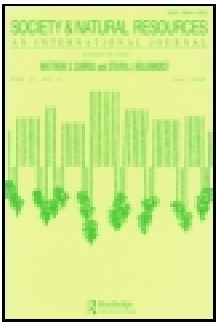

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Public Participation GIS: A Method for Identifying Ecosystem Services

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Public Participation GIS: A Method for Identifying Ecosystem Services

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This study evaluated the use of an Internet-based public participation geographic information system (PPGIS) to identify ecosystem services in Grand County, Colorado. Specific research objectives were to examine the distribution of ecosystem services, identify the characteristics of participants in the study, explore potential relationships between ecosystem services and land use and land cover (LULC) classifications, and assess the methodological strengths and weakness of the PPGIS approach for identifying ecosystem services. Key findings include: (1) Cultural ecosystem service opportunities were easiest to identify while supporting and regulatory services most challenging, (2) participants were highly educated, knowledgeable about nature and science, and have a strong connection to the outdoors, (3) some LULC classifications were logically and spatially associated with ecosystem services, and (4) despite limitations, the PPGIS method demonstrates potential for identifying ecosystem services to augment expert judgment and to inform public or environmental policy decisions regarding land use trade-offs.

Keywords ecosystem services, GIS, public participation

The natural landscape provides necessary and beneficial services for human and ecosystem well-being. For example, forests may supply timber and wood fiber, regulate climate by absorbing carbon dioxide, provide and regulate water resources, provide genetic resources for medicines, attract people for recreation and tourism, and support nutrient recycling and soil formation. The types of benefits that people obtain from ecosystems are known as ecosystem services (Millennium Ecosystem Assessment [MEA] 2003). Ecosystem services are fundamental to human life; however, many of these services are in danger of being destroyed (Carpenter, Bennett, and Peterson 2006; Daily 1997; Ehrlich and Mooney 1983). Thus, it is important to safeguard the benefits of ecosystem services while ensuring that the ecosystem

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services are available to support human well-being in the future (Cowling et al. 2008; Maskey 2008).

Ehrlich and Ehrlich (1981) are credited with the phrase "ecosystem services" when trying to convey the value of ecosystem functions to a public with little understanding of the linkages between those functions and their own well-being (Peterson et al. 2009). In the last two decades, the concept of ecosystem services has been used with hope that it will contribute to better natural resource management decision making, but questions remain about what it means to value ecosystem services and how one goes about measuring that value. Economic valuation (e.g., cost–benefit analyses, hedonic pricing, contingent valuation, willingness to pay) of ecosystem services has been the predominant valuation technique. While there has been much support for continued research on the economic valuation of ecosystem services (Daily et al. 2009; Ninan 2009; NRC 2005), concerns have been voiced that noneconomic social valuation of ecosystem services also should have a role in the decision-making process (Kumar and Kumar 2008; Peterson et al. 2009). This is in part because "prices are not to be confused with values, and prices are not the only values that are important" (Cowling et al. 2008, 9845). Although some values (e.g., direct economic returns from wood products) may be appropriately assessed by economic techniques, economic values do not and cannot capture the full value of ecosystems, especially those services that tend to fall outside of the sphere of markets (Martin-Lopez et al. 2009). These types of services often fall under supporting or cultural services (Beaumont et al. 2007; Martin-Lopez et al. 2009), which the MEA defines as the services necessary for other ecosystem functions, such as soil formation (supporting), and the services that provide nonmaterial benefits such as spiritual value or sense of place (cultural). It is important that the values of the immaterial benefits associated with cultural services be captured because they are often central to public discontent with natural resource management decisions (Satterfield and Roberts 2008). Thus, it is important that ecosystem service frameworks evolve in a way that engages participants in the identification and valuation of ecosystem services (Kumar and Kumar 2008). One way that these frameworks have evolved is through landscape value mapping using public participation geographic information systems or PPGIS (Brown 2005; Landscape Values Institute 2010).

The landscape values mapping process provides a medium for integrating social and ecological aspects of ecosystem service management. Biophysical and economic values are traditionally used to define high-priority hotspots in planning for conservation and environmental management (Raymond et al. 2009). Identifying and mapping these hotspots can help illustrate the degree of spatial similarity between services and management regimes (Daily 2000) and will help to enhance systematic regional planning for environmental management (Bryan and Crossman 2008). Identifying and mapping ecosystem services can provide decision makers valuable information on where and how the public values landscape functionality (Willemen et al. 2008). Mapping can also help forecast changes and societal need for ecosystem services under alternative future scenarios of demographic and land-use change (Daily 2000).

