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Is PPGIS good enough? An empirical evaluation of the quality of PPGIS crowd-sourced spatial data for conservation planning

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ABSTRACT

A significant barrier to the use of public participation GIS (PPGIS) and crowd-sourcing for conservation planning is uncertainty about the quality of the spatial data generated. This study examines the quality of PPGIS data for use in conservation planning. We evaluate two dimensions of spatial data quality, positional accuracy and data completeness using empirical PPGIS data from a statewide study of public lands in Victoria, Australia. Using an expert-derived spatial conservation model for Victoria as a benchmark, we quantify the performance of a crowd-sourced public in their capacity to accurately and comprehensively identify areas of high conservation importance in the PPGIS process. About 70% of PPGIS points that identified biological/conservation values were spatially coincident (position accurate) with modeled areas of high conservation importance, with greater accuracy associated with locations in existing protected areas. PPGIS data had less positional accuracy when participants identified biological values in urban areas and on non-public lands in general. The PPGIS process did not comprehensively identify all the largest, contiguous areas of high conservation importance in the state, missing about 20% of areas, primarily on small public land units in less densely populated regions of the state. Preferences for increased conservation/protection were over-represented in areas proximate to the Melbourne urban area and under-represented in more remote statewide locations. Our results indicate that if PPGIS data is to be integrated into spatial models for conservation planning, it is important to account for the spatial accuracy and completeness limitations identified in this study (i.e., urban areas, non-public lands, and smaller remote locations). The spatial accuracy and completeness of PPGIS data in this study suggests spatial data quality may be "good enough" to complement biological data in conservation planning but perhaps not good enough to overcome the mistrust associated with crowd-sourced knowledge. Recommendations to improve PPGIS data quality for prospective conservation planning applications are discussed.

Introduction

Spatial planning for conservation primarily uses biological data to identify priority areas through quantification and modeling (see Moilanen et al., 2009). Measures such as species richness, diversity, or rarity, in combination with area representativeness and complementarity (Pressey et al., 1994; Smith and Theberge, 1986; Margules et al., 1988; Pressey et al., 1993; Bonn and Gaston, 2005; Margules and Pressey, 2000; Myers et al., 2000) form the basis of many conservation models. A supplementary approach identifies conservation opportunities and constraints using a range of social, economic, and political factors in the specific context of the social-ecological system of the planning region (Knight and Cowling, 2007). The appropriate focus of conservation planning has been debated in the conservation literature (Pressey and Bottrill, 2008; Knight and Cowling, 2008) but there is agreement as to the fundamental importance of identifying threats to biodiversity and that conservation initiatives can be improved by explicitly incorporating social and economic opportunities in spatial planning.

While the importance of identifying opportunities and constraints for spatial conservation planning is acknowledged in the literature (Knight and Cowling, 2007, 2008), integration with biological data has been constrained by the lack of spatially commensurate social data. The development of public participation GIS (PPGIS) methods for natural resource management (Brown, 2005)

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has enabled the generation of spatially explicit social variables at scales appropriate for conservation planning. Public participation GIS (PPGIS) and participatory GIS (PGIS) refer to participatory methods that generate spatial information for a variety of urban, regional, and environmental applications (Brown and Kyttä, 2014; Sieber, 2006), including the identification of ecosystem services (Brown and Fagerholm, in press). The distinction between PPGIS and PGIS largely reflects the situational context with PGIS emphasizing social learning and community engagement in developing countries and PPGIS emphasizing sample representativeness and the quality of the data for planning applications. A related concept, volunteered geographic information (VGI) refers to systems that create, assemble, and disseminate geographic data provided voluntarily by individuals (Goodchild, 2007). While there is increasing academic interest in public participation GIS (Brown and Kyttä, 2014), there is yet little tangible evidence of adoption by agencies or NGOs for actual decision support (Brown, 2012a). A significant barrier to increased use of PPGIS is the important question of spatial data quality derived from crowd-sourced or non-expert sources. Quality is of greatest concern when data are being used to indicate actual physical or biological reality. The absence of trust in the quality of PPGIS data derived from non-authoritative sources means the spatial data is unlikely to be used for natural resource planning and decision support, including conservation planning. Whether such data merits the trust of natural resource planners and managers is central to this study.

Whitehead et al. (2014) presented the first study to examine the potential influence of spatially explicit social values and preferences generated through PPGIS on modeled spatial conservation priorities with biological data in the Hunter Valley region of Australia. In the study, modeled conservation spatial priorities generated from biological species data changed with the inclusion of PPGIS data in the model, however, the combined biological and social data produced conservation solutions of approximately equivalent biological value. Lechner et al. (in press) used PPGIS data from the same Hunter Valley study to examine the potential effects of values and preferences on landscape connectivity, an important component of spatial conservation planning. The modeled outcomes showed consistency between the public's conservation orientation operationalized from the PPGIS data and the ecological rationale for increasing connectivity within the region.

The integration of PPGIS data with biological data in conservation modeling is an innovative approach to assess the influence of social values and preferences on conservation planning. And yet, the putative benefits of integration are uncertain without better understanding of the quality of PPGIS data for use in such applications. This paper seeks to address this issue by presenting empirical research that evaluates the spatial quality of PPGIS data for potential use in conservation planning in Australia.

