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

Greg Brown<sup>1\*</sup>  
and  
Pat Reed<sup>2</sup>

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<sup>1</sup> Greg Brown is Associate Professor, School of Geography, Planning, and Environmental Management, University of Queensland, Brisbane, QLD, 4072 and Research Associate, Central Washington University, 400 E. University Way, Ellensburg, WA 98926 [greg.brown@uq.edu.au](mailto:greg.brown@uq.edu.au)

<sup>2</sup> Pat Reed is National Human Dimensions Program Social Scientist, USDA Forest Service, 3301 C Street, Anchorage, AK 99503 [preed01@fs.fed.us](mailto:preed01@fs.fed.us)

\* Correspondence author

**Abstract**

30

31

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

44

45 **Keywords:** social metrics, public participation, PPGIS, place values, landscape perception

## 46 **Introduction**

47

48           Landscape metrics measure the geometric properties of landscape features and  
49 ecological functions and their relative positions and distribution (Botequilha Leitão et al., 2006).  
50 Traditionally, landscape metrics have sought to quantify the structure and distributional pattern  
51 of landscape elements that have an obvious physical presence on the landscape such as plants,  
52 animals, geographical features, and human settlement patterns. Much less developed, and the  
53 focus of this paper, is the structure and distributional pattern of human perceptions of landscape  
54 including the human attribution of place values, perceptions, and preferences. We argue that the  
55 human process of valuing landscapes results in structural and distributional patterns on the  
56 landscape that although not directly observable, constitute latent patterns of social and  
57 psychological complexity that can ultimately be measured and quantified. There appears to be  
58 large potential for this type of social research including landscape metrics useful for landscape  
59 management and planning (Uuemaa et al., 2009).

60           One of the key research priorities identified by landscape ecologists is better  
61 integration of humans and their activities into landscape ecology including the development of  
62 “synthetic or holistic metrics that reflect social, cultural, and ecological diversity and  
63 heterogeneity...” (Wu & Hobbs, 2002). And yet, there have been few published articles on  
64 landscape metrics that address social aspects and landscape perceptions (Uuemaa et al., 2009).  
65 The ability to integrate the social and cultural aspects of humans into landscape ecology has been  
66 hindered, in part, by a lack of systematic spatial inventories of human perceptions and values of  
67 landscape and a set of diagnostic metrics that can be applied to these inventories for planning and  
68 management purposes. The development of participatory geographic information systems

69 technology in the in the 1990s has provided new opportunities to systematically capture and  
70 measure the spatial distribution of social values, perceptions, preferences, and other attributes  
71 using a variety of spatial techniques. Participatory mapping has emerged as a valuable tool to  
72 capture spatial information on social landscape values (Soini, 2001; Brown, 2005; Gunderson &  
73 Watson, 2007; Tyrväinen et al., 2007; Fagerholm & Käyhkö, 2009).

74 The term “public participation geographic information systems” (PPGIS) was  
75 conceived in 1996 at the meeting of the National Center for Geographic Information and  
76 Analysis (NCGIA). PPGIS combines the academic practice of GIS and mapping at local levels to  
77 produce knowledge of place. Since the 1990s, the range of PPGIS applications has been  
78 extensive, ranging from community and neighborhood planning to mapping traditional  
79 ecological knowledge of indigenous people (see Sieber, 2006; and Sawicki & Peterman, 2002 for  
80 a review of PPGIS applications). PPGIS systems have increasingly exploited internet  
81 technology to capture spatial attributes from local and regional populations (Kingston et al.,  
82 2000; Carver et al., 2001; Kingston, 2007; Beverly et al., 2008; Brown & Reed 2009).

83 In an early public lands application, Brown & Reed (2000) asked individuals to  
84 identify the location of landscape values for the Chugach National Forest (U.S.) planning  
85 process. Reed & Brown (2003) subsequently developed a quantitative modeling approach using  
86 the PPGIS mapped attributes to determine whether management alternatives were generally  
87 consistent, and place-consistent with publicly held forest values. Additional PPGIS research was  
88 conducted to identify the location of highway corridor values (Brown, 2003); to identify  
89 “coupled social-ecological” hotspots (SES) where human and biophysical systems are closely  
90 linked (Alessa et al., 2008); to identify preferences for tourism and residential development  
91 (Brown, 2006); to identify priority areas for conservation (Raymond & Brown, 2006; Pfeuller et

92 al., 2009); to identify place attachment (Brown & Raymond, 2007); to measure urban park and  
93 open space values for park planning (Brown, 2008), and to identify national park visitor  
94 experiences and perceived environmental impacts (Brown et al., 2009). Researchers with the  
95 Canadian Forest Service designed and developed the first internet-based participatory mapping  
96 application to collect data on the locations of forest values across a 2.4 million ha study area in  
97 the province of Alberta, Canada (Beverly et al., 2008). Three additional internet-based PPGIS  
98 landscape value and special place mapping studies were completed for forest values in the U.S.  
99 (Brown & Reed 2009).