The term "public participation geographic information systems" (PPGIS) was conceived in 1996 at the meeting of the National Center for Geographic Information and Analysis (NCGIA). The concept describes the process of using GIS technologies to produce local knowledge with the goal of including and empowering marginalized populations. PPGIS methods can range from simple paper-based applications (participants identify attributes and locations on a paper map using markers or stickers) to more sophisticated computer-based applications (participants identify locations using digital tagging or drawing). Since the 1990s, the variety of PPGIS applications has been extensive, ranging from community and neighborhood planning to mapping traditional ecological knowledge of indigenous people (for a review of PPGIS applications see Sieber 2006 and Sawicki and Peterman 2002). In an early paper-based PPGIS application, Brown and Reed (2000) asked individuals to identify the location of general landscape values such as aesthetic, recreational, economic, and ecological, in addition to more intangible and symbolic landscape values such as spiritual and intrinsic values, as part of the Chugach National Forest (U.S.) planning process. Subsequent research using PPGIS has been conducted in the United States, Australia, and Canada to identify the location of forest values (Beverly et al. 2008; Brown and Reed 2009), highway corridor values (Brown 2003), "coupled social-ecological" (SES) hotspots where human and biophysical systems are closely linked (Alessa, Kliskey, and Brown 2008), preferences for tourism and residential development (Brown 2006), priority areas for conservation (Pfueller et al. 2009; Raymond and Brown 2006;), place attachment (Brown and Raymond 2007), urban park and open space values (Brown 2008; Tyrvainen, Makinen, and Schipperjin 2007), and national park visitor experiences and perceived environmental impacts (Brown and Weber, 2011).

Of particular relevance to this study was a study by Raymond et al. (2009) that used a landscape values PPGIS methodology to identify the location of 31 ecosystem services with a modified and expanded list of ecosystem services from the MEA (2003). The study quantified and mapped values and threats to natural capital assets and ecosystem services in a region in Australia and generated maps that showed the spatial distribution of natural capital and ecosystem service values and threats. However, that study used structured interviews with a purposive sample that included natural resource management decision-makers and community representatives. To our knowledge, the use of Internet-based PPGIS methods for collecting public perceptions of ecosystems services and values has not been implemented and evaluated.

The purpose of this article is to evaluate the use of an Internet-based PPGIS system for identifying ecosystem services and values using the results of an exploratory study implemented in Grand County, Colorado. Because PPGIS research has yet to establish either a set of best practices or a technique to demonstrate whether or not PPGIS is a suitable approach for a given problem (Sieber 2006), there is no formal evaluation framework available. PPGIS is intended to be part of a broader public participation process that may (or may not) use survey research methods and that may (or may not) involve human–computer interaction. Each of these potential foci (public participation, survey research, human–computer interaction) offers potential evaluation frameworks. Because our study was not linked to a specific public participation process, a participation evaluation framework (e.g., Rowe and Frewer 2000) is not appropriate. Instead, we apply evaluation constructs from survey research to assess data quality by examining overall and item response rates and the potential for bias. We also evaluate the face validity of the ecosystem spatial measures by examining their spatial association with various land uses/types that should be logically related and by comparing the frequency distribution of our results with the only other published PPGIS study of ecosystem values (Raymond et al. 2009). Finally, we evaluate the usability of the human–computer PPGIS interface based on respondent perceptions of the system.

Specific research questions to guide our evaluation included the following: (1) What is the distribution of ecosystem services identified by study participants and how do the results compare other methods of ecosystem services data collection, for example, the structured survey approach used by Raymond et al. (2009)? (2) What are the characteristics of respondents in the study and are these characteristics related to the number and type of ecosystem services identified? (3) Are there significant relationships between widely available land use and land cover (LULC) classifications and mapped ecosystem services such that certain LULC classifications may be said to represent a subset of ecosystem service classifications? (4) Does an Internet-based PPGIS method that allows unlimited numbers of ecosystem service markers by study participants influence (i.e., potentially bias) the results? This research question is relevant given that Internet-based PPGIS survey methods may attract fewer, but highly engaged, respondents (Brown and Reed 2009). (5) What are the strengths and weaknesses of using PPGIS for identifying ecosystem services based on respondents' evaluation of the Internet-based PPGIS system that can inform future research?

Methods

Overview

To evaluate the effectiveness of a PPGIS system for collecting ecosystem services, a website was developed using the Google Maps application programming interface (API). Grand County, Colorado, was selected as a test location and sampled residents were invited by mail to access the website (URL) provided in the cover letter explaining the study. Invitees were provided with a unique access code. After entering the access code on the opening screen, a short set of instructions appeared, followed by the Google Maps interface displaying a set of panels containing markers representing different ecosystem services (see Figure 1). Study participants simply drag and drop different ecosystem service markers on the map in the locations where

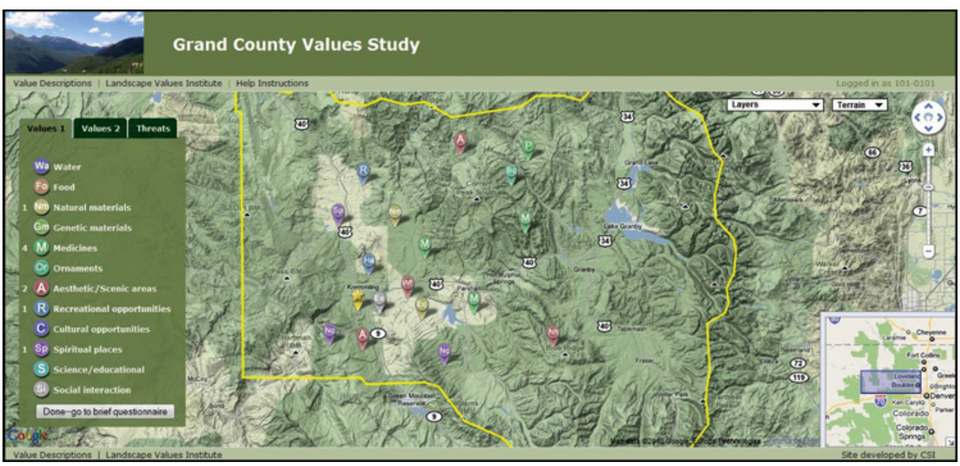

Figure 1. Screen image of PPGIS system for identifying ecosystem services. (Color figure available online.)

they think the ecosystem services are located. Participants can optionally annotate each marker with explanatory text. Following participant identification and mapping of different ecosystem services, the participant was directed to a webpage that asked a series of survey questions to assess participant characteristics. The spatial and nonspatial data provided by study participants were analyzed to answer the research questions presented in this article.

