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An Evaluation of Landscape Units

Land system delineation on the basis of photographic image tone, texture, and pattern is proposed as a technique for obtaining land classification entities in a timely and cost effective manner for the Guadalupe Mountains National Park of west Texas.

Abstract: *Land system delineation on the basis of photographic image tone, texture, and pattern was proposed as a technique for obtaining land classification entities in a timely and cost effective manner for the Guadalupe Mountains National Park of west Texas.*

A quantitative method was developed which showed that (1) the boundaries of the delineated units were real in terms of slope, vegetative, and geologic variables; (2) the units were unique and internally homogeneous; and (3) homogeneity involved the biophysical composition of sites as well as the number of sites.

The land system concept accommodates the need for detailed information from which broader generalizations can be drawn, and it concomitantly organizes the collection and analysis of data in such a way that the interrelationships of physical and biological characteristics are recognized and preserved.

Introduction

Guadalupe Mountains National Park (GMNP) in southwest Texas was established in 1972 largely because of its striking beauty and geological significance, as well as because it contains several indigenous or endangered species of plants and animals. The Guadalupe Mountains are composed largely of limestone, a remnant of a huge reef called the Capitan Barrier Reef (see Figures 1 and 2). The Park, approximately 31,376 hectares (77,500 acres), contains the entire range of plant communities from xeric desert shrub to mesic coniferous forest and it includes animals as diverse as cottontails and mountain lions, porcupines, and elk (National Park Service, 1973).

As a consequence of the diversity of the Park and the need to protect the resources as well as provide for the enjoyment of visitors, the Park Service needs to identify and assess quickly the land areas which will require different management practices. If this is to be done economically, a technique must be used which obviates a great deal of field work since the mountains are extremely rugged and access is difficult. To be practical, areas must be homogeneous enough to respond predictably to a given management practice, yet large enough to prevent differing management practices from coming into conflict.

The land system or landscape concept is a technique which has potential for application to the needs cited. Initially developed through the work of Bourne (1931) and Unstead (1933), this method defines small areas and combines them into larger areas on the

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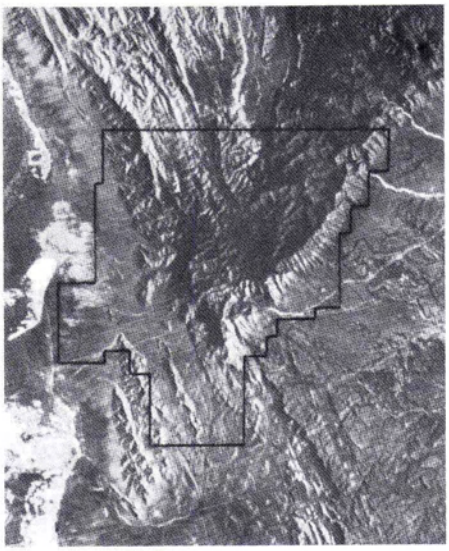

FIG. 1. Satellite photograph of the Guadalupe Mountains with Park boundaries superimposed (Skylab Photo SL2-94-291).

basis of the interrelation of many factors, one or more of which may be dominant at a given time or place. Australian researchers have further refined the landscape concept by defining and then identifying land units and land systems on aerial photographs (Christian and Stewart, 1953, 1968).

They defined the land system as "an area or group of areas, throughout which there [was] a recurring pattern of topography, soils, and vegetation." The recurring pattern was caused by land units each defined as having a distinct combination of topography, soil, and vegetation. A further subdivision, the site, was defined as being "for all practical purposes, uniform through its extent in landform, soil, and vegetation" (Christian and Stewart, 1968).

Christian and Stewart (1968) primarily delineated boundaries along a "discernable geological or geomorphogenic feature or process." They assigned equal importance to "all significant factors, landform, soil, vegetation, drainage, climate, and impact of man." Although not explicitly stated, they implied that a boundary line may occur due to any one or a combination of factors. Extensive use of aerial photographs was made both in the laboratory and in the field initially to define boundaries which were refined if necessary based on ground truth derived from sample transects in the final field work.

Major contributions to land classification have also come from Great Britain, the Soviet Union, and the United States. Though terminology varies with authors, the basic units are defined essentially as those of Christian and Stewart (Bourne, 1931; Flynn, 1974; Keuper, Peplies, and Gillooly, 1977; MacPhail, 1971; Nichol, 1975; Peplies and Flynn, 1972; Peplies and Wilson, 1970; Solntsev, 1962; Vinogradov *et al.*, 1962; Webster and Beckett, 1970).

Although the techniques of land classification were potentially applicable to the GMNP, it was considered necessary to develop some quantitative method by which the boundaries of land areas could be tested. Only by demonstrating the reality of the boundaries could the land classification technique (using aerial photographs) be considered practical for park management applications.

