (1982). Where the BLU concept differs is that earlier techniques relied on the delineation of photomorphic areas traced from panchromatic aerial photographs, black-and-white satellite images, or satellite color enhanced images (see, for example, Nichol (1975), Ackerson and Fish (1980), and Morain (1986)). We will show, however, that BLUs can be "delineated" in both the spectral and spatial domains from data obtained at ground level, or from aerial and satellite altitudes, using digital data and computer processing. Whereas the "land system" and its component "land units" are delineable on small scale photo mosaics, the BLU is not necessarily photomorphically delineable. Its descriptors result from themes superimposed as layers in a geographic information system (GIS). Thus, the boundaries shown on paper printouts may not be readily observable on the ground, or on photographs as photomorphic regions; but, by definition, they separate adjacent sets of biophysical attributes. Where BLU and photomorphic boundaries coincide, there are major physical and biological disjunctions in the landscape. The fact that units can be printed in map form but not necessarily observed in the field is no problem because each picture element can be geocoded to standard land survey systems.

An additional attribute of BLUs generated by digital data processing is that they reveal ecological "patchiness." In our experience, photomorphic land units, being manual delineations, have never been efficient at explaining variability within polygons. To confirm our experience, we refer the reader to Galloway *et al*. (1974), or to any of the other reports in Australia's *Land System* series. Variability of elements within their land units can only be described in a general way, not shown as an actual "patchy" distribution in a spatial variability context. In our view, BLUs provide strategic Earth resource information to a wide range of land management specialists, as do land systems and land units, yet go beyond that general application to provide tactical data for unique planning needs.

METHODOLOGY

To define and plot the BLUs of the El Malpais NCA, remote sensing and GIS techniques were merged. Their combination results in an image-based, geocoded database that can be quickly and scientifically updated to (a) assess the impacts of management decisions; (b) provide an early warning system where new strategies are required; (c) track naturally occurring longer and shorter term environmental changes; and (d) compare these trends with impacts arising from human use of the region. A signal characteristic of BLUs is that they provide the framework for determining the "limits of acceptable change" occurring within a management area (Stankey *et al*., 1985).

For the El Malpais NCA, vegetation, slope, soil type, and surface drainage were chosen as the defining attributes. These have been merged with management boundaries and roads to enable land managers to better understand environmental conditions within the NCA's manangement units. Plate 1 displays the resulting BLUs, as defined in 1990, and Table 1 describes their characteristics. The complexities of land ownership, grazing allotments, and other cultural, economic, and political features of El Malpais will be added as the database matures; and these will no doubt reveal an element of "anthropogenic patchiness" superimposed on an already naturally patchy environment.

Because vegetation is the resultant manifestation of an area's climatology, pedology, lithology, hydrology, topography, and human impacts, it is the most dynamic component of any BLU, and the one that eventually mirrors changes in all other components. The floristics, structure, and physiognomy of vegetation tell something about the status of the environments they occupy. At El Malpais, field-derived vegetational information has been spotty because the area is rugged and remote. Floristic data were available in detail for some settings, but totally lacking in others. Likewise, structure and physiognomy were poorly known in any systematic way. For these reasons, the database required a vegetation cover layer developed from satellite Thematic Mapper (TM) data collected in June, 1984. It constitutes the image base upon which the other themes are stacked. These layers include (a) soil type as derived from Soil Conservation Service (SCS) 1:24,000-scale maps; (b) surface drainage from 1:100,000-scale USGS digital line graphs (DLGs) and 1:24,000-scale BLM field inventory data; and (c) terrain data (slope, aspect, and elevation) taken from USGS 1:24,000-scale digital elevation models (DEMs). The soil and drainage data sets were converted from vector to raster format to be compatible with the terrain and cover type data; and Boolean operations were then performed to generate the "core" BLUs. All data were formatted to a 100-metre grid for display, but very complex areas can be telescoped to a 30-metre grid.

