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Social Landscape Metrics: Measures for Understanding Place Values from Public Participation Geographic Information Systems (PPGIS)

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ABSTRACT Landscape metrics are used in landscape ecology to quantify landscape characteristics related to structure, function and change by quantifying the structure and distributional pattern of landscape elements such as plants, animals and other physical landscape features. To date, there has been little published research on landscape metrics that include social perceptions of landscape. In this paper, we introduce the concept of social landscape metrics that quantify human perceptions of place resulting from the use of public participation geographic information systems (PPGIS). We present and explain a set of social landscape metrics that measure the composition and configuration of human perceptions of landscapes from multiple study areas using empirical data from PPGIS studies. We distinguish between two classes of social landscape metrics, boundary and inductive, present methods to develop them, and describe some of their applications to land use planning and management. We conclude with a discussion of future research needs for advancing knowledge about social landscape metrics.

KEY WORDS: Social metrics, public participation, PPGIS, place values, landscape perception

Introduction

Landscape metrics measure the geometric properties of landscape features and ecological functions and their relative positions and distribution (Botequilha Leitão *et al.*, 2006). Traditionally, landscape metrics have sought to quantify the structure and distributional pattern of landscape elements that have an obvious physical presence on the landscape such as plants, animals, geographical features, and human settlement patterns. Much less developed, and the focus of this paper, is the structure and distributional pattern of human perceptions of landscape including the human attribution of place values, perceptions, and preferences. We argue that the human process of valuing landscapes results in structural and distributional patterns on the landscape that although not directly observable, constitute latent patterns of social

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and psychological complexity that can ultimately be measured and quantified. There appears to be large potential for this type of social research including landscape metrics useful for landscape management and planning (Uuemaa *et al.*, 2009).

One of the key research priorities identified by landscape ecologists is better integration of humans and their activities into landscape ecology including the development of “synthetic or holistic metrics that reflect social, cultural, and ecological diversity and heterogeneity ...” (Wu & Hobbs, 2002, p. 361). And yet, there have been few published articles on landscape metrics that address social aspects and landscape perceptions (Uuemaa *et al.*, 2009). The ability to integrate the social and cultural aspects of humans into landscape ecology has been hindered, in part, by a lack of systematic spatial inventories of human perceptions and values of landscape and a set of diagnostic metrics that can be applied to these inventories for planning and management purposes. The development of participatory geographic information systems technology in the 1990s has provided new opportunities to systematically capture and measure the spatial distribution of social values, perceptions, preferences, and other attributes using a variety of spatial techniques. Participatory mapping has emerged as a valuable tool to capture spatial information on social landscape values (Brown, 2005; Brown & Weber, 2011; Fagerholm & Käyhkö, 2009; Gunderson & Watson, 2007; Soini, 2001; Tyrväinen *et al.*, 2007).

The term ‘public participation geographic information systems’ (PPGIS) was conceived in 1996 at the meeting of the National Center for Geographic Information and Analysis (NCGIA). PPGIS combines the academic practice of GIS and mapping at local levels to produce knowledge of place. Since the 1990s, the range of PPGIS applications has been extensive, ranging from community and neighbourhood planning to mapping traditional ecological knowledge of indigenous people (see Sieber, 2006; and Sawicki & Peterman, 2002 for a review of PPGIS applications). PPGIS systems have increasingly exploited internet technology to capture spatial attributes from local and regional populations (Beverly *et al.*, 2008; Brown & Reed, 2009; Carver *et al.*, 2001; Kingston, 2007; Kingston *et al.*, 2000).

In an early public lands application, Brown and Reed (2000) asked individuals to identify the location of landscape values for the Chugach National Forest (US) planning process. Reed and Brown (2003) subsequently developed a quantitative modelling approach using the PPGIS mapped attributes to determine whether management alternatives were generally consistent, and place-consistent with publicly held forest values. Additional PPGIS research was conducted to identify the location of highway corridor values (Brown, 2003); to identify ‘coupled social-ecological’ hotspots (SES) where human and biophysical systems are closely linked (Alessa *et al.*, 2008); to identify preferences for tourism and residential development (Brown, 2006; Raymond & Brown, 2007); to identify priority areas for conservation (Pfeuller *et al.*, 2009; Raymond & Brown, 2006); to identify place attachment (Brown & Raymond, 2007); to measure urban park and open space values for park planning (Brown, 2008), and to identify national park visitor experiences and perceived environmental impacts (Brown *et al.*, 2009). Researchers with the Canadian Forest Service designed and developed the first internet-based participatory mapping application to collect data on the locations of forest values across a 2.4 million ha study area in the province of Alberta, Canada (Beverly *et al.*, 2008). Three additional

internet-based PPGIS landscape value and special place mapping studies were completed for forest values in the US (Brown & Reed, 2009).

To extend the set of analytical tools available for PPGIS data, we present and distinguish two classes of social landscape metrics—‘boundary’ and ‘inductive’ and compare the relative merit of each type.

