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A GIS application for assessing, mapping, and quantifying the social values of ecosystem services

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ABSTRACT

As human pressures on ecosystems continue to increase, research involving the effective incorporation of social values information into the context of comprehensive ecosystem services assessments is becoming more important. Including quantified, spatially explicit social value metrics in such assessments will improve the analysis of relative tradeoffs among ecosystem services. This paper describes a GIS application, *Social Values for Ecosystem Services* (SolVES), developed to assess, map, and quantify the perceived social values of ecosystem services by deriving a non-monetary Value Index from responses to a public attitude and preference survey. SolVES calculates and maps the Value Index for social values held by various survey subgroups, as distinguished by their attitudes regarding ecosystem use. Index values can be compared within and among survey subgroups to explore the effect of social contexts on the valuation of ecosystem services. Index values can also be correlated and regressed against landscape metrics SolVES calculates from various environmental data layers. Coefficients derived through these analyses were applied to their corresponding data layers to generate a predicted social value map. This map compared favorably with other SolVES output and led to the addition of a predictive mapping function to SolVES for value transfer to areas where survey data are unavailable. A more robust application is being developed as a public domain tool for decision makers and researchers to map social values of ecosystem services and to facilitate discussions among diverse stakeholders involving relative tradeoffs among different ecosystem services in a variety of physical and social contexts.

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Introduction

As the human use of most ecosystem services continues to increase, there is a critical need for research involving the quantification of tradeoffs among various ecosystem services (Carpenter et al., 2009). Ecosystem services can be defined as the conditions, processes, and components of the natural environment that provide both tangible and intangible benefits for sustaining and fulfilling human life (Daily, 1997). The Millennium Ecosystem Assessment (MA), an integrated ecosystem assessment established with the involvement of governments, the private sector, nongovernmental organizations, and scientists, presented a framework for understanding the connections between ecosystem services and human well-being (2003). The MA framework distinguishes four categories of ecosystem services: supporting services, provisioning services, regulating services, and cultural services (2003). This framework represents a social–ecological system requiring for its analysis information drawn from the broad range of natural and social sciences (Carpenter et al., 2009). Some suggested elements of ecosystem services analysis include: the measurement of their flows and underlying processes, the dependence of human well-being on these flows, valuation, and provisioning (Brown, Bergstrom, & Loomis, 2007). This study attempts to address one aspect of current research needs by building on previous efforts such as Reed and Brown's values suitability analysis (VSA) methodology, which involved the construction of a numerical rating system for evaluating consistencies between land management prescriptions and publicly held ecosystem values (2003). The diversity of stakeholder attitudes and preferences associated with such values are a source of ongoing difficulty for land and resource managers as they employ various approaches when attempting to account for the resulting value conflicts in their decision-making processes (Zendehdel, Rademaker, De Baets, & Van Huylenbroeck, 2009).

For the current study, we develop a geographic information system (GIS) application designed to calculate and map the relative social values of ecosystem services as perceived by diverse groups of ecosystem stakeholders. While achieving this development objective, it is understood that the relationships between the social value

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typology used by the application and the ecosystem service typology defined by the MA or alternative ecosystem service typologies such as those proposed by Wallace (2007) or Raymond et al. (2009) will require additional research and data collection efforts to refine and more effectively implement. Even without these refinements, however, the application's current design reflects a framework in which social values represent measurable ecological end-products or endpoints of ecosystem services at their interface with human well-being (Boyd & Banzhaf, 2007). Within this framework, the value of ecological endpoints can be accounted for distinctly from the elements and processes of the ecosystems that produce them while still acknowledging the dependency of these endpoints on the condition of the ecosystem (Boyd & Banzhaf, 2007). Furthermore, the application provides the functionality to assess the relationship of these social value endpoints to both their physical and social contexts in a manner that is informative to decision makers and scientists and that could be incorporated into broader ecosystem services assessment and valuation studies.

Economic valuation

Various economic valuation methods focusing on utilitarian values are often used to quantify the benefits of ecosystem goods and services. Challenges related to a lack of economic market data are frequently encountered, however, when attempting to conduct such valuations. As noted by Costanza et al. in their study estimating the total economic value of the world's ecosystem goods and services, much of what ecosystem services provide exists as public goods with their benefits bypassing the money economy (1997). In the absence of market data, techniques such as the travel cost method can be used to indirectly derive monetary value. Hein, van Koppen, de Groot, and van Ierland (2006) for example, estimated the value of recreational services provided by a wetland area based on the demand for the services relative to the additional cost of traveling to them from greater distances. In other instances, data indicating economic value might be borrowed from other locations. The method of value transfer involves adapting known values from one context (a source study site) in which primary economic studies were conducted to another context (a target policy site) where values are not known (Troy & Wilson, 2006). As is often cautioned, however, critical to value-transfer methodology is ensuring that both the biophysical and socioeconomic contexts of the source and target areas are similar enough to provide reasonably accurate estimates for the target area (Rosenberger & Loomis, 2001; Spash & Vatn, 2006; Troy & Wilson, 2006).

Expanding value definitions

The previous examples of valuation methods are, by design, focused on the economic utility of ecosystem services, with each resulting in an estimation of monetary value. While these valuation methods assign tangible values to ecosystem services allowing them be accounted for in land and resource management decision-making, it is not always possible or necessary to express the economic value of an ecosystem service in monetary terms. The required information to do so often might not exist, the service might not be readily adaptable to standard techniques of economic valuation (Carpenter et al., 2009), or the inclusion of monetary terms might be a distraction as different individuals and stakeholder groups disagree over assigned values and lose focus on the overriding issue of ecosystem management (USDA, 2008). Also absent from these valuation methods is the consideration of values perceived by stakeholders, which may or may not be utilitarian but could assist decision makers by their expression in quantitative, although not monetary, terms.

A common theme that emerges out of recommendations from a broad range of research perspectives is the need for ecosystem service valuation to more effectively incorporate the values perceived by those who benefit from the services. It is important for decision makers to assess the full range of ecosystem values including the socio-cultural, the ecological, and the intrinsic in addition to utilitarian values (Millennium Ecosystem Assessment, 2003) and to be informed by the analysis of integrated socioeconomic and biophysical data (De Lange, Wise, Forsyth, & Nahman, 2010). Greater management emphasis should be placed on the linkages between social and ecosystem change including the indirect drivers of ecosystem change such as demographic and cultural factors (Carpenter et al., 2006). Researchers developing models for mainstreaming ecosystem services assessments into the work of land- and water-use managers have suggested that the valuation of ecosystem services should include information resulting from both social and biophysical assessments (Cowling et al., 2008). Psycho-social and cultural research perspectives suggest that value be considered as a psychological and cultural concept related to human perception (Nijkamp, Vindigni, & Nunes, 2008). The values perceived by ecosystem stakeholders are inadequately captured by conventional utilitarian valuation methods, which neglect the value of the psychological well-being derived from an individual's relationship with nature (Kumar & Kumar, 2008). Even as these additional values are taken into account, however, the next issue becomes: how can we quantify and spatially represent these values across the landscape so that we may more effectively relate them to the ecosystem services we wish to assess?

Mapping stakeholder values

Many examples exist where public value and attitude survey results have been used to map values perceived by stakeholders, or social values, as we refer to them in this paper. Variations of a typology of forest values validated by Brown and Reed (2000) and frequently used in social value mapping studies are alternatively referred to as ecosystem values (Reed & Brown, 2003), environmental values (Brown, Reed, & Harris, 2002, Brown, Smith, Alessa, & Kliskey, 2004), landscape values (Alessa, Kliskey, & Brown, 2008), and wilderness values (Brown & Alessa, 2005). Some methods rely on mapping results according to pre-defined planning or management units (Tyrväinen, Mäkinen, & Schipperijn, 2007), while other research pursues more flexible, and seemingly more scalable, methods that rely on calculating the weighted density of points marked on maps by survey respondents (Alessa et al., 2008; Brown, 2005; Brown et al., 2004). This mapping of survey results provides a means to express social values in a manner that is similar to monetary expressions of economic value (Brown, 2005). Social value maps can also assist with procedures such as hotspot identification where important areas that might require special attention from land and resource managers are indicated (Alessa et al., 2008; Brown, 2005; Brown et al., 2004) and values suitability analysis to evaluate the consistency of management prescriptions for an area with the values that the public holds for the area (Reed & Brown, 2003). More recent value mapping research has also made efforts to explicitly present values in an ecosystem services context by modifying the MA framework to serve as a guide for collecting and mapping information regarding stakeholder or community values (Raymond et al., 2009).