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

103 Inductive landscape metrics derived from PPGIS are the same as traditional landscape  
104 ecology metrics in their calculation and terminology with the key difference being that landscape  
105 “patches” consist of higher intensities of human perceptions and values for the landscape rather  
106 than the presence of some biological or physical landscape feature. We call these metrics  
107 “inductive” because they are emergent landscape features from the PPGIS data collection and  
108 analysis process. The delineation of landscape patches—areas of either dominant or relatively  
109 homogenous landscape perceptions—occurs in analysis by applying heuristic but consistent  
110 decision rules to the spatial data. Similar to traditional ecological landscape metrics, the  
111 managerial implication of inductive social metrics at the landscape scale requires judgment—  
112 thresholds wherein the ranges of metric values would logically trigger consistent interpretation.  
113 Like traditional ecological metrics, the process of calculating social landscape metrics is  
114 relatively straightforward once the inventory and delineation of landscape patches has been

115 completed. Following the typology of landscape metrics proposed by McGarigal & Marks  
116 (1995) and Botequilha Leitão et al. (2006), we describe the *composition* and *configuration* of  
117 perceptual landscapes using metrics that operate at the patch or landscape scale of analysis.

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

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

136 The paper is organized into sections that: 1) describe the perceptual attribute data  
137 collected (i.e., landscape values) and the process for collecting the data, 2) provide definitions,

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

143

## 144 **Methods**

### 145 *PPGIS Data Collection*

146 Social data measuring the type and location of different landscape values was collected  
147 using a internet-based PPGIS for three national forests in the U.S.—the Coconino National  
148 Forest in Arizona and the Deschutes/Ochoco National Forests and Mt. Hood National Forests in  
149 Oregon (see Brown & Reed, 2009 for a more detailed presentation of the methods). These  
150 forests were selected as pilot studies based on their potential use of the PPGIS data for the  
151 national forest plan revision process (Coconino NF), for travel management planning  
152 (Dechutes/Ochoco NFs), and for recreation facilities planning (Mt. Hood NF). The PPGIS  
153 attributes mapped consisted of a typology of landscape values (Brown & Reed 2000) represented  
154 by points and included the following attributes: aesthetic, economic, recreation, life sustaining,  
155 learning/scientific, biological diversity, spiritual, intrinsic/existence, historic/cultural,  
156 therapeutic, and wilderness. Definitions for each value attribute were provided. For example,  
157 aesthetic value was defined as “I value these areas for their scenic qualities” and life sustaining  
158 value was defined as “I value these areas because they help produce, preserve, and renew air,  
159 soil, and water.” Study participants would drag and drop markers representing these values onto  
160 a map location associated with these values. The three websites developed for collecting  
161 landscape value data had similar user interfaces and used Adobe Flash® and MySQL database

162 software. The Coconino NF website can be viewed here:

163 <http://www.landscapemap2.org/coconino> (use access code 101-0101).

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

170 The sample sizes for the 3 pilot studies were based primarily on administrative feasibility  
171 and budgetary constraints. A total of 3,009, 3,056, and 1,825 invitations were mailed to  
172 households located proximate to the Coconino, Deschutes/Ochoco, and Mt. Hood National  
173 Forests respectively. The survey response rates for the three studies were 10.1%, 11.4% and  
174 11.8% resulting in 257, 344, and 179 respondents. The response rates were low but consistent  
175 with other reported rates for random, general public surveys. Analysis of non-response did not  
176 indicate any systematic bias associated with non-participation. The primary reasons for non-  
177 participation were lack of convenient internet access, lack of familiarity with the study area, or  
178 lack of time (Brown and Reed, 2009).

179 Landscape value point data collected from the three internet PPGIS studies were  
180 converted to ArcGIS® for analysis. The number of mapped attributes (points) available for  
181 analysis ranged from 9,699 (Deschutes/Ochoco NF) to 4,614 (Mt. Hood NF). The average  
182 number of landscape values mapped by each respondent was 36 (Coconino NF), 28  
183 (Deschutes/Ochoco NF), and 26 (Mt. Hood NF) out of a total of 78 attribute markers available to  
184 each study participant.

