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Landscape and Urban Planning 69 (2004) 201–218

LANDSCAPE AND URBAN PLANNING

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Using spatial metrics to predict scenic perception in a changing landscape: Dennis, Massachusetts

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Received 1 October 2002; accepted 5 August 2003

Abstract

This paper investigates residents' perceptions of scenic quality in the Cape Cod community of Dennis, Massachusetts during a period of significant landscape change. In the mid-1970s, Chandler [Natural and Visual Resources, Dennis, Massachusetts. Dennis Conservation Commission and Planning Board, Dennis, MA, 1976] worked with a community group to evaluate the natural resources of their town, an important component of which was scenic value. In the mid-1990s, the original views were re-photographed and another sample of Dennis residents surveyed. Landscape metrics grounded in the landscape ecology literature were used to predict residents' perception of scenic value for each time period. The results indicate that approximately half of the variation in scenic perceptions can be explained by spatial landscape metrics and that this model retains its predictive efficacy after 20 years. These results provide some guidance for landscape planners and designers about the preferred composition and configuration of human landscapes. In particular, they provide additional support for the contribution of natural-appearing landscapes with a complex pattern of edges to a community's scenic quality.

Keywords: Landscape ecology; Landscape assessment; GIS; Visual quality; Landscape perception; Landscape change; FRAGSTATS

1. Introduction

The public's sensitivity to scenery—how the landscape looks—was historically one of the first and is perhaps still one of the most important catalysts of environmental awareness and action (Zube, 1980; Nassauer, 1992). In 1969, recognizing the need for defensible assessment techniques and information on which to base scenic quality policies and public land management, Elwood Shafer posed the question that opened the field of landscape perception research:

> In trying to cope with the problem of landscape abuse and destruction, one of the questions that natural resource planners frequently ask is: "Why is one landscape preferred more than another?" (Shafer et al., 1969, p. 1).

He went on to formulate the commonly accepted justification for a science that predicts people's perceptions of the landscape:

> ... to identify what quantitative variables in a natural landscape are significantly related to public preference for that landscape. By knowing what quantitative features in a landscape affect its aesthetic appeal, natural resource planners can make decisions on a factual basis about purchasing, developing, or preserving these features (Shafer et al., 1969, p. 1).

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doi:10.1016/j.landurbplan.2003.08.010

Shafer proceeded to describe a research design where he measured attributes of photographs taken at eye-level. These attributes included the area and length of edges for water, vegetation, and non-vegetation as seen in the foreground, middle ground and background of the photograph. He then had selected people express their preference for the landscapes represented in the photographs. A regression analysis explained over half of the variation in landscape preference from knowledge of the landscape attributes.

This approach to landscape perception assessments implies a causal link between landscapes changes made on the ground and the perception of scenic value. This link, which includes several assumptions, proceeds in this way. Land planners and managers develop and implement plans or take other actions that change the landscape. These changes are conceived by planners and managers as spreading out over a specified area. They typically develop and represent their intentions using maps or other spatial representations (Marsh, 1997). Normally these changes are visible from many different viewpoints within the landscape. People standing at these viewpoints see the changes in perspective, as landscape views, and make scenic judgments based primarily on what they see. A selected portion of a view is optically similar to a photograph (Gibson, 1979), which is thought to be a fair representation of the landscape's visible condition (Sheppard, 1989). Shafer's approach further assumes that people apprehending a view (or photograph) can effectively express their affective or cognitive reactions using rating scales or other response formats (Nunnally, 1978).

The model implicit in this commonly used approach to landscape perception assessment is specified by a set of variables that describe the relationship between people's response to landscape scenes and changes to that landscape proposed or expressed by planners and managers. Since the justification of landscape perception assessment is to manage the landscape's future condition for people's appreciation, the dependent variables are almost always measures of people's reactions. However, the independent variables used to specify the relationship vary widely in how they have been derived, and include planimetric measures of the land (e.g., Zube et al., 1974), pictorial measures of the perspective view (e.g., Shafer et al., 1969), and psychometric measures of people's perceptions (e.g., Kaplan and Kaplan, 1989). While interesting research may develop from using pictorial and psychometric independent variables, they are not directly transferable to land planners and managers who work primarily with maps and other areal representations of the landscape, not with individual perspective views, or people's thoughts and perceptions.

As part of many current planning processes, planners are expected to project the changes that would result from their plans and evaluate their impacts. The National Environmental Policy Act of 1969 called for the development of new methods to:

> ... insure that presently unquantified environmental amenities and values may be given appropriate consideration in decision making along with economic and technical considerations (42 USC § 4332, Section 102(B)).

Shafer and others responding to this mandate expected that planners would calculate the appropriate metrics during the environmental impact assessment process in order to predict the public's reactions to the changes. More than 15 years later, Sell and Zube (1986) reviewed the literature on the perception of landscape change and concluded that there was still a significant need for research in this area.

> Perhaps most notable in this review is the absence of research addressing the issue of change at the urban fringe ... there appears to be a paucity of information about perception and response to incremental change on the fringes of cities (Sell and Zube, 1986, p. 48).

While there have been studies during the past 30 years that developed landscape metrics to predict public perceptions, there is still a "paucity of information" about perceptions of landscape change, and there has yet to be a study testing whether predicted perceptions were accurate.

The study reported here begins to address this gap in our understanding of landscape perception assessment. It is particularly important to conduct such studies because perceptions can change both in response to changes in social norms and expectations and as a result of a changing landscape. This research first establishes that over a 20-year period, local residents' norms of scenic value for the Cape Cod, Massachusetts under study are reliable and have not changed appreciably. Then it proceeds on the belief that landscape perception can best be explained as a reaction to external landscape properties, such as the size of land use patches, the density of edges between land uses, or the relative naturalness of the land uses with a landscape view (Zube et al., 1982; Daniel and Vining, 1983). It looks to the field of landscape ecology to obtain spatial landscape metrics (Forman and Godron, 1986; McGarigal and Marks, 1995).

1.1. Landscape ecological concepts applied to landscape perception assessment

Landscape ecology is the study of spatial and temporal patterns on the land and their consequences to organisms, populations, communities, and the ecosystem (Giles and Trani, 1999). While it may sometimes make sense to investigate only land patterns (e.g., Ritters et al., 1995), it seems generally more reasonable that there should also be a behavioral or perceptual response component. Often land patterns only have consequence in relation to organisms. Since we know that many landscape metrics are sensitive to scale, it is particularly awkward to interpret studies like Ritters et al. (1995) that do not state their ecological context. In order to frame a landscape ecology study, one must consider the ecological appropriateness of the landscape's extent, grain, and elements, all of which gain meaning and consequence from an organism of concern.