The social values for ecosystem services application

The use of a GIS for conducting integrated analyses of social and environmental data in a variety of contexts is well-documented (e.g., Albritton and Stein, 2011; Saqalli, Caron, Defourny, & Issaka, 2009; Silberman & Rees, 2010; Snyder, Whitmore, Schneider, & Becker, 2008; Wyman & Stein, 2010). This paper presents a GIS application, *S*ocia*l* *V*alues for *E*cosystem *S*ervices (SolVES), available at solves.cr.usgs.gov, which integrates attitude and preference survey results regarding the perceived social values of Colorado's Pike and San Isabel National Forests (PSI) (Clement & Cheng, 2006) with data characterizing the physical environment of the study area ecosystem. The survey design and subsequent analysis of its results (Clement, 2006; Clement & Cheng, submitted for publication) were based on procedures and methods described by Brown et al. (2002). The application was developed with this and other work including Reed and Brown's values suitability analysis methodology (2003) in mind. It provides a tool for generating maps that illustrate the distribution of a quantitative, non-monetary value metric, or Value Index, across the landscape along with graphical and tabular reports containing metrics characterizing the physical environment at locations across the range of the Value Index for different social value types as calculated for various subgroups of survey respondents. A case study is also presented to demonstrate existing SolVES functionality and to consider enhancements for future versions. The intent is for SolVES to serve as a model for the future development of more advanced tools that will be useful to decision makers, stakeholders, and researchers.

Methods

Study area

The PSI extends from Mount Evans and Interstate 70 in the north to near the New Mexico border in the south and from the Front Range in the east to the Continental Divide in the west (Fig. 1). The area includes over two million acres containing the majority of Colorado's mountain peaks higher than 14,000 feet and nine Wilderness areas. As examples of the varied ecosystem services the area provides, over 60 percent of the Denver metropolitan area's water supply originates in the PSI while the area also ranks third in the nation among National Forests for recreational visits (USDA, 2009a). Under the mandate of the National Forest Management Act (NFMA), the PSI has been in the process of updating its Land and Resource Management Plan, which was previously completed in 1984 (USDA, 2009b). As one means of obtaining public input during this update process, a public values and attitudes survey regarding the PSI was conducted (Clement & Cheng, 2006), and its results serve as the basis for this study.

Survey data

A mail survey of a random sample of 2000 households located within 45 miles of the PSI was conducted in late 2004 and early 2005 (Clement & Cheng, 2006). The response rate was approximately 33 percent, with 684 surveys being returned. The survey was divided into five sections. Section 1 requested information regarding each respondent's familiarity with the PSI such as when and how often they visited, if they derived any income from the PSI, and their interest level in what happens to the PSI in the next 10–15 years. Section 2 requested respondents to indicate whether they favored or opposed each of 18 public uses of the PSI (Table 1). Section 3 allowed respondents to indicate their views regarding various issues impacting the PSI such as the extent and purpose of road building and logging, reservoir development, and tradeoffs between recreational use and environmental quality. The first part of section 4 (4a) requested respondents to allocate or "spend" $100 among 12 different social value types associated with the PSI (Table 2). While dollar units were used for convenience to express value denominations (e.g., points could have been used instead of dollars), it was explained in the survey instructions that this was not a reference to any actual money, either the respondents' or the Forest Service's. Because of the existing discrepancies between social value and ecosystem service typologies, it should be noted that while some of these social values correspond more directly with specific ecosystem services as they are often defined (e.g., Aesthetic and Recreation as cultural services and Biodiversity and Life Sustaining as provisioning and supporting services) others, such as Future, might be better considered as an attribute cross-cutting through all ecosystem services (e.g., the bequest (future) value of preserving a wilderness area or a critical wetland). Following the allocation exercise, respondents were instructed in the second part of Section 4 (4b) to hand-mark points (later digitized into a geographic data layer) on a series of maps of the PSI corresponding to the social value types to which they had allocated dollars. If the respondent had allocated dollars to Aesthetic value, for example, they were to place a mark or marks on the map at up to four locations indicating Aesthetic value, and label and number each mark accordingly. Of the 684 surveys returned, 55 percent included completed mapping sections. Finally, Section 5 of the survey requested various demographic and socioeconomic information from each respondent.

Spatial database development

The digitized survey points derived from survey section 4b were loaded into a geodatabase as a point feature class while data from each of the other survey sections were loaded into separate database tables. Each survey point and data record included a unique identifier (Survey_ID) so all data from a single survey could be related. Also loaded were 30-m resolution rasters to generally characterize the physical environment of the PSI: a Digital Elevation Model (DEM) (USGS, 2007a), slope (in percent) derived from the DEM, distance to roads (DTR) indicating the horizontal distance to the nearest road (USGS, 2007b; Watts et al., 2007), distance to water (DTW) measuring the horizontal distance to the nearest lake, pond, river, stream, or spring calculated from the National Hydrography Dataset (NHD) (USGS, 2007c), Southwest Regional Gap Analysis Project (SWReGAP) landcover (USGS, 2004), and landforms (USGS, 2007a). The geodatabase schema was generalized so that survey and landscape data from other study areas could replace the PSI data with minimal development effort. The intent was to facilitate the portability of SolVES for the assessment of other study areas.

Application development

SolVES was developed as a series of models using ESRI®[1] ModelBuilder and augmented, as necessary, using Python and VB.NET. Each model carries out specific functions and calls on other models and scripts to complete additional tasks (Fig. 2). This modular approach allows changes to be isolated to individual application components.

SolVES is designed to accept user-entered parameters describing both a particular public use and the survey respondents' attitude or preference regarding that public use within the PSI from survey Section 2. These parameters provide the criteria for selecting the value allocation amounts from survey section 4a and the related mapped points from survey section 4b for the specified survey subgroup. The amounts allocated to each social value type along with their associated points are used to produce weighted density