185

186 *Data Analysis—Boundary Social Landscape Metrics*

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

198         The landscape value point data were geographically intersected with administrative  
199 landscape units provided by the national forests. The choice of administrative boundaries was  
200 based on the potential to inform an existing national forest planning process. For the Coconino  
201 NF, the administrative or boundary units were designated areas from the previous forest plan that  
202 were largely based on biological or physical landscape features such as timber suitability (i.e.,  
203 potential for tree regeneration) or geologic features (e.g., the “red rock” area near Sedona). At  
204 the time of the study, the existing administrative units from the forest plan were deemed most  
205 useful by the forest interdisciplinary planning team to examine the distribution of landscape  
206 values. The administrative or boundary units for the Deschutes/Ochoco NFs were identified by  
207 members of a travel management planning team as potentially useful for implementing travel

208 management plans (i.e., the location of ATV/ORV routes and restrictions). The Mt. Hood  
209 administrative areas were suggested by recreation planners as potentially useful for the recreation  
210 facilities planning process. The boundaries for these areas were created by drawing 5 km buffers  
211 around known recreation sites on the forests. This heuristic method provided boundaries to  
212 examine the quantity and mix of landscape values in, and adjacent to, existing recreation sites.

213 To calculate the boundary-derived social metrics, the intersected point data was imported  
214 into a spreadsheet model called Values Compatibility Analysis. Input to the model is the number  
215 and type of landscape values per boundary area and the output consists of a series of calculated  
216 social metrics defined in Table 1. The *value sum* (**P0**) metric counts the number of landscape  
217 value point locations by type within the boundary while the *value sum percent* (**P1**) metric  
218 calculates the percent of mapped value points in a landscape unit relative to the total number of  
219 mapped landscape values across all units. The *dominant value* (**D**) metric is the landscape value  
220 with largest count of points within the boundary unit. The *value dominance index* (**D1**) metric  
221 quantifies the dominance relationship between the dominant landscape value within the  
222 boundary unit and the next most common landscape value on scale that ranges from 0 (i.e., there  
223 is no difference in dominance among values) to 1.0 (there is only one landscape value in the  
224 boundary unit). The *value density* (**D2**) metric calculates the relative density of landscape values  
225 per boundary area while the *value frequency* (**F**) metric shows the relative frequency of  
226 landscape values by type within a boundary unit compared to the frequency of all mapped  
227 landscape values. The *value diversity index* (**D3**) metric is the standard Shannon diversity index  
228 commonly used in ecological studies calculated within a landscape unit. The *value conflict*  
229 *potential index* (**C**) metric is a calculated index based on *a priori* estimates of the inherent  
230 conflict between each pair of landscape values. As such, the derivation of this metric requires an

231 initial, subjective judgment about the relative compatibility of landscape values occupying the  
232 same geographic space.

233

234 **[Insert Table 1]**

235

236 *Data Analysis—Inductive Social Landscape Metrics*

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

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

254 **[Insert Figure 1 here]**

255 Kernel density rasters were generated in ArcGIS Spatial Analyst® from each landscape  
256 value using a grid cell size of 500 meters and search radius of 3000 meters for the Mt. Hood NF  
257 and Coconino NF and 2000 meters and 5000 meters for the Deschutes/Ochoco NF. The grid cell  
258 sizes and search radii choices were based on potential mapping error from participant point  
259 placement and differences in the size and map scale of the study areas. Since kernel estimation  
260 generates a continuous density function over the study area, a decision rule must be implemented  
261 to generate patches from landscape value point distributions. Given the unequal number of  
262 points mapped per landscape value, a standardized, relative density threshold was preferred over  
263 an absolute density threshold. Patch boundaries were operationally derived for each landscape  
264 value by selecting the highest one-third (greater than 1 standard deviation from the mean) of the  
265 density values for a given landscape value. This procedure yielded relatively high density  
266 patches for each landscape value in the study areas.

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

276

277 **Results**

278           The boundary and inductive social metrics described herein were calculated from  
279 landscape value PPGIS data collected for 3 national forest study areas in the western U.S.  
280 Selected results are presented in tables to illustrate the range of values and to establish baselines  
281 for future studies.

282           The boundary metric results (Table 3) show a high degree of variability across the 3  
283 forests, in part due to the different sizes of the boundary areas. The smaller landscape or  
284 boundary units on the Mt. Hood NF associated with recreation sites have much higher landscape  
285 value densities (**D2**) on average than management units on the other national forests. The Mt.  
286 Hood landscape units also have less value diversity on average (**D3**), the likely result of greater  
287 dominance (**D1**) of recreation values over other landscape values. The Coconino NF has the  
288 highest variability in landscape value counts per unit (**P1**) in the different management units  
289 resulting in the highest frequency index (**F**) indicating that at least one unit has 9 times more  
290 landscape values than the average value frequency per unit. The Deschutes/Ochoco NF has the  
291 largest landscape units by area, on average, driving value densities (**D2**) lower, but increasing the  
292 diversity of values (**D3**) found in each unit.