Extent is operationally defined as "the area encompassed by an investigation or within the landscape boundary" (McGarigal and Marks, 1995, p. 7). However, a landscape ecology study needs to investigate an ecologically appropriate area. This is identified by With (1994, p. 25) as "the largest scale that an organism perceives." Alternately, Kolasa and Rollo (1991, p. 7) identify extent as "the range at which a relevant object can be distinguished from a fixed vantage point". Both of these definitions make it clear that a study's extent must be based on the organism's perception of the landscape. The methodological decision for the study presented here is: What is the appropriate extent for a landscape perception study of Cape Cod residents? There are two answers, because there are two ways of defining extent. In the first definition, extent is analogous to "home range"—the area around an animal's home that is used during its daily activities (Forman and Godron, 1986, p. 594). For Cape Cod residents, the residential lot or neighborhood seems too small an area to accommodate the pattern of daily activities. On the other hand, the state of Massachusetts or the New England region seems unnecessarily large. A small city or rural township is a sufficiently large extent to accommodate the daily activities of residents and therefore seems appropriate for this study. The second definition of extent focuses on the area that an organism can apprehend from a fixed viewpoint. In landscape perception assessment this is termed the seen area or a viewshed (Smardon et al., 1986).

Grain is operationally defined as "the size of the individual units of observation" (McGarigal and Marks, 1995, p. 7). However, grain also has ecological meaning. With (1994, p. 25) defines grain as "the finest resolution at which an organism perceives spatial heterogeneity." Forman and Godron (1986, p. 182) define grain as "the distance or area to which the species is sensitive in carrying out its functions". In this case, residential lots or similar property divisions seem the appropriate resolution. People can perceive finer detail within these classes. For instance, residential areas are composed of buildings, trees, gardens, lawns, and paved areas. There are even finer resolution clues that can be important—the placement of porches, doors, swing sets, and so forth, or the difference between a driveway and walkway. However, these details are not generally central in determining the broader patterns of daily life within the landscape.

Landscape elements are "the basic, relatively homogenous, ecological units, whether of natural or human origin, on the land at the scale of a landscape" (Forman and Godron, 1986, p. 595). One type of landscape element is the patch—"a nonlinear surface area differing in appearance from its surroundings" (Forman and Godron, 1986, p. 597). An important question when framing a landscape perception assessment is how many meaningful types of landscape patches might people in the landscape distinguish? For instance, Ritters et al. (1995) used 37 land classes from Anderson et al.'s (1976) Level II taxonomy. Might it be more appropriate to use the six or seven Level I classes, or perhaps there should be 100 or more classes? Previous research has found that ordinarily people can distinguish about seven distinct classes at any one time (Miller, 1956; Rosch and Lloyd, 1978). Local residents also seem to come up with around seven classes when asked to identify meaningful groups of similar landscape views. For instance, in a study of Massachusetts' Connecticut River valley the classes were industry, towns, farms, meadows and woods, forested hills, open water, and wetlands and streams (Palmer, 1976). On Cape Cod, Massachusetts, residents identified commercial/industrial, high-density seasonal housing, low-density housing, open space, beaches and water, woods and wetlands (Palmer, 1983).

Metrics describing the types of land cover or uses that make up the extent refer to the landscape's *composition*. These metrics include the total land area and the percent of the viewshed occupied by individual land use types. While these elements certainly hold particular meaning in and of themselves, one of the more consistent findings in the landscape perception research is that the more natural appearing the elements composing a view, the higher the scenic value (Kaplan and Kaplan, 1989). Zube et al. (1974) developed a naturalism index to measure how 'natural' the visible land uses are.

Metrics that describe the pattern or arrangement of elements within the extent refer to the landscape's *configuration*. For instance, homogeneity in the landscape is indicated by the dominance of the single largest patch. In contrast, increasing patch density means that the landscape's grain is becoming finer, indicating greater heterogeneity and fragmentation. Greater homogeneity increases coherence, while fragmentation decreases it. Coherence is generally thought to have a positive relation to scenic value (Kaplan and Kaplan, 1989). Another configuration metric is edge density, or the length of edge between different patches per unit area. A metric of landscape shape is based on the perimeter-to-area ratio for all the land use patches in a landscape. Both edge density and landscape shape index provide an indication of visible landscape complexity, which is thought to contribute to scenic value (Kaplan and Kaplan, 1989). Landscape diversity is generally considered to have two components, richness and evenness. Patch richness density is a measure of how many different land cover types are present per unit area. Shannon's evenness index is a measure of how evenly the different cover types are represented in the view. It is the opposite of dominance, and measures the distribution of the land use patches.

In summary, a study that proposes to apply spatial data to describe landscape perceptions must use a database with an extent, grain, and classification of elements that are appropriate to the organism being studied. In this study these considerations are investigated in relation to both the composition and configuration of the elements.

1.2. Objectives

This study investigates the power of commonly used landscape spatial metrics to explain the perception of scenic value in a landscape after 20 years of change. There are two objectives:

1. Document changes in a landscape and perceptions of landscape scenic quality over 20 years.
2. Test the efficacy of a scenic perception model to predict the perceptions of the same landscape 20 years later.

2. Methods

This study requires a site that has undergone significant landscape change. In addition, spatial land use and landscape perception data must be available that document the change. Dennis, Massachusetts, a Cape Cod town, was selected for this case study of landscape change and the perception of landscape aesthetics.

This section describes the study area and how it qualifies as a landscape that has undergone recent change. It then describes how scenic perception data were collected in 1976 and 1996, and how landscape data were gathered into a GIS database. Each viewpoint from which a photograph was taken was located in the GIS and used to map the viewshed, or potential area seen, in the photograph. The GIS database was also used to calculate landscape metrics that describe the study area and each viewshed. These metrics were used to predict scenic quality, as well as changes in scenic quality over the 20-year study period.

2.1. Site description

Cape Cod is a large sandy glacial peninsula extending about 100 km into the Atlantic Ocean. The topography has relatively little relief, with the highest point being less than 50 m above sea level. Archeological

Table 1
U.S. Census statistics for Dennis, Massachusetts: 1970 and 1990

	1970	1990	Change (%)
Population	6454	13864	114.8
Median age	44.4	44.3	−0.2
Median per capita income (CPI adjusted to 1989, US$)[a]	12224	15436	26.3
Persons below poverty level (%)	11.4	10.5	−7.9
Housing units	7329	14498	97.8
Occupied housing units	2476	6190	150.0
Median people per unit (owner occupied)	2.2	2.0	−9.1

Source: US Bureau of the Census (1973a,b, 1992a,b).
[a] 1969 per capita income was US$ 3618.

remains indicate at least 9000 years of habitation. English colonists first settled the area that became Dennis in 1639. The town's population ranged between 1400 and 3700 inhabitants during the 19th century and remained around 2000 for the first half of the 20th century (Reid, 1996). After World War II, Dennis experienced a housing boom as a result of the exurban growth that swept across the country (Jackson, 1987; Cohen, 2003). Between 1950 and 1970, the population increased by 158%, and grew another 115% between 1970 and 1990. Median per capita income grew by 26% after accounting for inflation between 1970 and 1990. These trends in the growth of population and wealth are seen in Table 1, which presents the basic social statistics for Dennis from the 1970 and 1990 US Censuses.