The objectives of this research program were (1) to test thoroughly the boundaries delineated from aerial photographs using complete ground truth data on slope, vegetation, and geology; (2) to compare all land areas with each other to determine their degree of uniqueness; and (3) to examine the homogeneity of the delineated areas in terms of the patterns of the aforementioned factors.

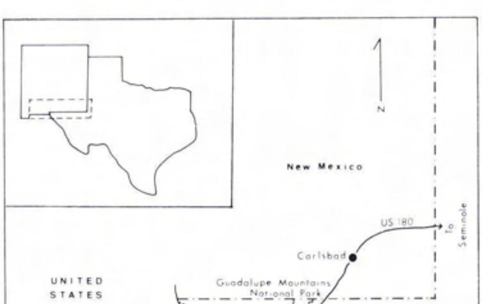

FIG. 2. Location map.

METHODOLOGY

The major steps to achieve the objectives set forth were to (1) delineate landscape unit boundaries on aerial photographs; (2) determine the kinds and quantities of various physical and biological factors in each landscape unit from ground truth; (3) test the aerial photographic delineations with ground truth in order to verify the boundaries; (4)

test for any similarities among landscape units and; (5) test the landscape units for internal homogeneity.

Land areas were delineated on the basis of homogeneous image signatures proposed by Lueder (1959) using black-and-white vertical aerial photographs (average scale 1:32,500). This identification and delineation involved the use of several diagnostic characteristics associated with "photo image signatures," which included a combination of tone, pattern, and texture. Stereoscopic study permitted further refinements to be made on the basis of major topographic characteristics in the study area. These delineations did not solely depict either major geologic or geomorphogenic changes or single landforms (the criteria for Christian and Stewart's land systems and land units respectively), but they did reveal repetitive patterns. As a result, it was decided that the delineations represented an intermediate classification, the landscape unit, and that the elements of the repetitive patterns were the sites. Thus the landscape unit is defined as an area exhibiting a unique photographic image on the basis of tone, texture, pattern, and topographic factors, the boundaries of which do not necessarily coincide with major geologic or geomorphologic divisions or specific landforms, but which are determined by the occurrence of groups of repetitive sites.

The landscape unit delineations were enlarged to a scale of 1:24,000 to provide easy comparison with United States Geological Survey (USGS) topographic maps of the Park (Figure 3). Complete ground truth for the Park consisted of maps of vegetation associations, surface geology, and slope. Soils data were not available. The maps were all brought to a scale of 1:24,000.

The vegetation map describes 139 different associations based on community form and descending order of genera or species dominance by growth form (Interagency Browse Survey Map, 1974). The surface geology map depicts the eight major geological classifications in the Park (Goolsby, 1974), and the slope map, prepared from USGS maps, uses three classes to indicate gentle, moderate, and steep slopes.

The four maps—landscape units, vegetation, geology, and slope—were overlaid and a composite map was drawn. Within each landscape unit, sites were delineated which consisted of one class each of the factors slope, vegetation, and geology. Following this, the area of each landscape unit and its associated sites were measured.

One additional term, the distinct unit, must be defined. A distinct unit consists of one or more sites having the same combination of slope, vegetation and geology. To illustrate this concept, a map of landscape unit 32 is presented (Figure 4) and a tabular description of each site in that landscape unit is given (Table 1). Each site on the map is numbered and corresponds to the site description in the table. All sites which have

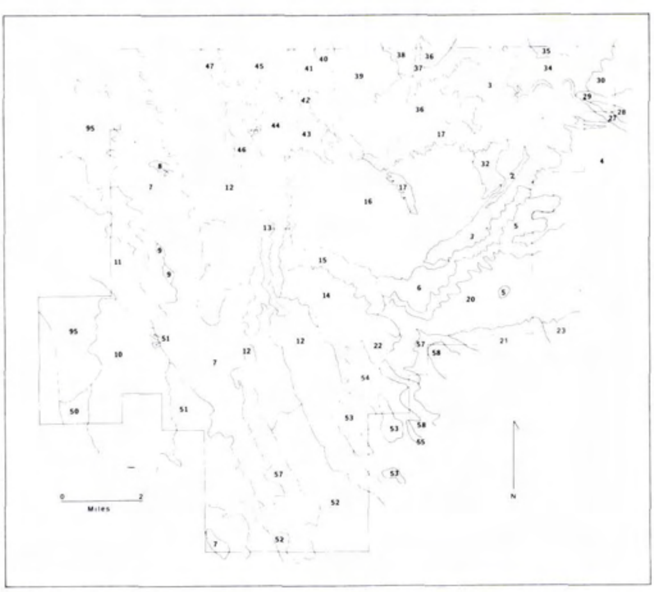

FIG. 3. Landscape units in Guadalupe Mountains National Park.