The BLM District Office in Albuquerque is equipped with a Level-B Prime minicomputer[1]. Terminals include a Tektronix 4111 and Pericom MX 7000 color displays. There is also a Tektronix 4696 color ink-jet printer which produces small scale, coarse resolution graphics. For digitizing, there is a GraphOn monochrome terminal and an Altek AC40 Datatab controller and digitizing tablet. Finally, a Calcomp high-speed electrostatic

[1]There is no explicit or implicit endorsement intended in the use of manufacturer's or brand names. They are intended purely to assist those readers who may be familiar with system designs and configurations.

TABLE 1. BIOPHYSICAL LAND UNITS IN THE EL MALPAIS NATIONAL CONSERVATION AREA (Source: Bureau of Land Management Planning Team, 1991)

BLU	Slope (%)	Soils	Vegetation	Surface Water/ Drainage	Acreage in NCA	% of NCA
A	1-10	Sandy clay loams	Grass-shrub	Playas	86,500	32
B	1-10	Sandy clay loams	Sparse-bare/grass shrub	Drainages/springs	2,800	1
C	3-50	Cobbly gravelly loams	Shrub-conifer	Small drainages	42,300	16
D	1-10	Lava	Shrub-conifer	No known surface water	6,300	2
E	1-3	Alkaline sandy clay loams	Sparse-bare/grass shrub	Marshy areas	3,300	1
F	1-12	Lava	Lava-lichen-shrub complex, grass-shrub, sparse-bare	Small pockets of standing water	5,000	1
G	1-10	Lava	Mixed conifer	Small pockets of standing water	9,500	3
H	10-50	Cobbly gravelly loams	Mixed conifer	Small drainages on slopes	43,500	16
I	<60	Cobbly sandy loams/high erosion potential	Grass-shrub/shrub-conifer/mixed conifer	Large drainages on steep slopes/springs	41,400	15
J	<60	Cobbly clay loams	Grass-shrub/ shrub-conifer/ mixed conifer	Some drainages on steep slopes/ springs	15,000	5
K	1-30	Volcanic & non-volcanic soils	Ponderosa-oak/ deciduous groves	No known surface water	5,600	2
L	1-10	Sandy clay loams, cobbly sandy loams	Sparse-bare	Drainages, playas	1,200	<1
		Areas with non-conforming landcover (do not fit BLU model because of surface disturbance)			700	<1

plotter is available for plotting the complex BLU data using an array of solid colors.

Software includes the Primos operating system and, for digitizing and editing thematic maps, the Automated Digitizing System (ADS) is available. The analytical software is version 90.12, 32-bit version of the Map Overlay and Statistical System (MOSS). MOSS can address digital map data in both vector and raster formats. The raster processing capabilities are referred to as the Map Analysis and Processing System (MAPS), and, because both the vegetation and the topographic (Digital Elevation Model, DEM) data are in raster format, overlay analysis and derivation of BLUs was done in MAPS.

Image processing for land cover was done on a Microvax II minicomputer using ELAS software. An unsupervised classification was used to partition TM data from channels 2 (green), 3 (red), and 4 (reflective infrared). The resulting 44 classes were converted to topographic quad-based transparencies and analyzed in the field to determine which classes should be combined to form the June, 1984 vegetation categories. Eight cover types were defined by this procedure and are listed in Table 2.

INTERPRETATION OF COVER TYPES AND BLUs

Figure 2 is a two-channel plot showing the red/infrared locations of each of the 44 spectral classes and their aggregation into the vegetation types given in Table 2. Rather than present the customary interpretation of Figure 2, we interpret it, below, in terms of land management methods and practices. For example, the lowest spectral reflectivities represent water, shadowed areas, and some of the most recent lava flows. Even though these particular flows support a wealth of floristic diversity, the total reflective leaf area is small compared to the energy absorption properties of lava. The result is that vegetation on the most recent flows cannot be monitored from space using existing Earth observing systems. Moreover, impacts of visitor use and other environmental changes cannot be addressed using spectral data alone, but must be augmented using the relational database of other data layers.