These social changes were accompanied by significant changes in Dennis' landscape (see Fig. 1) (MacConnell et al., 1974, 1991). For instance, in 1951 forests covered 58% of the town. By 1971 forest cover had dropped to 47%, and by 1990 it fell to only 29%. In contrast, residential land uses occupied 12% of the town in 1951, 27% in 1971, and 41% in 1990. These changes indicate a shift from a landscape where single-family residential housing is now becoming the landscape's matrix rather than the forest. Table 2 gives the percent change between 1971 and 1990 for 24 land uses grouped into seven classes.

Table 2
Land use change in Dennis, Massachusetts: 1971 and 1990

Land use type	Area (ha)		Change (%)
	1971	1990	
Agricultural and open land	318.1	319.7	0.5
Crop land	38.9	44.1	13.4
Pasture	4.0	5.7	42.5
Open land	259.0	248.1	−4.2
Cranberry bog	14.2	17.0	19.7
Woody perennial, orchard	2.0	4.9	145.0
Forest	2588.0	1610.3	−37.8
Forest	2588.0	1610.3	−37.8
Recreation	119.0	187.0	57.1
Participation recreation	2.4	9.7	304.2
Spectator recreation	40.1	104.0	159.4
Water based recreation	53.0	48.6	−8.3
Golf course	13.0	14.2	9.2
Marina	10.5	10.5	0.0
Lower density residential	924.7	1569.8	69.3
Medium density residential	594.9	870.5	46.3
Low density residential	329.8	699.3	112.0
Other urban	745.9	967.6	29.7
Multi-family residential	0.8	31.2	3800.0
High density residential	547.1	646.3	18.1
Commercial	106.4	157.8	48.3
Industrial	9.7	31.6	225.8
Urban open, public	42.5	52.6	23.8
Transportation	39.3	48.2	22.6
Waste	69.2	103.6	49.7
Mining	29.9	34.0	13.7
Waste disposal	39.3	69.6	77.1
Wetland and open water	766.9	761.6	−0.7
Inland wetland, fresh water	165.9	163.1	−1.7
Salt wetland	397.8	395.4	−0.6
Water	203.2	203.2	0.0
Total area (ha)	5531.8	5519.9	−0.2

Source: Table 8 in MacConnell et al. (1991). Areas are converted from acres.

2.2. Landscape representations and perceptions

During the mid-1970s the Town of Dennis organized a series of citizen committees to inventory and assess its natural and cultural resources and to prepare a town plan (Chandler, 1976). One of these committees was charged with assessing the visual resources. They began in 1976 by identifying locations they thought represented the range of visual landscape conditions throughout the town. These locations were photographed between 10 a.m. and 3 p.m. using a 35 mm lens on a 35 mm single lens reflex camera. The committee selected 56 photos they thought best represented the local landscape's diversity (Palmer, 1983). A random sample of citizens was invited to come to

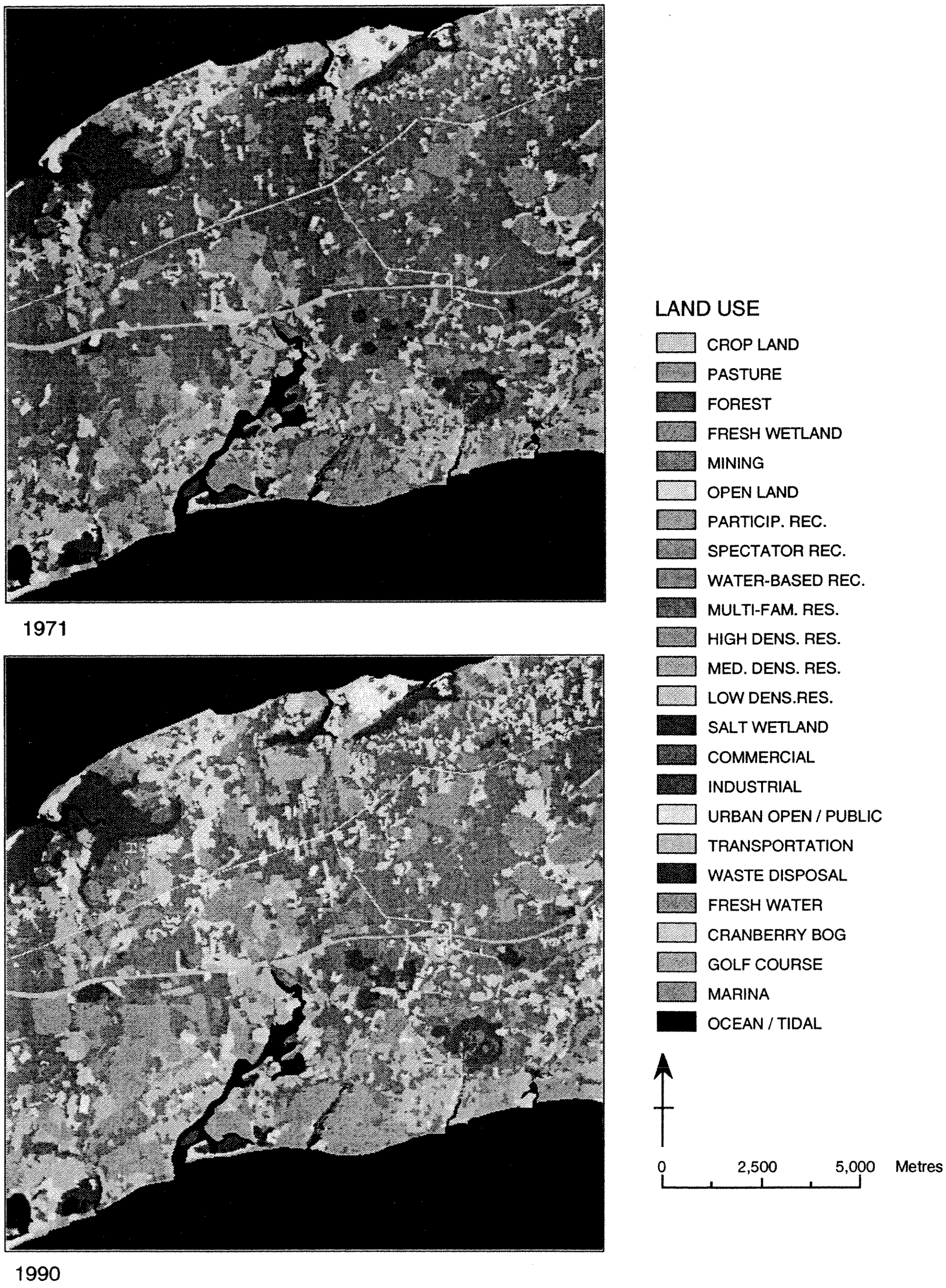


Fig. 1. Maps showing 20 years of land use change for the area surrounding Dennis, Massachusetts.