Study Location

Grand County, Colorado, lies on the Western Slope of the Rocky Mountains in the upper Colorado River basin and offers an excellent locale for an exploratory study of ecosystem services. The county is approximately 1.2 million acres in size and consists of steep, mountainous uplands and areas of glacial drift. Elevation ranges from 6,850 feet in the southwest portion of the county to more than 13,500 feet on the east side near the Continental Divide; the average elevation is 7,360 feet above sea level. The headwaters of the 1,400-mile-long Colorado River begin in Grand County. The county is sparsely populated with a total population of approximately 11,000.

Historically, the economy of Grand County was based on ranching, logging, and mining. More recently, the economic sector has diversified and has been strengthened by the creation of governmental agencies, tourism, and service providers. This is in large part due to the amount of "public land" under federal or state management and administration (73%). Specific federal public lands include Rocky Mountain National Park, Arapaho National Recreation Area, and Arapaho and Routt National Forests. The county also contains six wilderness areas.

The present economy of Grand County is tightly coupled with natural resources and ecosystem services. Grand County is a critical provider of freshwater to a large portion of Colorado's population. Approximately 60% of Grand County's waters are diverted to meet the needs of water users elsewhere. The mountain ecosystems of Grand County regulate water quantity and quality through the timing of snowmelt, filtering impurities from water, and regulating soil erosion and flooding. Ideally, forest vegetation in Grand County would provide climate regulating services; however, due to a decade-long mountain pine beetle (MPB) epidemic, this ecosystem service is at risk. Another regulating service currently threatened in Grand County is natural hazard regulation. Fire suppression in mountain ecosystems and exurbanization have increased the risk of catastrophic events beyond the historic range of variability (ILTER 2008).

Important cultural ecosystem services in Grand County consist of its scenic vistas and recreational opportunities, attracting visitors that come for day trips as well as extended stays. In 2003, for example, recreation and tourism generated almost $170 million in revenue in Grand County (Jaffe 2008).

PPGIS Markers and Survey Questions

A set of ecosystem services and their definitions were selected and operationalized from the MEA (2003) and a typology by de Groot et al. (2002) that recognize four broad categories of ecosystem services: provisioning services (e.g., freshwater), regulating services (e.g., climate and water regulation), cultural services (e.g., recreational, aesthetic), and supporting services (e.g., nutrient cycling, soil formation). The MEA (2003) identified 29 ecosystem services, while the de Groot et al. (2002)

typology recognized 23 ecosystem functions. While the MEA (2003) is the most widely acknowledged list of services, there is room for debate on the inclusion or exclusion of certain ecosystem services. For example, we consider habitat for plants and animals to be an essential ecosystem service, as do de Groot, Wilson, and Boumans (2002), but this service does not appear in the MEA report. We felt the need to modify the MEA typology slightly to create a more parsimonious list for operationalizing in PPGIS. We combined some MEA services that appeared to be closely related (e.g., air quality and climate regulation, pest and disease regulation, knowledge and education opportunities, and cultural diversity and cultural heritage), we added two services (habitat support and ornamental provisioning) from de Groot et al. (2002), and we excluded the supporting services of primary production and photosynthesis for purely pragmatic reasons of fitting the attributes in the PPGIS web interface.

In total, 22 ecosystem services were included in the final ecosystem services typology and these appear in Table 1. Operation definitions were presented with each PPGIS marker. For example, water regulation was operationalized as "these

Table 1. Frequency distribution of all mapped ecosystem services

Ecosystem service	Number of markers	Percentage of markers	Ecosystem service category
Recreation	341	19	Cultural
Aesthetic	304	17	Cultural
Water	246	14	Provision
Habitat	171	9	Supporting
Water regulation	106	6	Regulation
Natural materials	83	5	Provision
Social interaction	78	4	Cultural
Food	76	4	Provision
Science	68	4	Cultural
Spiritual	65	4	Cultural
Cultural	45	3	Cultural
Air quality	31	2	Regulation
Natural hazard	30	2	Regulation
Erosion control	30	2	Regulation
Waste treatment	28	2	Regulation
Genetic materials	24	1	Provision
Nutrient cycling	19	1	Supporting
Medicines	18	1	Provision
Pollination	16	1	Regulation
Soil formation	15	1	Supporting
Ornaments	13	1	Provision
Biological control	8	0	Regulation
Total ecosystem services	901	50	Cultural
by category	460	25	Provisioning
	249	14	Regulating
	205	11	Supporting

places help filter and purify water, maintain natural irrigation or drainage of water (e.g., rivers, wetlands), reduce flooding, or provide channels for the flow of water.''