Inductive landscape metrics derived from PPGIS are the same as traditional landscape ecology metrics in their calculation and terminology with the key difference being that landscape ‘patches’ consist of higher intensities of human perceptions and values for the landscape rather than the presence of some biological or physical landscape feature. We call these metrics ‘inductive’ because they are emergent landscape features from the PPGIS data collection and analysis process. The delineation of landscape patches—areas of either dominant or relatively homogenous landscape perceptions—occurs in analysis by applying heuristic but consistent decision rules to the spatial data. Similar to traditional ecological landscape metrics, the managerial implication of inductive social metrics at the landscape scale requires judgement—thresholds wherein the ranges of metric values would logically trigger consistent interpretation. Like traditional ecological metrics, the process of calculating social landscape metrics is relatively straightforward once the inventory and delineation of landscape patches has been completed. Following the typology of landscape metrics proposed by Botequilha Leitão *et al.* (2006) and McGarigal and Marks (1995), we describe the *composition* and *configuration* of perceptual landscapes using metrics that operate at the patch or landscape scale of analysis.

Unlike traditional ecological landscape metrics, the boundary metrics described herein have little foundation in the existing research literature. These metrics are grounded in the need for relevant decision criteria for land *allocation* and *management*. Boundary metrics are calculated by analyzing the distribution of mapped PPGIS attributes that fall within pre-defined management areas of interest or spatial areas that have boundaries. The management areas could be watersheds, political boundaries, administrative areas, recreation sites, or simply areas of heightened managerial concern. The metrics presuppose a need to understand the type and mix of human perceptual attributes that occupy a given management area thus providing decision-makers with data to engage in landscape value trade-off analysis. The metrics are calculated based on the predefined boundaries. Some of the boundary metrics described include attribute frequency, dominance, density, and diversity as well as indices that measure conflict potential.

To illustrate the derivation and use of inductive and boundary social metrics, we use landscape value point data because these attributes have been the focus of at least 12 separate PPGIS studies. Specifically, we show the range of these metrics that were derived from three geographic regions in the western US representing national forests. However, it is important to note that the metrics described herein are not contingent on the type of perceptual attribute collected (e.g. a landscape value typology) and can be applied to virtually any point data collected through PPGIS.

The paper is organized into sections that: 1) describe the perceptual attribute data collected (i.e. landscape values) and the process for collecting the data, 2) provide definitions, calculations, and methods for the boundary and inductive social metrics,

and 3) present selected empirical results from applying the metrics to three PPGIS studies involving different study areas that used similar PPGIS data collection procedures. We close with a discussion on how these metrics can be implemented in a decision support system for environmental and resource management planning processes such as national forest planning.

Methods

PPGIS Data Collection

Social data measuring the type and location of different landscape values was collected using an internet-based PPGIS for three national forests in the US—the Coconino National Forest in Arizona and the Deschutes/Ochoco National Forests and Mt Hood National Forests in Oregon (see Brown & Reed, 2009, for a more detailed presentation of the methods). These forests were selected as pilot studies based on their potential use of the PPGIS data for the national forest plan revision process (Coconino NF), for travel management planning (Deschutes/Ochoco NFs), and for recreation facilities planning (Mt Hood NF). The PPGIS attributes mapped consisted of a typology of landscape values (Brown & Reed, 2000) represented by points and included the following attributes: aesthetic, economic, recreation, life sustaining, learning/scientific, biological diversity, spiritual, intrinsic/existence, historic/cultural, therapeutic, and wilderness. Definitions for each value attribute were provided. For example, aesthetic value was defined as “I value these areas for their scenic qualities” and life sustaining value was defined as “I value these areas because they help produce, preserve, and renew air, soil, and water.” Study participants would drag and drop markers representing these values onto a map location associated with these values. The three websites developed for collecting landscape value data had similar user interfaces and used Adobe Flash[®] and MySQL database software. The Coconino NF website can be viewed at: <http://www.landscapemap2.org/coconino> (use access code 101-0101).

The PPGIS studies sampled randomly selected households in communities within, and proximate to the national forest administrative boundary. The method for household contact followed the tailored design method (Dillman, 2000) and consisted of an initial cover letter explaining the study as well as the internet address and a unique code for accessing the internet mapping website. Two follow-up mailings with access codes were sent to non-respondents. The PPGIS websites were open for participant mapping for approximately two months.

The sample sizes for the three pilot studies were based primarily on administrative feasibility and budgetary constraints. Totals of 3009, 3056 and 1825 invitations were mailed to households located proximate to the Coconino, Deschutes/Ochoco, and Mt Hood National Forests respectively. The survey response rates for the three studies were 10.1%, 11.4% and 11.8% resulting in 257, 344, and 179 respondents respectively. The response rates were low but consistent with other reported rates for random, general public surveys. Analysis of non-response did not indicate any systematic bias associated with non-participation. The primary reasons for non-participation were lack of convenient internet access, lack of familiarity with the study area, or lack of time (Brown & Reed, 2009).

Landscape value point data collected from the three internet PPGIS studies were converted to ArcGIS[®] for analysis. The number of mapped attributes (points) available for analysis ranged from 9699 (Deschutes/Ochoco NF) to 4614 (Mt Hood NF). The average number of landscape values mapped by each respondent was 36 (Coconino NF), 28 (Deschutes/Ochoco NF) and 26 (Mt Hood NF) out of a total of 78 attribute markers available to each study participant.

Data Analysis—Boundary Social Landscape Metrics

The goal of generating boundary metrics for landscape values is to answer questions with management implications such as the prioritization of scarce management resources or the zoning of areas for particular activities. For example, where is the greatest concentration of identified public values for recreation or wildlife? Where are values most similar? Where are values most diverse? What is the dominant value for the region? What is the dominant value for each administrative unit? Given a set of value-to-value compatibility relationships (e.g. economic value from resource extraction may be incompatible with biological diversity value), where are the areas with the greatest potential for conflict based on the spatial distribution of values? And given a set of activity and value compatibilities (e.g. off-road vehicle use may be incompatible with ‘wilderness’ value), where are the areas with the greatest potential for conflict?

