The Derivation of Scenic Utility Functions and Surfaces and Their Role in Landscape Management[1]

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Abstract: This paper outlines a methodological approach for determining relevant physical landscape features which people use in formulating judgments about scenic utility. This information, coupled with either empirically derived or rationally stipulated regression techniques, may be used to produce scenic utility functions and surfaces. These functions can provide a means for setting landscape management objectives and evaluating the efficiencies of alternative management strategies.

INTRODUCTION

The problem areas of landscape preference prediction and aesthetic impact assessment have emerged as important research topics. This research has been legislatively mandated, and that mandate is reinforced by our desire to properly allocate and manage scenic resources. Vision plays an extremely important role in processing information and has even been demonstrated to dominate other sense modalities (Rock and Harris 1967). Despite the fact that a significant proportion of the information that man processes is visual, we have limited knowledge about how visual bits of information are modified and interpreted to stimulate sensations of pleasure and displeasure.

However, over the past ten years, concentrated research efforts have produced several workable prediction models, a variety of methodological frameworks and some surprisingly consistent results. Much of the foregoing research has been somewhat molecular in nature -- that is, it has concentrated on predicting preferences for limited subject populations, methodological testing and development, validity testing of simulations, prediction of preference of singular landscape modifications and checking for biases in landscape research which could affect the internal validity of our models and techniques. Nevertheless, it is our feeling that these research efforts were properly limited in scope. Without such simplified testing and methodological probing, we would be attempting to build an atomic reactor without first understanding the nature of sub-atomic particles.

It appears that the point has been reached where the development of more elaborate and theoretically rational models can proceed.[3] Specifically, these detailed models should be able to make predictions of overall preference for scenic beauty <u>magnitudes</u> and estimate changes in these values resulting from physical landscape changes. The requirement of interval scaling is necessary, we believe, since this

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[3]A rational model is one which is based in theory, and is distinct from empirical models which are derived strictly by means of fitting functions to data.

allows the planner to answer the question of "how much better?" or its corollary of "how much worse? ." Rank or ordinal values of preference do not, technically, permit such answers. Obviously, the model should also permit the assessment of changes in quantities of preference resulting from changes or differences in a mix of landscape dimensions or elements. This would then allow us to begin thinking within the framework of objective aesthetic impact assessment.

Shafer et al.'s (1969) work was an early attempt to develop a predictive model for landscape preference. Specifically, physical landscape measures taken from photographs were used to predict a rank-sum value of preference. Through examination of Shafer et al.'s model, many researchers obtained a glimpse of the effects of certain physical variables on visual preference. However, because the intent of model was prediction and not explanation, the mathematical complexity of some of the combinatory variables defied even conceptual cause-effect explanation. In addition, the dependent variable (visual preference) was still only an ordinal value.

Interest in the measurement of magnitudes of preference and scenic beauty led Daniel and Boster (1976) to develop a method based on Signal Detection Theory whereby Scenic Beauty Estimates (SBE's) could be computed for landscapes. This method has been successfully used to develop models of landscape assessment using mensurational parameters as predictors of preference (Arthur 1977), to gauge the visual effects of silvicultural treatments (Daniel et al. 1973, Schweitzer et al. 1976) and to develop a mapping procedure for scenic beauty in forested landscapes (Daniel et al. 1977). Other attempts at measuring interval preferences also rest on the foundations of psychophysical scaling methods similar to Signal Detection Theory. Jackson et al. (1978) utilized the Law of Comparative Judgment and the Luce Axiom to obtain estimates of visual impacts of power-line corridors.

Therefore, it seems that magnitude estimates of preference can be made for an overall scene. The problem, then, is to relate fluctuations in these magnitudes to specific physical changes in the visual environment. In this way it might he possible to specify mathematical models or functions which characterize the visual perceptual process and which eventually may lead to the development of scenic utility functions. The purpose of this paper is to discuss some possibilities for research in this area.