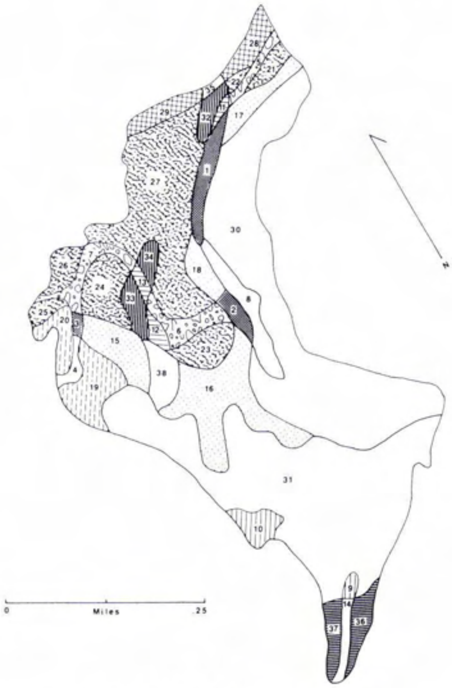

FIG. 4. Landscape unit 32.

identical descriptions within a single landscape unit were combined for the purpose of analysis and the resulting unit is called a distinct unit. This is indicated on the map by assigning each set of the identical sites one graphic pattern each. Sites which occur only once are left blank. Brackets are used in the table to show which sites have been combined into distinct units. Distinct units may contain several sites or only one site.

The significance of distinct units lies in the relationship between the total number of sites and the total number of distinct units within a particular landscape unit. If the ratio of sites to distinct units increases, this implies repetition within the landscape unit. That is to say, the landscape unit is composed of a relatively smaller number of uniquely different sites which are recurring or repeating throughout the landscape unit.

BOUNDARY TEST

The boundary test was developed to determine if the lines delineated on the aerial photographs represented actual differences between adjacent landscape units. Each physical factor (slope, vegetation, and geology) was compared independently. The percent composition for each class of a factor was obtained by dividing the area of a given class by the total area of the appropriate landscape unit. These percent compositions were then paired with the percent compositions of adjacent landscape units. The similarity level was obtained by adding the lower percent composition in each class and summing these. Table 2 presents a hypothetical example of the testing procedure.

The lower percent composition number in each class of the two landscape units was assumed to represent the greatest degree to which the landscape units were similar; therefore, the lower numbers were added and the sum equaled the minimum similarity level between the landscape units for the particular factor being considered.

Because boundaries are rarely distinct, if two adjacent landscape units had similarity levels of at least 90 percent in all three factors, they would be considered identical and the boundary line would be removed; they then became one landscape unit. If similarity was less than 90 percent in even one factor, the boundary was deemed real.

The 90 percent level was chosen because mountain landscapes have such variety that different management practices may be essential for their protection and enjoyment. If a lower level of agreement was accepted, some landscape units might appear similar, yet if managed the same, serious harm could result. Thus, a stringent similarity test allows a safety margin which can be later relaxed if more detailed study so indicates.

SIMILARITY TESTS

The landscape units were tested for similarity by using ground truth data to verify the qualitative results of the photo interpretation which indicated that each landscape unit was visually different from all others in the Park in terms of tone, texture, and pattern.

A pairwise comparison of all landscape units, whether adjacent or not, was made using the percent compositions of the classes for the slope, vegetation, and geology factors (each factor being tested separately). If two landscape units had similarity levels of at least 90 percent in all three factors, they were considered similar.

One important aspect of the similarity level test was to determine to what degree the landscape units were dissimilar. It was decided that they had to be more than 10 percent dissimilar to be considered unique, but, if all the landscape units evidenced greater degrees of dissimilarity, this would further support the contention that the delineated units were unique. This was accomplished by choosing the pair of land-