The landscape value point data were geographically intersected with administrative landscape units provided by the national forests. The choice of administrative boundaries was based on the potential to inform an existing national forest planning process. For the Coconino NF, the administrative or boundary units were designated areas from the previous forest plan that were largely based on biological or physical landscape features such as timber suitability (i.e. potential for tree regeneration) or geologic features (e.g. the ‘red rock’ area near Sedona). At the time of the study, the existing administrative units from the forest plan were deemed most useful by the forest interdisciplinary planning team to examine the distribution of landscape values. The administrative or boundary units for the Deschutes/Ochoco NFs were identified by members of a travel management planning team as potentially useful for implementing travel management plans (i.e. the location of ATV/ORV routes and restrictions). The Mt Hood administrative areas were suggested by recreation planners as potentially useful for the recreation facilities planning process. The boundaries for these areas were created by drawing 5 km buffers around known recreation sites on the forests. This heuristic method provided boundaries to examine the quantity and mix of landscape values in, and adjacent to, existing recreation sites.

To calculate the boundary-derived social metrics, the intersected point data was imported into a spreadsheet model called Values Compatibility Analysis. Input to the model is the number and type of landscape values per boundary area and the output consists of a series of calculated social metrics defined in Table 1. The *value sum* (P0) metric counts the number of landscape value point locations by type within the boundary while the *value sum percent* (P1) metric calculates the percent of mapped value points in a landscape unit relative to the total number of mapped landscape values across all units. The *dominant value* (D) metric is the landscape

Table 1. Boundary-determined social landscape metrics useful for landscape analysis

Definition	Calculation	Usefulness	Limitations
Value Sum Absolute (P0)—the total count of all landscape points located within a landscape unit	Sum all the landscape value points within the landscape unit. Ranges from 0.000 to no set upper range $P0 = \sum p_i$	Indicates the most valued landscape unit by comparing value sums across landscape units	Larger landscape units may have higher point counts simply by virtue of the larger landscape unit
Value Sum Percent (P1)—the percent of mapped value points in a landscape unit relative to the total number of mapped landscape values across all units	where: p_i = number of landscape value points mapped within landscape unit i Sum of all landscape values within landscape unit divided by the total number of landscape values mapped $P1 = \frac{\sum p_i}{P}$	Reveals the landscape units with the highest proportions of all mapped landscape values	
Dominant value (D)—the landscape value with largest count of point locations within the landscape unit	where: p_i = number of landscape value points mapped within landscape unit i P = total number of mapped landscape value points By definition, the landscape value with largest count of points within the landscape unit $D = \max \left(\sum v_i \right)$	Shows the dominant landscape value within a landscape unit	A landscape unit can have multiple values close in total count and a focus on the dominant value would mask small differences.
Value dominance index (D1)—an index that quantifies the dominance relationship between the dominant landscape value within the landscape unit and the next most common value	where: v_i = number of mapped landscape value points for a given value v in a given landscape unit i Calculates the difference between the landscape value with the highest point count and the next highest point count (second rank) within a landscape unit and expresses as a percent of the highest point count. The index can range between 0.000 (no difference) to 1.000 where there is only one landscape value located in the landscape unit $D1 = \frac{\max(\sum v_i) - \max(\sum v_i)^{(2)}}{\max(\sum v_i)}$	Shows whether the dominant value is distinct or only slightly more common than other landscape values in the landscape unit	Only examines the difference in the top two values in a landscape unit. An evenness index should be used when counts between all landscape values are important.
	where: v_i = number of mapped landscape value points for a given value v in a given landscape unit i		

(continued)

Table 1. (Continued)

Definition	Calculation	Usefulness	Limitations
Value density index (D2)—an index that measures the relative density of landscape values per landscape unit by area	$D2 = \frac{\sum p_i}{h_i}$	All factors being equal, larger landscape units would have more landscape values mapped. This index complements the F index by removing the influence of the size of the landscape unit	Does not indicate whether values are diverse or uniform within the landscape unit
Value frequency index (F)—the relative frequency of landscape values within a landscape unit compared to the average frequency of mapped landscape values across all landscape units	$F = \frac{\sum p_i}{\frac{n-1}{n} \sum \bar{X}_j}$	Shows whether a given landscape unit, has greater relative frequency of values ($F > 1.0$) or less frequency of values ($F < 1.0$) than the average number of mapped landscape values across all landscape units	
Value diversity index (D3)—is the standard Shannon diversity index used in ecological studies calculated for the different landscape values located within a landscape unit	$D3 = - \sum_{i=1}^n p_i \ln p_i$	High diversity scores could indicate multiple, competing interests for the same landscape unit	Does not fully indicate the potential for conflict because some landscape values may be complementary rather than competitive
Value conflict potential index (C)—is a calculated index based on <i>a priori</i> estimates of the inherent conflict between each pair of values		Provides a complement to D3 index	The conflict relationship between different landscape values requires subjective judgment

Sum of all landscape value points per landscape unit divided by the number of acres or hectares in the unit

$$D2 = \frac{\sum p_i}{h_i}$$

where: p_i = number of landscape value points mapped within landscape unit i
 h_i = number of hectares within landscape unit i