293 **[Insert Table 3 here]**

294           The inductive metric results (Table 4) also show significant variability across the 3  
295 national forests. The number of inductive landscape value patches (**NUMP**) is largest on the  
296 Coconino NF and smallest on the Deschute/Ochoco NF. This leads to the inverse result in mean  
297 patch sizes (**MPS**) which are smallest on the Coconino and largest on the Deschutes/Ochoco NF.  
298 The most irregular shaped patches (**MSI**) are found on the Deschutes/Ochoco NF while the other  
299 two national forests have similar shaped patches. Value patches are most isolated on the

300 Dechutes/Ochoco NF as indicated by the larger mean nearest neighbor (**MNN**) metrics, and least  
301 isolated on the Mt. Hood NF. The inductive metrics are influenced by the size of the study area  
302 and the number of mapped point attributes. To control for these influences and to explore the  
303 relationship between patch size and study area, the number of patches (**NUMP**) and mean patch  
304 size (**MPS**) were standardized and plotted for four selected landscape values (see Figure 2) for  
305 the three national forests as well as data from four other PPGIS studies that collected the same  
306 landscape value attributes. While the relationship between the number of value patches and  
307 patch size showed variability across studies, a few trends can be observed: 1) there were  
308 relatively fewer recreation patches than other landscape value patches (Figure 2a), 2) there were  
309 fewer aesthetic patches but they tend to be larger than other landscape patches (Figure 2b), 3)  
310 scientific/learning patches tend to be smaller in size (Figure 2c), and 4) intrinsic patches tend to  
311 be relatively more numerous but variable in size (Figure 2d). Although not shown, there were no  
312 obvious trends in life sustaining and biological diversity patches across PPGIS studies.

313 **[Insert Table 4 and Figure 2 here]**

314

315

316

## 317 **Discussion**

318 In this paper, we provide the beginnings of what we hope will be extended research into  
319 the development, use, and refinement of social landscape metrics. The value of landscape  
320 quantification using social metrics, however, is tied to the validity, reliability, and interpretability  
321 of the metrics and their potential applications to land use planning and management.

322           The potential for social metrics appears especially large in the planning and management  
323 of public lands such as national forests, parks, and resource management areas, especially given  
324 the statutory requirement that accompanies most public land designations to manage these lands  
325 for a variety of public values and purposes. As evidence of the potential, the U.S. Forest Service  
326 has requested approval to complete up to 15 PPGIS studies for national forests over a 3 year  
327 period (Federal Register, 2010, p. 16719). Metrics derived from landscape values can identify  
328 the location and quantify the type of values that exist on public lands. This information can  
329 provide management decision support, for example, by modeling which potential management  
330 activities are compatible with the values located in different places (Reed & Brown, 2003).  
331 Metrics can also be calculated based on different PPGIS spatial attributes such as activities,  
332 experiences, preferences, facilities needs, subsistence locations, and place meanings, among  
333 others. For example, Brown et al. (2009) collected national park visitor experiences and  
334 perceived environmental impacts in a PPGIS and suggest that a boundary metric based on the  
335 ratio of positive visitor park experiences to environmental impacts within a park management  
336 zone or a metric based on the density of perceived environmental impacts would provide  
337 information to compare different park zones to determine priorities for the allocation of agency  
338 resources.

339           Administrative boundary designations and management zones in land use plans are often  
340 based on historical decisions that may or may not be relevant to land use in the modern context.  
341 Social landscapes, like physical landscapes, are dynamic and subject to change. Inductive  
342 metrics provide an opportunity to reexamine management boundaries based on PPGIS data to  
343 determine if the boundaries still make sense. For example, what if a management zone  
344 designated for intensive timber management in a forest plan had metrics indicating high value for

345 aesthetics and recreation? Would it make sense to rezone this area for recreational use? At the  
346 very least, the management agency would want to know what social values were being traded-off  
347 and where public resistance was likely to be encountered with respect to management initiatives.  
348 Social landscape metrics hold the promise of reconciling human perception and understanding of  
349 a landscape with a rational management scheme for the landscape.

350         The reliability of the social metrics rests, in part, on the data collection methods,  
351 sampling, and the comprehensiveness of the participatory process. Are the PPGIS attributes  
352 collected accurately, without bias, and inclusive of all relevant human communities? We have  
353 described the calculation of metrics based on point data but there is no inherent reason why  
354 social metrics could not be calculated from polygon or line data collected in a PPGIS process.  
355 Point data do have an advantage in the simplicity of data collection and analysis (Brown & Reed,  
356 2009). One requirement with point data, however, is that there must be a sufficient quantity of  
357 points and coverage of the study area to derive meaningful metrics. Boundary metrics are  
358 particularly sensitive to PPGIS sample size because partition of the landscape into units requires  
359 sufficient observations to draw meaningful inferences about the units.