TABLE 1. LANDSCAPE UNIT 32 SITE DESCRIPTIONS

Site	Area in Square Miles	Slope Factor Classes[1]	Vegetation Factor Classes[2]	Geology Factor Classes[3]	Distinct Unit
1	0.008	5-50	10-Acgr-PP-Psme-Arte	Ml	
2	0.005	5-50	10-Acgr-PP-Psme-Arte	Ml	I
3	0.002	5-50	10-Acgr-PP-Psme-Arte	Ml	
4	0.004	5-50	5-Cebr-Cegr-QUER-DALE	Ml	II
5	0.007	5-50	5-DALE-QUER-Cebr-Cegr	Ml	
6	0.010	5-50	5-DALE-QUER-Cebr-Cegr	Ml	III
7	0.012	5-50	5-DALE-QUER-Cebr-Cegr	Ml	
8	0.017	5-50	6-PP-Acgr-Arte-QUER	Ml	IV
9	0.002	5-50	6-PP-Psme-Acgr-QUER	Ml	
10	0.007	5-50	6-PP-Psme-Acgr-QUER	Ml	V
11	0.004	5-50	5-DALE-QUER-Cebr-Cegr	Tl	
12	0.004	5-50	5-DALE-QUER-Cebr-Cegr	Tl	VI
13	0.003	5-50	5-DALE-QUER-Cebr-Cegr	Tl	
14	0.004	5-50	6-PP-Psme-Acgr-QUER	Tl	VII
15	0.018	50	10-Acgr-PP-Psme-Arte	Ml	
16	0.040	50	10-Acgr-PP-Psme-Arte	Ml	VIII
17	0.010	50	10-Acgr-PP-Psme-Arte	Ml	
18	0.010	50	10-Acgr-PP-Psme-Arte	Ml	
19	0.020	50	5-Cebr-Cegr-QUER-DALE	Ml	
20	0.008	50	5-Cebr-Cegr-QUER-DALE	Ml	IX
21	0.007	50	5-DALE-QUER-Cebr-Cegr	Ml	
22	0.002	50	5-DALE-QUER-Cebr-Cegr	Ml	
23	0.012	50	5-DALE-QUER-Cebr-Cegr	Ml	
24	0.017	50	5-DALE-QUER-Cebr-Cegr	Ml	X
25	0.005	50	5-DALE-QUER-Cebr-Cegr	Ml	
26	0.008	50	5-DALE-QUER-Cebr-Cegr	Ml	
27	0.070	50	5-DALE-QUER-Cebr-Cegr	Ml	
28	0.009	50	5-DALE-QUER-Cebr-Gawr	Ml	
29	0.009	50	5-DALE-QUER-Cebr-Gawr	Ml	XI
30	0.148	50	6-PP-Acgr-Arte-QUER	Ml	XII
31	0.154	50	6-PP-Psme-Acgr-QUER	Ml	XIII
32	0.004	50	5-DALE-QUER-Cebr-Cegr	Tl	
33	0.008	50	5-DALE-QUER-Cebr-Cegr	Tl	XIV
34	0.004	50	5-DALE-QUER-Cebr-Cegr	Tl	
35	0.002	50	5-DALE-QUER-Cebr-Gawr	Tl	XV
36	0.008	50	6-PP-Psme-Acgr-QUER	Tl	XVI
37	0.006	50	6-PP-Psme-Acgr-QUER	Tl	
38	0.012	50	10-Acgr-PP-Psme-Arte	Tl	XXVII

[1] Percent Slope Ranges
[2] Community Types: 5 - Mountain Shrub; 6 - Conifer; 10 - Hardwood
Dominant Plants: Acgr - Acer grandidentatum - big-tooth maple
Arte - Arbutus texana - Texas madrone
Cebr - Cerocarpus breviflorus - mountain mahogany
Cegr - Ceanothus greggii - desert ceanothus
DALE - Dalea Spp. - indigo bush
Gawr - Garrya wrightii - Wright silktassel
PP - Pinus ponderosa - ponderosa pine
Psme - Pseudotsuga menziesii - Douglas fir
QUER - Quercus Spp. - oak
[3] Tl - Thin bedded limestone and/or dolomite.
Ml - Massive or thick bedded limestone and/or dolomite.

scape units which had the highest percent compositions in all three factors. For this pair, the lowest percent composition of the three factors was subtracted from 100 percent and the result was the absolute minimum degree of dissimilarity among all pairs of landscape units. For example, if the landscape unit pair having the highest percent compositions in all three factors had these similarity values: 60 percent, 100 percent, and 100 percent in vegetation, slope, and geology, respectively, then by subtracting 60 percent from 100 percent the result would be 40 percent dissimilarity. Obviously, for any other landscape unit pair having percent compositions less than those in the example, the result would be greater dissimilarity.

TABLE 2. HYPOTHETICAL AGREEMENT LEVEL TEST FOR ALL FACTORS

	Landscape Unit A	Landscape Unit B	Agreement Level
Slope factor classes			
<5%	0	0	0
5-50%	46	48	46
>50%	54	52	52
			98
Geology factor classes			
Thin bedded limestone	88	82	82
Massive limestone	3	4	3
Sandstone	9	14	9
			94
Vegetation factor classes			
Mountain Shrub characterized by Nolina texana, Cercocarpus breviflorus, Dalea spp. and Quercus spp.	14	24	14
Mountain Shrub characterized by Pinus/Juniperus, Quercus spp. Mahonia trifoliata and Opuntia imbricata	44	8	8
Mixed forest characterized by Pinus ponderosa, Pseudotsuga menziesii, Acer grandidentatum and Quercus spp.	0	68	0
Desert shrub characterized by Viguiera stanoloba, Larrea tridentata, Parthenium incanum and Dalea spp.	42	0	0
			22

Because of the variety within the landscape units it was possible that two might appear unique using the similarity levels of slope, vegetation, and geology separately, and yet they might be similar in terms of the *dominant distinct units*, i.e., those distinct units whose areas summed to 50 percent or more of a landscape unit area. As a result, all landscape unit pairs were further tested for uniqueness using the descriptions of the dominant distinct units. Landscape units were considered unique if the dominant distinct units occurred only once among all 46 landscape units. If a particular dominant distinct unit occurred in more than one landscape unit and it was the only dominant distinct unit in each landscape unit, then the landscape units would be considered similar.

