Transactions in GIS

Review Article

Transactions in GIS, 2016, 00(00): 00–00

A Review of Sampling Effects and Response Bias in Internet Participatory Mapping (PPGIS/PGIS/VGI)

Greg Brown

University of Queensland, Brisbane

Abstract

Global interest in participatory mapping described as public participation GIS (PPGIS), participatory GIS (PGIS), and volunteered geographic information (VGI) continues to grow, but systematic study of spatial data quality and sampling effects is limited. This article provides a review and meta-analysis of Internet-based PPGIS studies conducted during the period 2006–2015 (n=26) to answer the following research questions: (1) How does mapping effort, as a proxy measure for spatial data quality, differ by sampling group? (2) Does the purpose and context of PPGIS influence mapping results? (3) What is the potential for mapping bias through sampling design? (4) Given the results, what should be the focus of future PPGIS research? Mapping effort was highest in sampling groups whose livelihoods were closely related to the purpose of the study, there was greater mapping effort in household sampling groups compared to volunteer groups, and participant domicile had strong effects on mapped results through spatial discounting. The use of online Internet panels provides higher response rates but lower spatial data quality. Future research should focus on increasing sampling response rates, assessing social trade-offs using alternative spatial weighting schemes, and examining the capacity of the public to select land use alternatives as a complement to traditional expert-driven planning systems.

1 Introduction

The related fields of research and practice called public participation GIS (PPGIS), participatory GIS (PGIS), and volunteered geographic information (VGI) describe participatory processes where geographic information is a core component. PPGIS/PGIS promote the inclusion and empowerment of marginalized or under-represented populations in the development and use of spatial information while VGI describes a phenomenon where citizens create, assemble, and disseminate geographic information. These fields have experienced significant growth as evidenced in the number of applications and academic publications (Brown and Kyttä 2014). The growing interest in PPGIS/PGIS/VGI over the last two decades has been accompanied by multiple conferences, workshops, and special journal issues devoted to the subject (Mukherjee 2015). And yet, the social impact attributable to these spatial mapping methods has not been evident due to multiple social and institutional constraints, including a lack of trust in the origin and quality spatial data generated (Brown 2012). Further, the promise and potential of new mobile mapping technologies and social media to engage citizens in planning has been described as "a lot of wishful thinking" (Kleinhans et al. 2015, p. 237). Thus, a significant gap exists between participatory mapping processes and aspirational goals for public participation which include increasing trust, reducing conflict, informing and educating the public,

Address for correspondence: Greg Brown, University of Queensland, School of Geography, Planning and Environmental Management, Brisbane, Queensland, Australia 4072. Email greg.brown@uq.edu.au

 doi: 10.1111/tgis.12207

incorporating public values into decision making, and improving the quality and legitimacy of decisions (Bierele 1999; Dietz and Stern 2008).

In practice and the academic literature, there is continuing ambiguity over the use of the terms PPGIS, PGIS, and VGI. As noted by Tulloch (2008), researchers and practitioners from different backgrounds have brought diverse vocabularies to the field of PPGIS, the original term conceived in 1996 at meetings of the National Center for Geographic Information and Analysis (NCGIA) to describe how GIS technology could support public participation for a variety of applications (NCGIA 1996a, b; Sieber 2006). As described by Tulloch (2008), one type of PPGIS involves public participation in mapping activities to inform planning processes (the focus of this article) while another variant of PPGIS uses information and maps developed with GIS to alter the outcome of a decision-making process. The term "participatory GIS" or "PGIS" emerged from participatory approaches in rural areas of developing countries from the merging of Participatory Learning and Action (PLA) methods with geographic information technologies (Rambaldi et al. 2006). The term volunteered geographic information (VGI) was introduced by Goodchild (2007) to describe the harnessing of tools to create, assemble, and disseminate geographic data provided voluntarily by individuals. From a conceptual and research perspective, VGI intersects with the more established field of PPGIS in the development of Internet-based tools that facilitate the collection of spatial information (Hall et al. 2010).

Brown and Kyttä (2014) provide some distinction between PPGIS, PGIS and VGI by differentiating the concepts on the dimensions of mapping purpose, sponsors, global context, importance of spatial data quality, sampling approach, data collection and ownership, and mapping technology. Whether a particular mapping application is described as PPGIS, PGIS, or VGI remains subjective. PPGIS has typically been implemented by government planning agencies or academics to enhance public participation in developed countries for urban, regional, and environmental planning, often using digital mapping technology, with a primary focus on spatial data quality. In contrast, PGIS has been typically been sponsored by NGOs in rural areas of developing countries to build social capital using non-digital mapping technology, where spatial data quality is of secondary importance. Both PPGIS and PGIS seek to include marginalized or non-traditional participants in the generation and use of geographic information technology. The issue of sampling, or who generates the spatial information, has been one of the more distinguishing characteristics in practice, with PPGIS often using random household sampling to engage the "silent majority" in the process, PGIS using purposive sampling to engage community leaders and stakeholder groups to identify and map current and historical connections to place, and VGI tapping into volunteers and "crowds" with an active interest in spatial information and technology. And yet, PPGIS and PGIS often include purposive and volunteer sampling components, further blurring potential differences between use of the terms PPGIS, PGIS, and VGI. For simplicity, the term PPGIS is used throughout this article to refer collectively to the empirical PPGIS/PGIS/VGI studies and applications described herein, although some of the studies could be described as PGIS or VGI.

Of the many institutional barriers to the implementation of PPGIS, understanding who the "public" is in PPGIS (Schlossberg and Shuford 2005) and the quality of spatial information generated for decision support appear central to expanded use of the methods by planning and management authorities. The term "public" can include decision makers, implementers, affected individuals (i.e. stakeholders), interested observers, or the random public (Schlossberg and Shuford 2005, p. 22). Adding further complexity, the "public" can include geographic populations proximate or distant from the focus area of the PPGIS process. As a general proposition, local populations are more affected by land use planning and management decisions because of the potential influence on local economic conditions and quality of life.

There is no single or simple answer regarding who should participate in the generation of spatial information with the potential to influence decisions about place. Normatively, a PPGIS sampling design should consider individual vs. collective interests, direct vs. indirect interests, and proximate vs. distant interests, or simply stated, "Whose voice counts"? The sampling design should also consider who has the spatial knowledge needed for the process and the potential for bias when targeting the various "publics" in the process. The purpose of this article is to evaluate the potential effects of sampling choices when designing a PPGIS process. Both trust in the quality of PPGIS spatial data and confidence that the participatory mapping process is unbiased appear to be prerequisites for use of PPGIS spatial data for decision support.

To assess the quality of PPGIS spatial data and the potential for bias attributable to sampling, this study reviews empirical, Internet-based PPGIS studies completed between 2006 and 2015 (n=26) to describe central tendencies and variability in data quality and sampling effects, a type of meta-analysis. The challenge for this type of comparative research is the high degree of inter-application variability characterized by diverse spatial attributes and mapping methods, heterogeneous human populations being sampled, and geographic variability in the places that are mapped. Each PPGIS study or application may be viewed as a unique case study with relatively limited external validity for extrapolation to other settings and populations. But even with the large diversity in PPGIS studies, there is value in exploring and identifying patterns across applications where commonalities do exist. The purpose of the review is to provide some guidance for future research in PPGIS/PGIS/VGI applications.