The set of survey questions used in the study to assess participant characteristics included general demographic variables (age, gender, level of formal education, length of residence); self-rated knowledge of the study region, nature, and science; amount of time spent in nature and a perceived relationship with nature; and a set of questions to evaluate the PPGIS Internet implementation (ease of use and navigation, comprehension of ecosystem service marker definitions, and the challenge of identifying ecosystem services). We presupposed that individuals with greater knowledge of the study area, in terms of nature and science, would identify more and potentially different ecosystem services and that one's time spent in nature, consistent with a favorable orientation toward nature, would result in greater ecosystem service mapping activity.

Sampling

A random sample of 500 households in Grand County, Colorado, was selected from county property tax records after eliminating obvious corporate property owners. In February 2010, selected households were sent a cover letter explaining the purpose of the study, ''to determine which values and threats to nature are most common and where they are located. Our research goal is to determine if Grand County residents can identify values they find in nature using a new Internet mapping method.'' The letter was accompanied by a simple one-page set of instructions showing how to navigate to the web URL, showing how to place markers as well as navigate on the Google Maps interface, and showing how to complete the survey questions following the ecosystem services mapping activity. Each letter contained a unique seven-digit access code that was linked to the household address. This access code provided a means to identify nonrespondents after the initial letters were sent. After approximately 3 weeks, households that had not participated in the study were sent a second letter encouraging them to visit the website and participate in the study. Given that the primary purpose of the study was to evaluate the efficacy of the PPGIS method for identifying ecosystem services, not to obtain a high response rate per se, the sampling effort was limited to two rounds of mailing. There were 14 letters confirmed as undeliverable, leaving 486 letters that were presumed to be delivered.

Phone calls were made to 45 nonresponse households to identify reasons for nonparticipation. This effort to determine potential nonresponse bias was not successful, with only two completions of the nonresponse survey questions, highlighting the increased challenge of conducting household phone surveys using traditional phone numbers. The 43 unsuccessful calls consisted of 14 phone numbers that were unreachable after calling twice and receiving voice mail both times, 14 numbers with no answer and no voicemail, and 15 successful connections where the respondent either indicated that they didn't receive the letter of invitation or otherwise refused to participate in the brief phone survey.

Analyses

Both descriptive and inferential statistics were used to answer the different research questions. To describe the pattern of responses for identifying ecosystem services, we generated frequency distributions and percentages for the number of ecosystem services identified both individually and grouped by ecosystem service category (i.e., provisioning, regulating, supporting, and cultural). These responses were standardized and plotted on two dimensions representing the total number of markers mapped and the number of respondents that identified at least one of the ecosystem services. We ran chi-squared statistics and analysis of residuals to determine whether the number of observed ecosystem service points showed under- or overrepresentation in the four ecosystem service categories. To compare our Internet-based PPGIS results with the structured survey approach used by Raymond et al. (2009), we ranked ecosystem services from most to least frequently identified for the categories that were common to both studies. A Spearman rank correlation coefficient was calculated to measure the degree of similarity in the frequency of identified ecosystem services in the two studies.

To describe the characteristics of participants in the study, we ran descriptive statistics on the demographic variables, the questions that asked respondents to self-rate knowledge of the study region, nature, and science, the amount of time spent in nature, and a question that described the respondent's general relationship with nature.

To determine whether there are significant relationships between land use and land cover (LULC) classifications, we intersected the ecosystem service point data with GIS data layers for LULC in Grand County, Colorado. LULC data consists of historical land use and land cover classification data based primarily on the manual interpretation of 1970s and 1980s aerial photography. There are 21 possible categories of cover type. LULC data is widely available for the coterminous United States and Hawaii. We ran chi-squared statistics and analysis of residuals to determine whether the number of observed ecosystem service points differed significantly from the number of points that would be expected based on the relative size of the LULC classification within the study area. Significant relationships may indicate the potential for using selected LULC classifications as proxies for some ecosystem services.

Previous experience with PPGIS systems indicated relatively high variability among respondents in the number of attributes mapped, which suggests the potential for a few individuals to bias the results. To evaluate the methodological question of the effect of allowing unlimited numbers of ecosystem service markers by participants, we divided the respondents into two groups, the "intensive-mappers" ($n = 7$) who identified approximately 50% of the total ecosystem services, and the remainder of the PPGIS participants. Potential differences in the number of ecosystem services by category were assessed between the two groups using an independent samples t test.

To determine the strengths and weaknesses of an Internet-based PPGIS for identifying ecosystem services, we generated frequency distributions for the survey items that asked respondents to evaluate the system. These items included questions about the user interface, the clarity of ecosystem service definitions, and the difficulty of identifying and mapping ecosystem services.

Results

Survey Response

There were in total 58 full or partial responses out of 486 invitations presumed to be delivered for a response rate of 11.9%. A "response" consisted of an individual mapping one or more ecosystem services, whether or not the person completed the survey questions following the mapping activity. The total number of mapped attributes identified by respondents was 2,179.

Frequency Distribution of Ecosystem Services

Table 1 shows the frequency distribution of all mapped ecosystem services arranged from most frequent to least frequent. The cultural services of recreation and aesthetic opportunities were the most frequently identified, followed by the provisioning service of water and the supporting service of habitat. The least frequently identified services were the regulatory service of biological control, the provisioning service of ornaments, the supporting service of soil formation, and the regulating service of pollination. To provide greater depth of understanding, the number and type of ecosystem services identified were plotted in two dimensions—by the number of points mapped (standardized with the highest number of points equal to 1.0) and by the number of individuals that mapped at least one point in the ecosystem service category (standardized with the highest number of individuals equal to 1.0) (see Figure 2). The plot reveals that cultural ecosystem services were the most frequently mapped in terms of number of points (recreation, aesthetics) or number of individuals (social interaction). Ecosystem services appearing in the lower left quadrant were those with the fewest number of points mapped or the fewest number of individuals identifying those services; examples include services such as biological control, pollination, ornaments, and genetic materials.