HOMOGENEITY TESTS

Closely associated with the concept of uniqueness is the concept of internal homogeneity of the designated landscape units. For utility and viability of landscape units as management entities, the delineated landscape unit must display a greater level of homogeneity than would a series of randomly configured units of comparable size. That is to say, the landscape units are internally more homogeneous than randomly configured units.

Given the great diversity of slope, vegetation, and geology in the landscape units and the range of sizes (areal extent), some means of analyzing the site composition of landscape units had to be devised which would accommodate the variety and yet not make size a limiting criterion.* A totally

* If the size of a landscape unit were the determinant factor in landscape unit analysis, then every landscape unit would have to be analyzed individually, which would preclude a synthesis of information and thus eliminate the landscape unit concept as a predictive tool.

homogeneous landscape unit is one which, throughout its extent, is made up of only one combination of slope, vegetation, and geology. Thus, it would have one site and one distinct unit. A totally heterogeneous landscape unit would have many singular sites and an equal number of distinct units.

Sites, although not defined in terms of areal extent, are generally much smaller than individual landscape units; therefore, increase in landscape unit size is a function of increasing numbers of sites being included within a particular landscape unit. Thus, the key element in evaluating homogeneity for a given landscape unit is site repetitiveness within the unit.

If a landscape unit were to approach homogeneity, (1) sites would have to become repetitious; (2) the number of distinct units per unit area would not increase at a rate equal to the rate of area increase and; (3) the number of dominant distinct units would tend to remain low (Table 3).

To test whether the delineated landscape units are, in fact, entities with greater internal homogeneity than comparably sized randomly configured units, three minor null hypotheses were devleoped. These assumed that the delineated units were not effective in reducing internal homogeneity; that is, they were no better than a series of randomly drawn units. The three null hypotheses were

- The number of distinct units per unit area was independent of landscape unit size,
- The number of sites per dominant distinct unit was independent of landscape unit size, and
- The ratio of dominant distinct units to total number of distinct units in a landscape unit was independent of landscape unit size.

These three hypotheses were tested using Hotelling and Pabst's test for Rank-Order Correlation with $H_0 :: p = 0$ (Bradley, 1968). Rejection of the null hypothesis (the variables are independent) points to acceptance of the two possible alternative hypotheses, namely: there is a positive correlation between variables; or there is a negative correlation between the variables.

A caveat must be inserted at this point concerning hypothesis (b). A paradox arises when totally homogeneous landscape units and totally heterogeneous landscape units are tested. Since the totally homogeneous landscape unit would have one site and one dominant distinct unit, the ratio of the number of sites per dominant distinct units would be one. In contrast, a completely heterogeneous landscape unit would have many unique sites and an equal number of distinct units. As a result, the ratio of the number of sites to dominant distinct units would also equal one. Thus, both the homogeneous and heterogeneous landscape units would have the same ratio value. Apart from these two exceptions, and remembering that they deal with models rather than reality, the tests presented appear to be viable means of evaluating the hypotheses.

Results and Discussion

Several landscape unit pairs showed high degrees of boundary similarity in two factors, but at least one factor in each case had a low boundary similarity. Thus, the first major hypothesis, that the boundaries delineated using aerial photographs were real, was verified.

All landscape units were compared by pairing each landscape unit with every other landscape unit in order to find the individual similarity levels for slope, vegetation, and geology. In every case, one or two factors exhibited less than 90 percent similarity. The least dissimilarity that occurred was 39 percent in the landscape unit pair 11 and 95; thus, not only were the landscape unit pairs not similar, but they also were dissimilar at a minimum of 39 percent.

The dominant distinct units, those whose areas summed to at least 50 percent of a landscape unit, were listed for all possible landscape unit pairs and their descriptions, using slope, vegetation, and geology simultaneously, were compared with all other dominant distinct units. This additional test was performed because it was possible that two landscape units might appear unique in the individual factors, but could be similar if they each only had a single identical dominant distinct unit. With the exception of three landscape unit pairs—21 and 23, 28 and 30, and 11 and 95—all other landscape units were found to be unique in terms of dominant distinct units.