the town hall and employ one of several methods to evaluate these landscape views. One of these was a Q-sort technique, where the 56 color 13 cm × 18 cm photographs were sorted into seven piles from highest to lowest scenic value according to a fixed, "normal" distribution (Pitt and Zube, 1979). Sixty-eight local citizens made scenic value judgments of these 56 landscape scenes using this Q-sort method (Palmer, 1983).During the summer of 1995, all but one of the original 56 sites were re-photographed by a volunteer from the Dennis Planning Department. The viewpoints were located using a copy of the 1976 study's field map. The single un-photographed site overlooked a wooded wetland that appeared to have been erroneously located on the field map. The photographs were taken using a 35 mm single lens reflex camera and 35 mm lens. Each image was taken from the same general location as the corresponding 1976 photograph. During 1996 a total of 25 Dennis residents visiting the Town Hall evaluated slides of the 1976 and then the 1995[1] views. The same random order was used to arrange the sites for both years. The judgments were recorded using a 10-point rating scale of scenic value.

Photographic media have generally been found to be valid representations of the landscape in scenic quality studies. Palmer and Hoffman's (2001) meta-analysis of 19 studies comparing evaluations of photographic representations to the actual views found a size effect of $r = 0.80$, which supports the use of photographic representations for scenic quality studies. However, they also found evidence that photographic images may not be valid because they are not representative of the conditions seen in the field. The validity of the viewpoints used in this study is affirmed because they were all originally selected by a committee of local residents who identified them as representative. However, there are some compositional differences between the 1976 and 1996 photographs for some locations. In addition, 1976 was drier than 1996, the 1976 photos tend to be lighter (i.e., more exposed), and were taken earlier in the season than they were in 1996.

A second possible concern is that evaluations were made using a Q-sort in 1976 and a rating scale in 1996. Stamps' (2000) meta-analysis of nine studies that compared different scaling methods found a size effect of $r = 0.99$, indicating essential equivalence among the scaling methods. In this study of the Dennis landscape, it was necessary to compare the 1976 and 1996 values, therefore each person's ratings were standardized (i.e., z-scores). RMwin software uses the raw ratings to calculate standardized 'by-slide' scenic beauty estimates (SBE), which have a mean of 0 and a standard deviation of 100 (Brown and Daniel, 1990; Meitner, 1999). All the ratings made by residents in 1996 are used when calculating the SBEs for the 1976 and 1996 scenes. This maintains a uniform scale across these judgments that permits the effects of change to be investigated. The judgments made in 1976 were also transformed to SBEs.

2.3. Viewsheds of the landscape representations

The extent of the study area was a 225 square kilometers area encompassing the Town of Dennis. A grain of 30 m was used, which is slightly smaller than a residential lot at a density of 4 dwelling units per acre (i.e., a lot size of 0.22 acres or 0.09 ha). Thus, the extent corresponded to the area of the community being studied and the grain to an area smaller than the division of land with which they were most familiar (i.e., a residential lot), making them appropriate for the studying Dennis residents' perceptions. These attributes led to the creation of a 500 × 500-cell raster GIS with a 30 m resolution.

The GIS database included topography from the mid-1990s. Raw point-elevation data derived from aerial photos were obtained from the Massachusetts' Office of Geographic and Environmental Information (MassGIS). These data were used to create a TIN (triangulated irregular network) model, which was converted to a 30-m raster grid using ArcInfo™ software.

The viewshed or area seen from each viewpoint was identified using the topographic data without modifications for land use heights (a.k.a. maximum visibility model) (Kirby, 1999). An eye-level of 1.5 m and a 56° cone of vision were used, which corresponded to the camera's placement and angle of view when the photos were taken. A unique viewshed represented the land surface potentially visible in each photograph.

[1] The photographs were taken during the summer of 1995, but residents evaluated them in 1996. The text will reference 1996 for both the photos and rating to reduce confusion.

Table 3
Description of landscape metrics

Landscape metric	Description
Landscape composition	
Agricultural and open land	Percent of total area in crops, pasture, open land, and cranberry bogs
Forest	Percent of total area in forest
Recreation	Percent of total area in participant recreation, spectator recreation and water recreation
Lower density residential	Percent of total area in medium and low density residential
Other urban	Percent of total area in multi-family and high density residential, commerce, industry, urban open land, and transportation
Waste	Percent of total area in mining, and waste disposal
Wetland and open water	Percent of total area in wetlands, salt marsh, and freshwater
Naturalism index	The area-weighted mean "naturalness" rating of land use types (Zube et al., 1974)
Landscape configuration	
Largest patch index	Percent of total area occupied by the largest patch
Patch density	Number of patches per 100 ha
Edge density	Meters of edge, including the background edge, per hectare
Landscape shape index	Total edge in meters, including the background edge, divided by the root of the total area in meters squared, and adjusted for a standard square raster
Patch richness density	Number of different land uses per 100 ha
Shannon's evenness index	Equals 1 if the distribution of area among all land uses is equal, approaches 0 as one land use becomes dominant, and is 0 if there is only 1 land use. It is based on Shannon's diversity index

Notes: See McGarigal and Marks (1995) for details of calculation, unless otherwise noted. Total area refers to the viewshed, excluding the ocean.

2.4. Landscape metrics

The GIS database also included 24 land uses mapped in 1971 and 1990 and obtained from MassGIS as ArcInfo coverages. These data were used to calculate the spatial metrics described in Table 3 for each viewshed. The composition metrics included seven class-level measures describing the relative coverage for each aggregated land use category used to organize the detailed land use types (MacConnell, 1973): agricultural and open land, forest, recreation, lower density residential, other urban, waste, wetland and open water, and naturalism. These seven land use categories more closely correspond to the residents' perceptions of how to classify landscapes than do the 24 land uses (Palmer, 1983, 1997). The final compositional metric, naturalism, is an index based on the average 'naturalness' of all land uses within a viewshed. It was calculated based on ratings of perceived naturalness of each land use by 10 air photo interpretation professionals with natural resource management training (Zube et al., 1974).