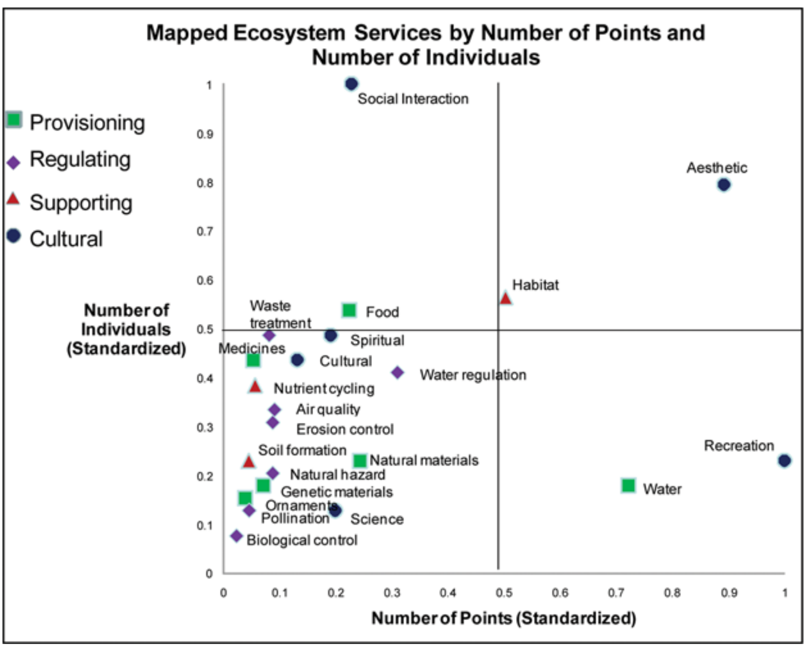

Figure 2. Plot of mapped ecosystem services by number of points and number of individuals. (Color figure available online.)

The frequency distribution of ecosystem services was compared with those reported by Raymond et al. (2009). There were 21 ecosystem services in common to both studies, and both studies provided a means to identify the relative importance of the ecosystem services in the study area (i.e., by stacking plastic chips on a paper map in the Raymond et al. study or by placing more web markers in this study). The ecosystem services were ranked based on frequency distribution and the Spearman rank correlation coefficient was .73 ($p \leq .05$), indicating general consistency in measurement between the two studies. Key differences in rank were for "waste treatment" and "biological control" services where the item definitions appear significantly different enough to influence the results. In general, cultural ecosystem services were the most frequently identified in both studies while supporting services were the least frequently identified. The frequencies of identifying, provisioning, and regulating ecosystem services were in between cultural and supporting services.

The frequency distribution of ecosystem services were also examined by major category of ecosystem service—provisioning, regulating, supporting, and cultural. The number of points mapped per ecosystem service category deviate from expected probabilities ($\chi^2 = 545.5$, $df = 3$, $p < .001$). The absolute values of standardized chi-squared residuals (R) greater than 1.96 indicate categories that were a major influence on the significant chi-squared result. The placement of cultural points was significantly overrepresented in participant responses ($R = 18.6$), while the numbers of regulating services ($R = -13.7$) and supporting services ($R = -3.07$) were significantly underrepresented. The number of provisioning services ($R = -1.4$) fell within the predicted range based on the probabilities of placement by category.

Respondent Characteristics

Analysis of respondent characteristics was based on the responses of 40 individuals that completed the survey questions following the ecosystem service mapping activity. There were 32 male respondents (80%) and 8 female respondents (20%) with an overall average age of 57 years. The youngest participant was 27 years of age and the eldest 79 years of age. About 58% of respondents reported having a bachelor's degree or higher in formal education. A majority of respondents reported having excellent or good knowledge of places in the study area (72.5%) compared to average or below average knowledge of places (27.5%), reported having good or excellent general knowledge of nature (80%) compared to average or below average general knowledge of nature (20%), and reported having more or much more knowledge of science (65%) compared to those with the same knowledge of science as others (35%). The majority of respondents self-reported above-average or high level of intelligence (70%) compared to those that self-reported an average level of intelligence (30%). A large proportion of respondents reported spending more or much more time in nature as a youth (90%) compared to those that spent an average amount of time in nature as a youth (10%). More than half of the respondents (53%) described their relationship with nature as "passionate" where "nature is one of the most important aspects of their life," compared to 45% that describe their relationship with nature as "enjoyable" where they "prefer to spend their leisure time in nature." Only one respondent described his/her relationship with nature as "neutral" where "spending time in nature is okay, but he/she would prefer other activities." No respondents described their relationship with nature as "uncomfortable" where they "spend as little time in nature as possible."

Relationship Between Ecosystem Services and Land Use/Land Cover

Chi-squared statistics and analysis of standardized residuals (difference between observed and expected cell counts) were completed to indicate those ecosystem services that were disproportionately represented (individually or in aggregate) within the LULC classifications. Analyses were completed for total or aggregate ecosystem services by LULC and for individual ecosystem service by LULC. Standardized cell residuals greater than 1.96 indicate that a given ecosystem service/LULC relationship significantly contributes to the overall significant relationship.