Psychological Disutility Functions -- A Start

In an effort to estimate the aesthetic impacts of southern pine beetle (SPB) damage, Buhyoff and Leuschner (1978) were able to estimate reliably magnitudes of preference for forest landscape scenes with a variety of types and levels of SPB damage. Preference was measured using the Case III assumptions of the Law of Comparative Judgment. Details of this methodology can be found in Buhyoff and Riesenman (in press). This methodological procedure produced interval preference scores for landscapes which were then correlated with changes in SPB damage. Non-linear regression techniques were used to estimate the drop in scenic preference with increases in SPB damage. The resulting curves, shown in Figure 1 for both informed and naive subjects, were called

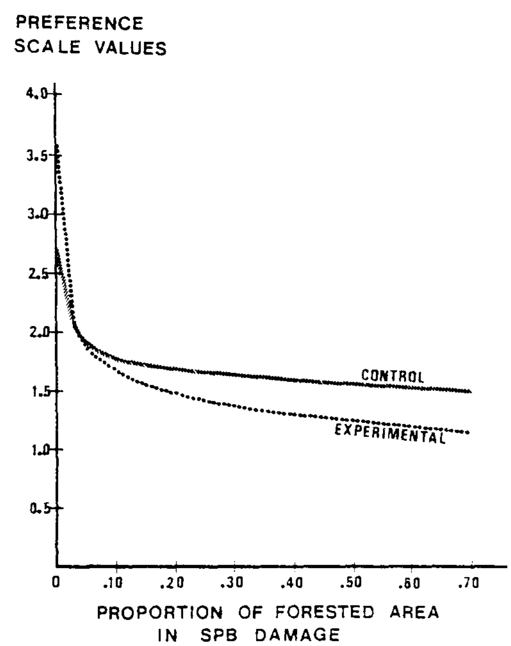

Figure 1. An example of a two-dimensional psychological disutility function. Reprinted with permission of Forest Science.

psychological disutility functions (Buhyoff and Leuschner 1978). The inflection points of these functions can be used to set practical management guidelines. For example, for the experimental group in Figure 1, the slope of the disutility function is very steep at low levels of insect damage, while declines in preference for SPB damage past approximately 10 percent of the visible forested area much less rapid. Experimental data collection techniques permitted "forced" subject cueing on a single dimension, thereby producing non-linear models which accounted for approximately 0.86 of the variability in landscape preference scores. Lower amounts of variability in preference (R^2 = 0.33) were accounted for when people did not cue on a single dimension. These findings indicate that a multidimensional space must be defined, since the viewing process is undoubtedly more holistic than that which is artificially created by experimentally manipulating the overall landscape scene and/or the dimensions and characteristics which are viewed.

The construction of multidimensional scenic utility functions is a natural extension of such two-dimensional procedures. Two types of techniques will be discussed wherein the landscape perception process may be quantitatively represented as the interaction of (N) dimensions which produce a mathematical surface. One technique, multidimensional scaling, is appropriate when the underlying dimensions of a landscape are not known. Judgments of similarities between landscapes produce a perceptual map identifying dimensions important to the judge(s). A similar technique, Smallest Space Analysis, has been previously and successfully applied to landscape research (Kaplan *et al*. 1972, Kaplan 1975). A second technique, policy-capturing, is a simple extension of the SPB example in that preference judgments for landscapes are regressed on several dimensions of known levels, thereby providing a policy. Policies obtained from several individuals may then be clustered to obtain composite policies. This methodological approach has not been used until recently (Propst 1979) for the analysis of visual configurations. Both approaches can be useful in developing theories of landscape preference and in producing scenic utility surface topographies.

Multidimensional Scaling

Multidimensional scaling (MDS) is a procedure that can be used for determining the dimensions that individuals use when comparing stimuli. In general, MDS will be a useful analytical procedure any time that an investigator (1) can develop a procedure for comparing stimuli (in terms of difference/similarity or preference), (2) has reason to believe that the judgments made about the stimuli will be based on more than a single dimension and (3) is not certain what dimensions individuals will use in making comparison judgments.