Six landscape-level configuration metrics available through FRAGSTATS were also included in the analysis: largest patch index, patch density, edge density, landscape shape index, patch richness index, and Shannon's evenness index (McGarigal and Marks, 1995). These particular metrics were chosen because they characterized different aspects of the landscape, and were appropriate for comparing areas of different size (i.e., the viewsheds).

The landscape metrics were calculated for the complete study area (the first definition of extent) and for the viewshed, or seen area, corresponding to each photograph (the second definition of extent). The viewshed calculation for each photograph was the same in both time periods, because it was based only on topography, which did not appreciably change during the study period. Therefore, the landscape attributes describing each of the 56 views were derived from the same seen areas. Landscape change for each view was calculated as the difference between the 1990 and 1971 metrics.

2.5. Statistical analysis

Correlations and a regression analysis were conducted in JMP^{TM} version 5.0.1a (SAS, 2002). As previously noted, one viewpoint was not re-photographed in 1995 and could not be evaluated. Therefore, correlation or regression analyses that involved perceptions of the 1995 views used 55 rather than 56 cases.

Several strategies were used to identify the regression solutions reported in the findings. Stepwise regressions using both forward and backward strategies were evaluated. In addition, regressions with high multiple-Rs from among all possible regression solutions with three, four, or five variables entered were considered. Mallow's C_p criterion indicated that solutions with this number of variables were appropriate (Mosteller and Tukey, 1977). The selected model was the one with the highest multiple-R where all the coefficients for the included variables were significant ($P < 0.05$).

3. Results and discussion

The findings begin with a description of the mean landscape metrics for the study area in 1971 and 1990, as well as their change over this period. This is followed by a presentation of the correlation between the scenic value ratings of landscape views with the corresponding landscape metrics describing those views. The third section presents the results of multiple regression analyses using the landscape metrics to predict scenic value. In the fourth section the change in scenic value is correlated with the change in landscape metrics. The final section presents the multiple regression analysis that predicts change in scenic value based on change in landscape metrics.

3.1. Dennis, Massachusetts: a changing landscape

A comparison of the land use patterns in Fig. 1 for 1971 and 1990 makes it quite apparent that the Dennis landscape is undergoing development-associated change. Table 4 summarizes the landscape metrics used in this study for 1971 and 1990, as well as the percent change for each metric over that period. The presentation is organized around the landscape's composition and configuration.

3.1.1. Landscape composition

The landscape compositional changes within the study area mirror the changes within Dennis shown in Table 2. Residential and other urban uses have increased significantly, at the expense of forest cover. This trend is represented in Fig. 2 where the forest on either side of a rural road is converted into single-family residences. Agricultural use is relatively unchanged, but it is a rather small component in the landscape. Waste, which includes gravel mining and land fills, is another small component, but it has increased substantially. The change in wetlands and fresh water is minor, reflecting their special legal status. Fig. 3 illustrates how protection of an ecologically sensitive landscape can also conserve places that may be visually sensitive to change from development.

These values indicate a shift from a landscape that in 1971 was still dominated by land uses generally thought to be "natural" to a nearly 50–50 split between natural and developed areas in 1990. This change in landscape composition is reflected in the naturalism index, which shows an overall 13% decrease over this period.

Table 4
Mean landscape metrics for study area: 1971 and 1990

Landscape metric	1971	1990	Change (%)
Landscape composition			
Agricultural and open land	4.5	4.3	−4.4
Forest	50.8	35.3	−30.5
Recreation	1.9	3.1	63.2
Lower density residential	16.3	25.8	58.3
Other urban	10.5	14.9	41.9
Waste	0.8	1.3	62.5
Wetland and open water	15.3	15.2	−0.7
Naturalism index	6.5	5.7	−12.3
Landscape configuration			
Largest patch index	22.5	16.7	−25.8
Patch density	6.8	8.4	23.5
Edge density	65.9	76.4	15.9
Landscape shape index	25.7	29.7	15.6
Patch richness density	0.1	0.1	0.0
Shannon's evenness index	0.6	0.7	16.7

3.1.2. Landscape configuration

The configuration metrics all exhibit changes, though not as substantial as some of the composition measures. The size of the largest patch relative to the study area has decreased and patch density has increased. This trend is indicative of greater landscape heterogeneity and fragmentation. Edge density and the landscape shape index have both increased, indicating an increase in complexity.

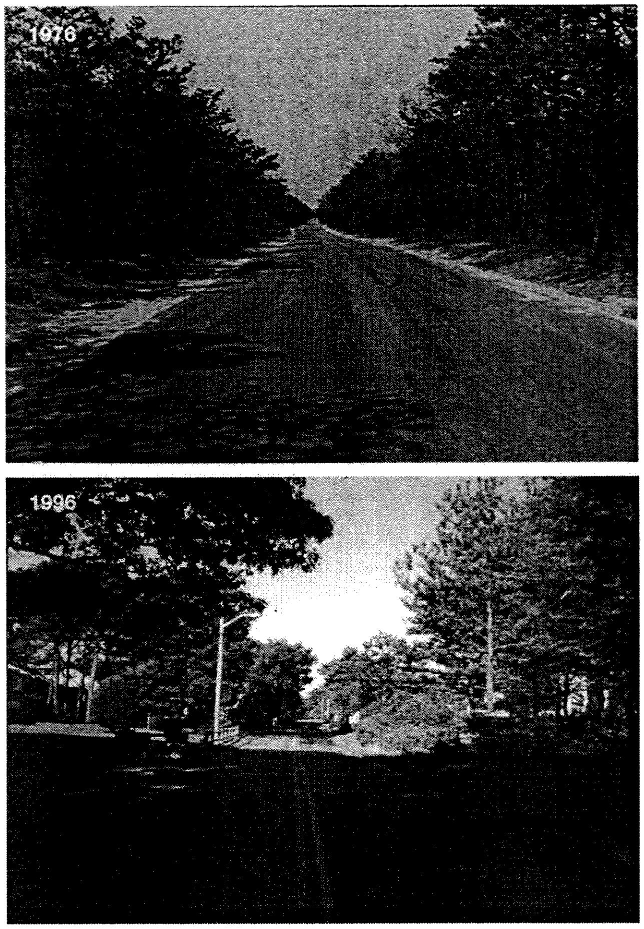


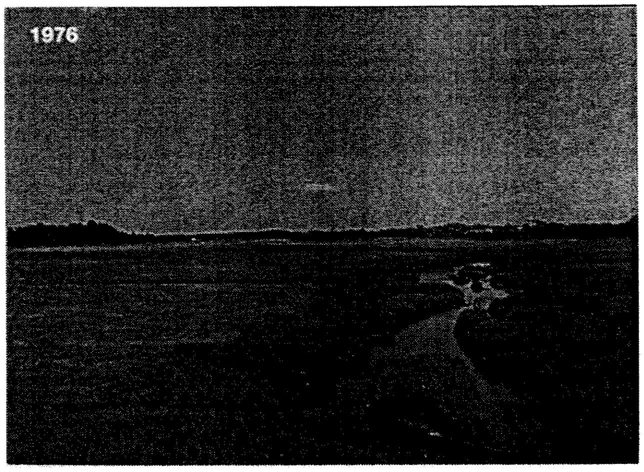
Fig. 2. The forest matrix is being reduced and fragmented primarily by expansion of residential development. Scenic value changed at this location from 57.6 SBE units in 1976 to 40.3 SBE units in 1996.