The Sparse/Barren category is characterized by moderate to very high reflectances in both spectral channels. As is true of the lava surface, there is little leaf area to mask reflectance from the soil; but, unlike the lava, seasonal increases and decreases in plant cover can be recorded from spacecraft and analyzed for their significance to land management strategies. Satellite observations obtained annually, and preferably seasonally, will establish the normal environmental flux of this category, and determine if it is expanding or shrinking as a consequence of land-use impacts. Depending upon location and other BLU components, management strategies should aim at decreasing the landscape area represented by these spectral classes.

Grass/Shrubland is characterized by lower reflectivities. Its response mirrors the fact that there is greater leaf area and plant cover than in either of the previous two cover types. The separation of grass/shrubland from sparse/barren is qualitative, and fluctuates with seasonal and longer term influences. It will be important to monitor the spatial distribution of this category to assess the impacts of uses such as recreation or grazing. The spectral classes of this category will probably continue to exist, but the areas may expand or decline. This category is therefore a "zone of sensitivity" between coniferous categories on the one hand, and an unwanted expansion of sparsely vegetated terrain on the other. In terms of these abilities to herald environmental health at El Malpais, management strategies should promote the expansion of grass/shrubland, not its decline.

Four of the 44 classes in Figure 2 were used to define the shrub/conifer plant community; three were used to define pinon/juniper woodlands; three more were used to delimit the