Considering the fact that there were 1425 possible pairs of landscape units evaluated in the uniqueness testing, it is remarkable that only three landscape unit pairs were not clearly designated as singularly unique. Further examination of these three pairs revealed that, while each pair did have a single identical dominant distinct unit, the site distribution caused a sufficiently different pattern (on the aerial photographs) between members of a pair to be indicative of a "uniqueness" which could possibly be of significance in the management of these areas. Therefore, it was deemed desirable to

TABLE 3. HOMOGENEITY DATA

Landscape Unit	Area in Square Miles	Number of Sites	Number of Distinct Units	Number of Distinct Units/ Square Mile	Sites/ Dominant Distinct Unit	Number of Dominant Distinct Units	Ratio of Dominant Distinct Units to Total Distinct Units
8	0.113	11	6	53.10	1.50	2	0.33
9	0.145	3	2	13.79	2.00	1	0.50
28	0.153	4	3	19.61	2.00	1	0.33
29	0.154	10	9	58.44	1.00	2	0.22
2	0.193	6	5	25.91	1.50	2	0.40
23	0.209	5	4	19.14	1.00	1	0.25
37	0.220	10	8	36.36	1.00	3	0.38
27	0.298	26	16	53.69	3.50	2	0.13
38	0.385	27	20	51.95	1.00	3	0.15
50	0.425	2	2	4.71	1.00	1	0.50
22	0.479	22	15	33.40	1.00	1	0.06
42	0.503	15	11	21.87	1.67	3	0.27
46	0.514	28	16	31.13	3.00	3	0.19
41	0.630	20	11	17.46	3.50	2	0.18
32	0.680	38	17	25.00	3.00	3	0.18
58	0.683	47	19	27.82	4.00	3	0.16
47	0.753	29	10	13.28	4.50	2	0.20
21	0.832	10	6	7.21	2.00	1	0.17
13	0.999	51	28	28.03	4.00	3	0.11
53	1.007	47	21	20.85	4.00	4	0.19
40	1.025	29	13	12.67	5.50	2	0.15
43	1.127	78	27	23.96	6.00	3	0.11
30	1.220	6	5	4.10	1.00	1	0.20
44	1.445	55	23	15.92	7.00	2	0.09
11	1.525	13	7	4.59	6.00	1	0.14
95	1.544	16	5	3.24	5.00	1	0.20
15	1.617	98	28	17.32	12.00	2	0.07
54	1.620	105	49	30.25	4.57	7	0.14
17	1.849	79	32	17.31	4.00	3	0.09
6	1.992	52	24	12.05	1.00	1	0.04
4	2.090	40	18	8.61	4.00	2	0.11
5	2.263	160	54	23.86	6.71	7	0.13
34	2.268	55	21	9.26	2.00	1	0.05
39	2.377	152	33	13.88	13.20	5	0.15
45	2.404	79	23	9.57	4.50	2	0.09
14	3.129	84	25	8.31	11.00	2	0.08
52	3.469	77	46	13.26	1.33	6	0.13
51	3.514	105	50	14.23	5.00	5	0.10
57	3.759	132	74	19.69	2.00	10	0.14
36	4.007	257	61	15.22	12.83	6	0.10
20	5.746	120	44	7.66	8.50	2	0.05
10	6.692	60	31	4.63	3.00	2	0.07
3	8.023	240	60	7.47	3.20	5	0.08
16	12.394	724	108	8.71	24.86	7	0.07
7	16.112	304	150	9.31	3.33	9	0.06
12	17.369	867	243	13.99	8.63	30	0.12

consider also these landscape units to be unique at this time.

The third major hypothesis dealt with the internal homogeneity of the landscape units, and this was examined by postulating three minor null hypotheses, all of which were tested using Hotelling and Pabst's Test for Rank-Order Correlation (Bradley, 1968).

The first postulated that the number of distinct units per unit area was independent of landscape unit size. A negative correlation ($r = -0.57$) was obtained, and the null hypothesis was rejected. The alternative hypothesis of negative correlation was accepted or, as landscape unit area increased, more repetitive sites were being included within the landscape unit boundary. Although the total number of distinct units may have increased with increasing landscape unit size, the number increased at a much lower rate because more repetitive sites were being encountered (see Table 4).

The second null hypothesis was that the number of sites per dominant distinct unit was independent of landscape unit size. In this case the number of sites per dominant distinct unit was positively correlated to landscape unit area ($r = 0.70$). The alternative hypothesis of positive correlation was accepted. The implication was that sites which constituted dominant distinct units were repeating themselves more frequently as a landscape unit area increased.

The third null hypothesis states that the ratio of the number of dominant distinct units to the total number of distinct units in a landscape unit was independent of landscape unit size. The correlation was negative ($r = -0.75$); thus, the null hypothesis was rejected and the alternative hypothesis of negative correlation was accepted. This result implied that the number of dominant distinct units was remaining low, or increasing only slightly as landscape unit area increased. Hence, not only was site repetition becoming more frequent, it was becoming more frequent in the very restricted range of slope, vegetation, and geology of the dominant distinct units.

In consequence, the following conclusions were drawn: (1) that identical sites were recurring as landscape unit area increased; (2) that the repetitive sites were recurring frequently; and (3) that the frequent recurrence was particularly associated with the dominant distinct units.