1.1 PPGIS Spatial Data Quality

The validity and quality of traditional GIS data is typically evaluated using criteria such as spatial resolution, position and attribute accuracy, logical consistency, and completeness. This *validity-as-accuracy* perspective (Spielman 2014) has been applied to VGI systems where assessments of spatial data quality examined the positional accuracy and completeness of volunteer contributions to OpenStreetMap (OSM) against authoritative geospatial data (Haklay 2010; Girres and Touya 2010). For example, Haklay et al. (2010) found between between 80 and 86% spatial accuracy in a test case of OSM volunteer mapping in England. The *validity-as-accuracy* has also been applied to some PPGIS studies for mapped spatial attributes corresponding to physical landscape features. For example, Brown (2012) found relatively low spatial error when public participants were requested to identify the location of native vegetation in New Zealand, Cox et al. (2014) found high levels of accuracy in identifying suitable habitat for threatened species conservation, Brown et al. (2015) found about 70% of mapped biological/conservation values were spatially coincident (position accurate) with expert-modelled areas of high conservation importance, and Cox et al. (2015) found variable spatial accuracy when public participants were asked to identify places providing watershed services.

The special strength of PPGIS, however, is not generating spatial data that identify physical landscape features. This task is much better suited to expert GIS systems that use remotely-sensed data. Rather, the power in PPGIS is the capacity to generate spatially explicit, subjective descriptors of place that can assess the social acceptability of land use planning and management alternatives. Spatial attributes such as place values, activities, experiences, and preferences are commonly mapped using PPGIS, but these attributes lack objective benchmarks to assess spatial accuracy. For most PPGIS applications, the relevance, representativeness, and credibility of the participants to the mapping purpose is central to effective PPGIS outcomes. This *validity-as-credibility* perspective assumes greater importance than *validity-as-accuracy* when evaluating the quality of the spatial data generated. Sampling design and implementation is a critically important factor in assessing the credibility of a PPGIS process.

In the absence of objective benchmarks for subjective PPGIS data, Brown et al. (2012b) proposed *mapping effort* to evaluate response quality in PPGIS applications. Low mapping effort in PPGIS surveys may be indicative of participant "satisficing" or suboptimal responses where respondents with lower motivation engage in satisficing rather than optimizing (Kaminska et al. 2010; Krosnick 1991). In contrast, participants with greater interest and motivation in the PPGIS process are likely to spend more time mapping, thus enhancing the quality of spatial information generated. To evaluate these suppositions, a regional PPGIS study in Australia compared the responses of an online Internet panel with random household and volunteer PPGIS participants. Volunteer participants differ from random household and Internet panelists in that their individual identity is not known in advance and they are not specifically recruited to participate in the mapping activity. Volunteers can learn about a PPGIS process through multiple information channels such as social media, stakeholder groups, and personal referrals. Internet panelists were found to be less engaged with the PPGIS mapping process, spending less time and mapping fewer markers compared to household or volunteer samples (Brown et al. 2012b). The authors suggested that cognitive demands of PPGIS mapping activity might amplify the satisficing effect, especially in sampling groups that are accustomed to completing easier text-based surveys where incentives are based on survey completion, not effort.

Mapping effort, as operationalized through clock time and number of markers mapped, appears to be a reasonable proxy of PPGIS spatial data quality for subjective spatial attributes. However, the cognitive challenge of mapping different types of spatial attributes may vary by type of spatial attribute. For example, the mapping of place activities are hypothesized to be less cognitively challenging than the mapping of place values (Brown 2012b) which can influence the amount of time participants spend mapping. This leads to a testable hypothesis that, all else being equal, PPGIS applications where participants map place activities would take less effort and time than applications where participants map place values. Thus mapping effort, as an indicator of spatial data quality, would need to account for the type of spatial data requested.

Adding further complexity to mapping effort as an indicator of spatial data quality is the supposition that PPGIS mapping may involve a type of participant "judgment" about land use that requires greater cognitive reflection than the mere expression of simple opinions (Brown 2015). Yankelovich (1991) defines public judgment as a type of high-quality opinion that is firm, consistent, and consequential to the person holding the opinion. For many PPGIS applications, the goal is to have PPGIS participants express a type of judgment about appropriate and/or future land use. If a type of public judgement is being measured in PPGIS, applications that request participants to identify land use preferences, in addition to place values, would take more time and effort to formulate and express those judgments. This leads to a testable hypothesis that PPGIS applications involving place values and preferences would require greater time and effort than applications that do not involve judgments about future land use.

1.2 Review of Sampling Effects

In response to declining response rates in survey research (a e.g. de Leeuw and de Heer 2002; Curtin et al. 2005), PPGIS researchers have increasingly turned to other sources for participant recruitment including online Internet panels, stakeholder groups, social media, and general public appeals for participation. These latter types of recruitment constitute a type of volunteer sample that differs from conventional random household sampling or the use of online survey panels.

The potential effects of sampling in PPGIS may be related to the motivation for participation. For example, a decision to participate can be motivated by a perceived change in participant position (gain or loss), or motives like personal responsibility that reflect a sense of civic duty. Further, financial incentives may be used to increase PPGIS participation and may confound the interpretation of results. There are no published PPGIS studies that directly examined the relationship between participant motivation and mapped spatial data, thus leaving the effects of participant motivation to inference. In one of the few empirical studies to analyze PPGIS mapped results of different sampling groups for national forest planning – randomly sampled households compared to volunteers – the volunteer sample expressed stronger utilitarian values and consumptive use preferences while the sampled households expressed more amenity values (Brown et al. 2014a). The PPGIS results, if actually used by planning authorities, would lead to different planning decisions. Another PPGIS study examined different stakeholder "interests" contained within a large volunteer sample and concluded that stakeholder perspectives can influence place-based management preferences for public lands (Brown et al. 2015). Thus, the limited research to date reinforces the perspective that "who" participates is critically important to PPGIS process outcomes.

Multiple PPGIS studies have used random sampling of households within and proximate to the study region. The location of PPGIS participants relative to the study area is known to influence the distribution of mapped attributes through a process called spatial or geographic discounting (Hannon 1994; Brown et al. 2002; Pocewicz and Nielsen-Pincus 2013) wherein people prefer to live close to positive place features and further away from negative place features. Spatial discounting could result, for example, in sampled households mapping types and quantities of spatial attributes different from volunteers who live further away from the study area where land use changes are more indirect. This leads to the hypothesis that one would expect PPGIS participants in households proximate to the study area to be more vested in land use decisions and thus spend more time and effort in PPGIS mapping than volunteers less connected to the study area.