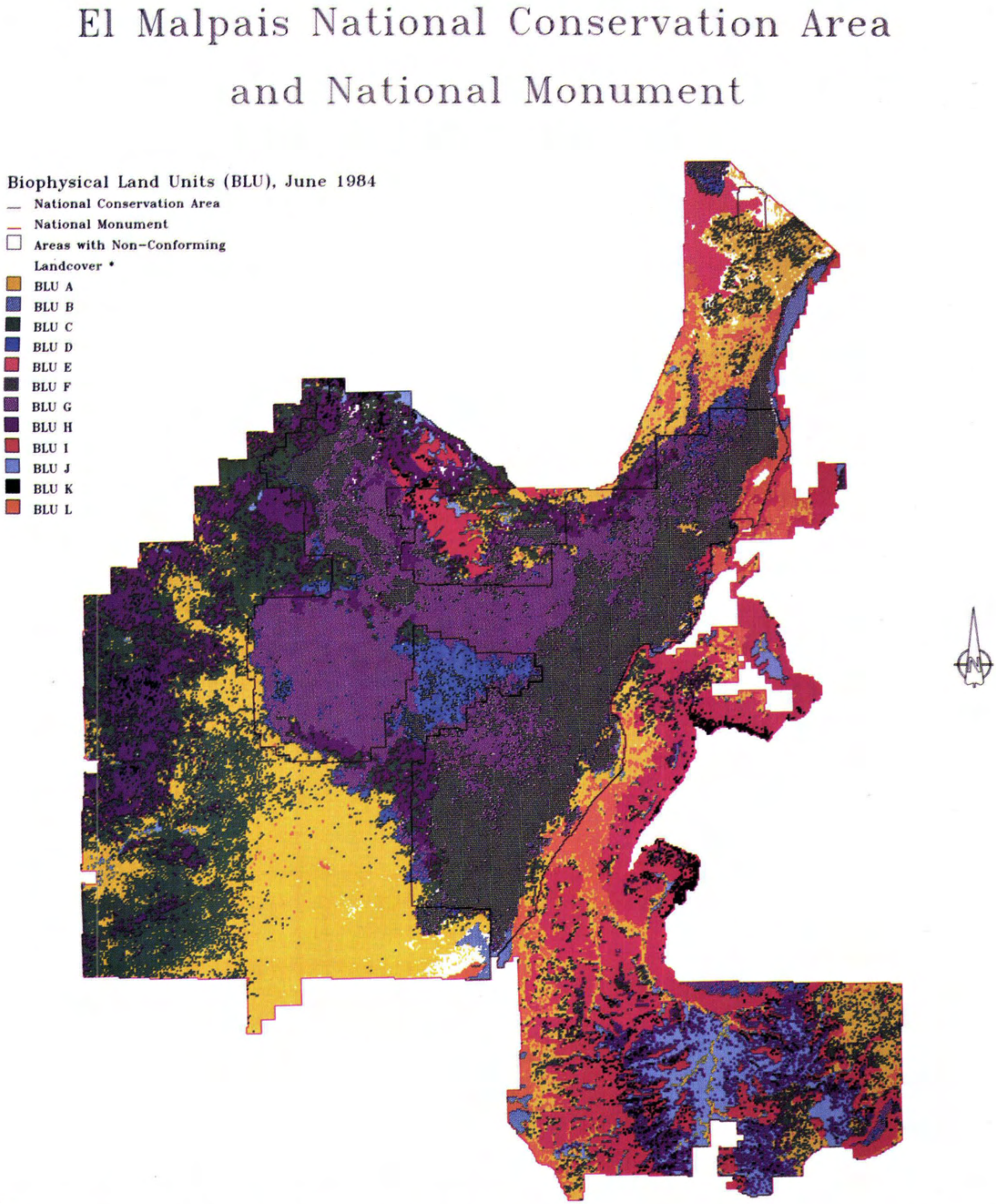

PLATE 1. Initial Biophysical Land Units of the El Malpais based on vegetation cover, slope, soil type, and surface hydrology. To enhance management capabilities, future BLUs will include additional physical and cultural attributes.

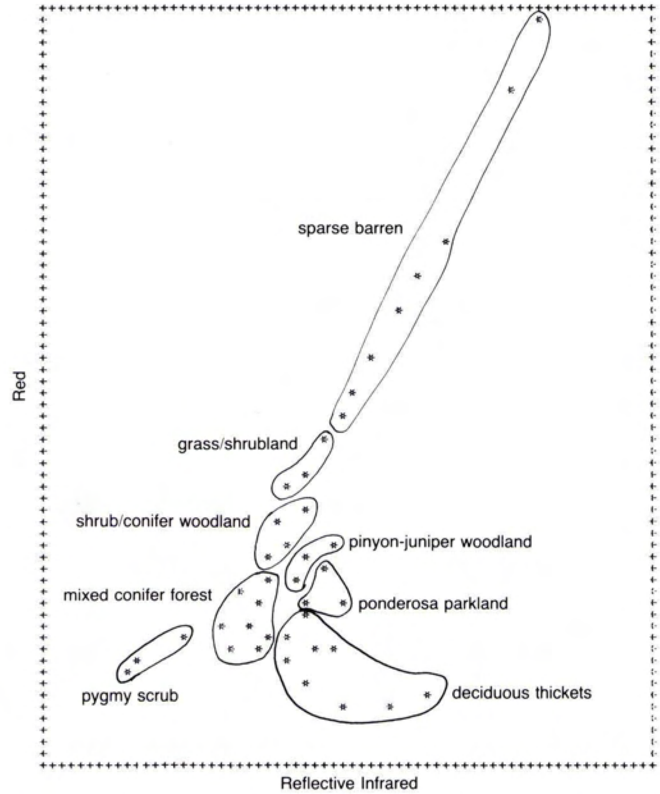

FIG. 2. Two-channel spectral plot of red versus reflective infrared intensity. Each of the 44 spectral classes identified through an unsupervised classification have been clustered into eight cover classes on the basis of subsequent field examination and verification.

ponderosa parklands; and eight were needed to locate the mixed conifer forest. In the two-dimensional space of Figure 2, there is no suggestion as to how these classes should be partitioned; only field examination can provide that knowledge. In a regional context, there may be one "super" category of coniferous vegetation that unifies the growthforms and vegetational structures defined by all 18 of these spectral classes.