Patch richness density and Shannon's evenness index both increased. This indicates that the changing land use pattern is leading to greater visual diversity. The average 1976 viewshed included 7.8 out of 24 land uses; in 1996 the average was 8.7 land uses.

3.2. Landscape scenic value

It is important to establish that while beauty may be in the eye of the beholder, there is substantial agreement among the residents of Dennis about scenic value in their landscape (Palmer and Hoffman, 2001). The group intraclass reliability of the 1976 SBEs is $r = 0.99$. The reliability of the SBEs from the ratings made in 1996 is $r = 0.97$ for the 1976 views, and $r = 0.97$ for the 1996 views. Dennis residents from 1996 and 1976 gave very similar ratings to the 1976 scenes ($r = 0.82$). These results are similar to those from an earlier study demonstrating the relative stability between 1976 and 1986 of landscape perceptions among Dennis' residents (Palmer, 1997).

In 1996 Dennis residents evaluated both the 1976 and 1996 views. The SBEs were calculated using all the scenes from both years, making it is possible to determine change in scenic value. The mean SBE for the 1976 views was 7.97, and it had dropped to −8.12 in 1996. This drop of 16 points in 20 years indicates a



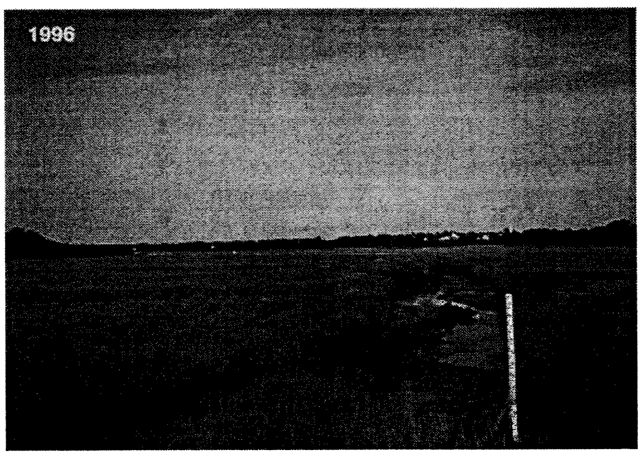


Fig. 3. This salt marsh is protected because of its ecological importance, which has the added benefit of conserving scenic quality. The SBE is 140.8 for the 1976 view and 135.7 for the 1996 view.

significant decrease in scenic value ($t = -2.57$, $P = 0.013$).

The relationship of perceived scenic value to metrics describing the visible landscape is presented in Table 5. The SBE ratings are taken from judgments by Dennis citizens in 1976 and 1996 of the 1976 views, and in 1996 of the 1996 views. In the following discussion of the results, reference is made to the average correlation (i.e., mean r) across the three SBE ratings with a landscape spatial metric.

3.2.1. Landscape composition

The correlations in Table 5 indicate that landscape composition metrics were more closely related to scenic value than were the configuration metrics. Scenic value was most positively related to the relative amount of agricultural and related open lands (correlation of $r = 0.37$ in 1976 and $r = 0.38$ in 1996 for the 1976 views, and $r = 0.31$ in 1996, with a mean of $r = 0.35$). The next most positively related land use was wetlands and open water (mean $r = 0.31$). The naturalism index also had considerable predictive power (mean $r = 0.34$). However, forested area, the most common 'natural' cover in Dennis, did not have a significant statistical correlation with scenic value.

The most intensive urban land uses, such as higher density housing, commercial and industrial areas, were negatively associated with scenic value

Table 5
Correlation of scenic value with landscape metrics

Landscape metric	1976 views	1996 views		Mean
	1976 SBE	1996 SBE	1996 SBE	
Landscape composition				
Agricultural and open land	0.37***	0.38***	0.31**	0.35
Forest	−0.08	−0.22	−0.04	−0.11
Recreation	0.09	0.31**	0.31**	0.24
Lower density residential	0.20	0.07	−0.01	0.09
Other urban	−0.45***	−0.35**	−0.35***	−0.38
Waste	−0.30**	−0.27**	−0.33**	−0.30
Wetland and open water	0.28**	0.31**	0.33**	0.31
Naturalism index	0.34**	0.23*	0.44***	0.34
Landscape configuration				
Largest patch index	0.04	0.21	0.15	0.13
Patch density	0.12	−0.00	−0.02	0.03
Edge density	0.42***	0.22*	0.19	0.28
Landscape shape index	−0.10	−0.21	−0.16	−0.16
Patch richness density	0.21	0.18	0.13	0.17
Shannon's evenness index	0.20	0.06	0.07	0.11

* $P < 0.10$.
** $P < 0.05$.
*** $P < 0.01$.

(mean $r = -0.38$). Waste areas, including landfills and sand mines, had low scenic value (mean $r = -0.30$). The correlation of lower density residential areas with scenic values was not statistically significant.

The compositional metrics are simple measures of what is present within the view. Their importance is largely the meaning that we associate with them. The strength of these correlations suggests that there is a strong association between this meaning and scenic value.

3.2.2. Landscape configuration

In general, the configuration metrics had weak correlations with scenic value. Edge density had a positive relation to scenic value in the 1976 views (mean $r = 0.32$), but it was not significant in 1996. The other configuration metrics were not significantly correlated to scenic value.

These configuration metrics measure the coherence and complexity of patterns, and the diversity within a scene. While they are conceptually related to scenic value, as measured most did not relate as directly to residents' rating of the scenes as did the compositional metrics.

3.3. Modeling landscape scenic value

The regression model developed from the landscape metrics to explain scenic value perceived by residents in 1976 is shown in Table 6. All five variables in the model made a significant contribution ($P < 0.05$) and taken together they accounted for approximately half the variation in scenic value ($R^2 = 0.521$).

Edge density made the strongest contribution to the model, indicating that this aspect of landscape complexity had an important relation to scenic value. This was moderated by the positive contribution of the largest patch index, which is an indication of visual coherence and the potential unifying influence of a single dominant land use patch.