The sum of all landscape value points within a landscape unit boundary divided by the mean number of landscape values mapped for all other landscape units. Has no set upper range

$$F = \frac{\sum p_i}{\frac{n-1}{n} \sum \bar{X}_j}$$

where: p_i = number of landscape value points mapped within landscape unit i
 n = total number of landscape units excluding

\bar{X}_j = mean number of landscape values per landscape unit j

$$D3 = - \sum_{i=1}^n p_i \ln p_i$$

where: p_i = the proportional abundance of the i th landscape value = (n_i/N) .
 n_i = the number of mapped landscape values in the i th landscape value category

N = the total number of all mapped landscape values

\ln = natural logarithm

v = the number of landscape value categories

The calculated diversity index may be normalized to a scale ranging between 0.000 and 1.000 where higher index values indicate higher value diversity within the landscape unit.

Calculation will vary based on a table that quantifies the complementary or competitive relationship between landscape values. The index is designed to range between 0.000 and 1.000 where 0.000 indicates there are no conflicting values in the landscape unit and 1.000 would indicate complete conflict between the values located in the landscape unit

value with largest count of points within the boundary unit. The *value dominance index* (D1) metric quantifies the dominance relationship between the dominant landscape value within the boundary unit and the next most common landscape value on a scale that ranges from 0 (i.e. there is no difference in dominance among values) to 1.0 (there is only one landscape value in the boundary unit). The *value density* (D2) metric calculates the relative density of landscape values per boundary area while the *value frequency* (F) metric shows the relative frequency of landscape values by type within a boundary unit compared to the frequency of all mapped landscape values. The *value diversity index* (D3) metric is the standard Shannon diversity index commonly used in ecological studies calculated within a landscape unit. The *value conflict potential index* (C) metric is a calculated index based on *a priori* estimates of the inherent conflict between each pair of landscape values. As such, the derivation of this metric requires an initial, subjective judgment about the relative compatibility of landscape values occupying the same geographic space.

Data Analysis—Inductive Social Landscape Metrics

The goal of social landscape metrics, similar to landscape ecology metrics, is to better understand how ecological and human processes shape the landscape, and vice versa, how human processes are influenced by landscape pattern. Inductive metrics for landscape values provide a starting point for basic research questions that first quantify and describe the perceptual landscape, then seek to relate these metrics to ecological and cultural processes. For example, is there a relationship between ecological landscape features and social values? Are complex ecological landscapes associated with complex cultural landscapes? Is there a relationship between human development patterns and landscape values? What are the ecological and cultural consequences of fragmented social landscapes? One useful application of inductive social landscape metrics is to help identify coupled social-ecological space, areas that have both high ecological and social value (Alessa *et al.*, 2008).

The inductive social landscape metrics were derived by first estimating patches or polygons of landscape values from point data using kernel density estimation combined with a heuristic density threshold to yield landscape value patches (Figure 1). Kernel density estimation is an interpolation technique for individual point locations that generates a symmetrical surface over each point by evaluating the distance from the point to a reference location and then summing the value of all the surfaces for that reference location.

Kernel density rasters were generated in ArcGIS Spatial Analyst[®] from each landscape value using a grid cell size of 500 metres and search radius of 3000 metres for the Mt Hood NF and Coconino NF and 2000 meters and 5000 meters for the Deschutes/Ochoco NF. The grid cell sizes and search radii choices were based on potential mapping error from participant point placement and differences in the size and map scale of the study areas. Since kernel estimation generates a continuous density function over the study area, a decision rule must be implemented to generate patches from landscape value point distributions. Given the unequal number of points mapped per landscape value, a standardized, relative density threshold was preferred over an absolute density threshold. Patch boundaries were operationally derived for each landscape value by selecting the highest one-third (greater than 1

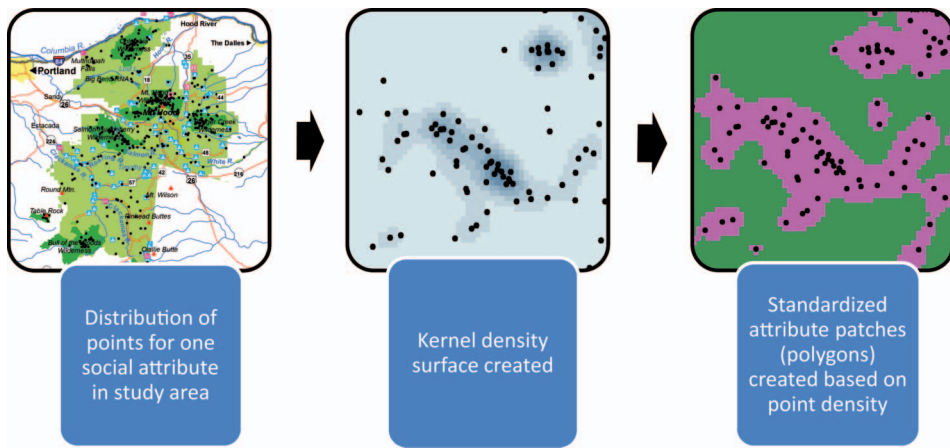


Figure 1. The creation of inductive 'patches' from landscape value points.

standard deviation from the mean) of the density values for a given landscape value. This procedure yielded relatively high density patches for each landscape value in the study areas.