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

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

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

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

387 The selection and use of social landscape metrics will ultimately be determined by their  
388 utility in landscape planning and management across a variety of landscapes. While there are  
389 many potential criteria for the selection of social metrics, our initial list would include the  
390 following: ease of collection, cost effective, simple and understandable, reflective of underlying

391 social processes, potential for correlation with other landscape features, and relevant to a broad  
392 range of land use decisions. With the rapid growth in PPGIS systems worldwide, social data will  
393 invariably be collected with these systems. Research will be needed to determine which social  
394 metrics provide the greatest planning and management decision support in specific land use  
395 planning contexts. Our initial selection of social landscape metrics provides a humble starting  
396 point for future inquiry.

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

Definition	Calculation	Usefulness	Limitations
<b>Value Sum Absolute (P0)</b> —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. $P0 = \sum p_i$ where: $p_i$ = number of landscape value points mapped within landscape unit $i$	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
<b>Value Sum Percent (P1)</b> —the percent of mapped value points in a landscape unit relative to the total number of mapped landscape values across all units.	Sum of all landscape values within landscape unit divided by the total number of landscape values mapped. $P1 = \frac{\sum p_i}{P}$ where: $p_i$ = number of landscape value points mapped within landscape unit $i$ $P$ = total number of mapped landscape value points	Reveals the landscape units with the highest proportions of all mapped landscape values.	
<b>Dominant value (D)</b> —the landscape value with largest count of point locations within the landscape unit	By definition, the landscape value with largest count of points within the landscape unit $D = \max(\sum v_i)$ where: $v_i$ = number of mapped landscape value points for a given value $v$ in a given landscape unit $i$	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.
<b>Value dominance index (D1)</b> —an index that quantifies the dominance relationship between the dominant landscape value within the landscape unit and the next most common value,	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 $D1 = \frac{\max(\sum v_i) - \max(\sum v_i)^{(2)}}{\max(\sum v_i)}$ where: $v_i$ = number of mapped landscape value points for a given value $v$ in a given landscape unit $i$	Shows whether the dominant value is distinct or only slightly more common than another 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.

**Table 1 (Continued)**

<b>Value density index (D2)</b> —an index that measures the relative density of landscape values per landscape unit by area	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 $i$	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.
<b>Value frequency index (F)</b> —the relative frequency of landscape values within a landscape unit compared to the average frequency of mapped landscape values across all landscape units.	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. $F = \frac{\sum p_i}{\frac{1}{n-1} \sum \bar{X}_j}$ 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 $j$	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	
<b>Value diversity index (D3)</b> —is the standard Shannon diversity index used in ecological studies calculated for the different landscape values located within a landscape unit.	$D3 = - \sum_{i=1}^v p_i \ln p_i$ 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.	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.
<b>Value conflict potential index (C)</b> —is a calculated index based on <i>a priori</i> estimates of the inherent conflict between each pair of values.	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.	Provides a complement to D3 index.	The conflict relationship between different landscape values requires subjective judgment.

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

<b>Landscape Value Composition Metrics</b>	
<p><b>Patch richness (PR)</b>—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><b>Class area proportion (ZLAND)</b>—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  <math>a_{ij}</math> = area of landscape value patch <math>ij</math></p>
<p><b>Shannon's Diversity Index (SDI)</b>—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  <math>P_i</math> = proportion of landscape occupied by landscape value patch type <math>i</math></p>	<p><b>Simpson's Evenness Index (SIEI)</b>—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> $SIEI = \frac{1 - \sum_{i=1}^m P_i^2}{1 - \left(\frac{1}{m}\right)}$ <p>where: m = number of landscape value patch types  <math>P_i</math> = proportion of landscape occupied by landscape value patch type <math>i</math></p>
<b>Landscape Value Configuration Metrics</b>	
<p><b>Number of patches (NUMP)</b>—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><b>Mean Patch Size (MPS)</b>—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><b>Mean Nearest Neighbor Distance (MNN)</b>—the Euclidean distance between each discrete landscape value patch and its nearest neighboring 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  <math>n'</math> = number of landscape value patches of patch type <math>i</math>  <math>h_{ij}</math> = distance from landscape value patch <math>ij</math> to nearest neighboring landscape value patch of the same type  <math>N'</math> = total number of landscape value patches that have nearest neighbors</p>	<p><b>Mean Patch Shape Index (MSI)</b>—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: <math>P_{ij}</math> = perimeter of landscape value patch <math>ij</math>  <math>a_{ij}</math> = area of landscape value patch <math>ij</math>  <math>n</math> = number of landscape value patches</p>