These results would not occur in a series of randomly configured landscape units delineated on aerial photographs. As random units increased in size, they would certainly encompass a larger amount of sites; however, site repetitiveness within such a unit would occur only by chance which should not have to lead to rejection of the established null hypotheses. Thus, the contention that the landscape units do represent internally homogeneous areas with respect to the variables of interest is supported by the ground truth data analysis.

Thus, research indicates that the delineated landscape units are indeed distinct entities which display a greater degree of internal homogeneity than would a series of randomly configured units of similar size.

Conclusions

Unit delineation on the basis of photographic image tone, texture, and pattern was proposed as a technique for obtaining land classification entities in a timely and cost effective manner.

In managing for preservation and recreation or, indeed, any other kind of land management, the data used for analysis must meet two basic criteria. Initially, the data must include those natural elements whose interactions are predominant in the area of interest. Not all data can be derived from one source, but aerial photography can provide much of it, and other elements or their effects can be inferred. The data must be detailed enough to provide adequate information for small or unique areas which will require intensive management. Concomitantly, the data should be able to provide information from which meaningful generalizations can be drawn. As a result, the data must be suitable for analysis.

The second basic requirement concerns the organization of the data. Natural elements do not occur in isolation; rather, they form associations whose effects are often more than the sum of the parts. Consequently, data organization should take this into account.

The land system concept accommodates the need for detailed information from which broader generalizations can be drawn as required and, at the same time, organizes the collection and analysis of data in such a way that the interrelationships of elements are recognized and preserved.

Specifically, for boundary delineations it was found that photographic interpretation distinguished fine differences in slope, vegetation, and geology. Though further studies or management considerations may indicate that these fine distinctions can be ignored, it is well to note that those differences do exist. Similarly, the tests which showed the uniqueness of the landscape units were made at a very stringent level requiring 90 percent agreement among all three factors of slope, vegetation, and geology. This could also be relaxed, but, the stringent test provides a margin of safety in the event that future studies show differences to be important.

The concept of homogeneity is particularly important to management because it can be used to guide the development of various practices. Homogeneity involved the physical and biological composition of sites as well as the number of sites. In regard to the latter, it was noted that the sites exhibited repetitiveness and that the frequency of repetition was particularly associated with the dominant distinct units, those which made up 50 percent or more of a given landscape unit.

TABLE 4. TEST OF HYPOTHESIS THAT THE NUMBER OF DISTINCT UNITS PER UNIT AREA WAS INDEPENDENT OF LANDSCAPE UNIT SIZE.

Landscape Unit	Landscape Unit Rank (by area)	Distinct Units per Unit Area Rank	Rank Difference d_i	Rank Difference Squared d_i^2
8	1	44	−43	1849
9	2	19	−17	289
28	3	29	−26	676
29	4	46	−42	1764
2	5	36	−31	961
23	6	28	−22	484
37	7	42	−35	1225
27	8	45	−37	1369
38	9	43	−34	1156
50	10	5	5	25
22	11	41	−30	900
42	12	32	−20	400
46	13	40	−27	729
41	14	27	−13	169
32	15	35	−20	400
58	16	37	−21	441
47	17	18	− 1	1
21	18	6	12	144
13	19	38	−19	361
53	20	31	−11	121
40	21	16	5	25
43	22	34	−12	144
30	23	2	21	441
44	24	24	0	0
11	25	3	22	484
95	26	1	25	625
15	27	26	1	1
54	28	39	−11	121
17	29	25	4	16
6	30	15	15	225
4	31	10	21	441
5	32	33	− 1	1
34	33	12	21	441
39	34	20	14	196
45	35	14	21	441
14	36	9	27	729
52	37	17	20	400
51	38	22	16	256
57	39	30	9	81
36	40	23	17	289
20	41	8	33	1089
10	42	4	38	1444
3	43	7	36	1296
16	44	11	33	1089
7	45	13	32	1024
12	46	21	25	625

$$\sum_{i=1}^{n} d_i^2 = 25388$$

$$r_s = 1 - \frac{6\,(25388)}{97290}$$

$$= 1 - 1.57$$

$$= -0.57$$

The critical values of r_s for $n = 46$ are $-0.50 \geq r_s \geq 0.50$ with $\alpha = 0.0005$

Site repetition is important because it may suggest the existence of catena or continuum relationships or, at least, significant associations. If an area has groups or associations of identical sites, then a management practice can be developed on a broader scale, avoiding the necessity and virtual impossibility of individual site management. It would also indicate the diversity of a landscape unit and aid in determining how flexible specific site management practices might have to be.

The management of a land area is concerned with many things, including how much of the area is made up of the same or similar kinds of distinct units. If 50 percent or more of an area is made up of only a few distinct units, then management practices could be geared toward these few with the smaller areas identified and used as limiting factors. The smaller areas may be of critical importance in terms of how they respond to management practices, so it is important that they be included in the analysis.