[1] Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

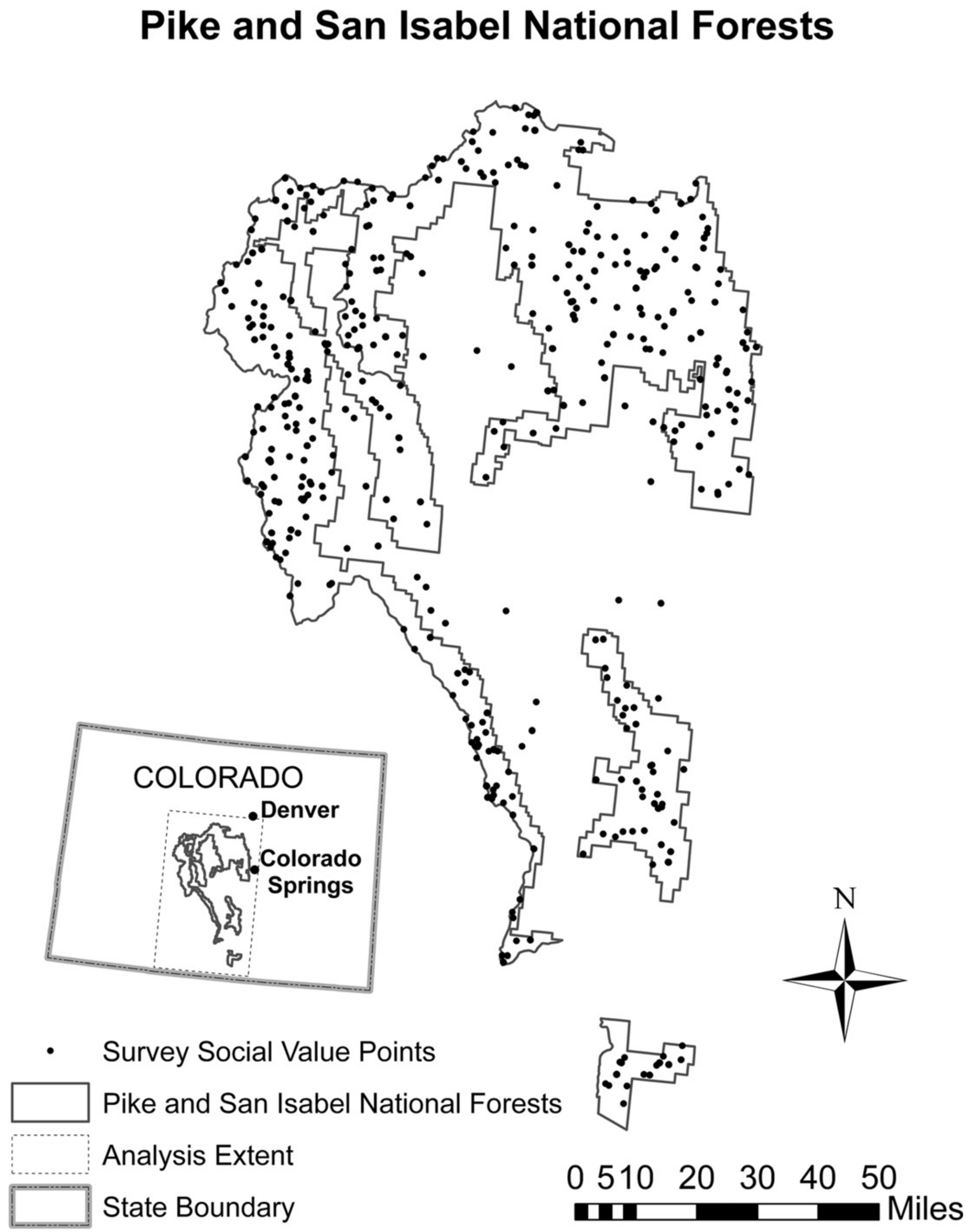

Fig. 1. The Pike and San Isabel National Forests along with points from public attitude or preference survey.

surfaces for the selected survey subgroup. Points having higher value amounts allocated to them receive a greater weighting and thereby result in higher density values. The surfaces are generated as kernel densities following a methodology similar to that of Alessa et al. in their mapping of social–ecological hotspots on Alaska's Kenai Peninsula (2008). As opposed to simple point density, the basis of kernel density is a quadratic kernel function (Silverman, 1986). This function defines a smoothly curved surface fit over each point and extending out to a defined search radius. The volume below each surface is equal to the weight assigned to the point. Given the similar spatial extents of the two study areas, the kernel density search radius parameter of 5000 m used by Alessa et al. (2008) was also used here. The kernel density output cell-size parameter was set to 450 m as determined from the approximate scale of the original survey maps, 1:400,000–1:500,000. It was assumed that survey respondents could resolve the locations they marked to at best 450 m. This also provided output cells that would align with 15×15 arrays of the 30-m cells of the rasters from which landscape metrics were to be calculated.

For the selected survey subgroup, SolVES generates weighted density surfaces for each of the 12 social value types. The surface containing the cell having the maximum overall weighted density value is identified, and this value is then used to normalize each of the 12 weighted density surfaces. Normalization results in the value of every cell on every weighted density surface being scaled relative to the most highly valued geographic location and to the most

Table 1
The public uses as presented in Section 2 of the Clement and Cheng (2006) PSI study.

Public uses
Sight-seeing (including driving for pleasure)
Sport fishing
Non-motorized recreation (e.g., hiking, canoeing)
Sport hunting
Helicopter skiing/hiking
Wildlife viewing/observing
Motorized recreation (e.g., snowmobiles, ATV's, jet-skiing)
Logging for fuels reduction
Commercial mining
Gathering forest products (e.g., berries, mushrooms)
Logging for increased water collection
Oil/gas drilling
Logging for wood products
Commercial outfitting/guiding
Communication sites/utility easements
Wilderness
Fish and wildlife habitat
Other

highly valued social value type as rated by the selected survey subgroup. These normalized values are then standardized to produce an integer surface containing a consistent 10-point scale, the Value Index. The Value Index can be used to measure and compare the magnitude of value differences within and among survey subgroups as well as to produce social value maps and associated landscape metrics. The higher the value attained on the Value Index by a social value type within a survey subgroup, the more highly it is valued by that survey subgroup. Within a single survey subgroup, a social value type that attains a 10 on the Value Index corresponds to one or more locations within the study area where that survey subgroup values that social value type more highly than at any other location and more highly than any of the other social value types regardless of location. For social value types that attain less than a 10 on the Value Index, the maximum index value that they do attain (9, 8, 7, etc.) corresponds to locations where that social value type is valued more highly than at any other location within the study area. Among different survey subgroups, the maximum attained index value can be used to make some general comparisons regarding the relative value each subgroup places on a social value type.

Table 2
The social value types as described in section 4 of the Clement and Cheng (2006) PSI study.

Social value type	Social value description
Aesthetic	I value these forests because I enjoy the scenery, sights, sounds, smells, etc.
Biodiversity	I value these forests because they provide a variety of fish, wildlife, plant life, etc.
Cultural	I value these forests because they are a place for me to continue and pass down the wisdom and knowledge, traditions, and way of life of my ancestors.
Economic	I value these forests because they provide timber, fisheries, minerals, and/or tourism opportunities such as outfitting and guiding.
Future	I value these forests because they allow future generations to know and experience the forests as they are now.
Historic	I value these forests because they have places and things of natural and human history that matter to me, others, or the Nation.
Intrinsic	I value these forests in and of themselves, whether people are present or not.
Learning	I value these forests because we can learn about the environment through scientific observation or experimentation.
Life Sustaining	I value these forests because the help produce, preserve, clean, and renew air, soil, and water.
Recreation	I value these forests because they provide a place for my favorite outdoor recreation activities.
Spiritual	I value these forests because they are a sacred, religious, or spiritually special place to me or because I feel reverence and respect for nature there.
Therapeutic	I value these forests because they make me feel better, physically and/or mentally.

SolVES calculates spatial statistics describing the relative dispersion, clustering, or randomness of the mapped points to assist users with selecting social value types for further analysis. Following the example of Brown et al. (2002) and Clement (2006), the point data are subjected to Completely Spatially Random (CSR) hypothesis testing through the calculation of average nearest neighbor statistics. The ratio of the observed distance between points to the expected distance between points, or R value, along with each R value's number of standard deviations from the mean, or Z score, identify point patterns for which statistically significant clustering is observed. Such clustering is described by R values of less than 1 having highly negative Z scores. Users can refer to these statistics to limit their focus to social value types occupying locations with specific levels of significance on the landscape as determined by the selected survey subgroup. SolVES then accepts the user's request for a specific social value type, generates the corresponding Value Index surface, displays it on a map, and uses it to calculate landscape metrics. The integer values composing the Value Index define zones for which SolVES calculates zonal statistics including mean values for elevation, slope, DTR, and DTW as well as dominant landcover and landform.

An ESRI® ArcMap document serves as the SolVES user interface. Here users can access the parameter selection screens, and a predefined map layout displays an integrated view of the requested social value map along with associated landscape metrics. Users can examine the geographic distribution of social values across the landscape as well as how these values relate to the varying physical characteristics of the landscape. The map layouts for various survey subgroups and social values can be generated, saved, and compared.