The second most important contribution to the model came from the naturalism index. The importance of green nature to scenic value is a common research finding (Kaplan and Kaplan, 1989). That wasteland made a significant negative contribution is also congruent with past findings. However, the negative contribution of forest cover is more difficult to explain, since forest cover is the most common 'natural' land use in Dennis. This negative contribution had the effect of moderating the influence of naturalism.

Table 6
Regression model predicting scenic value from landscape metrics

Variable	Unstandardized coefficients		Standardized coefficient	F-ratio	Probability
	B	S.E			
Intercept	−257.08	48.98	0.00		
Forest	−1.12	0.52	−32.64	4.66	0.037
Waste	−4.59	1.88	−25.03	6.13	0.017
Naturalism index	34.41	9.02	52.83	14.55	<0.001
Largest patch index	0.97	0.43	29.74	5.17	0.027
Edge density	1.55	0.35	54.31	20.12	<0.001

Notes: $n = 56$, $R^2 = 0.521$, R^2-adjusted $= 0.473$, F-ratio $= 10.9$, $P < 0.0001$.

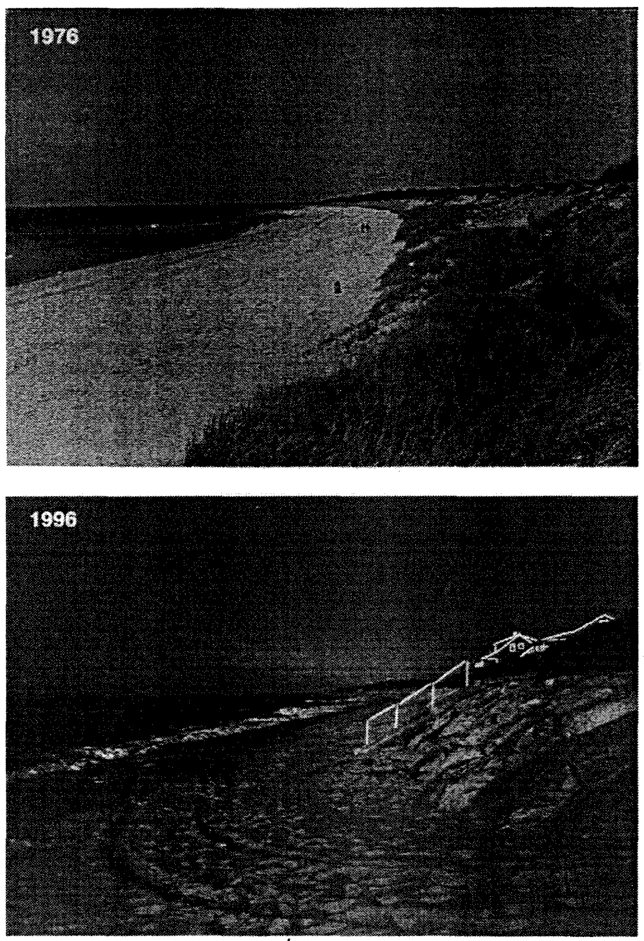


Fig. 4. New houses not only intrude on the scenic quality of what was once a secluded beach, but also bring other intrusive uses as indicated by the vehicle tracks on the upper beach and the need to harden the slope around the stairs. Scenic value fell from 153.1 SBE units in 1976 to 99.2 SBE units in 1996.

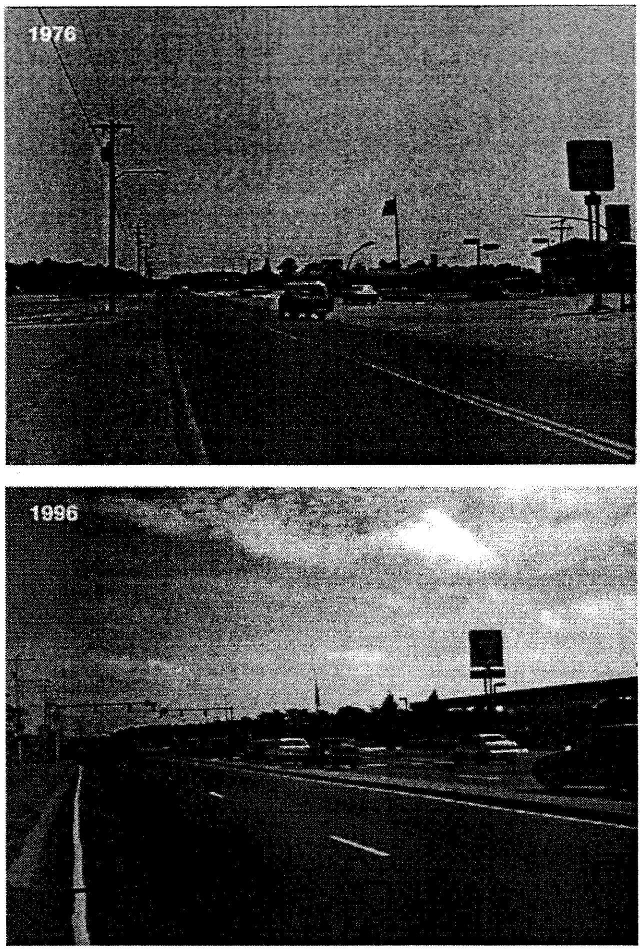


Fig. 5. The widening of this highway, the significant increase in traffic, and other visible changes contribute to a drop in scenic value from −102.9 to −145.8 SBE units.

The coefficients from this model can be used to predict the scenic value ratings made by Dennis residents in 1996 of the 1976 and 1996 views. The Pearson correlation between the predicted and actual 1976 SBEs was $r = 0.622$ ($P < 0.001$) and 1996 SBEs was $r = 0.560$ ($P < 0.001$).