These limited empirical studies suggest that sampling design and implementation is critically important to PPGIS outcomes. And yet, given the large diversity of PPGIS applications, sampling effects may be contextually less important than the type of spatial information requested and its intended use. For example, one might hypothesize that the mapping of place-based activities, a largely descriptive mapping activity, would be less subject to sampling effects than the mapping of place-based values and preferences that are more closely associated with perceived participant gains or losses as a result of the PPGIS process. There is empirical evidence that participants do translate some of their non-spatial values and preferences into behavioral choices when mapping place-specific values and preferred uses (Brown 2013), suggesting that sampling effects might be greater in PPGIS studies with clearer planning and management implications for participants. In practical terms, PPGIS studies that request participants to identify specific future land use preferences by location have a closer nexus to future land use decisions.

1.3 Research Questions

The purpose of this study is to identify the factors that can influence the quality spatial data and potential sampling effects through analyses of participatory mapped data across multiple PPGIS studies – a type of meta-analysis. This study seeks answers to the following research questions: (1) How does mapping effort, as a proxy measure for spatial data quality, differ by sampling group (e.g. random household, volunteer, online internet panel)? (2) Does the purpose and context of the PPGIS application, including the type of spatial information requested, influence mapping effort and thus spatial data quality? (3) What is the potential for mapping bias though sampling design? and (4) Given the results from the previous questions, what should be the focus of future PPGIS research?

2 Methods

The data used for analysis were collected in Internet-based PPGIS studies (n=26) between 2006 and 2015 (see Table 1). The studies span a wide range of applications, geographic locations, computer interfaces, and sampling methods. The specific purpose for each PPGIS study is described in the referenced sources provided in Table 1. The majority of PPGIS studies were implemented by academics to collect spatial data to inform or evaluate land use planning processes, with some studies sponsored by the government agencies responsible for planning. The PPGIS studies were diverse and included applications for national forest and national park planning, natural resource management, conservation planning, and urban planning. The earliest PPGIS applications (2006-2009) used an Adobe® Flash computer interface where participants would drag and drop markers representing place values onto a digital base map of the study location (n=5 studies). Later PPGIS applications (n=21) used Google Maps with an application programming interface (API) to create a "mash-up". The first digital markers mapped in PPGIS were place values (n=4), but in subsequent PPGIS studies, the digital markers were expanded to include place activities and/or experiences (n=5), or a combination of place values with management or development preferences (n=15). Other PPGIS applications mapped ecosystem services (n=1) and coral reef conditions (n=1). The majority of PPGIS studies used in this analysis were conducted in North America (n=11) and Australia/New Zealand (n=11), with fewer studies in Europe (n=3) and Asia (n=1). The sampling groups consisted of randomly sampled households (n=19), volunteer samples (n=16), online panels (n=2), on-site recruitment (n=3), and sampling groups called "communities of interest" with a close nexus to the PPGIS mapping purpose (n=2). The sampling groups analyzed in this study are as follows:

1. Household: Residences are randomly sampled from a list of residential addresses in the study area (sampling frame) and a specific individual is invited to participate. Household sampling in all the reviewed studies was implemented through postal (rather than phone) contact.
2. Volunteer: Individuals and/or groups are invited to participate through a range of communication channels such as websites, social media, printed flyers, personal referrals, and organized groups that distribute the invitation through mail or email lists.
3. Online panels: A company builds and maintains a database of individuals willing to participate in survey research in exchange for some type of compensation. Study participants are selected from the database based on a "profile" that meets sampling criteria such as living in the study area.
4. On-site recruitment: Individuals are recruited at a destination within the study area such as a national park.
5. Communities of interest: Individuals or groups with a close nexus to the planning or management outcomes in the study area, often identified by occupation or livelihood.

Table 1 Internet-based PPGIS/PGIS/VGI studies included in the meta-analysis, mapping effort by sampling group, and analysis for potential bias in mapped preferences between household and volunteer sampling groups

Year of Study	Location	Study Purpose	Mapping interface	Spatial attributes	Study reference	Sampling groups	Markers (mean)	Response (minutes)	Evidence for potential bias
2015	Kimberley Coast, Western Australia	Marine protected area planning	Google Maps	*Place values and management preferences*	Unpublished	Household (n=26) Volunteer (n=504) Online panel (n=247) Invalid/incentive scam (n=113)	46.6 38.8 19.8 5.5	14.2 15.1 6.8 0.6	Yes. n=6 preferences: recreation facilities; access; oil/gas development; new port development; other development
2014	US Virgin Islands	Coral reef assessment	Google Maps	*Coral reef conditions, threats, best places*	Unpublished	Occupational divers (n=98)	84.3	39.2	N/A
2014	Norway (Sogn region)	Protected area management	Google Maps	*Place values and land use preferences*	Hausner et al. (2015)	Household (n=76) Volunteer (n=364)	19.1 20.8	8.2 11.2	Yes. n=3 preferences: All-terrain vehicles; grazing; fishing.
2014	Norway (Nordland region)	Protected area management	Google Maps	*Place values and land use preferences*	Brown et al. (2015)	Household (n=383) Volunteer (n=93)	18.3 20.5	9.6 11.8	No.
2014	Poland (Tatras region)	Protected area management	Google Maps	*Place values and land use preferences*	Brown et al. (2015)	Household (n=36) Volunteer (n=257)	18.8 16.5	8.9 7.2	Yes. n=2 preferences: grazing; other use
2014	Baffle Basin Region, Queensland, AU	Natural resource planning	Google Maps	*Place values and land use preferences*	Karimi et al. (2015)	Household (n=154) Volunteer(n=29)	30.1 25	18.2 6.9	No.
2014	Perlis, Malaysia	Urban and regional planning	Google Maps	*Place values and land use preferences*	Unpublished	Facilitated (n=289) Volunteer (n=64)	20.0 9.5	8.5 5.7	N/A
2014	Victoria, Australia	Public land management	Google Maps	*Place values and management preferences*	Brown et al. (2014b)	Volunteer (n=1884)	18.6	6.6	N/A
2014	Southeast region, South Australia	Natural resource management	Google Maps	*Place values and development preferences*	Auricht et al. (2014)	Household (n=263) Volunteer (n=65) Community of Interest (n=117)	19.3 22.3 37.5	16.7 12.9 23.9	No.
2013	Tongass National Forest, Alaska, US	National forest planning	Google Maps	*Place values and management preferences*	Schroeder (2014)	Household (n=70) Volunteer (n=19)	43.1 30.3	16.3 12.7	No.
2013	Adelaide, Australia	Urban park planning	Google Maps	*Urban park activities*	Brown et al. (2014b)	Volunteer (n=239)	22.9	9.1	N/A
2012	New South Wales, Australia	Recreation planning	Google Maps	*Mountain biking activities*	Wolf et al. (2015)	Volunteer (n=658)	17.3	9.1	N/A
2012	Three national forests, California, US	National forest planning	Google Maps	*Place values and management preferences*	Brown et al. (2014a)	Household (n=139) Volunteer (n=81)	28.4 28.8	15.8 17.8	Yes. n=9 preferences: timber harvest; fuels treatment; wilderness; energy development; rural development; urban development; industrial development; other development