After patches were generated for each landscape value, the study area landscapes were analyzed using Patch Analyst for ArcGIS[®] (Rempel, 2008). Of the many potential landscape metrics used in ecological studies, a subset was selected based on their relevance to describing the composition and configuration of landscapes for potential use in planning (Botequilha Leitao *et al.*, 2006). Descriptions of the traditional ecological landscape metrics modified for use with social landscape values appear in Table 2. The metrics of patch richness, patch area proportion, Shannon's diversity index, and Simpson's evenness index describe the perceptual composition of the landscape while the metrics of the number of patches, patch size, patch shape, and Euclidean nearest neighbour describe the configuration of values on the landscape.

Results

The boundary and inductive social metrics described herein were calculated from landscape value PPGIS data collected for three national forest study areas in the western US. Selected results are presented in tables to illustrate the range of values and to establish baselines for future studies.

The boundary metric results (Table 3) show a high degree of variability across the three forests, in part due to the different sizes of the boundary areas. The smaller landscape or boundary units on the Mt Hood NF associated with recreation sites have much higher landscape value densities (D2) on average than management units on the other national forests. The Mt Hood landscape units also have less value diversity on average (D3), the likely result of greater dominance (D1) of recreation values over other landscape values. The Coconino NF has the highest variability in landscape value counts per unit (P1) in the different management units resulting in the highest frequency index (F) indicating that at least one unit has nine times more

Table 2. Inductive social landscape metrics derived from point data using kernel density estimation

Landscape Value Composition Metrics	
<p>Patch richness (PR)—the number of different landscape values present in the landscape</p> $PR = M$ <p>where: M = number of different landscape value patches within boundary (e.g. aesthetic, economic, recreation value, etc.)</p>	<p>Class area proportion (ZLAND)—the proportion of the landscape comprised of a particular landscape value</p> $ZLAND = \frac{\sum_{i=1}^j a_{ij}}{A}$ <p>where: A = total landscape area a_{ij} = area of landscape value patch ij</p>
<p>Shannon's Diversity Index (SDI)—a measure of the relative diversity of landscape value patches</p> $SDI = - \sum_{i=1}^m (P_i * \ln P_i)$ <p>where: m = number of landscape value patch types P_i = proportion of landscape occupied by landscape value patch type i</p>	<p>Simpson's Evenness Index (SIEI)—a measure of the distribution of area among landscape value patches. Measures 1 when distribution of area is exactly even among landscape value patches, approaches 0 as landscape become more dominated by one landscape value</p> $SIEI = \frac{1 - \sum_{i=1}^m P_i^2}{1 - (\frac{1}{m})}$ <p>where: m = number of landscape value patch types P_i = proportion of landscape occupied by landscape value patch type i</p>
Landscape Value Configuration Metrics	
<p>Number of patches (NUMP)—the total number of landscape value patches in the landscape of a landscape value type</p> $NUMP = N$ <p>where: N = number of landscape value patches in the landscape of a landscape value type (e.g. aesthetic value)</p>	<p>Mean Patch Size (MPS)—the size of discrete landscape value patches, summarized across all landscape value patches of a particular type in the landscape as simple arithmetic mean</p> $MPS = \frac{A}{N}$ <p>where: A = total landscape area N = number of landscape value patches</p>
<p>Mean Nearest Neighbour Distance (MNN)—the Euclidean distance between each discrete landscape value patch and its nearest neighbouring value patch of the same type, summarized across all value patches of particular value patch type as simple arithmetic mean.</p> $MNN = \frac{\sum_{i=1}^m \sum_{j=1}^{n'} h_{ij}}{N'}$ <p>where m = number of landscape value patch types n' = number of landscape value patches of patch type i h_{ij} = distance from landscape value patch ij to nearest neighbouring landscape value patch of the same type N' = total number of landscape value patches that have nearest neighbours</p>	<p>Mean Patch Shape Index (MSI)—a standardized measure of landscape value patch shape calculated for each discrete landscape value patch, then summarized across all patches for a particular landscape value in the landscape as a simple arithmetic mean.</p> $MSI = \frac{\sum_{j=1}^n \left(\frac{P_{ij}}{2\sqrt{\pi * a_{ij}}} \right)}{n_i}$ <p>Where: P_{ij} = perimeter of landscape value patch ij a_{ij} = area of landscape value patch ij n = number of landscape value patches</p>

Table 3. Selected boundary-determined social landscape metrics for three national forests in US

Rationale for landscape unit designation Metric	Deschutes/Ochoco NF	Mt Hood NF	Coconino NF
	Travel management planning process (<i>n</i> = 18 units) Max./min./mean	Recreation site facilities management (<i>n</i> = 22 units) Max/min/mean	Forest plan designations under existing forest plan (<i>n</i> = 25 units) Max/min/mean
Landscape Unit Size (acres)	411,859/1585/ 120,455	38/38/38	512,725/757/ 62,183
Value Sum Percent (P1)	16.42/0.54/5.56	8.15/3.21/4.55	26.92/0.11/2.56
Value Dominance Index (D1)	0.53/0.04/0.19	0.78/0.06/0.50	.64/.10/.32
Value Frequency Index (F)	2.96/0.10/1.0	1.79/0.71/1.0	9.17/0.04/1.0
Value Density (D2) Index (points per acre)	0.14/0.00/0.01	2.47/0.97/1.38	0.029/0.00/0.01
Value Diversity (D3) Index	0.99/0.90/0.96	0.89/0.57/0.76	0.98/0.68/0.87

landscape values than the average value frequency per unit. The Deschutes/Ochoco NF has the largest landscape units by area, on average, driving value densities (D2) lower, but increasing the diversity of values (D3) found in each unit.