**Table 3. Selected boundary-determined social landscape metrics for 3 national forests in U.S.**

	<b>Deschutes/Ochoco NF</b>	<b>Mt. Hood NF</b>	<b>Coconino NF</b>
Rationale for landscape unit designation	Travel management planning process (n=18 units)	Recreation site facilities management (n=22 units)	Forest plan designations under existing forest plan (n=25 units)
Metric	Max/min/mean	Max/min/mean	Max/min/mean
Landscape Unit Size (acres)	411,859 / 1,585 / 120,455	38 / 38 / 38	512,725 / 757 / 62,183
Value Sum Percent ( <b>P1</b> )	16.42 / 0.54 / 5.56	8.15 / 3.21 / 4.55	26.92 / 0.11 / 2.56
Value Dominance Index ( <b>D1</b> )	0.53 / 0.04 / 0.19	0.78 / 0.06 / 0.50	.64 / .10 / .32
Value Frequency Index ( <b>F</b> )	2.96 / 0.10 / 1.0	1.79 / 0.71 / 1.0	9.17 / 0.04 / 1.0
Value Density ( <b>D2</b> ) Index (points per acre)	0.14 / 0.00 / 0.01	2.47 / 0.97 / 1.38	0.029 / 0.00 / 0.01
Value Diversity ( <b>D3</b> ) Index	0.99 / 0.90 / 0.96	0.89 / 0.57 / 0.76	0.98 / 0.68 / 0.87