Table 1 *Continued*

Year of Study	Location	Study Purpose	Mapping interface	Spatial attributes	Study reference	Sampling groups	Markers (mean)	Response (minutes)	Evidence for potential bias
2012	Chugach National Forest, Alaska, US	National forest planning	Google Maps	*Place values and management preference*	Brown and Donovan (2014)	Household (n=275)	35.9	19.4	N/A
2012	Squam Lakes, New Hampshire, US	Recreation and lake management	Google Maps	*Place qualities and activities*	Veilleux (2013)	Household (n=167) Volunteer (n=125)	21.9 23.6	10.2 11.7	N/A
2011	Otago Region, New Zealand	Conservation planning	Google Maps	*Place values and development preferences*	Brown and Brabyn (2012)	Household (n=60) Volunteer (n=357)	21.6 22.4	15.7 14.2	No.
2011	Southland Region, New Zealand	Conservation planning	Google Maps	*Place values and development preferences*	NZ DOC (2011)	Household (n=21) Volunteer (n=182) On-site (n=67)	15.4 18.9 11.8	10.2 14.5 11.0	No.
2011	Kangaroo Island, South Australia	Regional planning	Google Maps	*Place values and development preferences*	Brown and Weber (2012)	Household (n=104)	33.8	15.3	N/A
2010	Southwest Victoria, Australia	National park planning	Google Maps	*Park activities*	Brown et al. (2012b)	Volunteer (n=41) Online panel (n=359)	11.1 8.8	5.0 2.0	N/A
2010	Colorado, US	Ecosystem service assessment	Google Maps	*Ecosystem services*	Brown et al. (2012a)	Household (n=57)	38.2	15	N/A
2010	Southern Wyoming, US	Conservation planning	Google Maps	*Place values and land use preferences*	Pocewicz et al. (2012)	Household (n=99)	18.0	9.0	N/A
2009	Victoria, Australia	National park planning	Adobe® Flash	*Experiences/impacts*	Brown and Weber (2011)	On-site visitors (n=253)	14.0	6.9	N/A
2007	Deschutes/Ochoco National Forests, Oregon, US	National forest planning	Adobe® Flash	*Place values*	Brown and Reed (2009)	Household (n=321)	32.4	14.7	N/A
2007	Mt. Hood National Forest, Oregon, US	National forest planning	Adobe® Flash	*Place values*	Brown and Reed (2009)	Household (n=180)	25.6	14.7	N/A
2006	Coconino National Forest, Arizona, US	National forest planning	Adobe® Flash	*Place values*	Brown and Reed (2009)	Household (n=254)	32.9	12.6	N/A
2006	Crown lands, Alberta, Canada	Crown land planning	Adobe® Flash	*Place values*	Beverley et al. (2008)	Household (n=305)	26.4	9.3	N/A

2.1 Assessing Data Quality through Mapping Effort

With Internet-based PPGIS, participants are instructed to place digital markers in the study area that identify attributes such as place values or management preferences. The number and type of PPGIS markers mapped is recorded for each participant in a web-server database. Sampling groups are identified by blocks of access codes distributed to targeted groups such as random households. In contrast, volunteers request a dynamic access code on the website that is unique from other sampling groups.

Each mapped marker is time-stamped and stored in the web-server database. Mapping effort was operationalized as the elapsed clock time between the first and last marker placed by each participant. Within each study, there were an estimated 10 and 15 participants with excessively large elapsed clock time given the number of markers placed, indicating the participant was likely engaged in other tasks while mapping or was away from the computer for a significant period of time. For these participants, the response time was adjusted by averaging the response times of other participants who had mapped the same number of markers.

In some studies, a very small number of participants mapped an excessively large number of markers. These "super-mappers" represent outliers in terms of PPGIS response. To limit the potential effect of outliers on the statistical results, the analysis was limited to participants who mapped 350 or fewer markers. The one exception was a PPGIS study of coral reef conditions in the US Virgin Islands that targeted "expert" occupational divers who were encouraged to map as much knowledge about reef conditions as possible.

The mean number of markers and response times were plotted for all sampling groups. Pearson product-moment correlations were calculated for all sampling groups, and separately for the household and volunteer sampling groups. Statistical tests for difference in the mean number of markers and response time were assessed using the independent variables of *sampling group*, *computer interface*, *location of study*, and *thematic content* of the spatial attributes requested to be mapped.

2.2 Assessing Potential Bias by Sampling Group

The potential for bias in the mapped results was assessed by analyzing whether random household samples or volunteers were more or less likely as a sampling group to map land use preferences in the PPGIS studies that contained preference attributes ($n=10$). Mapped preferences were selected for this analysis because preferences have the closest nexus to management policies and/or land use allocation decisions. A bias in mapped preferences could result in incorrect inferences about support for important future land use decisions. This analysis examined the proportion of participants in each sampling group (household vs. volunteer) that mapped one or more markers for a given preference using a chi-square test of independence and Fisher's exact test for small sample sizes.

3 Results

3.1 Mapping Effort

A scatterplot of the mean number of markers by response time for all sampling groups appears in Figure 1a. The plot reveals considerable variability by sampling group, but a strong, overall linear relationship between the number of markers placed and response time ($r=0.86$, $p < 0.001$). The relationship between the number of markers and response time was somewhat stronger for volunteer groups ($r=0.71$, $p < 0.01$) than household groups ($r=0.52$, $p < 0.05$). The plot also shows