The results for aggregated or total ecosystem services by LULC indicate that open water, wetlands, and developed areas have more ecosystem services than would be expected based on proportion of area, while barren land, deciduous forest, and grassland/herbaceous have fewer mapped ecosystem services than would be expected by LULC proportion (see Table 2).

Analysis of individual ecosystem service results by LULC indicates that the open water classification has proportionately more water provision and recreation

Table 2. The distribution of all ecosystem service points by USGS LULC[a]

USGS LULC classification	Area (sq km)	Percent of area	Total number of points	Percent of points	Conclusion (over- or underrepresented)
Open water[b]	101.53	0.83%	153	7.26%	Over
Perennial ice/snow	172.27	1.40%	18	0.85%	Under
Developed, open space	94.63	0.77%	40	1.90%	Over
Developed, low intensity	54.7	0.45%	29	1.38%	Over
Developed, medium intensity	12.55	0.10%	6	0.28%	Over
Developed, high intensity	1.23	0.01%	0	0.00%	Same
Barren land (rock/sand/clay)[c]	510.61	4.16%	52	2.47%	Under
Deciduous forest	910.21	7.42%	43	2.04%	Under
Evergreen forest	6304.66	51.36%	1061	50.36%	Same
Mixed forest	80.51	0.66%	4	0.19%	Under
Shrub/scrub	2019.01	16.45%	313	14.86%	Under
Grassland/herbaceous	1404.65	11.44%	139	6.60%	Under
Pasture/hay	230.64	1.88%	71	3.37%	Over
Cultivated crops	1.44	0.01%	0	0.00%	Same
Woody Wetlands	310.66	2.53%	147	6.98%	Over
Emergent Herbaceous Wetlands	65.2	0.53%	31	1.47%	Over
Total	12274.5	100.00%	2107	100.00%	

[a]Overall relationship is statistically significant ($\chi^2 = 4.745\text{E}2$, $p \leq .001$).

[b]Dark shaded cells indicate statistically significant relationship (overrepresentation with standardized residuals >1.96).

[c]Light shaded cells indicate statistically significant relationship (underrepresentation with standardized residuals >1.96).

opportunity services than other classifications while the woody wetlands classification has proportionately more habitat services. The LULC developed classifications contain proportionately more social interaction and cultural opportunity services. Although total ecosystem services are proportionately underrepresented in the grassland/herbaceous LULC classification, aesthetic opportunities are more abundant in this classification than would be expected by chance. The shrub/scrub land classification has proportionately more food provision services and proportionately fewer habitat services, indicating a competitive relationship between food and habitat ecosystem services in at least some land cover types.

Of the ecosystem services that were infrequently mapped, there are suggestive relationships based on small, disproportionate distributions: Genetic materials may be associated with deciduous forest and pollination may be associated with emergent herbaceous wetlands. The provision of ornaments is disproportionately associated with shrub/scrub and grasslands/herbaceous areas.

The Effect of "Intensive-Mappers" on Ecosystem Service Distribution

The potential effect of "intensive-mappers" resulting from not limiting the number of ecosystem service markers that can be placed by individual respondents was assessed by comparing the number, type, and distribution of markers between individuals that mapped extensively (50% of markers) and the remainder of respondents. Seven individuals (i.e., the "intensive-mappers") identified 50.9% of all markers, while the other 50 respondents identified 49.1% of all markers.

By definition, intensive-mappers identified more locations for most ecosystem services. But which ecosystem service categories were mapped with significantly more markers by intensive-mappers? Intensive-mappers identified significantly more locations for the two most commonly mapped ecosystem services—aesthetic ($t = 3.63$, $p \leq .05$) and recreation ($t = 4.10$, $p \leq .05$)—as well as two of the less commonly mapped ecosystem services including air quality/climate regulation ($t = 3.16$, $p \leq .05$) and erosion control ($t = 3.02$, $p \leq .05$). Intensive-mappers also identified a greater number of two ecosystem services that were in the mid-range of mapping frequency: water regulation ($t = 3.56$, $p \leq .05$) and science opportunities ($t = 4.49$, $p \leq .05$). Although the sample size is small and inferences necessarily tentative, intensive-mappers don't appear to unduly bias the mapping results, as these individuals appear to map more ecosystem services across both common and less common ecosystem service categories.

Evaluation of Internet-Based PPGIS System by Respondents

The PPGIS system contained a number of survey questions to evaluate the PPGIS system. A majority of respondents (about 68%) agreed or strongly agreed that the website was easy to use, easy to navigate (65%), and the marker definitions were easy to understand (55%). About one-third of respondents agreed with the statement that "identifying the values found in nature was a difficult task." About 18% of respondents agreed with the statement that they would have "identified more values in nature if I were more familiar with Grand County" and 20% agreed with the statement that they would have "identified more values in nature if I were more knowledgeable about nature."

In summary, the majority of respondents found the Internet-based PPGIS system relatively easy to use and navigate and the instructions were clear. A significant minority of respondents found the task of indentifying the ecosystem services to be cognitively challenging, and having more knowledge about Grand County or nature in general would not have likely changed their responses significantly.

Discussion

The purpose of this study was to evaluate the efficacy of using Internet-based PPGIS as a means for collecting data about ecosystem services and to explore potential relationships of the data collected with other widely available GIS reference data layers. As with many exploratory research methodologies, there are mixed messages in the study results.