The inductive metric results (Table 4) also show significant variability across the three national forests. The number of inductive landscape value patches (NUMP) is largest on the Coconino NF and smallest on the Deschute/Ochoco NF. This leads to the inverse result in mean patch sizes (MPS) which are smallest on the Coconino and largest on the Deschutes/Ochoco NF. The most irregular shaped patches (MSI) are found on the Deschutes/Ochoco NF while the other two national forests have similar shaped patches. Value patches are most isolated on the Dechutes/Ochoco NF as indicated by the larger mean nearest neighbour (MNN) metrics, and least isolated on the Mt Hood NF. The inductive metrics are influenced by the size of the study area and the number of mapped point attributes. To control for these influences and to explore the relationship between patch size and study area, the number of patches (NUMP) and mean patch size (MPS) were standardized and plotted for four selected landscape values (see Figure 2) for the three national forests as well as data from four other PPGIS studies that collected the same landscape value attributes. While the relationship between the number of value patches and patch size showed variability across studies, a few trends can be observed: 1) there were relatively fewer recreation patches than other landscape value patches (Figure 2a), 2) there were fewer aesthetic patches but they tend to be larger than other landscape patches (Figure 2b),

Table 4. Selected inductive social landscape metrics for three national forests in the US

		Deschutes/Ochoco NF							
Study area Method	Study area size	Nearest neighbour statistics ^b		Patch Metrics ^a					
		R (Rank)	Z	NUMP (Rank)	MPS	PSSD	MSI	MNN	MPI
Landscape Values (Deschutes/Ochoco NF)		.43 (2)	-34.9	18436.4	25323.5	1.40	5172.7	74.4	405,600.0 (12%)
		.48 (7)	-25.3	16688.0	18336.8	1.44	4973.4	47.2	417,200.0 (13%)
		.46 (5)	-27.6	15614.8	24808.7	1.34	4098.3	61.4	421,600.0 (13%)
		.46 (5)	-34.0	19050.0	32813.6	1.42	4691.2	113.5	457,200.0 (14%)
		.39 (1)	-39.2	14144.0	26055.4	1.36	4177.6	40.4	353,600.0 (10%)
		.48 (7)	-22.6	12193.6	16704.8	1.35	4688.6	44.0	378,000.0 (12%)
		.48 (7)	-24.6	16000.0	19650.6	1.38	3842.2	59.4	432,000.0 (13%)
		.43 (2)	-28.3	12303.5	22195.8	1.33	4256.2	50.6	356,800.0 (11%)
		.48 (7)	-22.4	11988.6	19043.5	1.32	3369.8	66.4	419,600.0 (13%)
		.48 (7)	-21.6	Spiritual	9022.2	16468.6	1.25	4058.6	40.2
	.50 (12)	-21.9	Therapeutic	18383.3	21754.2	1.43	4242.4	70.6	441,200.0 (14%)
	.44 (4)	-33.1	Wilderness	11369.2	18317.6	1.33	4201.2	28.2	295,600.0 (9%)
Mt Hood NF									
		Kernel density (500 m grid cell, 3000 m search using ArcGIS Spatial Analyst [®])							
Study area Method	Study area size	Nearest neighbour statistics		Patch Metrics					
		R (Rank)	Z	NUMP (Rank)	MPS	PSSD	MSI	MNN	MPI
Landscape Values (Mt Hood)		.56 (3)	-19.7	3547.7	7244.9	1.34	2659.9	111.1	113,525.0 (11%)
		.59 (6)	-14.1	1569.8	3072.8	1.19	2372.4	18.2	97,325.0 (12%)
		.60 (8)	-14.0	3753.4	9295.9	1.30	1803.8	179.7	165,150.0 (16%)
		.59 (6)	-18.6	5265.8	10290.6	1.39	2405.3	166.0	157975.0 (16%)
		.47 (1)	-23.8	2431.1	4187.4	1.20	2348.2	23.9	80225.0 (10%)
		.58 (4)	-12.4	2444.6	7758.6	1.24	3111.1	46.1	102675.0 (11%)
		.66 (12)	-11.0	3219.4	4670.9	1.33	2247.2	69.8	144875.0 (16%)
		.54 (2)	-13.9	2216.7	3064.2	1.28	2613.6	25.6	106400.0 (12%)
		.61 (9)	-12.4	2690.5	2715.0	1.34	2504.2	25.7	113000.0 (14%)
		.58 (4)	-12.5	Spiritual	3251.8	6475.5	1.30	2395.9	95.6
	.62 (11)	-11.5	Therapeutic	4445.1	5714.6	1.38	2070.8	100.2	160025.0 (15%)
	.61 (9)	-15.3	Wilderness	2010.0	4796.4	1.23	2616.3	94.3	120600.0 (12%)

(continued)

Table 4. (Continued)