Data analysis

SolVES output was analyzed for a series of survey subgroups and social value types to demonstrate the utility of the tool in decision support and research contexts, as well as to identify additional capabilities that could augment the application's functionality. Survey subgroups are defined by the user-selected parameters—a selected public use and the attitude or preference regarding that use. Six public uses were selected for analysis based on two criteria. First, there had to be a significant amount of disagreement regarding the public use. The survey subgroups favoring or strongly favoring a public use were compared to those opposing or strongly opposing that public use (Table 3). Neutral attitudes or preferences were not included. This ensured a large enough sample for a statistically valid comparison of survey respondents with differing attitudes or preferences. Second, the selected public use had to represent an activity that has or could potentially have significant impacts on the PSI landscape. As a baseline for comparison, output was also generated without survey subgroup parameters to produce results from all survey responses. The social value types included in the analysis were reduced from the total of twelve to six: Aesthetic, Biodiversity, Future, Life Sustaining, Recreation, and Therapeutic. These social value types were selected on the basis of Clement's CSR hypothesis testing which found them to more likely be clustered than the remaining six social value types (2006).

For each public use, attitude or preference, and social value type described above, SolVES output was generated. Preliminary statistical analyses were then conducted to measure the significance of any correlations between the index values for each social value type

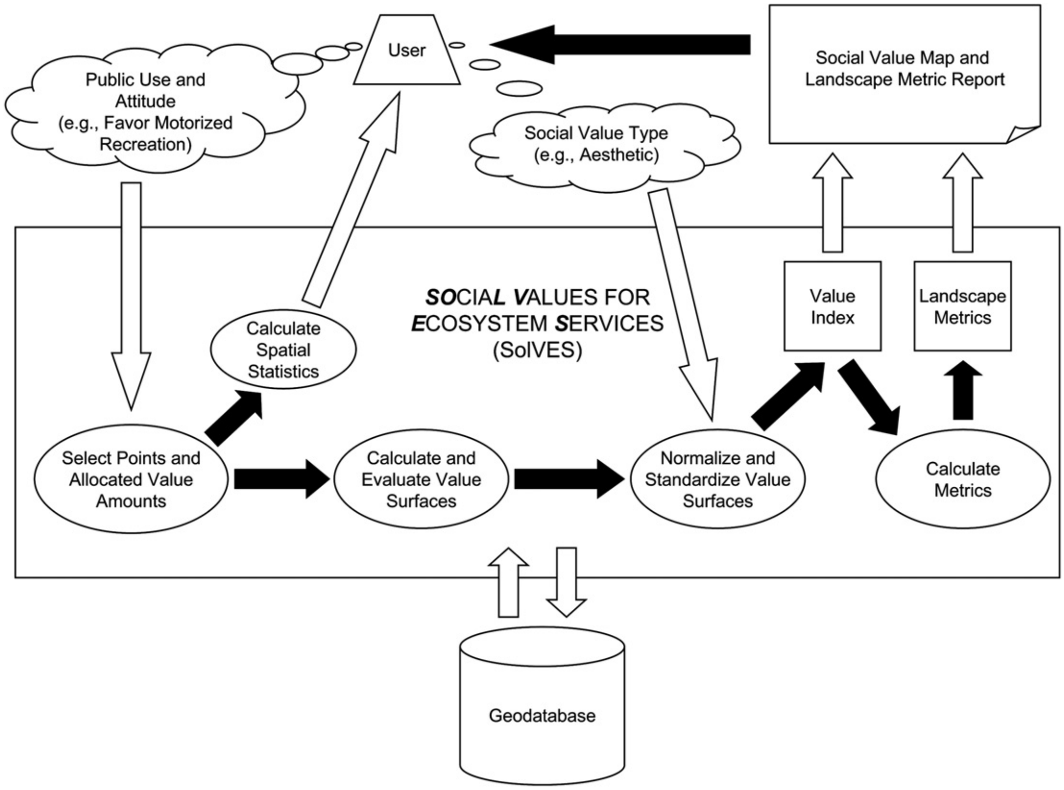

Fig. 2. The system diagram illustrates the general structure and process flow of the *Soc*ial *V*alues for *E*cosystem *S*ervices (SolVES) application.

attaining a 7 or higher on the Value Index and the mean value of the four quantitative landscape metrics (elevation, slope, DTR, and DTW). Attained index values of 7 or higher were chosen to limit further analyses to a manageable number of outputs and to provide an adequate number of data points for correlation analysis.

Once significant correlations were identified, a final analysis was performed to evaluate the potential of the results to produce predicted social value maps through multiple regression analysis for areas where survey data are unavailable. Since this was only meant to demonstrate one possible approach, the validity of the multiple regression analysis on the basis of multi-collinearity among the independent variables, non-linear relationships between the independent and dependent variables, the significance of the regression coefficients, or other factors were not evaluated further. The approach loosely followed methods used by Troy and Wilson to evaluate the use of a GIS for applying value-transfer methods to ecosystem services valuation (2006). In their study, valuation coefficients for individual landcover classes were extracted from previous ecosystem valuation studies and applied to landcover data in three different target areas to produce maps and dollar-value estimates of ecosystem service flows for each of these areas (Troy & Wilson, 2006). For the current analysis, regression coefficients from the multiple regressions of landscape metrics with index values served a similar role to valuation coefficients to produce a predicted value map for the PSI. A sample case was selected where each of the four quantitative landscape metrics (independent variables) was significantly correlated with the index values (dependent variable) for a specified survey subgroup and social value type. Using map algebra, the coefficients derived from the multiple regression analysis were applied to their respective rasters to produce a predicted social value map. This output was visually compared with the corresponding Value Index map produced by the kernel density method. Based on this comparison, an additional model for selecting regression coefficients matching user-entered public use, attitude or preference, and social value type parameters and applying them to environmental data layers was developed to serve as a starting point for enhancing SolVES with value-transfer functionality.

Table 3
The public uses included in the analysis were selected on the basis of there being significant disagreement regarding each use and their actual or potential impact on the PSI landscape.[a]

Public use	Favor or strongly favor		Oppose or strongly oppose	
	Count	Percent	Count	Percent
Communication sites and utility easements	213	33%	214	33%
Logging for fuels reduction	366	56%	181	28%
Logging for increased water collection	249	38%	222	34%
Logging for wood products	223	35%	321	50%
Motorized recreation	235	36%	341	53%
Oil and gas drilling	137	21%	417	64%

[a] Survey responses with a neutral attitude are not included.

Results

Spatial clustering

Statistically significant ($p < 0.01$) spatial clustering of point locations was found for all but one of the 78 combinations of survey subgroups and social value types (Table 4). The one exception included the Therapeutic points mapped by those who favor oil and gas drilling and likely resulted from the low number of points ($N = 33$).

Table 4
The average nearest neighbor statistics consistently show statistically significant clustering across nearly all survey subgroups and social value types as indicated by *R* values of less than 1 and highly negative *Z* scores.