Scaling stimuli using multidimensional analysis is similar to both factor and discriminant analysis and is based on the same mathematical models (Nunnally 1978). Because the mathematical models are complex and numerous MDS methods are available, no attempt will be made to describe the calculations explicitly. Interested readers are directed to Torgerson's (1958) classic test, to Shepard et al. (1972) or to Nunnally (1978) for a general overview of MDS. There are several reasons why MDS may be preferable to other data reduction or clustering techniques for use in landscape preference research. Since the respondent is simply asked to judge how similar the stimuli are, predesignation of the dimensions by the researcher is avoided. This may be particularly beneficial in landscape preference research where one of the goals is the discovery of relevant dimensions. In addition, the demands placed on respondents in terms of the types of judgments required are kept to a minimum, although this advantage is partially offset by the number of judgments required (as discussed below).

The objective in MDS is to produce by scaling analysis a representation of the perceived characteristics of the landscape. In order to determine the dimensionality of a set of photographs, respondents would be asked to indicate the degree of similarity between pairs of stimuli. For example, assume the investigator has 10 representative photographs of the landscapes of interest. Each respondent would, then, view all possible pairs (N = 45) of photographs.[4/] It is assumed that respondents' judgments of landscape similarity are a function of the characteristics or dimensions that distinguish the landscapes. One also assumes that the respondents are capable of providing metric judgments about the proximity of the stimuli directly. In fact, the measurement scale used by the respondents can range from ratio to ordinal with relatively little difference in interpretation (Nunnally 1978). Even though the measurement scale used does not substantially affect dimension interpretation, interval scaling of judgments allows the

[4/] Nunnally (1968) indicates that most demonstrations of MDS have been limited to fewer than 20 stimuli. Only when the landscape stimuli are the only ones of interest - i.e., you are not interested in generalizing beyond these stimuli - would this few stimuli be adequate.

researcher to use morn powerful statistical techniques when dimension values are used for subsequent analyses.

The results of these complex numerical analyses can be quite straightforwardly presented in a visual display. The dimensions of the photographs, as recovered by the scaling analysis, can be presented as a cognitive map (usually geometrically represented in euclidean space) much as a map locating cities in the United States can be constructed by knowing the longitude and latitude of each city. Figure 2 presents a hypothetical two-dimensional visual display of a cognitive map for a group of

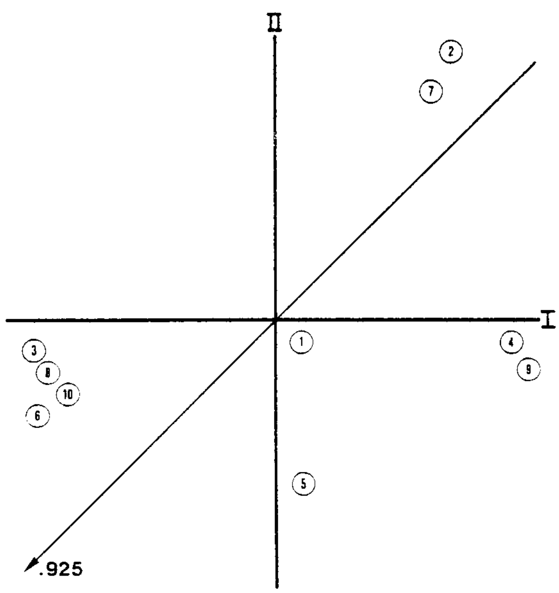

Figure 2. Dimensions I and II of the scaling solution for all respondents. The arrow travels toward the highest perceived surface topography.

respondents (ignore for the moment the arrow). Of course, the photographs may contain more than two dimensions, in which case visual maps of each pair of dimensions may be produced showing the location of each photograph with respect to each combination of dimensions. Photographs that are far apart are dissimilar; those close together share common characteristics.

The names of the dimensions may be determined from a careful inspection of the maps. For example, to define the horizontal axis or dimension I, the investigator would compare photographs 3, 8, 10, and 6 with photographs 4 and 9 since these clusters are maximally separated on this dimension. When obvious differences are present between these two clusters of photographs, the underlying feature(s) on which they differ may be proposed as the name of the dimension. The same rationale may be applied to naming the other dimensions. The similarity to factor labeling is obvious.