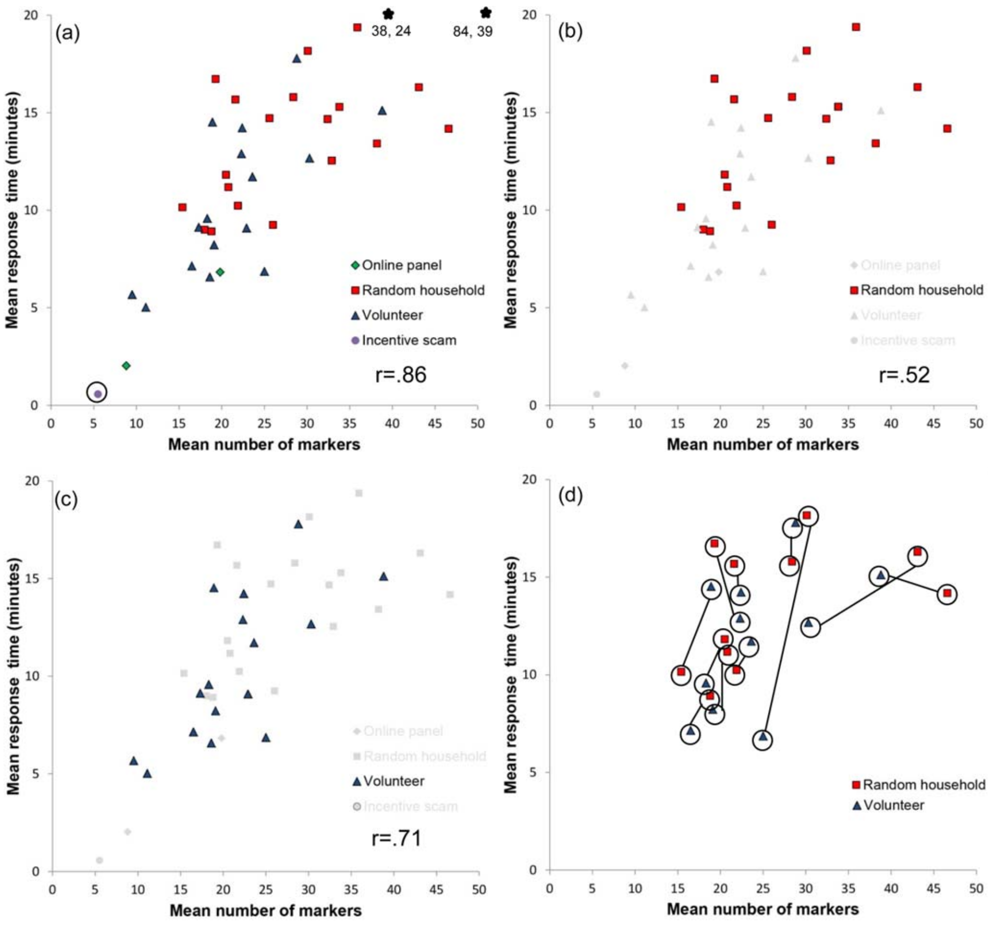

Figure 1 Scatterplots with mean number of markers and response time for: (a) all sampling groups (b) random households; (c) volunteers; and (d) paired sampling groups in the same study. Plots (b) and (c) show results across different PPGIS studies while connecting lines in (d) show results of sampling groups within same PPGIS study

that online panel groups (n=2) had significantly lower mapping effort than household groups and the majority of volunteer groups. Figure 1d shows the mapping effort for paired household and volunteer sampling groups within the same study, revealing there is not a consistent pattern in response across studies. In some studies, household effort exceeded volunteer effort, while in other studies, the volunteer group exceeded the mapping effort of the household group.

Figure 1a contains one anomalous point with very low mapping effort labelled as "incentive scam" group. The Kimberley region (Australia) study conducted in 2015 advertised a $10 incentive (gift voucher) on the opening page of the website for participation, the only PPGIS study to advertise this incentive on the main web page. Individuals with IP addresses originating in the US learned of the PPGIS website and circulated the website URL to others. More than 100 individuals with IP addresses originating outside Australia visited the website, placed a few markers, and then answered text-based survey questions that clearly indicated false responses such as how they learned about the study.

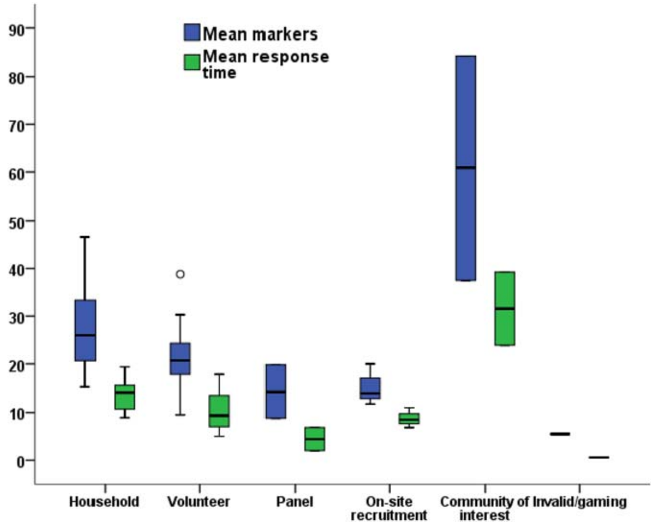

Figure 2 Boxplots of PPGIS sampling groups by mean number of markers and response time (minutes). Boxplots show the minimum and maximum values, median, and first and third quartiles. The "invalid/gaming" sampling group plots are associated with invalid responses in a PPGIS study in the Kimberley region of Australia

Figure 1a also shows two higher mapping effort outliers. One PPGIS study conducted in southeast South Australia targeted individuals called "communities of interest" who identify with livelihoods associated with the forestry, agriculture, and conservation sectors, interests that are closely related to regional planning outcomes. Mapping effort ($\bar{x}=37.5$ markers, $\bar{x}=23.9$ minutes) was significantly higher with this group than with other sampling groups in the same study and the majority of other PPGIS sampling groups in other studies. The US Virgin Islands PPGIS study in 2014 targeted occupational scuba divers who have extensive knowledge of coral reef conditions. This group of participants were instructed to map as much of their coral reef knowledge as possible. Their mean number of markers (84.3) and response time (39.2 minutes) were considerably larger than all other sampling groups.

Figure 2 shows the distribution of sampling groups using a boxplot that displays minimum and maximum values and quartiles. The household sampling groups (n=19) mapped significantly more markers ($t=2.3$, $df=33$, $p \leq 0.05$) on average ($\bar{x}=27.9$) than volunteer groups (n=16, $\bar{x}=21.4$) and household groups had a significantly longer response time ($t=2.7$, $df=33$, $p \leq 0.05$) on average (13.6 minutes) than volunteer groups (10.4 minutes). The small sample of panel groups (n=2) and community of interest (n=2) preclude meaningful statistical tests of difference, but visually, the panel groups had significantly less mapping effort while the community of interest groups had significantly more mapping effort than household and volunteer groups.

The PPGIS Internet studies used two different software interfaces. The early studies used an Adobe Flash interface (2006-2009) while subsequent PPGIS studies used a Google Maps interface. The sampling groups using the Flash interface (n=5) and sampling groups using the Google Maps interface (n=17) were compared on the mean number of markers and response time. There was no significant difference in the mean number of markers or response time with the different software interfaces.

The geographic setting of the PPGIS studies were analyzed by the mean number of markers and response time for three regions—North America (n=11), Australia/NZ (n=11), and Europe (n=3). The analysis was limited to household and volunteer sampling groups. The mean number of markers mapped was significantly lower ($t=5.2$, $df=17$, $p<0.001$) in European studies ($\bar{x}=19.0$) than North American studies ($\bar{x}=29.6$) and the mean response time was also significantly less in Europe ($\bar{x}=9.5$ minutes) than North America ($\bar{x}=13.7$ minutes). These results were similar when comparing Australia/NZ studies to Europe with the mean number of markers (24.2 vs. 19.0) and response time (12.2 vs. 9.5 minutes) larger in the Australia/NZ studies. There was no statistically significant difference in the mean number of markers or response time between studies in North America and Australia/NZ.