Public use	Social value type	Favor or strongly favor			Oppose or strongly oppose		
		N	*R* value	*Z* score	*N*	*R* value	*Z* score
Communication sites and utility easements	Aesthetic	175	0.357	−16.275	232	0.286	−20.812
	Biodiversity	104	0.366	−12.370	101	0.313	−13.210
	Future	104	0.426	−11.196	107	0.321	−13.435
	Life Sustaining	108	0.375	−12.423	98	0.368	−11.978
	Recreation	196	0.380	−16.609	125	0.339	−14.137
	Therapeutic	55	0.640	−5.104	57	0.597	−5.821
Logging for fuels reduction	Aesthetic	339	0.279	−25.381	146	0.441	−12.911
	Biodiversity	177	0.327	−17.125	76	0.399	−10.023
	Future	190	0.334	−17.567	75	0.287	−11.816
	Life Sustaining	181	0.286	−18.369	70	0.386	−9.833
	Recreation	341	0.316	−24.154	62	0.494	−7.615
	Therapeutic	109	0.393	−12.127	36	0.602	−4.570
Logging for increased water collection	Aesthetic	227	0.296	−20.292	192	0.368	−16.762
	Biodiversity	101	0.438	−10.814	121	0.348	−13.731
	Future	103	0.394	−11.769	126	0.316	−14.685
	Life Sustaining	93	0.461	−9.951	120	0.386	−12.860
	Recreation	192	0.369	−16.715	142	0.364	−14.505
	Therapeutic	45	0.785	−2.763	72	0.449	−8.942
Logging for wood products	Aesthetic	161	0.353	−15.714	297	0.302	−23.026
	Biodiversity	77	0.515	−8.141	159	0.309	−16.674
	Future	86	0.421	−10.276	170	0.286	−17.822
	Life Sustaining	78	0.427	−9.680	160	0.367	−15.308
	Recreation	193	0.394	−16.096	186	0.316	−17.852
	Therapeutic	51	0.626	−5.103	83	0.450	−9.594
Motorized recreation	Aesthetic	180	0.397	−15.474	325	0.298	−24.203
	Biodiversity	110	0.355	−12.945	134	0.307	−15.342
	Future	123	0.325	−14.315	141	0.332	−15.170
	Life Sustaining	91	0.469	−9.688	143	0.362	−14.604
	Recreation	252	0.335	−20.189	163	0.318	−16.652
	Therapeutic	70	0.583	−6.675	77	0.500	−8.396
Oil and gas drilling	Aesthetic	80	0.504	−8.493	404	0.257	−28.571
	Biodiversity	51	0.650	−4.776	197	0.263	−19.777
	Future	45	0.569	−5.531	209	0.337	−18.350
	Life Sustaining	51	0.685	−4.298	186	0.335	−17.344
	Recreation	125	0.459	−11.575	258	0.274	−22.304
	Therapeutic	33	0.972	−0.307	111	0.335	−13.408
All surveys[a]	Aesthetic	573	0.242	−34.689	–	–	–
	Biodiversity	283	0.258	−23.884	–	–	–
	Future	302	0.306	−23.066	–	–	–
	Life Sustaining	268	0.278	−22.614	–	–	–
	Recreation	471	0.259	−30.776	–	–	–
	Therapeutic	168	0.355	−15.998	–	–	–

[a] Statistics are for all surveys regardless of public use, attitude or preference.

The value index

There were 46 instances where a social value type attained an index value of 7 or more on the Value Index (Table 5). The maximum attained index value for Aesthetic was consistent across survey subgroups. It was valued as high as 10 on the Value Index by nine of 12 survey subgroups. Recreation was the only other social value type to attain a 10 for any of the survey subgroups. In most instances, the survey subgroups opposed to the six public uses assigned a higher value, or at least the same value, to Biodiversity, Future, and Life Sustaining relative to those survey subgroups favoring these uses. In all instances, the survey subgroups favoring a public use assigned a higher value to Recreation as compared to those opposed to the use. Compared to all survey respondents, the maximum index values attained by Biodiversity and Life Sustaining were consistently as high or higher among the survey subgroups opposed to the public uses. Among these same survey subgroups, the maximum index value attained for Recreation was consistently lower than for all survey respondents. For each of the survey subgroups favoring the public uses, Recreation attained a higher maximum index value than it did among all survey respondents.

Value maps and landscape metrics

The value maps generated by SolVES provide a geographic representation of the index values calculated for each social value type and survey subgroup. The dimensions of space and place can be evaluated relative to specified social value types and the amount of value perceived by stakeholders. Additionally, these maps indicate the range and extent of the Value Index zones for which the metrics characterizing the physical environment are calculated. The following examples demonstrate how SolVES output is designed to communicate information describing the relationship of the intensity and location of social values with the underlying landscape.

A first example illustrates the social value map and landscape metrics for areas recognized for their Aesthetic value by the survey subgroup opposed to motorized recreation (Fig. 3). The northernmost hotspot on the map (indicated in red) is situated on and around Mount Evans, a scenic fourteen thousand-foot peak. For this survey subgroup, this is the location with which it associates the highest Aesthetic value (Value Index = 10), and it is the location relative to which all other locations and social value types are measured. The landscape metrics provide a generalized description of the physical

Table 5
A summary of the maximum value attained on the Value Index for each survey subgroup and social value type.

Public use	Attitude or preference	Aesthetic	Biodiversity	Future	Life Sustaining	Recreation	Therapeutic
Communication sites and utility easements	Favor or strongly favor	10	6	6	8	9	4
	Oppose or strongly oppose	10	8	9	8	6	4
Logging for fuels reduction	Favor or strongly favor	10	7	7	8	10	4
	Oppose or strongly oppose	10	7	7	7	5	4
Logging for increased water collection	Favor or strongly favor	10	6	6	7	9	3
	Oppose or strongly oppose	10	8	9	9	6	5
Logging for wood products	Favor or strongly favor	9	7	8	7	10	4
	Oppose or strongly oppose	10	7	8	8	6	5
Motorized recreation	Favor or strongly favor	7	5	7	5	10	3
	Oppose or strongly oppose	10	6	6	8	5	4
Oil and gas drilling	Favor or strongly favor	7	5	5	6	10	3
	Oppose or strongly oppose	10	6	7	7	6	4
All surveys[a]	N/A	10	6	8	7	7	4

[a] Values are for all surveys regardless of public use, attitude or preference.

environment associated with each index value. In this particular case, it can be seen that index values generally trend higher with increases in average elevation and average slope. Initially, the index values for Aesthetic increased with DTR, but DTR abruptly drops towards the higher end of the Value Index scale. The influence of Mount Evans on the data is observable—a road to its summit results in the sudden reversal of the relationship between DTR and the Value Index. DTW shows no readily discernable pattern relative to the Value Index. Finally, the dominant landcover, RockyMountain dry tundra, and the dominant landform, gently sloping ridges and hills, at the value hotspot are qualitative metrics rounding out the information provided by the social value map and metrics.

A second example illustrates areas valued for Recreation by the survey subgroup favoring motorized recreation (Fig. 4). In this case, the location having the highest index value of 10 can be seen in the northwestern quadrant of the map. It is situated in the Twin Lakes area, which is surrounded by an abundance of recreational opportunities, both motorized and non-motorized. Again, the landscape metrics describe the physical characteristics of the value hotspot. The high index value associated with the area is consistent with the low average slope and the nearness and dominance of open water reported for the higher end of the Value Index.

Each of the four quantitative landscape metrics demonstrated statistically significant correlations with index values (Table 6).