Up to this point the assumption has been that the investigator is not certain about the underlying dimensions of the landscapes. The researcher may, however, have a hypothesis about one or more of the dimensions based on previous findings, intuition, or some specific characteristic(s) of interest. For example, research evidence might indicate that the amount of surface variation affects judgments of landscapes. If this were the case, the investigator could include this hypothesis in the procedure by asking respondents also to make judgments about this feature of the photographs (features of the photographs might also be evaluated in a more objective fashion - e.g., grid analysis). The MDS analysis can now be related to the respondents' judgments of topographic variation because it is assumed that the same characteristics that produce similarity judgments also determine the perception of topographic variation.

The investigator now has a map representation of the photographs and perceptions of the amount of topographic variation. It is now possible to perform a correlational analysis relating the photographic dimensions issuing from the MDS to the perceived amount of topographic variation. This analysis can be visually represented by drawing an arrow through the map indicating the direction of increasing topographic variation (fig. 2). The further a photograph lies in this direction, the higher is its judged topographic variation. The direction of the arrow is determined by the correlations between the dimensions of the map(s) and the topographic variation judgments. This analysis results in an importance (beta) weight for each dimension as well as an overall multiple correlation. The squared multiple correlation is a measure of how much of the variance of the surface topographic judgments can account for all the dimensions combined. In the hypothetical example shown in Figure 2, the squared multiple correlation is indicated in parentheses at the tip of the arrow and shows that topographic variation is indeed an important variable for these photographs.

The preceding example provides an illustration of how MDS can be used to provide cognitive maps of landscapes and how the dimensions may be interpreted. Multidimensional analysis has several disadvantages that have limited the growth of its use, however. As noted previously, the number of stimuli needed to map accurately the dimensions underlying a class of stimuli would make the judgment task beyond reason for a respondent if many stimuli were needed (all possible pairs of 50 stimuli require 1,225 similarity judgments). When the occasion arises that a large number of visual stimuli is necessary to represent adequately landscape features, it is possible to have each respondent make judgments on a systematic subset of stimuli. The number of respondents should, however, be increased accordingly. Certain assumptions, as previously discussed, must also be made concerning the types of psychophysical responses required of respondents. Judgments made on an interval scale are not difficult for most respondents providing the scales are adequately anchored. Nevertheless, the researcher who can surmount these problems may well benefit from the results.

Policy Capturing

Much of the research in human judgment and information processing has concerned the way individuals weight and integrate available information into a decision. An individual's strategy for information integration, or "policy," can be mathematically represented in a procedure known as policy capturing. Policy capturing has been successfully used in a variety of applied decision-making situations including judgments made by medical pathologists (Einhorn 1974), performance appraisal and evaluation (Anderson 1977, Madden 1963, Robinson *et al*. 1974, and Taylor and Wilsted 1974), and graduate admission policy (Dawes 1971, Keely and Doherty 1972) to name a few.[5/] Regardless of the application, the use of the technique has resulted in useful descriptions of individual cue weighting policies.

A brief example will serve to illustrate the process through which we might mathematically represent an individual's preference judgments for landscape. Consider a situation where an individual is presented a series of stimuli each of which has been assigned a value for a number of different dimensions related to landscapes (e.g. topographic variation, contrast among elements). The individual's task is to examine and rate his overall preference for the stimulus. The preference ratings are then used as a criterion score where the dimension values are the predictors. Once this information is available, zero-order correlation coefficients and a multiple regression equation can be obtained for the individual. The raw score regression weights define the individual's hyperplane (assuming linear models) depicting the relative importance of the dimensions. The resultant R^2 indicates the degree to which the dimensions account for the total variance in the individual's policy.