**Table 4. Selected inductive social landscape metrics for 3 national forests in the U.S.**

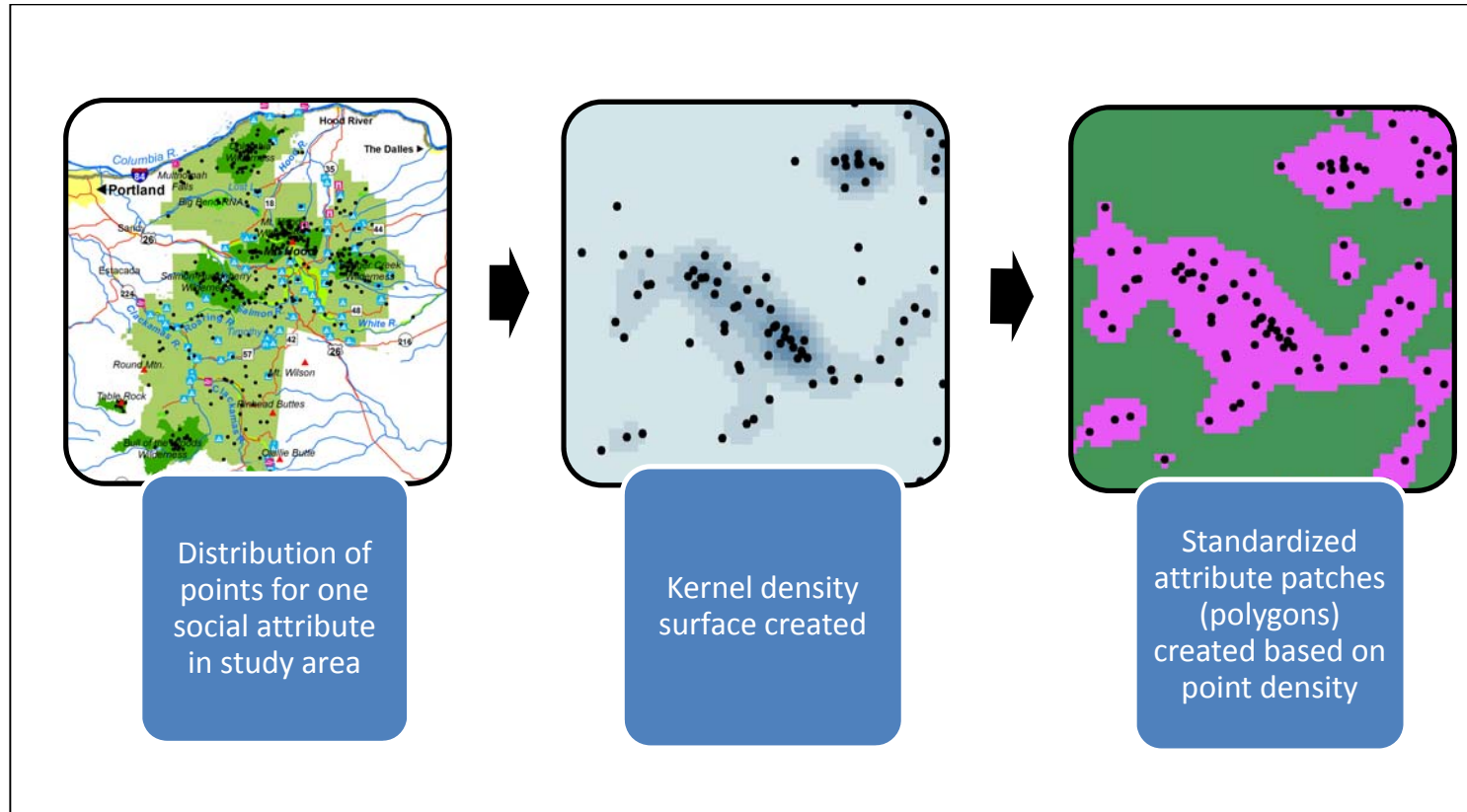
Study area			Deschutes/Ochoco NF								
Method			Kernel density (2000m grid cell, 5000m search using ArcGIS Spatial Analyst®)								
Study area size			Patches identified as density greater than 1 std. dev. from mean density								
			10993 km <sup>2</sup>								
			Nearest neighbor statistics <sup>2</sup>		Patch Metrics <sup>1</sup>						
			R	Z	NUMP	MPS	PSSD	MSI	MNN	MPI	PCT LAND
			(Rank)		(Rank)						
Landscape Values (Deschutes/Ochoco NF)	.43 (2)	-34.9	Aesthetic	22 (11)	18436.4	25323.5	1.40	5172.7	74.4	405,600.0 (12%)	
	.48 (7)	-25.3	Economic	25 (8)	16688.0	18336.8	1.44	4973.4	47.2	417,200.0 (13%)	
	.46 (5)	-27.6	Biological Div.	27 (5)	15614.8	24808.7	1.34	4098.3	61.4	421,600.0 (13%)	
	.46 (5)	-34.0	Prim. Recreation	24 (10)	19050.0	32813.6	1.42	4691.2	113.5	457,200.0 (14%)	
	.39 (1)	-39.2	Recreation	25 (8)	14144.0	26055.4	1.36	4177.6	40.4	353,600.0 (10%)	
	.48 (7)	-22.6	Historic	31 (3)	12193.6	16704.8	1.35	4688.6	44.0	378,000.0 (12%)	
	.48 (7)	-24.6	Intrinsic	27 (5)	16000.0	19650.6	1.38	3842.2	59.4	432,000.0 (13%)	
	.43 (2)	-28.3	Scientific/learning	29 (4)	12303.5	22195.8	1.33	4256.2	50.6	356,800.0 (11%)	
	.48 (7)	-22.4	Life sustaining	35 (2)	11988.6	19043.5	1.32	3369.8	66.4	419,600.0 (13%)	
	.48 (7)	-21.6	Spiritual	45 (1)	9022.2	16468.6	1.25	4058.6	40.2	406,000.0 (13%)	
	.50 (12)	-21.9	Therapeutic	24 (10)	18383.3	21754.2	1.43	4242.4	70.6	441,200.0 (14%)	
	.44 (4)	-33.1	Wilderness	26 (7)	11369.2	18317.6	1.33	4201.2	28.2	295,600.0 (9%)	
Study area			Mt Hood NF								
Method			Kernel density (500m grid cell, 3000m search using ArcGIS Spatial Analyst®)								
Study area size			Patches identified as density greater than 1 std. dev. from mean density								
			4476 km <sup>2</sup>								
			Nearest neighbor statistics		Patch Metrics						
			R	Z	NUMP	MPS	PSSD	MSI	MNN	MPI	PCT LAND
			(Rank)		(Rank)						
Landscape Values (Mt. Hood)	.56 (3)	-19.7	Aesthetic	32 (11)	3547.7	7244.9	1.34	2659.9	111.1	113,525.0 (11%)	
	.59 (6)	-14.1	Economic	62 (1)	1569.8	3072.8	1.19	2372.4	18.2	97,325.0 (12%)	
	.60 (8)	-14.0	Biological Div.	44 (5)	3753.4	9295.9	1.30	1803.8	179.7	165,150.0 (16%)	
	.59 (6)	-18.6	Primitive Recreation	30 (12)	5265.8	10290.6	1.39	2405.3	166.0	157975.0 (16%)	
	.47 (1)	-23.8	Recreation	33 (10)	2431.1	4187.4	1.20	2348.2	23.9	80225.0 (10%)	
	.58 (4)	-12.4	Historic	42 (6)	2444.6	7758.6	1.24	3111.1	46.1	102675.0 (11%)	
	.66 (12)	-11.0	Intrinsic	45 (4)	3219.4	4670.9	1.33	2247.2	69.8	144875.0 (16%)	
	.54 (2)	-13.9	Scientific/learning	48 (3)	2216.7	3064.2	1.28	2613.6	25.6	106400.0 (12%)	
	.61 (9)	-12.4	Life sustaining	42 (6)	2690.5	2715.0	1.34	2504.2	25.7	113000.0 (14%)	
	.58 (4)	-12.5	Spiritual	42 (6)	3251.8	6475.5	1.30	2395.9	95.6	136575.0 (14%)	
	.62 (11)	-11.5	Therapeutic	36 (9)	4445.1	5714.6	1.38	2070.8	100.2	160025.0 (15%)	
	.61 (9)	-15.3	Wilderness	60 (2)	2010.0	4796.4	1.23	2616.3	94.3	120600.0 (12%)	