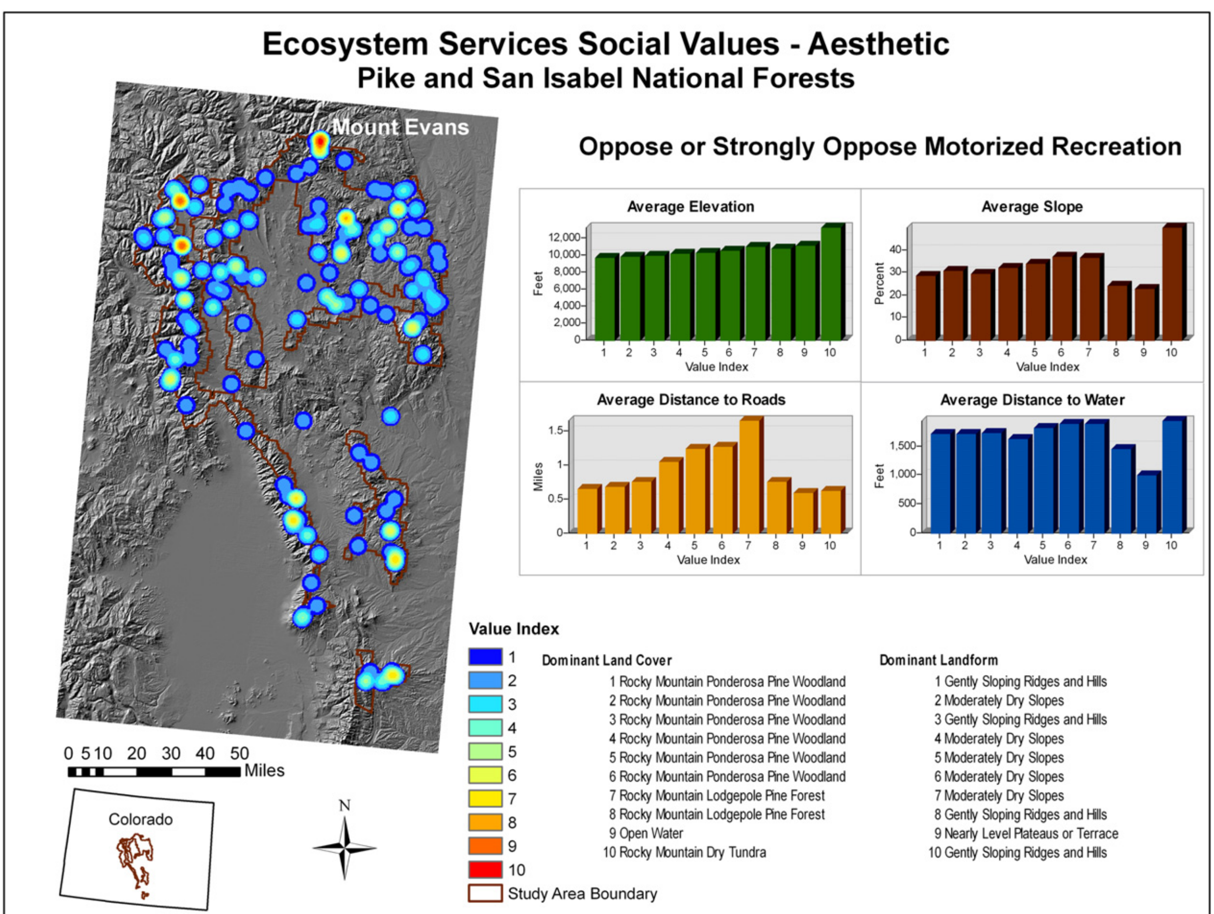

Fig. 3. Example SolVES output showing the Aesthetic social value type map and landscape metrics for the survey subgroup opposed to motorized recreation in the PSI.

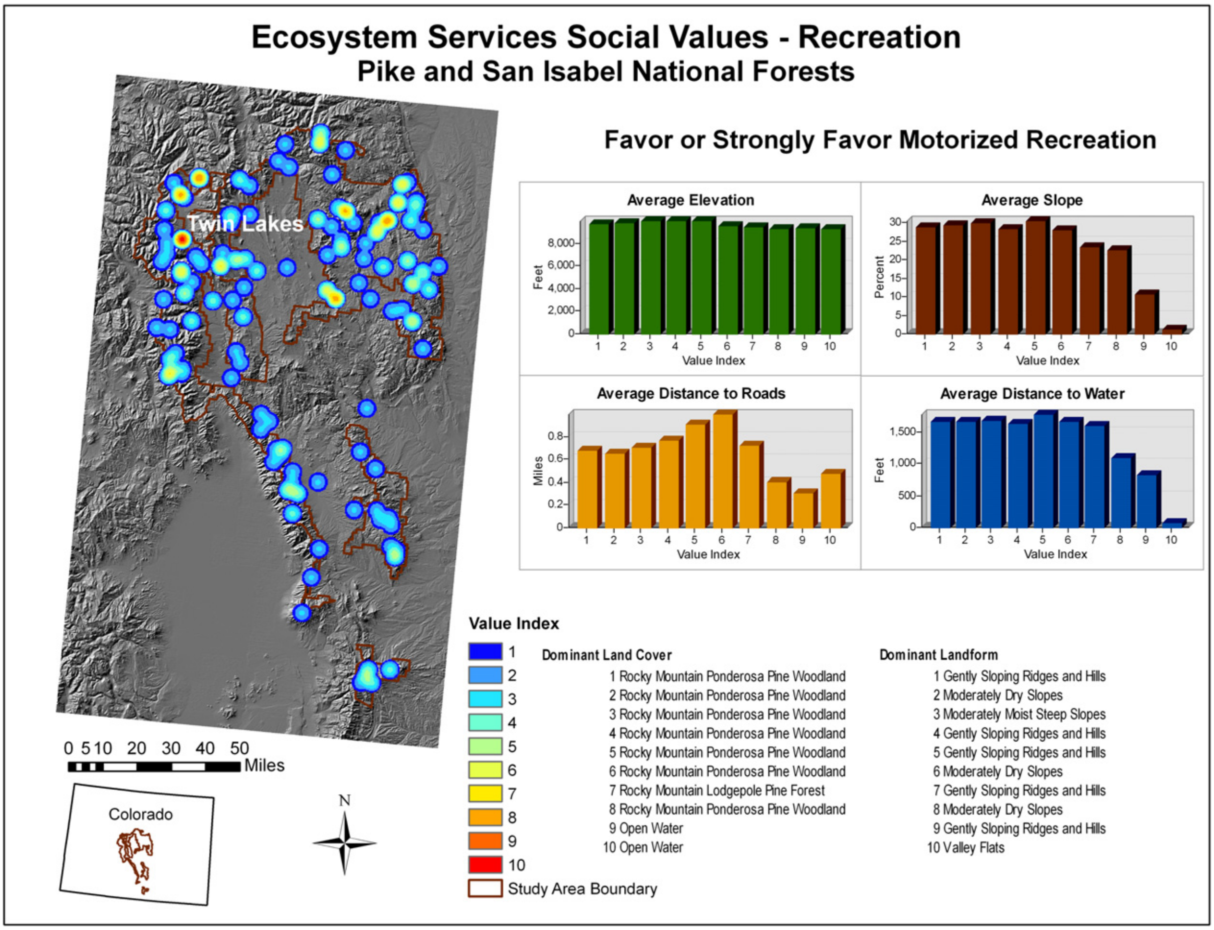

Fig. 4. Example SolVES output showing the Recreation social value type map and landscape metrics for the survey subgroup in favor of motorized recreation in the PSI.

Most often, and almost always, elevation was significantly correlated with index values. DTR followed closely. Less frequently, but in over 50 percent of cases, slope was significantly correlated. Finally, DTW was significantly correlated in just under 50 percent of cases. Except for DTW, the correlations were more likely to be positive, generally meaning that areas of higher elevation, steeper slopes, and further from roads were valued more highly. In the case of DTW, areas closer to water were slightly more likely to be valued highly. This was particularly true for Aesthetic and Recreation. Instances of negative correlations with the other metrics were mostly associated with Recreation. In short, regardless of the survey subgroup, higher index values for Recreation were associated with flatter areas closer to roads and water. In the cases of those favoring motorized recreation or oil and gas drilling, however, areas of lower average elevation were valued more highly for Recreation while the other survey subgroups assigned a greater value to higher elevation areas for Recreation.

Multiple regression and predictive maps

The final sample result compares output from the SolVES models relying on survey data with output from the model employing a form of value-transfer methodology. Shown are social value maps of Biodiversity for survey respondents opposed to communication sites and utility easements. One was generated by the kernel density method, and the other resulted from applying regression coefficients to their respective environmental data layers (Fig. 5). Although further validation of any predictive mapping techniques is required, including the application of the statistical results in independent study areas, visual examination of the preliminary maps reveals how the multiple regression method is capable of generating value hotspots at locations and intensities that approximate results obtained from the kernel density method. This holds promise for SolVES as a value-transfer tool for estimating and mapping relative social values in areas lacking survey data.