Study area Method	Nearest neighbour statistics			Patch Metrics							
	R (Rank)	Z		NUMP (Rank)	MPS	PSSD	MSI	MNN	MPI	PCT LAND	
Landscape Values (Cocconino NF)	.54 (3)	-27.6	Aesthetic	37 (10)	4181.1	9271.1	1.33	3129.0	34.2	154700.0 (12%)	
	.52 (2)	-19.9	Economic	36 (11)	2651.4	4121.7	1.25	4046.1	42.2	95450.0 (8%)	
	.60 (8)	-19.8	Biological Div.	91 (1)	2106.9	5234.4	1.20	2566.4	51.2	191725.0 (14%)	
	.58 (7)	-26.6	Recreation	50 (7)	3126.0	6595.5	1.24	3127.0	91.3	156300.0 (12%)	
	.51 (1)	-24.4	Historic	38 (9)	2444.7	3751.5	1.21	3688.8	16.4	92900.0 (7%)	
	.62 (9)	-17.0	Intrinsic	83 (2)	2251.5	6436.2	1.26	2261.1	53.0	186875.0 (15%)	
	.55 (4)	-21.1	Scientific/learning	44 (8)	2383.5	3591.3	1.27	2937.5	32.5	104875.0 (8%)	
	.56 (5)	-20.0	Life sustaining	77 (3)	2243.2	5679.6	1.26	2752.8	34.9	172725.0 (14%)	
	.56 (5)	-17.9	Spiritual	59 (5)	2294.1	8045.4	1.27	3673.6	27.0	135350.0 (11%)	
	.66 (11)	-14.2	Therapeutic	71 (4)	2698.2	8201.0	1.29	2642.2	40.7	191575.0 (16%)	
	.65 (10)	-18.7	Wilderness	53 (6)	2324.1	5779.2	1.22	3354.8	100.7	123175.0 (9%)	

^aNUMP = number of patches, MPS = mean patch size, PSSD = patch size standard deviation, MSI = mean shape index, MNN = mean nearest neighbour, MPI = mean proximity index, PCT LAND = proportion of study area covered by patches of landscape value.

^bThe *R* statistic is a global measure of the point distribution and tests the hypothesis that each distribution is completely spatially random (CSR). The *R* statistic is a ratio of observed distances between points to the expected distances between points if the points were randomly distributed. The *R* scale ranges from *R* = 0 (completely clustered) to *R* = 1 (random) to *R* = 2.149 (completely dispersed). From the *R* statistic, a standardized *z* score is computed to test the hypothesis that the point distribution deviates from randomness, either toward clustering or uniformity. *Z* scores greater than ± 1.96 (95% confidence level) lead to rejection of the null hypothesis of random point distribution.

3) scientific/learning patches tend to be smaller in size (Figure 2c), and 4) intrinsic patches tend to be relatively more numerous but variable in size (Figure 2d). Although not shown, there were no obvious trends in life sustaining and biological diversity patches across PPGIS studies.

Discussion

In this paper, we provide the beginnings of what we hope will be extended research into the development, use, and refinement of social landscape metrics. The value of

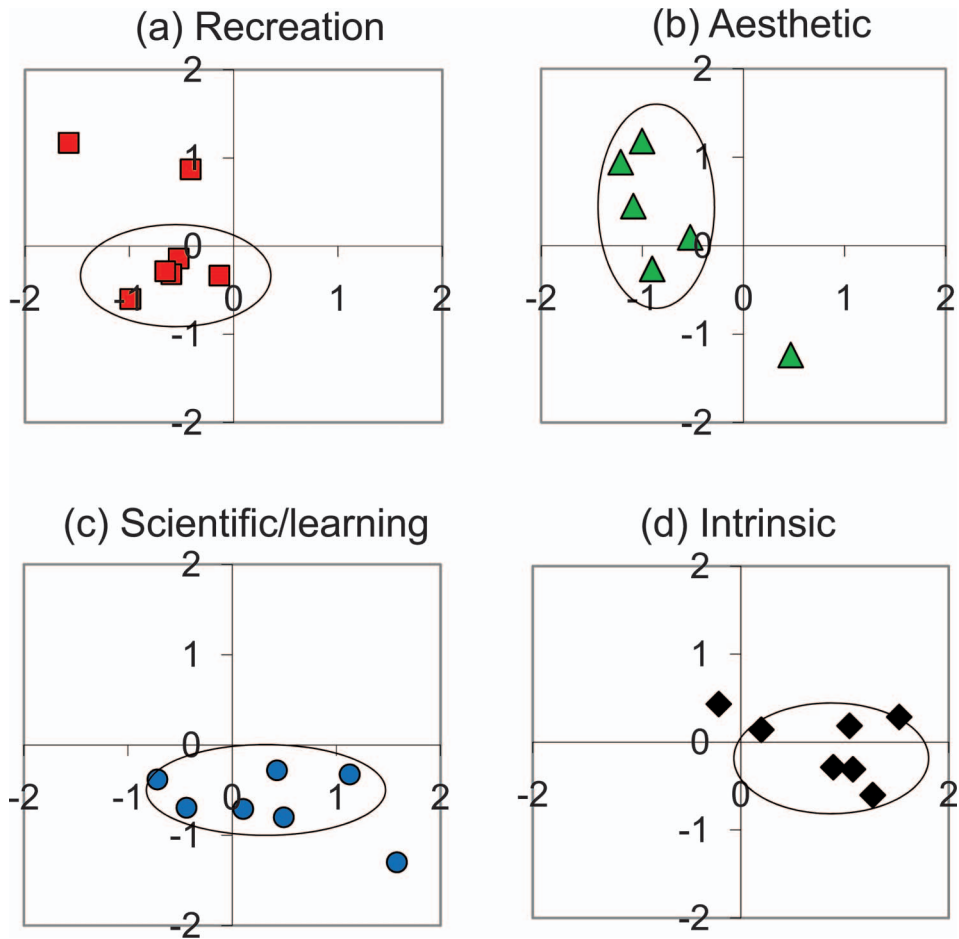


Figure 2. Plots of inductive landscape value metrics (number of patches by mean patch size) for four landscape values derived from seven different PPGIS studies.^a Standardized number of patches is on the horizontal axis and standardized mean patch size is on the vertical axis.