Lastly, deciduous thickets are described by nine spectral classes, which itself is evidence of their ecological patchiness. The components of this type are difficult to segregate from other vegetation communities, at least in late spring/early summer when the TM data used here were acquired; and it is only when their spectral properties are merged with other spatial data elements in the database that a defineable BLU emerges. BLU-"K" in Plate 1 is one of the smallest, yet most interesting, of the 11 BLUs because it *is* patchy, and because of its importance to wildlife. We have chosen it, therefore, to illustrate the validity and reliability of its defining attributes, the concordance of its actual and computer derived boundaries, and the information shed upon its management issues.

The deciduous element of BLU-K as studied on the Cerro Brillante quadrangle in the Chain of Craters Wilderness Study Area (see Figure 1 and Plate 1) consists of coppices, or thickets, of unusually large oaks in both tree and shrub form. These provide mast (an oil rich food) for turkeys, squirrels, various birds, chipmunks, deer, and bear. They also provide browse for deer, nesting cover, protection from inclement weather, and shade for a variety of species. There is evidence for the presence of all these wildlife forms in and around these coppices, so they function as a multipurpose habitat in the region. Adjoining the thickets, spatially and spectrally, are ponderosa parklands, which augment the overall habitat value by housing an understory that frequently includes currants, raspberries, gooseberries, sumac, and a variety of grasses, as necessary additional food sources for fawns, small mammals, birds, and bears. In the General Management Plan (1990) BLU-K is defined as a "patchy habitat," a description confirmed by its distribution on the Cerro Brillante quadrangle, and this is ecologically significant because wildlife are often known to prefer the "edges" of their natural habitat. For the Bureau of Land Management, the conservation strategy for BLU-K is therefore tied directly to its ecological importance as habitat.

CONCLUSIONS

This work represents a beginning effort for BLM to create an image-based GIS database for the El Malpais National Conservation Area. Using spectral and spatial data analysis, a management plan has been developed that has a sound scientific basis, as well as one that has currency in the long term through standardization of data processing techniques. At this stage in the BLU database development, it is evident that satellite-derived spectral and temporal data constitute an indispensable set of GIS layers for creating management scenarios. As the descriptive information of the cover types defined in Table 2 expand and are refined through a combination of spectral/temporal observations and concurrent field verifications, a more complete and detailed database will emerge on this pivotal attribute. Subsequent refinements in soil properties, finer resolution terrain analysis, and the inclusion of many more economic and cultural coverages can be expected to partition the current set of BLUs into a larger, but equally manageable, number of smaller units. Eventually, as the process approaches maturity, the Bureau of Land Management should possess a highly versatile and responsive system that enables their resource managers to assess the breadth and depth of their needs in a geographically precise and consistent manner.

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TABLE 2. COVER TYPES OF THE EL MALPAIS NATIONAL CONSERVATION AREA

1. SPARSE/BARREN: Consists of exposed rock or soil supporting low densities of bunch grass and stunted, scattered shrubs and forbs. Grasses include blue gramma (*Bouteloua gracilis*), galleta (*Hilaria jamesii*), and many of the warm season species (note: many warm season grasses were not present at the time of Landsat data acquisition in June, 1984. Data collected in August may allocate some of this category into "grass/shrubland"). Forbs include Kochia (*Kochia americana*), large areas of sunflowers, and other Compositae. Western wheat grass (*Agropyron smithii*) is dominant in playas.

2. GRASS/SHRUBLAND: Consists of blue gramma in a sod habit interspersed with forbs, mixed grasses, and shrubs such as *Tetradymia, Artemisia, Gutierrezia* and *Chrysothamnus*. Rabbitbrush (*Chrysothamnus nauseosus*) flats might be identifiable as a separate category using satellite TM data collected during the fall season. Juniper (*Juniperus spp.*) and pinon (*Pinus spp.*) are scattered in some areas, but, where present, are usually separated by several crown diameters. As crown cover increases, spectral reflectivity merges to "shrub/conifer".