Discussion

Lessons from the case study analysis

The current study worked towards goals similar to those stated by Reed and Brown in the development of their values suitability analysis methodology: place attention on the importance of human uses and values; attempt to systematically, interactively, and defensibly operationalize human dimensions of ecosystem management; and integrate social and biophysical data (2003). SolVES was developed to ultimately become a practical tool for achieving such goals. Through the case study analysis of the PSI, SolVES also provided an opportunity to explore some of the additional research needs expressed by Reed and Brown including closer examination of the relationship between values and uses as well as exploration of alternative techniques for representing the spatial extent of social value boundaries on a map (2003). SolVES also implements the idea of social–ecological space described by Alessa et al. (2008) through the analysis of social values overlaying physical environmental variables while also moving beyond this overlay analysis to consider

Table 6
A summary of social value types by survey subgroup having significant correlations between landscape metrics and the range of index values.

Public use	Social value type	Favor or strongly favor				Oppose or strongly oppose			
		Elevation	Slope	DTR	DTW	Elevation	Slope	DTR	DTW
Communication sites and utility easements	Aesthetic	0.45**	− 0.25*	0.02	−0.39**	0.86**	0.41**	0.68**	− 0.08
	Biodiversity	–	–	–	–	0.81**	0.27*	0.93**	0.48**
	Future	–	–	–	–	0.69**	− 0.09	0.95**	0.22*
	Life sustaining	0.93**	0.65**	0.74**	0.22*	0.50**	0.05	0.89**	0.29**
	Recreation	0.37**	− 0.05	0.07	− 0.44**	–	–	–	–
Logging for fuels reduction	Aesthetic	0.89**	0.46**	0.70**	0.13	0.81**	0.13	− 0.04	− 0.25*
	Biodiversity	0.61**	0.15	0.82**	0.21	0.39**	0.23	0.63**	− 0.04
	Future	0.60**	0.05	0.94**	0.04	0.73**	0.08	0.51**	− 0.18
	Life sustaining	0.47**	0.06	0.90**	0.20	0.79**	0.48**	0.55**	− 0.12
	Recreation	0.36**	− 0.52**	− 0.08	− 0.50**	–	–	–	–
Logging for increased water collection	Aesthetic	0.49**	− 0.28**	0.34**	− 0.40**	0.86**	0.33**	0.60**	0.04
	Biodiversity	–	–	–	–	0.87**	0.49**	0.89**	0.27*
	Future	–	–	–	–	0.37**	0.02	0.92**	0.01
	Life sustaining	0.63**	0.49**	0.69**	0.33**	0.87**	0.21	0.80**	0.11
	Recreation	0.31**	− 0.26*	− 0.35**	− 0.70**	–	–	–	–
Logging for wood products	Aesthetic	0.80**	0.00	0.33**	− 0.33**	0.85**	− 0.03	0.57**	− 0.17
	Biodiversity	0.69**	0.16	0.87**	0.06	0.56**	− 0.10	0.80**	0.39**
	Future	0.51**	0.08	0.88**	0.18	0.62**	− 0.03	0.94**	0.10
	Life sustaining	0.77**	0.65**	0.40**	0.36**	0.90**	0.38**	0.94**	0.27*
	Recreation	0.16	− 0.71**	− 0.52**	− 0.69**	–	–	–	–
Motorized recreation	Aesthetic	0.89**	0.36**	0.63**	0.21	0.82**	0.21*	0.20*	− 0.22*
	Future	0.33**	− 0.15	0.91**	0.12	–	–	–	–
	Life sustaining	–	–	–	–	0.56**	0.24*	0.92**	0.03
	Recreation	− 0.46**	− 0.67**	− 0.39**	− 0.62**	–	–	–	–
Oil and gas drilling	Aesthetic	0.90**	0.71**	0.63**	0.44**	0.87**	0.23*	0.48**	0.02
	Future	–	–	–	–	0.59**	− 0.09	0.93**	0.15
	Life sustaining	–	–	–	–	0.92**	0.35**	0.89**	0.23
	Recreation	− 0.65**	− 0.66**	− 0.24*	− 0.62**	–	–	–	–
All surveys[a]	Aesthetic	0.87**	0.21*	0.43**	− 0.06	–	–	–	–
	Future	0.50**	0.04	0.92**	0.08	–	–	–	–
	Life sustaining	0.75**	0.25*	0.88**	0.17	–	–	–	–
	Recreation	0.65**	− 0.41**	0.25*	− 0.38**	–	–	–	–

*$p < 0.05$, **$p < 0.01$.
[a] Statistics are for all surveys regardless of public use, attitude or preference.

the potential of using the statistical relationships between the layers as part of a value-transfer mapping methodology.

Results from the case study analysis demonstrate the capabilities and potential of SolVES while providing useful insights into some of the patterns that can be discerned from the relationship between social values and public uses of the PSI. CSR hypothesis testing, as applied at the outset, provides a systematic means for identifying statistically significant spatial patterns of social values that warrant further investigation. While this impacted only one instance out of 78 in the current case study, it remains a defensible method for distinguishing potentially meaningful patterns from spatial randomness. The general indication of the remaining case study results is that there is widespread valuing for the Aesthetic in the PSI across all survey subgroups although those favoring potentially high-impact motorized recreation or extractive oil and gas drilling assign a higher value to Recreation. Opposition to any of the public uses corresponded to a higher assigned value for the social value types that are less related to direct or immediate human use (Biodiversity, Future, and Life Sustaining) than ones that are (Recreation). The ability to evaluate and summarize the results in such a manner is facilitated by the Value Index.

The calculation of the Value Index as a metric for the perceived, non-monetarized social value of ecosystem services provides a standardized, quantitative indicator which can express relative value across geographic extents and within survey subgroups without relying on dollar-value terms. Since the Value Index was developed as a ratio scale (i.e., there is a true zero value associated with locations where the relative weighted density of value points is zero), index values could be quantitatively analyzed within survey subgroups in a manner similar to that used for dollar values. This could potentially be in some form of tradeoff analysis, at least in a relative sense, within a geographic context where various conflicting or compatible value layers are combined in a manner that would spatially and quantitatively optimize among management alternatives. Similar analyses among different survey subgroups, however, will require adjustments to the Value Index calculation since comparisons among different survey subgroups cannot be as precisely quantified with the current normalization technique, which operates within rather than across survey subgroups.

The Value Index also provides the spatial context that is necessary for evaluating the relationship between the intensity of social values and characteristics of the underlying physical environment as well as a possible framework for suggested future research involving the development of statistical methods for investigating spatial correlations between socioeconomic and biophysical variables (e.g., De Lange et al., 2010). While the mapping of index values indicates locations on the landscape that are valued at varying intensities among survey subgroups for each social value type, such as the Aesthetic value of Mount Evans or the Recreation value of Twin Lakes for those opposing and favoring motorized recreation respectively, the spatial rendering of the Value Index as a range of value zones also facilitates the exploration of correlations between the variations in index values with measurable environmental attributes. The case study results demonstrate how this approach might be successful in identifying combinations of landscape attributes, social value types, and survey subgroups that could be useful for defining locations of potential compatible or conflicting uses to be addressed as part of the planning process. For instance, the case study results revealed the generally negative correlation of DTW with index values as