The final independent variable to be examined was whether the *thematic content* of PPGIS spatial attributes influenced participant mapping effort. Similar to location, data analysis was limited to household and volunteer sampling groups. Studies were classified into those requesting the mapping of place values only (n=4), activities/experiences (n=5), and values with preferences (n=25). Values only studies had a mean number of markers of 29.2, followed by values with preferences ($\bar{x}=24.8$), and activities/experiences ($\bar{x}=19.4$). The difference in means between values only and activities/experiences was statistically significant ($t=3.1$, $df=7$, $p \leq 0.05$). With regard to mean response time, values only studies had the longest mean response time (12.8 minutes), followed by values and preferences (12.6 minutes), and activities/experiences (9.0 minutes). The difference between values only and activities studies was statistically significant at $\alpha=0.10$ ($t=2.2$, $df=7$, $p \leq 0.10$). There was no significant difference in response time between studies that mapped values only and values with preferences.

3.2 Potential Bias by Sampling Group

A chi-square test of independence was conducted to determine whether household or volunteer sampling groups were proportionately more likely to map different types of land use preferences. There were 10 studies containing household and volunteer groups that requested the mapping of land use preferences, and a total of 173 separate preference markers to be mapped. Statistically significant associations between the sampling group and land use preferences were present in 4 of 10 studies (40%) with 19 of 173 preference markers (11%) indicating proportional differences in mapping. See Table 1.

The significant associations were present in studies spanning different countries and study contexts. In a study of forest management preferences in California (US), the household group was more likely to map rural residential development as *acceptable*, and the following preferences as *unacceptable*: timber harvest, urban development, rural development, industrial development, and energy development. In contrast, the volunteer group was more likely to map fuels treatment as acceptable and wilderness designation as unacceptable. In a regional study in the Tatras region of Poland, the household group was more likely to map preferences for increasing grazing in the region than the volunteer group. In a study in the Sogn region of Norway, volunteers were more likely to map preferences to increase all-terrain vehicle use, grazing, and fishing than the household group. And in a study of marine and coastal values in the Kimberly region of Australia, the household sample was more likely to map preferences for adding recreation facilities, increasing access in the region, new oil/gas development, and the development of port facilities.

The Kimberley region study was the only study that requested the mapping of preferences containing an online panel group that could be compared to household and volunteer groups. Compared with online panel participants, volunteer groups were more likely to map preferences to increase conservation while mapping more preferences to preclude commercial fishing, new oil/gas development, and the development of new port facilities. In contrast, the household sample, when compared to the panel, was more likely to map preferences to increase recreation facilities, increase access, and develop new port facilities, but also more likely to map preferences that preclude commercial fishing and new oil/gas development.

Overall, these results indicate a reasonably high potential (40%) for some type of response bias between household and volunteer groups in the same study, but the potential for bias on a per marker basis was relatively low (11%). Almost half of the marker preferences showing the potential for bias (n=9) were in the California study.

4 Discussion

This study examined Internet-based PPGIS mapping effort as an indicator of spatial data quality across multiple studies and evaluated the potential for mapping bias given the sampling design. Mapping effort was highest in PPGIS studies that targeted sampling groups whose livelihoods were closely related to the purpose of the study. This outcome can be attributed to both participant motivation and familiarity with the study area. For the most common sampling groups (household and volunteer), there was greater mapping effort in household groups, on average, compared to volunteer groups, but this finding was not consistent across all studies with almost half of the studies showing greater volunteer mapping effort. In two studies where the geographic location of household participants was known to be closer to the study area than volunteer participants, there was no significant difference in mapping effort, but there were differences in the types of spatial attributes mapped indicating the effects of spatial discounting.

The online panel groups included in the analysis revealed lower mapping effort than either household or volunteer samples. Mapping effort by an online panel in the 2015 Kimberley region study was greater than panel results reported by Brown et al. (2012b), but still significantly less than the majority of sampling groups examined in this study. An online panel was also used in a Netherlands study to identify highly valued places (de Vries et al. 2013). Although mapping effort was not reported, spatial data quality problems were reported with a significant number of participants placing markers outside designated study boundaries. Thus, while online panels achieve higher response rates, spatial data quality appears to be lower compared to other sampling groups.

There was evidence that the thematic content of spatial attributes influences mapping effort, with the mapping of activities requiring less time than mapping place values or combined place values with preferences. This finding supports the supposition by Brown (2012) that PPGIS spatial attributes can be differentiated based on the cognitive challenge and/or complexity of the spatial attributes requested to be mapped. The mapping of place values appears more cognitively challenging than the mapping activities/experiences. Adding the mapping of preferences to place values within a study did not appear to have a significant impact on mapping effort, suggesting that participant mapping effort is finite and will not increase simply by adding additional types of markers.

The potential for bias from sampling design was present in four out of 10 PPGIS studies. A closer examination of the four studies suggests two conditions that increase the potential for mapping bias: (1) the inclusion of preferences for controversial uses associated with negative externalities, and (2) spatial/geographic discounting caused by locational differences in domicile between sampling groups. These two conditions can function independently or interact to create the potential for spatial bias in the results. In the case of the California national forest study, the household sample targeted individuals living proximate to the national forest study area that want to preserve their lifestyle and thus were more likely to oppose development options with negative externalities, a "Not In My Backyard" (NIMBY) phenomenon. The domicile of volunteers was more distant from the study area and these individuals may have been mobilized for participation by interest groups favouring increased use of national forest resources (Brown et al. 2014a). Two particular issues—fuels treatment and the designation of wilderness areas have historically been controversial in national forest management. Fuels treatment is controversial because it imposes risks and/or burdens on individuals living proximate to the treatment area (e.g. smoke, increased risk of fire, logging activity). Wilderness designation tends to be a polarizing issue because it limits most types of forest utilization including logging and motorized use.

The results from the 2014 Poland study may also be attributable to the domicile of sampling groups. In Poland, the household group lives within the Tatras region and supports increased grazing activity as a part of their culture and livelihood (Brown et al. 2015). In contrast, the volunteer sampling group is more connected to the Tatras region through recreation, tourism, and nature conservation values, purposes that may not be viewed as compatible with grazing activity. Similarly, the results from the Kimberley coastal and marine study suggest the small household sampling group living in the study region support greater economic development in the form of oil/gas and new port development. In the Norway study, the relationship between the domicile of sampling groups (household vs. volunteer) and the potential for mapping bias is less clear because the volunteer group lives in same region as the household group. One possible explanation is that mapped values and preferences are influenced by the spatial distribution of different land tenures located in the study region (Hausner et al. 2015).

While the potential for sampling bias is often associated with volunteer sampling, random household sampling also deserves careful scrutiny, especially for non-response bias. In the California, Poland, and Kimberley region PPGIS studies, the household sample response rates were very low – in the single digits. Even when PPGIS participants appear demographically representative of the regional population based on census data, non-response bias in household sampling presents a significant threat to the validity and representativeness of mapped results.

4.1 Implications for the Future of PPGIS Research

There are three explicit or implicit components to PPGIS/PGIS/VGI systems that provide a basis for future PPGIS research: (1) *Who* participates (the "public" or "volunteer"); (2) *How* participation is implemented, including decisions (the "participation" or "participatory"); and (3) The geographic information system (the "GIS" or "GI"). While the meta-analysis in this study included all three components, the primary focus was on sampling or the "who" of PPGIS.