These findings indicate that landscape managers have a dependable way to assess the impacts of proposed landscape changes. While the ability to explain 50% of the variation in perceptions is quite powerful by social science standards, decision makers may hope for something greater. Anecdotal evidence from the residents indicates that they believe intense development has changed Dennis' character and its scenic quality. Sometimes these changes were evident from the GIS database, such as the change in Fig. 4 from water-based recreation (i.e., a secluded beach) to lower density residences. However, other more qualitative changes that may affect scenic value were not readily apparent in the GIS database. For instance, a lower density residential land use classification does not in itself provide information about the use of large rocks to harden the erodable back-beach or the use of the area by off-road vehicles as evidenced by the tracks in the sand. The land use classifications of the 1976 and 1996 views in Fig. 5 remain largely unchanged. However, the widening of the highway from two to four lanes with the introduction of a raised median

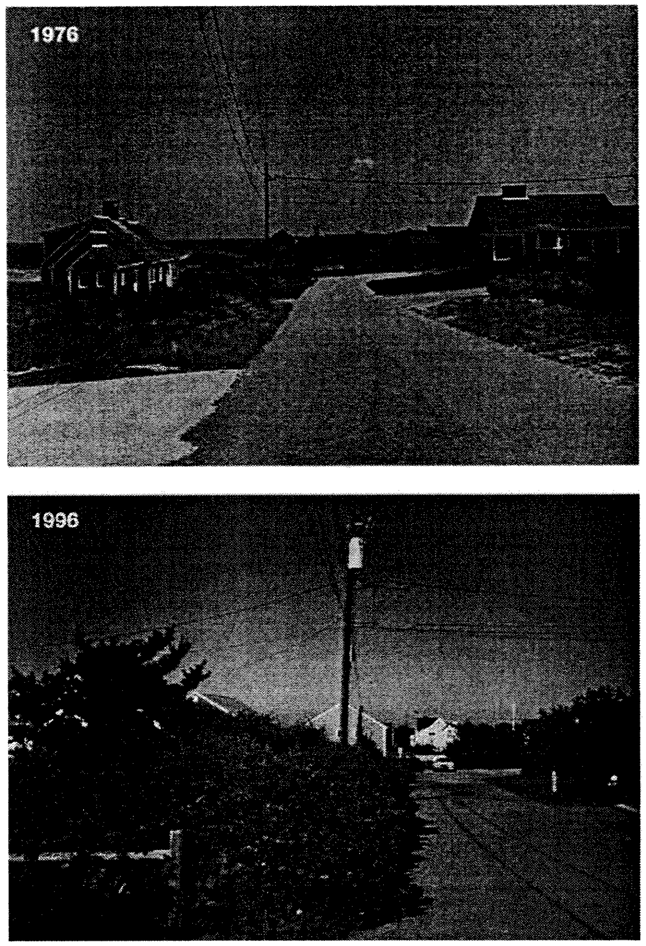


Fig. 6. Several new residences have been built on this modest road above the beach. However, the scenic impact is somewhat screened by planted trees and shrubs. The SBE changed from 20.8 to −8.7.

strip is accompanied by a significant increase in traffic, which brings a need for overhead traffic control lights and other changes that impact the experience of the landscape. In this particular instance, these changes resulted in a drop in scenic value of more than 40 SBE units. Another example is illustrated in Fig. 6 of a low-density residential area above the beach. While the increase in residential land use coverage for this viewshed is only from 43 to 46%, the visual impact of the structures is quite significant. An added complexity is that this impact is somewhat softened by the growth of planted vegetation. In this view, the scenic value changed from 20.8 to −8.7 SBE units.

4. Conclusions and implications

This study attempts to build upon a legacy of landscape perception research by Shafer et al. (1969), Zube et al. (1974), Sell and Zube (1986), and others to develop concepts and models to understand people's perceptions of changes made in the physical landscape. By looking at Dennis, Massachusetts, a landscape that has undergone considerable development-related landscape change within a 20-year period, the study's primary objectives were to document changes in this landscape and residents' scenic quality perceptions of them, and to test the validity of using landscape ecology-based spatial landscape metrics to predict scenic quality perceptions. Results showed a significant decrease in overall scenic quality in the landscape as the land use matrix shifted from one dominated by forest area to one where residential and related types of development predominated. While the landscape metrics that best explained scenic value in 1976 were equally as effective in explaining the scenic value of the 1996 landscape, those that dealt with the composition of the landscape were on the whole more effective predictors than those measuring landscape configuration.

Establishing the effectiveness of a landscape perception model in the context of a changing landscape is particularly important because it provides a basis for managing landscape character. While the landscape underwent substantial change, the human values that define scenic quality and its relation to landscape composition and configuration have remained relatively stable. In other words, the landscape scenic norms are relatively unchanged, which resonates with previous findings investigating the perceptions of Dennis' residents over time (Palmer, 1997). The results in Dennis indicate a preference for natural appearing landscapes with a mosaic of open and forested land. Preference is for a dominant large patch within a view, rather than a more fragmented pattern. In addition, patch edges should be complex, and simple geometric shapes should be avoided.

The good news is that this research relating GIS-generated landscape metrics to local scenic value explains about half of the variation in landscape perception, which appears very promising. The bad news is that half the variation in landscape perception is unexplained. There are several potential sources for this unexplained variation. There may be errors in the data or analysis. For instance, the viewpoints differ slightly between 1976 and 1996, and the viewsheds do not account for the screening effect of vegetation and structures. Predictive capacity may also improve with an increased understanding of how people think about their landscape and how this might be made more amenable to recording in a GIS database. For instance, experience of the landscape may be affected by traffic volume, or the size, density, and health of vegetation. These observations indicate the need for further investigations that replicate and improve upon this line of research by addressing the following questions.

What are the appropriate extent, grain, and classification of landscape elements? Is the extent of this study sufficiently large and diverse to understand the landscape character of a community? The data used here had a resolution of 30 m. Would a finer resolution better capture the subtleties in landscape configuration? Landscape elements were identified using common land use designations. Perhaps there is a different way to identify landscape elements that incorporates the qualitative aspects of built and natural elements, yet remains amenable to recording in a GIS database.

How accurate is the visibility analysis on which the scenic value analysis is based? The results presented here support the use of visibility analysis as a first step in describing the landscape being viewed. However, the visibility analysis used here only considered topographic variation. Vegetation and structures on the land also obstruct actual visibility. Standard procedures need to be developed and validated that account for the visual screening effect of land cover when determining a viewshed.

How do local citizens think their landscape has changed? It seems appropriate to extend the scope of this type of study by asking a sample of citizens directly about their perceptions of change in their local landscape. For instance, the change from a landscape matrix of forestland to one of residential yards may lead to a significantly different experience of the landscape. There is some anecdotal evidence from the 1996 respondents that Dennis residents feel things have gotten much worse. On the other hand, vegetation growth and landscape management has increased scenic value in some areas. Finally, the way that landscape planners, designers, and managers classify the landscape and its elements may not adequately represent the way residents think about it. After all, the model that maintains the ability to predict half the variation in scenic value after 20 years of change still leaves half of the variation unexplained.

Acknowledgements

Financial support for this research was received from the USDA Forest Service North Central Research Station, Urban Forestry Project in Evanston, Illinois. Lisa Swansey, an intern with the Dennis Planning Department, assisted by re-photographing the viewpoints in 1995. The Planning Department also helped in collecting responses from local residents in 1996. Jeffrey Hopson was the research assistant for this project. Thoughtful comments provided by Marla Emery, Paul Gobster, Eric Gustafson, and two anonymous reviewers helped improve the manuscript.

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