The preceding example demonstrates how an *individual's* policy may be determined. The same stimuli may be presented to a number of individuals and policy equations determined for each. Mathematical descriptions of individual policy may then be clustered to provide a composite policy for all individuals. The Judgment Analysis technique (JAN) developed by Christal (1963) groups individual policies according to the homogeneity of their regression equations. It accomplishes this by first comparing all possible, N(N-1)2, pairs of equations to find the most homogeneous equations to use for reducing the number of equations from N to N-l. This step is repeated with each iteration reducing the number of equations by one while retaining separate equations for all remaining policies and thereby minimizing the loss in predictive efficiency at each iteration. The JAN program produces a squared multiple correlation for the composite equation plus a squared multiple correlation for each remaining equation at each iteration until the individual policies have all been included in a composite policy. Inspection of the difference in multiple correlation from one grouping iteration to the next aids in deciding the number of policies to use. The greater the loss in predictive efficiency between iterations the stronger the evidence that more than one policy equation is needed to describe the relationship.

Policy Capturing offers several advantages as a tool in landscape research and management. At a practical level, the task itself is easy for respondents to understand and to perform. Propst (1979) was able to obtain one hundred landscape preference judgments from respondents in less than 30 minutes. The R^2 values issuing from this technique also provide estimates of individual judgment reliability and the ability of the dimensions to account for overall preference judgments (when the policies are clustered). Theoretically it offers an approach that is able to resolve, at least partially, the mixed results issuing from research on individual differences in landscape preferences. The capturing of individual policies and subsequent clustering of these policies into homogenous groups provide a basis for evaluating the nature and extent of individual differences.

APPLICATIONS TO RESEARCH AND MANAGEMENT

One of the biggest problems facing researchers has been the identification of relevant

[5/] Numerous applications of the technique may be found in review articles by Slovic and Lichtenstein (1971) and in Slovic et al. (1977).

physical landscape elements that can be used in modelling preferences. Previous investigations have turned up several apparently predictive variables such as amount of water, man impacted area, insect damage and amount of downed wood, Quite often these dimensions, which were uncovered by quantitative trial and error, proved to be very predictive in empirically derived linear and non-linear equations (Shafer et al. 1969; Arthur 1977; Buhyoff and Leuschner 1978; Jackson et al. 1978). The use of such techniques as MDS and Policy Capturing may provide the necessary insight about dimension weighting and interaction so that rational mathematical models may be stipulated a priori (Guilford 1954). It is possible that certain types of landscape elements behave in non-coincidental interactive ways so that "standard" utility surfaces can be generated for a given subset of salient elements. Through this type of research, applied in different physiographic regions with a broad variety of subjects, we may gain information which will permit the formulation of substantive landscape perception theory.

While many of the empirical models in the literature are linear formulations, there is some indication in our own research that nonlinear forms may be more appropriate. Therefore, we may find what economists already know about consumer utility analysis; that is, constant increases in the quantity of goods are not associated with constant increases in utility. It is reasonable to assume that landscape perception may occur in a similar manner. Of course, as we stated before, we cannot treat a landscape scene as a single dimension. Landscapes are a collection of elements or goods which are perceptually "consumed." For this reason, we need to specify the nature of the interactions between elements, thus producing scenic utility surfaces. Policy Capturing and MDS methodologies can aid in the investigation of this hypothesis.

Guidelines for the management of the visual resource issue directly from the determination of the relative importance of dimensions in landscapes through MDS, Policy Capturing or other techniques. To illustrate, we will use Buhyoff and Leuschner's (1978) Southern Pine Beetle (SPB) study as an example of how visual guidelines can be used to aid management decisions. Suppose, instead of making preference judgments based only on SPB damage, that the scenes also hypothetically varied with respect to another perceptually salient dimension of topography. These two dimensions, amount of insect damage and an index of topography, may combine to produce a non-linear surface which would result in decisions divergent from those based on either dimension viewed by itself (fig. 3). Consider points A, B, and C on this hypothetical surface. Point A shows that preference (scenic utility) is at a minimum when SPB damage is high and the topographic index is minimal. However, point B indicates that preference increases when both the SPB damage and the topographic index are high. Thus, we would make a faulty prediction of low scenic utility for a landscape with a large amount of SPB damage and a high topographic index by using a simple two-dimensional model relating only X to Y. Management decisions for point C would not differ from those based on either the amount of SPB damage or the