To enhance PPGIS research and practice, a focus on the technological component of PPGIS appears misplaced. The emergence of PPGIS in the 1990s was inspired by both the potential and the critique of geographic information as a means to provide marginalized populations (the "who") with information that could influence important social outcomes (the "how") ranging from local land use decisions to exerting claims for indigenous land rights. Over time, geospatial and mobile technologies (the "GIS" component) have received greater research attention by academics because of the attraction of new technology, the academic quest for novelty, and the sustained lack of evidence that "participatory" GIS processes actually produce positive social change.

The results of this meta-analysis and evidence from elsewhere indicate that the most relevant future research would target the use and integration of PPGIS that achieves social impact, not in the hypothetical, but through real-world examples. Given that a high-level purpose of PPGIS/PGIS (and to a lesser extent VGI), is to assess social acceptability to inform place-based decisions, who participates and how the spatial information is used (or not) will determine PPGIS social impact, not mapping technology per se. The technology variable in this study (Internet computer interface) showed no effect on spatial data quality while other studies cited previously have found reasonably high spatial accuracy using a variety of mapping technologies. A continued research focus of new spatial mapping technologies for PPGIS applications appears unnecessary when comparable spatial data quality and higher response rates can be achieved through low technology, hardcopy mapping (Pocewicz et al. 2012). In other words, there may be valid reasons for evaluating new mapping technology, but technology does not appear to be the limiting factor in achieving social impact with PPGIS.

Future PPGIS research would benefit from focusing on the implications of this meta-analysis. The following points provide some guidance:

1. Low response rates from random household sampling and low levels of participation from volunteer and other sampling groups increase uncertainty about the representativeness of the spatial data and exacerbate known weaknesses in sampling. Previous PPGIS research has established that random sampling does not result in a truly representative sample of the general public – there is bias toward older, more formally educated male participants with higher incomes, and under-representation of ethnic groups (Brown and Kyttä 2014). Sufficient data quality can be achieved using either household or volunteer sampling, but volunteer sampling has the greatest potential for mapping bias. Online panels offer a solution to lower response rates that reduce sampling error, but offer lower spatial data quality and uncertainty about the representativeness of the panel, i.e. increase the potential for non-sampling error. The effectiveness of PPGIS depends on achieving high participation and response rates and thus shares a common fate with effective general survey research. PPGIS research and practitioners should pay close attention to developments in the field of survey research to achieve higher response and participation rates. For example, social exchange theory (Dillman 1978), social psychological theories involving persuasion (Groves et al. 1992), and leverage-saliency theory (Groves et al. 2001) may offer some insight to enhance PPGIS participation, but these theories have not been specifically researched in PPGIS applications.
2. PPGIS is explicitly spatial and spatial discounting strongly influences the mapped results. Response and participation must also account for spatial representativeness in sampling, i.e. the domicile of participants matters. With household and community sampling, spatial representativeness is an additional requirement to statistical representativeness and merits greater research attention. But even when statistical and spatial representativeness are achieved in PPGIS sampling, the uneven spatial distribution of human settlement relative to the study area will still pose vexing questions about whose voice should matter more in decisions about land use. Spatial aggregation and weighting of PPGIS response is not a technical issue, but a social issue confronted by questions about interests, power, and equity. PPGIS has the capacity to identify stakeholder interests spatially (Brown et al. 2015), but would benefit from future research that examines the social trade-offs of alternative spatial aggregation and weighting schemes for social acceptability.
3. To date, the majority of PPGIS research has focused on the generation of spatial data to inform spatial planning processes. As such, PPGIS is implemented early in a planning

cycle to identify socially acceptable alternatives and trade-offs. Early participation is sound practice, but PPGIS can be more than a planning tool – it can also function to assess and adjudicate the social acceptability of planning alternatives after they have been identified. In most governance systems, the relationship between political representation and future land use is indirect at best. Land use decisions are made by politicians or administrative agencies under their control. What if PPGIS were explicitly linked to a voting system wherein citizens could evaluate and select preferred land use futures? In many jurisdictions in the US, for example, citizens must be consulted on important issues of local taxation. Arguably, important land use decisions have much greater potential impact on community quality of life than issues of taxation. With increased interest in crowd-sourcing as a solution to complex problems, future PPGIS research should examine the capacity of the public to identify land use alternatives as a complement or potential replacement to traditional expert-driven planning systems (Brown 2015).

The view that geospatial technology embedded within PPGIS systems can, by itself, leverage positive social change within the dominant, inequitable social and political structures, appears naïve. Land use planning and management decisions often involve wicked social value problems that do not have technical solutions. For PPGIS to have social impact, it must evolve from a perceived technical spatial tool into an impact analysis tool that identifies important social trade-offs in the distribution of costs and benefits associated with land use planning and management. But this evolution will require greater trust and credibility in the methods and the mapped results. Addressing the sampling and data quality issues identified in this study would be a reasonable place to start.

References

Auricht C M, Raymond C, Thackway R, and Imgraben S 2014 *Development of Socioecological Sub-regional Boundaries for Natural Resources Management in the South East NRM Region*. Brighton, South Australia, Auricht Projects (Report prepared for SE NRM Board)

Beverly J, Uto K, Wilkes J, and Bothwell P 2008 Assessing spatial attributes of forest landscape values: An internet-based participatory mapping approach. *Canadian Journal of Forest Research* 38: 289–303

Beierle T 1999 Using social goals to evaluate public participation in environmental decisions. *Policy Studies Review* 16: 75–103

Brown G 2012 Public Participation GIS (PPGIS) for regional and environmental planning: Reflections on a decade of empirical research. *URISA Journal* 24(2): 7–18

Brown G 2013 Relationships between spatial and non-spatial preferences and place-based values in national forests. *Applied Geography* 44: 1–11

Brown G 2015 Engaging the wisdom of crowds and public judgment for land use planning using public participation geographic information systems. *Australian Planner* 52: 199–209.

Brown G and Brabyn L 2012 An analysis of the relationships between multiple values and physical landscapes at a regional scale using public participation GIS and landscape character classification. *Landscape and Urban Planning* 107: 317–31

Brown G and Donovan S 2014 Measuring change in place values for environmental and natural resource planning using Public Participation GIS (PPGIS): Results and challenges for longitudinal research. *Society and Natural Resources* 27: 36–54

Brown G, Hausner V, Grodzińska-Jurczak M, Pietrzyk-Kaszyńska A, Olszańska A, Peek B, Rechciński M, and Lagreid E 2015 A cross-cultural study of protected area values and management preferences in Norway and Poland. *Journal for Nature Conservation* 28: 89–104

Brown G, Hausner V, and Lagreid E 2015 Physical landscape associations with mapped ecosystem values with implications for spatial value transfer: An empirical study from Norway. *Ecosystem Services* 15: 19–34

Brown G, Kelly M, and Whitall D 2014a Which "public"? Sampling effects in public participation GIS (PPGIS) and Volunteered Geographic Information (VGI) systems for public lands management. *Journal of Environmental Planning and Management* 57: 190–214