^aPlots use standardized scores from multiple PPGIS studies: Deschutes National Forest (US), Coconino National Forest (US), Mt Hood National Forest (US), Otways Region (Victoria, Australia), Kangaroo Island (South Australia), Chugach National Forest (US), Kenai Peninsula (US).

landscape quantification using social metrics, however, is tied to the validity, reliability, and interpretability of the metrics and their potential applications to land use planning and management.

The potential for social metrics appears especially large in the planning and management of public lands such as national forests, parks, and resource management areas, especially given the statutory requirement that accompanies most public land designations to manage these lands for a variety of public values and purposes. As evidence of the potential, the US Forest Service has requested approval to complete up to 15 PPGIS studies for national forests over a three-year period (Federal Register, 2010, p. 16719). Metrics derived from landscape values can identify the location and quantify the type of values that exist on public lands. This information can provide management decision support, for example, by modelling which potential management activities are compatible with the values located in different places (Reed & Brown, 2003). Metrics can also be calculated based on different PPGIS spatial attributes such as activities, experiences, preferences, facilities needs, subsistence locations, and place meanings, among others. For example, Brown *et al.* (2009) collected national park visitor experiences and perceived environmental impacts in a PPGIS and suggest that a boundary metric based on the ratio of positive visitor park experiences to environmental impacts within a park management zone or a metric based on the density of perceived environmental impacts would provide information to compare different park zones to determine priorities for the allocation of agency resources.

Administrative boundary designations and management zones in land use plans are often based on historical decisions that may or may not be relevant to land use in the modern context. Social landscapes, like physical landscapes, are dynamic and subject to change. Inductive metrics provide an opportunity to re-examine management boundaries based on PPGIS data to determine if the boundaries still make sense. For example, what if a management zone designated for intensive timber management in a forest plan had metrics indicating high value for aesthetics and recreation? Would it make sense to rezone this area for recreational use? At the very least, the management agency would want to know what social values were being traded-off and where public resistance was likely to be encountered with respect to management initiatives. Social landscape metrics hold the promise of reconciling human perception and understanding of a landscape with a rational management scheme for the landscape.

The reliability of the social metrics rests, in part, on the data collection methods, sampling, and the comprehensiveness of the participatory process. Are the PPGIS attributes collected accurately, without bias, and inclusive of all relevant human communities? We have described the calculation of metrics based on point data but there is no inherent reason why social metrics could not be calculated from polygon or line data collected in a PPGIS process. Point data do have an advantage in the simplicity of data collection and analysis (Brown & Reed, 2009). One requirement with point data, however, is that there must be a sufficient quantity of points and coverage of the study area to derive meaningful metrics. Boundary metrics are particularly sensitive to PPGIS sample size because partition of the landscape into units requires sufficient observations to draw meaningful inferences about the units.

Future research needs for social landscape metrics are similar to research needs for landscape ecology metrics. There is a large research need to determine landscape metrics useful for landscape management and planning, including the determination of significant values and ranges of landscape metrics for planning and management purposes (Uuemaa *et al.*, 2009). In the selection and use of inductive metrics, we focused on a subset of the many hundreds of metrics that are available in programs such as FRAGSTATS (McGarigal & Marks, 1995). Research is needed to determine which social metrics are most useful in practice across different landscapes and human populations.

Social metrics are also subject to the same problems of data aggregation and the zoning scheme known as the modifiable areal unit problem (Openshaw & Taylor, 1981). The grain size, zoning, and the areal extent of investigation can influence the results. Research is needed to determine their optimal values for each particular case.

Research is also needed to relate these social metrics to biological or physical landscape features to reveal correlated structures and patterns, leading to increased understanding of landscape processes of change. For example, are human values spatially correlated with dominant physical landscape features and do these values act as drivers of landscape modification, or are they the result of landscape modification?

Research is needed to determine if social metrics can predict future land use change and to identify landscape vulnerabilities. Land use changes are frequently caused by humans, directly or indirectly. Can social landscape metrics be used as predictors of areas of future change such as development? Or future risks from climate change? In a recent application, climate change risks (e.g. wildfire, sea level rise, biodiversity loss) and landscape values were identified using PPGIS (Raymond & Brown, 2010) and maps were generated to show areas of both high human value and high risk due to climate change. Research with the capacity to inform policy choices on climate change mitigation or adaptation is needed; social landscape metrics can contribute to this field of inquiry through the identification and selection of policy alternatives that incorporate social and cultural variables.

The selection and use of social landscape metrics will ultimately be determined by their utility in landscape planning and management across a variety of landscapes. While there are many potential criteria for the selection of social metrics, our initial list would include the following: ease of collection, cost effective, simple and understandable, reflective of underlying social processes, potential for correlation with other landscape features, and relevant to a broad range of land use decisions. With the rapid growth in PPGIS systems worldwide, social data will invariably be collected with these systems. Research will be needed to determine which social metrics provide the greatest planning and management decision support in specific land use planning contexts. Our initial selection of social landscape metrics provides a humble starting point for future inquiry.

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