3. SHRUB/CONIFER WOODLAND: Consists of an open conifer overstory and grass/shrub understory. Open shrub/grass meadows intersperse with the mixed conifers to form a patchwork. On south facing slopes at lower elevations (6800-7600 feet), conifers are pinons and junipers with an understory of blue grama, rabbitbrush, snakeweed (*Gutierrezia sarothrae*), currant (*Ribes spp.*), sumac (*Rhus spp.*), horsebrush (*Tetradymia canescens*), and other mixed grasses and forbs. As elevation increases and aspects shift northwards, ponderosa pine (*Pinus ponderosa*) becomes a common component in the pinon/juniper association, and in some cases becomes dominant. Alligator bark juniper (*Juniperus deppeana*) also appears. Oak (*Quercus*) species become common in the understory, and some become large enough and arealy extensive to be identified as a deciduous "patch." In the northwestern reaches of the Conservation Area, Douglas fir (*Pseudotsuga taxifolia*) and aspen (*Populus tremuloides*) are included in the understory.

4. MIXED CONIFER FOREST: Consists of the same species described in "shrub/conifer," but crown closure is greater and the open grass areas proportionately smaller. Some of the stands have both mature and regrowth trees ranging from one to thirty years in age.

5. PINON/JUNIPER WOODLAND: This is the "typical" or dominant vegetation category, and the one most often associated with vegetation in the American Southwest. It is generally characterized by a thick growth of mature, to nearly decadent trees, and at higher elevations is sprinkled with ponderosa pines. Little understory (perhaps less than 15 percent, overall) is visible from the air, but there is considerable spatial variability in this parameter. Despite its regional dominance, there are only small stands of pinon/juniper woodland in the El Malpais area.

6. DECIDUOUS THICKETS: Consists of small patches of nearly pure stands of oak, aspen, or willow (*Salix spp.*). Willow stands that follow some of the main drainage lines cannot be shown on small scale printouts, but can nevertheless be identified and stored in the database for more detailed field examination and management at 1:24,000 scale. This is also true of even smaller coppices of oak that string, discontinuously, along some of the lava/sandstone contacts. These have been identified and stored in the database because of their special place in the ecosystems represented at El Malpais, and because they have special management considerations.

7. PONDEROSA PARKLAND: This is the dominant vegetation type at elevations between 6800 and 7500 feet (2100-2300 metres), and is also recognized as the fire-maintained climax. Areas are typified by mature trees (usually 50 years or more in age) standing widely apart with a continuous grass understory dotted with occasional small coppices of oak, mountain mahogany (*Cercocarpus breviflorus*), rabbitbrush, and other low shrubs. The grass synusium is typically june grass (*Koeleria cristata*), mountain muhly (*Muhlenbergia montana*), mutton bluegrass (*Poa fendleriana*), and gramma species.

8. PYGMY SCRUB/SHRUBLAND/LAVA COMPLEX: The lavas of El Malpais are not everywhere barren of vegetation, but there are large exposures of bare lava. In some areas a dwarfed and knarled "pygmy" scrub is established consisting of ponderosa pine, pinon pine (*Pinus edulis*), and juniper scattered over the surface. Ponderosa pine seldom exceeds 10 feet (3 metres). Mixed within the scrub, and in some areas becoming the dominant synusium, are shrub species. Among others, these include apache plume (*Fallugia paradoxa*), New Mexico privet (*Forestiera neomexicana*), currant, oak species, and rabbitbrush. Forbs include many composites, mint relatives, ferns, liverworts, and mosses, the latter three lifeforms being found mainly in lava caves. Over 70 lichen species have been identified on the flows, as well as many species of Cactaceae. There is an "edge effect" where flows meet the surrounding sedimentary rock that is characterized by taller (more typical growthform) ponderosa pines with an understory of grass, shrub, and pinon. These edges do not always appear on small-scale printouts (i.e., 1:100,000), but do appear on 7.5 minute quadrangle maps at scales of 1:24,000.

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