Brown G, Weber D, and de Bie K 2014b Assessing the value of public lands using public participation GIS (PPGIS) and social landscape metrics. *Applied Geography* 53: 77–89
Brown G and Kytta M 2014 Key issues and research priorities for public participation GIS (PPGIS): A synthesis based on empirical research. *Applied Geography* 46: 122–36
Brown G, Montag J, and Lyon K 2012a Public Participation GIS: A method for identifying ecosystem services. *Society and Natural Resources* 25: 633–51
Brown G, Weber D, Zanon D, and de Bie K 2012b Evaluation of an online (opt-in) panel for Public Participation Geographic Information Systems (PPGIS) surveys. *International Journal of Public Opinion Research* 24: 534–45
Brown G and Reed P 2009 Public Participation GIS: A new method for national forest planning. *Forest Science* 55: 166–82
Brown G, Reed P, and Harris C C 2002 Testing a place-based theory for environmental evaluation: An Alaska case study. *Applied Geography* 22: 49–77
Brown G, Schebella M F, and Weber D 2014 Using Participatory GIS to measure physical activity and urban park benefits. *Landscape and Urban Planning* 121: 34–44
Brown G and Weber D 2011 Public Participation GIS: A new method for use in national park planning. *Landscape and Urban Planning* 102: 1–15
Brown G and Weber D 2012 Measuring change in place values using public participation GIS (PPGIS). *Applied Geography* 34: 316–24
Cox C, Morse W, Anderson C, and Marzen L 2014 Applying public participation geographic information systems to wildlife management. *Human Dimensions of Wildlife* 19: 200–14
Cox C, Morse W, Anderson C, and Marzen L 2015 Using public participation geographic information systems to identify places of watershed service provisioning. *Journal of the American Water Resources Association* 51: 704–718
Curtin R, Presser S, and Singer E 2005 Changes in telephone survey non-response over the past quarter century. *Public Opinion Quarterly* 69: 87–98
de Leeuw E and de Heer W 2002 Trends in household survey non-response: A longitudinal and international comparison. In Groves R M, Dillman D A, Eltinge J L, and Roderick J A (eds) *Survey Non-Response*. New York, John Wiley and Sons: 41–54
Dietz T and Stern P (eds) 2008 *Public Participation in Environmental Assessment and Decision-making*. Washington, DC, National Academies Press
Dillman D A 1978 *Mail and Telephone Surveys: The Total Design Method for Surveys*. New York, John Wiley and Sons
Girres J and Touya G 2010 Quality assessment of the French OpenStreetMap dataset. *Transactions in GIS* 12: 435–59
Goodchild M F 2007 Citizens as sensors: The world of volunteered geography. *GeoJournal* 69: 211–21
Groves R, Cialdini R, and Couper M 1992 Understanding the decision to participate in a survey. *Public Opinion Quarterly* 56: 475–95
Groves R, Singer E, and Corning A 2001 Leverage-saliency theory of survey participation. *Public Opinion Quarterly* 64: 299–308
Hall G B, Chipeniuk R, Feick R D, Leahy M G, and Deparday V 2010 Community-based production of geographic information using open source software and Web 2.0. *International Journal of Geographical Information Science* 24: 761–81
Haklay M 2010 How good is volunteered geographical information? A comparative study of OpenStreetMap and Ordnance Survey datasets. *Environmental Planning B* 37: 682–703
Haklay M, Basiouka S, Antoniou V, and Ather A 2010 How many volunteers does it take to map an area well? The validity of Linus' law to volunteered geographic information. *Cartographical Journal* 47: 315–22
Hannon B 1994 Sense of place: Geographic discounting by people, animals and plants. *Ecological Economics* 10: 157–74
Hausner V, Brown G, and Lagreid E 2015 Effects of land tenure and protected areas on ecosystem services and land use preferences in Norway. *Land Use Policy* 49: 446–61
Kaminska O, McCutcheon A, and Billiet J 2010 Satisficing among reluctant respondents in a cross-national context. *Public Opinion Quarterly* 74: 956–84
Karimi A, Brown G, and Hockings M 2015 Methods and participatory approaches for identifying social-ecological hotspots. *Applied Geography* 63: 9–20
Kleinhans R, Van Ham M, and Evans-Cowley J 2015 Using social media and mobile technologies to foster engagement and self-organization in participatory urban planning and neighbourhood governance. *Planning Practice and Research* 30: 237–47
Krosnick J A 1991 Response strategies for coping with the cognitive demands of attitude measures in surveys. *Applied Cognitive Psychology* 5: 213–36

Mukherjee F 2015 Public Participatory GIS. *Geography Compass* 9: 384–94
NCGIA 1996a *Summary Report: GIS and Society Workshop, South Haven, Minnesota, 2-5 March, 1996*. Santa Barbara, CA, National Center for Geographic Information and Analysis
NCGIA 1996b *Summary Report: Public Participation GIS Workshop, Orono, Maine, 10-13 July, 1996*. Santa Barbara, CA, National Center for Geographic Information and Analysis
NZ DOC (New Zealand Department of Conservation) 2011 Identifying Conservation Values, Park Experiences, and Development Preferences in the Southland Region of New Zealand. WWW document, http://www.doc.govt.nz/upload/documents/aboutdoc/role/policies-and-plans/cms/southland-values-survey-results.pdf
Pocewicz A and Nielsen-Pincus M 2013 Preferences of Wyoming residents for siting of energy and residential development. *Applied Geography* 43: 45–55
Pocewicz A, Nielsen-Pincus M, Brown G, and Schnitzer R 2012 An evaluation of Internet versus paper-based methods for Public Participation Geographic Information Systems (PPGIS). *Transactions in GIS* 16: 39–53
Rambaldi G, Kwaku Kyem A P, Mbile P, McCall M, and Weiner D 2006 Participatory spatial information management and communication in developing countries. *Electronic Journal of Information Systems in Developing Countries* 25: 1–9
Schlossberg M and Shuford E 2005 Delineating "public" and "participation" in PPGIS. *URISA Journal* 16(2): 15–26
Schroeder B 2014 Mapping Landscape Values and Forest Uses on the Tongass National Forest. Unpublished PhD Dissertation, University of Alaska
Sieber R 2006 Public participation geographic information systems: A literature review and framework. *Annals of the Association of American Geographers* 96: 491–507
Spielman S E 2014 Spatial collective intelligence? Credibility, accuracy, and volunteered geographic information. *Cartography and Geographic Information Science* 41: 115–24
Tulloch D 2008 Is VGI participation? From vernal pools to video games. *GeoJournal* 72: 161–71
Veilleux A 2013 Recreational Knowledge, Concern and Behavior for a Resource: A Spatial and Descriptive Analysis of Squam Lakes, NH Using Public Participation GIS. Unpublished MS Thesis, Plymouth State University
Wolf I, Wohlfart T, Brown G, and Bartolome Lasa A 2015 The use of public participation GIS (PPGIS) for park visitor management: A case study of mountain biking. *Tourism Management* 51: 112–30
Yankelovich D 1991 *Coming to Public Judgment: Making Democracy Work in a Complex World*. Syracuse, NY, Syracuse University Press