Study area			Coconino NF							
Method			Patch Metrics Kernel density (500m grid cell, 3000m search using ArcGIS Spatial Analyst®)							
Study area size			Patches identified as density greater than 1 std. dev. from mean density							
			8125 km <sup>2</sup>							
Nearest neighbor statistics			Patch Metrics							
R	Z		NUMP	MPS	PSSD	MSI	MNN	MPI	PCT LAND	
(Rank)			(Rank)							
.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%)	

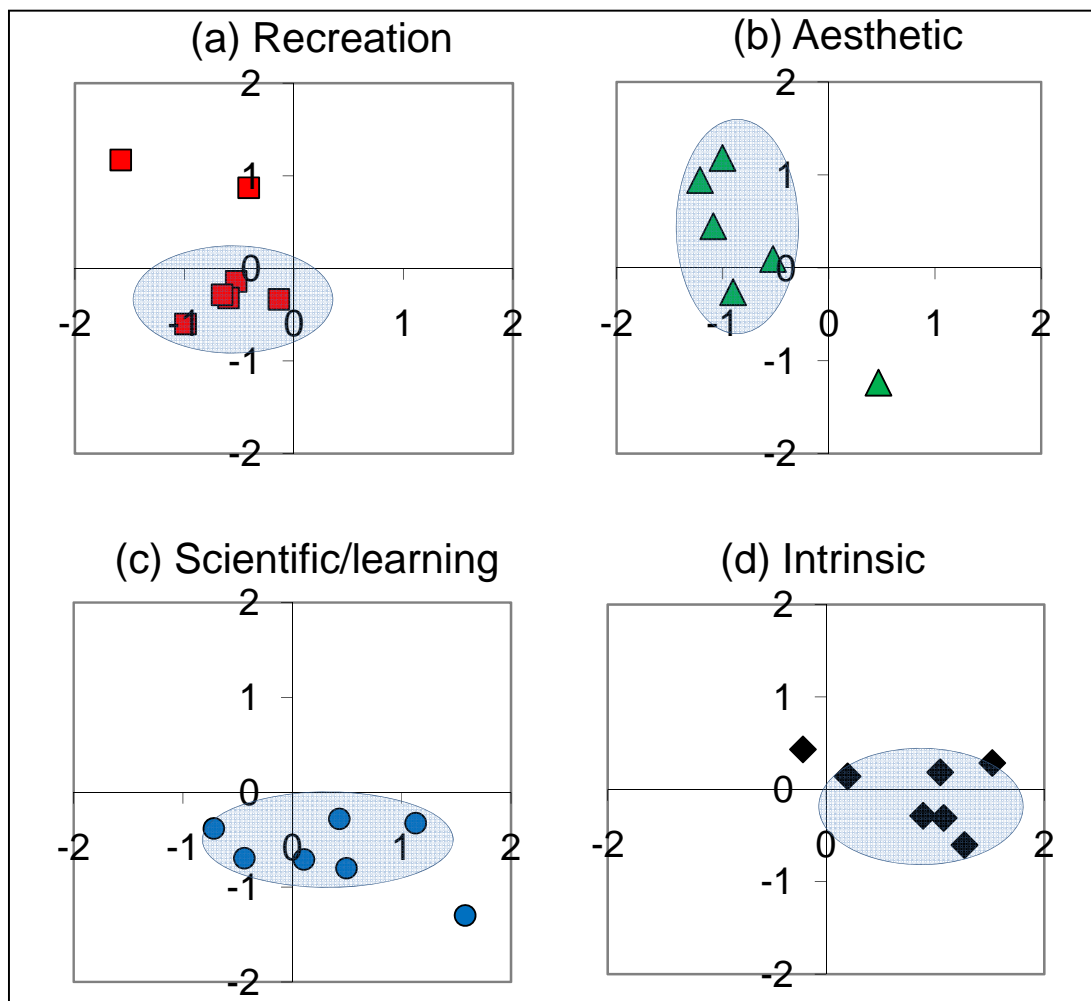
<sup>1</sup> NUMP=number of patches, MPS=mean patch size, PSSD=patch size standard deviation, MSI=mean shape index, MNN=mean nearest neighbor, MPI=mean proximity index, PCT LAND=proportion of study area covered by patches of landscape value.

<sup>2</sup> The 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.

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



**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<sup>1</sup>. Standardized number of patches is on the horizontal axis and standardized mean patch size is on the vertical axis.**



<sup>1</sup> Plots use standardized scores from multiple PPGIS studies: Deschutes National Forest (U.S.), Coconino National Forest (U.S.), Mt. Hood National Forest (U.S.), Otways Region (Victoria, Australia), Kangaroo Island (South Australia), Chugach National Forest (U.S.), Kenai Peninsula (U.S.)