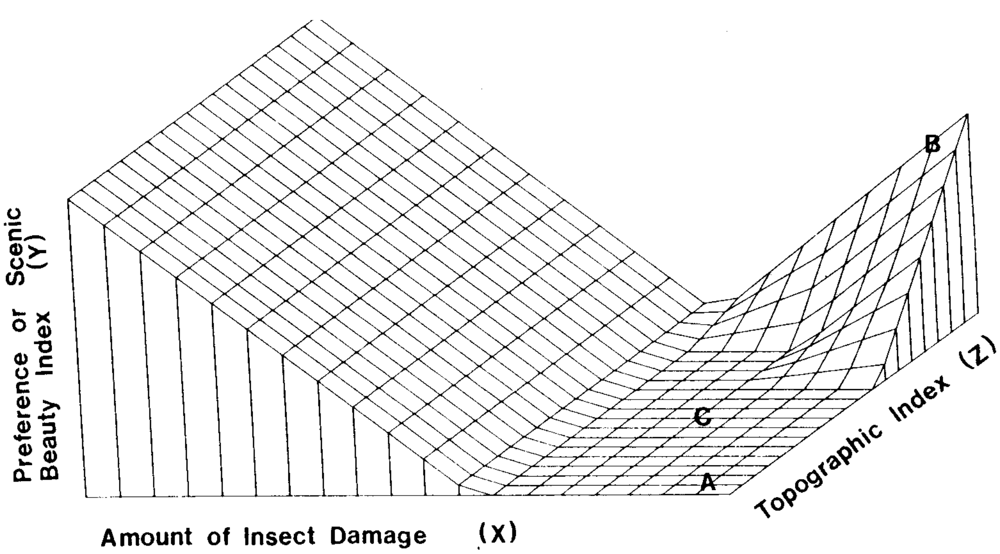

Figure 3. A hypothetical three dimension scenic utility surface.

topographic index. We also observe that point C is surrounded by a relatively large flat portion of the scenic utility surface. It follows, then, that if a given landscape were in the condition described by point C, small changes in either or both dimensions would not change the overall utility. Scenic utility surfaces may provide a means for judging the overall efficiency or cost-effectiveness of landscape modifications. The point is that preferences are seldom a function of a single feature of the environment and that several characteristics may combine in a complex fashion to produce optimal management guidelines. In fact, landscape management guidelines may well be set by the ridges, depressions and plateaus of scenic utility surfaces.

Our three-dimensional surface example may seem simplistic. However, it was necessary to deal with this type of illustration to make our point. In fact, it is not important that the surfaces be drawn if more than 2 landscape dimensions are used. The surface topography can be described and characterized mathematically, and management guides can be set just as easily.

CONCLUSION

The preceding sections have shown how MDS and Policy Capturing can help the investigator both to identify the relevant dimensions in landscapes and evaluate their relative importance in "causing" fluctuations in measures of scenic utility. The two techniques can provide unique, yet complementary information about landscapes which may direct us to the next step of theory formulation. MDS can aid the researcher in recovering preference or scenic beauty dimensions without forcing individuals to cue on specific dimensions. Dimensions so recovered may be quantified for use in Policy Capturing to provide estimates of their relative importance. Conversely, a researcher may begin with known or hypothesized dimensions and examine their relationships to dimensions issuing from MDS or their relative importance to preference or scenic beauty through Policy Capturing. At the very least these techniques offer alternatives that can provide a semi-basis for establishing the validity of constructs currently used to assess landscapes.

The intent of this paper was to outline a basic methodological approach for deriving scenic utility functions to be used in landscape assessment strategies. Techniques such as MDS and Policy Capturing may provide the means for stipulating a priori the salient manageable landscape elements which are used by people in their perceptual determinations of preference, utility, or scenic beauty. We have advanced a hypothesis about the existence of "standard" or "common" scenic utility surfaces -- that is, the existence of mathematically describable landscape element interactions. If such utility surfaces exist, then we may be provided some empirical information useful in theory construction. At a minimum, however, even locally specific scenic utility functions provide a logical means of formulating scenic management guidelines and estimating management efficiency and/or cost effectiveness.

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