The Internet-based PPGIS interface works reasonably well to collect ecosystem service data; results appear generally consistent with other more labor-intensive methods involving face-to-face interviews as implemented by Raymond et al. (2009). However, despite the "public" in PPGIS, respondents do not reflect a truly representative cross section of the general public in the study region. Respondents are more highly educated, are more knowledgeable about nature and science, and have a stronger connection to nature and the outdoors. On a continuum representing expert ecological knowledge on left, and lay ecological knowledge on right, respondents in the study may be said to be positioned left of center. This is not an indictment of the methodology, but recognition that the results may be closer to expert judgment than "public" judgment. Armed with this knowledge, researchers interested in mapping ecosystem services through PPGIS could choose to augment their general population sampling design by targeting specific groups with an established nexus to nature, such as outdoor activity clubs (e.g., hiking or climbing), hunting and fishing organizations, or individuals who participated in outdoor-oriented youth organizations such as Boy or Girl Scouts. Participation rates would likely be significantly higher among these target groups. However, it is imperative to analyze random and convenience sample responses separately because other researchers have found significant differences between these respondent samples (e.g., Brown and Reed 2009; Hunt, Gonder, and Hairder 2010).

The participation/response rate of about 12% is low for survey research but not inconsistent with published response rates for random samples of the general public using Internet surveys. For example, Brown and Reed (2009) achieved similar response rates in Internet-based PPGIS studies for three national forest areas in the United States, while Pocewicz, Schnitzer, and Nielsen-Pincus (2010) reported 10% for a recent Internet-based PPGIS study in Wyoming. Sampling effort could potentially increase response rate to at least 20% with the commonly implemented four rounds of survey contact such as those implemented by Beverly et al. (2008) in their Canadian study. Response rates could be further enhanced by utilizing a mixed-mode survey design by providing a paper-GIS option for individuals that lack convenient access to the Internet, although recent evidence from non-PPGIS survey research suggests that providing sampled persons with a choice of response mode does not appear to increase overall response rates (Couper and Miller 2008).

One objective of this study was to explore some potential relationships between the mapped ecosystem service data and widely available LULC classifications. This is a reasonable first step in examining the face validity of PPGIS generated ecosystem service data. A more definitive examination of the validity of the PPGIS ecosystem service data would require the overlay of PPGIS maps with "expert" maps for selected ecosystem services to determine the level of spatial congruence. Unfortunately, few such expert maps of ecosystem services exist because many ecosystem functions are largely invisible or otherwise not easily spatially delimited, except perhaps by proxy through other landscape features such as vegetation. We suspect that most experts would be challenged, for example, to generate meaningful pollination or biological control maps for Grand County without greater clarity and refinement of actual ecosystem service definitions. Nonetheless, we were impressed by the ability of some respondents to grapple with the more ambiguous ecosystem service concepts and to provide locations for these services that appear logical.

The quantity of spatial data collected in this exploratory study is insufficient to definitively and comprehensively examine the relationship between mapped ecosystem services and LULC classifications. However, the data that were collected are suggestive of meaningful relationships that are either logically consistent or grounded in ecological awareness. Logical relationships were found between open water and water provisioning services and between developed areas and human social interaction opportunities. The putative ecological relationships appear more interesting, especially for the ecosystem services that were less frequently mapped. For example, habitat ecosystem services were disproportionately associated with woody wetlands, forests were disproportionately associated with genetic materials, and herbaceous wetlands were disproportionately associated with pollination services. Although some individual mapping results may be spurious and contain obvious error, either logical or spatial, the identification of ecosystem service locations in aggregate by a random sample of Grand County residents does not appear to be, at least from this exploratory study, patently invalid. On the contrary, that these ecological associations between ecosystem services and LULC emerged with relatively minimal sampling effort is rather remarkable.

To increase the effectiveness of the PPGIS methodology, greater and more targeted sampling effort offers the best opportunity to improve research performance. It would be reasonable to expand the sampling effort for a major ecosystem services study to target 300 responses, which would require an initial sample size of approximately 1,500, given a projected response rate of 20%. By extrapolation, this type of sampling effort could be expected to yield approximately 10,000 to 12,000 ecosystem service points locations, a sufficient number to do extensive GIS analysis and modeling. Another change that would likely prove beneficial would be to include a brief primer or tutorial on ecosystem service concepts in the instructions prior to PPGIS participant mapping. The goal of the primer would be to make the "invisible" ecosystem processes more visible and to help participants discover the tacit knowledge of nature that is presumed to exist within. An illustration depicting a generalized natural landscape identifying where common ecosystem services are located could help participants visualize, through analogy, where these services might be located in their study area.

Although limiting the number of ecosystem markers per respondent may appear more egalitarian from a social perspective, and more valid from a research perspective, we believe this change in the PPGIS methodology would be counterproductive. There is no conclusive evidence from this study that providing individuals with unbounded capacity to express their ecosystem service knowledge unduly biases the results, or that "gamesmanship" to influence the study results will occur.

On the contrary, the opportunity to collect additional valid, place-based ecosystem service data would be lost. PPGIS data collection systems should be guided by the principle that participants have important knowledge, perceptions, and experiences to contribute, and the system should not arbitrarily truncate opportunities to express this information. Should the researcher determine, after the data have been collected, that a few individuals biased or attempted to game the results, the number of markers used in the analyses could be reduced to a specified limit, say *x*, by selecting the first *x* number of markers from each respondent in each ecosystem service category. In this regard, PPGIS data collection and analysis should follow sound scientific data analysis principles—eliminate or explain outliers and manage inherent data variability.