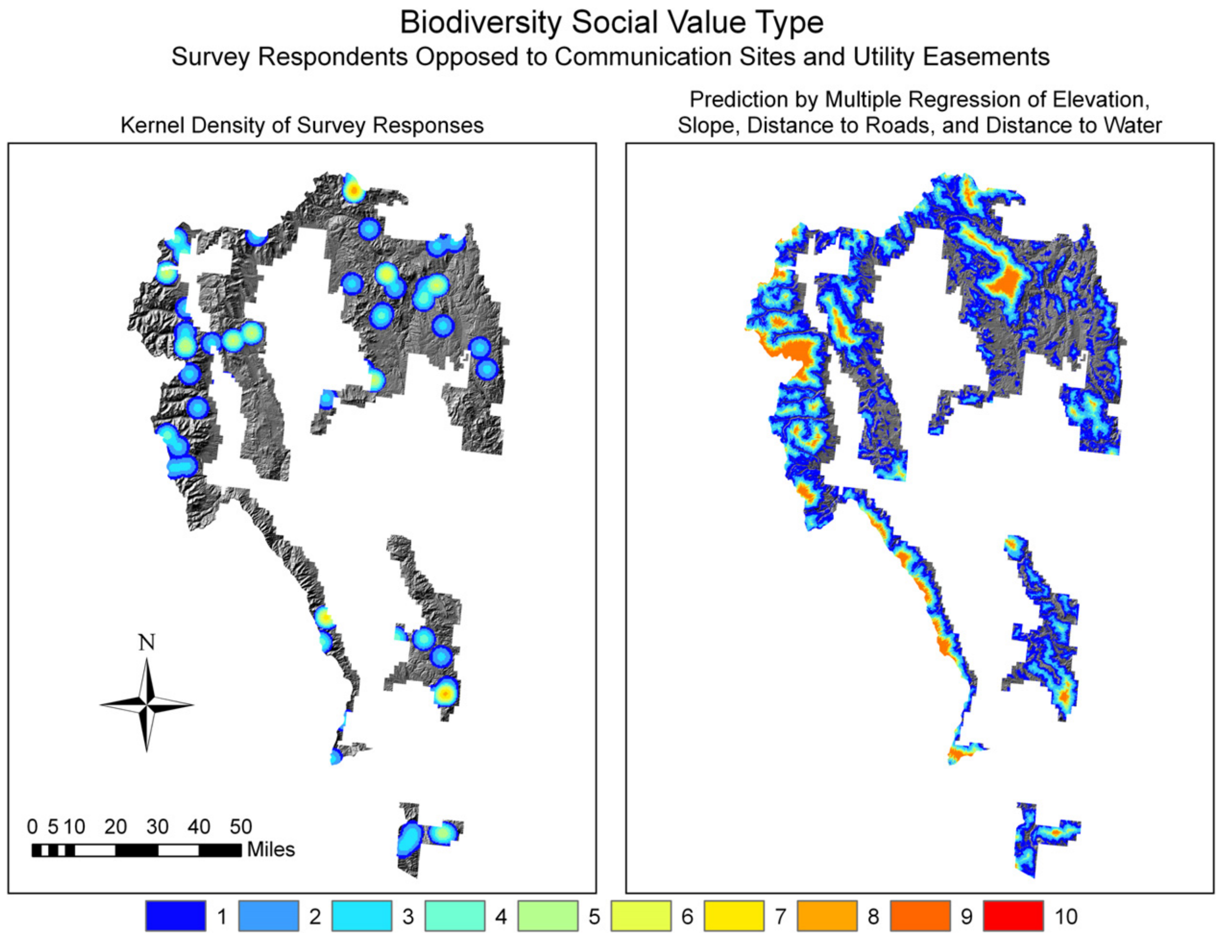

Fig. 5. The Biodiversity social value map for the survey subgroup opposed to communication sites and utility easements in the PSI produced using the kernel density method (at left) and the same social value map predicted using regression coefficients (at right).

opposed to the mostly positive correlations of the other landscape metrics. Also indicated is that the majority of negative correlations for any of the landscape metrics were associated with Recreation. This pattern of negative correlations is consistent across all landscape metrics for those favoring motorized recreation and those favoring oil and gas drilling. Availability of such information could prompt land and resource managers, for example, to more closely consider the implications of management alternatives for recreation in areas closer to water and to solicit public input addressing the desired public uses within such areas, recreational or otherwise. Taken further, as demonstrated with the multiple regression technique, such data describing the relationship between the Value Index and the underlying landscape, with further validation and additional data to improve the matching of social and physical contexts, holds promise for better informing the value-transfer methods that allow SolVES to generate predicted social values maps for areas of concern in the absence of or in complement to public attitude or preference surveys.

Future directions

Enhancements critical to SolVES' ultimate effectiveness could be more readily indentified by engaging land and resource managers in its application within the context of ongoing management and planning activities. Their feedback could drive the future development of additional functionalities and information products to better inform their decision-making processes. While management involvement is a top priority moving forward, closer examination of the current version of SolVES also reveals some potential areas for improvement. Given that SolVES focuses on social value types, an alternative and complementary approach for consideration in future development could be a place-based focus in which users could interrogate the GIS using place name parameters in addition to or rather than specific social value types. The point patterns of survey results could be used to define specific locations that could be dimensioned according to social values and their associated ecosystem services, value allocations, and individual survey subgroups. Future versions of SolVES could also include alternative methods for calculating value indices that still incorporate some of the qualities of the current Value Index and improve upon it as a means for representing social value differences in explicit and absolute quantitative terms as well as for the analysis of relationships between social and environmental data. Regardless of the chosen valuation method, it will also be necessary to consider approaches for integrating the resulting non-monetary value information with any available monetary value data included in more comprehensive ecosystem service assessment and valuation projects.

Future research would also be greatly assisted by input from land and resource managers. Potential research needs include the identification of additional data at appropriate scales and resolutions that could provide improved measures and descriptions of various environmental characteristics and ecosystem services. In particular, data that facilitate the measurement of small changes in ecosystem services might provide an opportunity to assess not only their total value but their marginal value as well. Additional quantitative variables and select qualitative variables (such as the currently included landcover and landform datasets) that could be adapted for use in regression analysis and the matching of physical contexts for value-transfer methods are needed to produce predicted social value maps for other study areas and ecosystems where survey data are not available. Such variables would provide more precise descriptions of the types and locations of the particular ecosystem services of interest and allow for the refinement of regression coefficients to better account for the separate influences of natural feature metrics such as elevation, DTW, or the presence of a scenic view versus manmade feature metrics such as DTR, proximity to urbanized areas, or the presence of culturally significant sites on predicted values. A greater temporal frequency of data along with the increasing feasibility of near real time collection of public attitude or preference survey data enabled by GPS, wireless, and participatory technologies (e.g., public participation GIS) (Brown & Reed, 2009; Wang, Yu, Cinderby, & Forrester, 2008) could also be valuable for change analysis and scenario development. Data from survey sections that are not currently used by SolVES could also be leveraged in the future. Analysis of the survey data describing respondents' familiarity with the study area, for example, could prove useful for identifying selection bias that might influence how values are weighted and locations are marked on the survey maps. Additional information regarding the social, economic, and demographic status of survey respondents would assist with matching the social contexts of ecosystem services to provide a stronger basis for applying value transfer in areas for which public attitude or preference survey data is not available. To this end, further study and management input regarding the design of future public attitude or preference surveys to facilitate the identification of statistically significant relationships with environmental data and assist with the cross-walk between social value and ecosystem service typologies is also needed.

Conclusion

SolVES demonstrates one alternative of how a GIS application can be developed and applied to unite concepts and methods from ecosystem services assessment and social values mapping. The case study results suggest SolVES has potential as a tool for researchers, decision makers, and stakeholders to explicitly quantify and illustrate the connections between social values, the attitudes and preferences that manifest these values, and the environmental characteristics, locations, and associated ecosystem services that elicit such values. By considering both the social and physical contexts of values associated with ecosystem services, this tool can improve efforts to integrate publicly held values into the decision-making processes of land and resource managers, even for areas where primary data regarding these values may be lacking. It can also facilitate communication between decision makers and various stakeholder groups with diverse interests regarding the real and perceived relative tradeoffs among various ecosystem services and their locations. The continued development, refinement, and validation of a more robust, public domain application that builds on the lessons learned from case study analyses and that is informed by research from both social and environmental perspectives as well as management expertise should have significant implications for ecosystem assessment, valuation, and planning.

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