This research has shown that landscape units can be effectively delineated in a region of extreme diversity and complexity. The boundaries of the delineated units were shown to be real in terms of slope, vegetative, and geologic variables. The units were shown to be unique and to be internally homogeneous when compared to randomly configured units of similar size. In addition, each landscape unit was dominated by limited associations of slope, vegetation, and geology. The recognition of dominant distinct units holds particular value for the application of the land system concept to rugged or remote areas. Provided that the landscape units are delineated with care, the necessity for complete ground truth is obviated; hence, only sampling would be required to obtain the necessary data for reliable extrapolation. Areas of particular or critical concern can also be readily identified and sampled more intensively as the situation demands.

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References

Bourne, R., 1931. Regional survey, *Oxford Forestry Memoirs*, v. 13, 7-62, as cited in J. A. Mabbutt, 1968, Principles of land classification and evaluation, in *Land Evaluation*, G. A. Stewart (ed.) 1968, Macmillan of Australia, Melbourne, Australia.

Bradley, James V., 1968. Distribution-free statistical tests. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Christian, C. S., and G. A. Stewart, 1953. *General report on survey of Katherine-Darwin region, 1946*, CSIRO Australian Land Research Series no. 1.

———, 1968. Methodology of integrated surveys, Aerial Surveys and Integrated Studies, Proceedings of the Toulouse Conference, UNESCO, Paris.

Flynn, Thomas J., Jr., 1974. *An analysis of the photomorphic concept: a case study of the Mississippi Delta*, Technical Report VI-74-1, University of Tennessee, Knoxville and East Tennessee State University, Johnson City, through Air Force Systems Command, USAF.

Goolsby, Jimmy E., 1974. *Surface rock material of the Guadalupe Mountains National Park Area, Texas*, Map, Department of Geosciences, Texas Tech University, Lubbock.

Interagency Browse Survey Map, 1974. In *range condition survey and wildlife browse analysis, Carlsbad Caverns and Guadalupe Mountains National Parks*, by M. R. Glass, R. E. Reisch and G. M. Ahlstrand. National Park Service, 15 p. (Mimeo)

Keuper, Harold F., Robert W. Peplies, and Robert F. Gillooly, 1977. *Photomorphic analysis techniques: an interim spatial analysis using satellite remote sensor imagery and historical data*, Final Report, National Aeronautics and Space Administration-Manned Space Flight Center, Environmental and Regional Research Associates, Inc., Report No. 74-17(R)-Y, Johnson City, Tennessee.

Lueder, D. R., 1959. *Aerial Photographic Interpretation: Principles and Applications*, McGraw Hill Book Company, New York, N.Y., 462p.

MacPhail, Donald D., 1971. Photomorphic mapping in Chile, *Photogrammetric Engineering*, v. 37, no. 11, pp. 1139-1148.

Nichol, Janet E., 1975. Photomorphic mapping for land-use planning, *Photogrammetric Engineering and Remote Sensing*, v. 41, no. 10, pp. 1253-1258.

Peplies, Robert W., and James D. Wilson, 1970. *Analysis of a space photo of a humid and forested region: a case study of the Tennessee Valley*, East Tennessee State University, Johnson City.

Peplies, Robert W., and Thomas J. Flynn, Jr., 1972. Spacecraft, photomorphic units, and regional analysis, Paper presented at the 1972 Southeastern Conference of the IEEE, University of Tennessee, Knoxville.

Semple, Ellen Churchill., 1911. Influence of Geographic Environment, as cited in G. R. Heath, 1956, A comparison of two basic theories of land classification and their adaptability to regional photo interpretation key techniques, *Photogrammetric Engineering*, v. 22, no. 1, pp. 144-168

Solntsev, N. A. (ed.), 1962. *The Morphological Structure of the Geographic Landscape*, Moscow State University, Moscow, as cited in A. G. Isachenko, 1973, *Principles of Landscape Science and Physical-Geographic Regionalization*, Melbourne University Press, Melbourne, Australia.

United States Department of the Interior, National Park Service, 1973. *Master Plan, Guadalupe Mountains National Park*, USGPO, Washington, D.C.

Unstead, J. F., 1933. A system of regional geography, *Geography*, no. 18, pp. 185-187, as cited in J. A. Mabbutt, 1968, Principles of land classification and evaluation, in *Land Evaluation*, G. A. Stewart (ed.), 1968, Macmillan of Australia, Melbourne, Australia.

Vinogradov, V. V., K. I. Gerenchuk, A. G. Isachenko, K. G. Raman, and Yu. N. Tsesel'chuk, 1962. Basic principles of landscape mapping, *Soviet Geography: Review and Translation*, v. 3, no. 6, pp. 15-20.

Webster, R., and P. H. T. Beckett, 1970. Terrain classification and evaluation using air photography: a review of recent work at Oxford, *Photogrammeteria*, v. 26, nos. 2 and 3, pp. 51-75.

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