The greatest potential benefit of PPGIS systems, whether collecting ecosystem services data or other data, is the ability to create maps for community discourse in a planning process. PPGIS-generated maps should be viewed as one of many valid data sources that can be used to inform public or environmental policy decisions regarding land use allocation trade-offs. Toward that end, simple Google Map viewers can be developed that allow individuals and groups to view the PPGIS results. For example, a data viewer was developed for this study that allows individuals to view specific ecosystem service "hotspots" (i.e., polygons) generated from high densities of points mapped by respondents.

Although the purpose of this exploratory research was not to scientifically validate the ecosystem service data generated through PPGIS, future research should undertake this challenge. While few would question the validity of using PPGIS to generate maps for identifying cultural ecosystem services, many would question the utility of consulting the "public" to identify more complex and "invisible" ecosystem services. To quote a popular book on the subject (Surioweki 2004), is there "wisdom in the crowds" and if so, how much? Comparative studies could be implemented that assess the similarities and differences between the maps generated by a panel of experts and the public for those services that involve more complex ecological processes such as climate regulation or soil formation. With an effective sampling plan and greater sampling effort, we believe that PPGIS can provide a useful "coarse filter" for identifying the location of ecosystem services, including the more intangible or abstract ecosystem services. Even the limited results of this exploratory study in Grand County provided the capability to generate ecosystem service maps where none existed previously.

An important distinction in the domain of ecosystem service research should be acknowledged for future research. The identification of ecosystem services through PPGIS is not the same as the valuing of ecosystem services. We would be reluctant to associate the frequency of ecosystem service identification in PPGIS with its value or importance, although we believe there is a relationship in the minds of the participants. It seems obvious that the aesthetic and recreational opportunities afforded by natural landscapes in Grand County, the most frequently identified ecosystem services in the study, are highly valued by its residents. Future research should attempt to expound the relationship between frequency of identification and ecosystem importance.

The research by Costanza and other ecological economists (1997) to quantify the economic value of ecosystem services is important and appears complementary rather than competitive to the use of PPGIS to spatially identify ecosystem services. While the use of PPGIS is not intended to provide economic valuation for ecosystem services, it can potentially assist in the refinement of economic value estimates by identifying the distribution of specific ecosystem services within a given area. To avoid overreaching assumptions about valuation, one must first assess the distribution of ecosystem services before they can be valued. PPGIS systems appear adaptable to assist in identifying the spatial range and intensity of ecosystem services, in particular, cultural and provisioning services. However, our empirical results suggest that the challenges of identifying and valuing regulating and supporting services by experts are also a challenge for the lay public. If one were to impute ecosystem service value simply by the frequency of mapped services in PPGIS, regulating and supporting services would appear to be undervalued as they have been in the economic valuation literature.

Conclusion

At the outset of this exploratory research, we were skeptical about the ability of a general population sample to understand and map ecosystem services, at least some of the more abstract and invisible regulating and supporting ecosystem services. We remain skeptical about the utility of PPGIS for identifying the full range of ecosystem services, in particular, regulating and supporting ecosystem services that require greater knowledge of ecological processes. This is unfortunate because regulating and supporting ecosystem services appear to be the least understood and most undervalued, yet provide the foundation for critical life support systems. Our results indicate the general public has the capacity to identify provisioning services and cultural opportunities that are more grounded in the experience of living in a region. This same conclusion was reached by researchers currently using participatory GIS research in Africa to identify ecosystem services; they decided to have participants only identify provisioning and cultural services that are "more concrete and easily articulated services and directly linked to the daily life of the rural people" (N. Fagerholm, personal communication, January 14, 2011).

There are methodological trade-offs between the two social data collection methods reported thus far in the literature for identifying and mapping ecosystem services—interviews with maps and self-administered Internet-based PPGIS systems. Interview-based mapping is very labor-intensive, beginning with field interviews and continuing through to the digitizing of the GIS data. The advantages of this method are that consistency in ecosystem service data collection can be actively monitored by the interviewer and the method can be implemented in areas where Internet access is not available.

The potential for Internet-based collection of ecosystem services appears large with the ability to target broad audiences while providing advanced cartographic features available with web maps (e.g., zoom, pan, multiple map types, overlays), but these strengths must be considered against the formidable challenges of low participation rates and the potential for bias where certain ecosystem services are over- or under-represented. All modes of survey data collection show declining response rates (Couper and Miller 2008), and web-based surveys show 11% lower response rates (on average) than other survey modes (Manfreda et al. 2008). Web-based PPGIS systems are likely to demonstrate even lower participation rates than traditional text-based surveys among general audiences because of the increased complexity and burden of the PPGIS elicitation process. A potential methodological middle ground would be the use of facilitated public workshops where participants could use an Internet PPGIS with computers set up for the purpose but guided by a facilitator to ensure data consistency and completion.

The results of this exploratory research to evaluate the viability of identifying ecosystem services through PPGIS are moderately encouraging, but ultimately inconclusive. Future research will be needed to determine whether an expanded sampling effort, additional instructional support, and a mixed mode of delivery can overcome some of the inherent challenges associated with this method of social science research.

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