The quality of PPGIS data

Spielman (2014) describes the challenge of evaluating the quality of spatial data created through crowd-sourcing in volunteered geographic systems (VGI) as a "tension between the *validity-as-accuracy* and *validity-as-credibility* perspectives" (p. 116) and this same tension applies to PPGIS data. The *validity-as-accuracy* perspective assumes spatial accuracy is the paramount validity criterion while *validity-as-credibility* emphasizes the reputation, trustworthiness, and motivations of the spatial data contributor. Traditional statistical concepts of uncertainty and bias are hard to apply to crowd-sourced spatial data while subjective measures of quality require examining the motivations and credibility of mapping contributors.

The quality of expert-derived spatial data is typically evaluated in terms of resolution, currency, positional accuracy, as well as the professional reputation of the authors. For example, the U.S. federal government developed specific data quality standards based on five dimensions: positional accuracy, attribute accuracy, logical consistency, completeness, and lineage (www.fgdc.gov/metadata/csdgm). The *validity-as-accuracy* perspective has been applied to VGI systems where assessments of spatial data quality have examined the positional accuracy and completeness of contributions to OpenStreetMap (OSM) against authoritative geospatial data (Haklay, 2010; Girres and Touya, 2010; Zielstra and Zipf, 2010). These studies indicate the positional accuracy of OSM data is comparable to geographical data maintained by national mapping agencies and commercial providers. Specifically, Haklay et al. (2010) reported spatial accuracy between 80% and 86% in a test case in England.

For PPGIS systems, the *validity-as-credibility* perspective has been more influential than the *validity-as-accuracy* approach in evaluating the validity of the data. This makes sense given the subjective nature of the mapped spatial attributes such as spatially explicit values and preferences. For example, one is unlikely to find a universally accepted reference map for areas of scenic beauty, a common spatial attribute mapped in PPGIS systems. Perhaps more vexing is the PPGIS mapping of land use preferences that equate to spatially explicit opinions about land use such as increased protection for conservation (e.g., no clearing of native vegetation).

In PPGIS, there has been some research to assess the spatial data quality of participatory data from a *validity-as-accuracy* perspective by examining the positional accuracy of PPGIS mapped data. The methods include (1) examining the spatial concurrence of PPGIS mapped data with biophysical landscape features, (2) comparing public mapped spatial data to expert-mapped spatial data, and (3) comparing the distribution of participatory data against random spatial data as a benchmark. Specifically, Brown et al. (2004) examined the spatial concurrence of public perceptions of biological marine values in Prince William Sound, Alaska, collected using PPGIS compared to an expert biological assessment collected through a workshop mapping process, finding that PPGIS points were statistically related to expert areas with a moderate degree of spatial coincidence/overlap (25–43%) between lay and expert areas of biological importance. In New Zealand, Brown (2012b) assessed the capacity of the general public to accurately identify locations of native vegetation and found an absolute mapping error of 6% for PPGIS mapped points compared to 22% for randomly generated points. Further, native vegetation points mapped by individuals with greater self-reported familiarity with study region had fewer absolute errors. And in Alabama, Cox et al. (2014) examined the ability of a lay public to identify wildlife habitat finding that between 75% and 84% of mapped PPGIS points fell within species habitat areas.

These assessments of the spatial quality of PPGIS data appear more suggestive, than definitive. As Spielman (2014) observes, not all crowd-sourced information is equal; some data have higher quality than others and some contributors make better contributions than others. Further, the credibility of PPGIS data cannot be fully addressed without reference to the intended purpose and potential use of the spatial data. For example, if authoritative spatial data exists for terrestrial features such as native vegetation from remote-sensed imagery, is there any added value to having the public identify its location using PPGIS? More generally, what type of spatial information can be provided by PPGIS that cannot otherwise be provided by expert-derived spatial data? We return to this question in section "Discussion".

Attribute accuracy of PPGIS data

Attribute error occurs when an attribute is assigned a value that differs from its true value. Some attribute error can be expected in PPGIS with marker placement, e.g., a participant identifies a recreation value when intending to identify a scenic value, or there is error in coding a marker type during digitization. However, with sound mapping instructions, attribute error will be small relative to total spatial data collected. Of greater concern is the construct validity of the PPGIS attributes that are mapped. In the social sciences, construct validity refers to how well an operational variable measures the theoretical construct that it was designed to measure. In PPGIS, common spatial attributes mapped include landscape values (Brown, 2005) also called social values for ecosystem services (Sherrouse et al., 2011). The broad and sometimes subjective nature of landscape values makes the determination of construct validity difficult and confounds the assessment of positional accuracy and completeness. For example, biological/conservation value was operationalized in this PPGIS study as "areas [that] are valuable because they provide a variety of plants, wildlife, and habitat". One possibility is that the PPGIS participant has observed or experienced plants, wildlife, or habitat in the mapped location and has come to personally value these features in the mapped location. Another possibility is that the participant has learned of the biological features in a location from external sources and is expressing his/her knowledge of this value regardless of personal value. The participant could also be expressing a combination of both personal value and knowledge from external sources. Because the human valuation process is complex, the sources of the valuation process are difficult to parse in a general PPGIS process. The different sources of the valuation process (personal or knowledge derived from external sources) leads to inter-participant variability in identifying features that contribute to the biological value. Thus, error, variability, and uncertainty in crowd-sourced spatial data are expected, both individually and in aggregate. The important question concerns the tolerance or threshold conditions where PPGIS spatial data can be confidently used for planning and policy making purposes, in this case, for conservation planning.

Assessing PPGIS spatial quality for conservation planning

In this study, we evaluate the capacity of a general public to identify locations of biological importance for conservation planning purposes using PPGIS data from a study of public lands in Victoria, Australia. We operationalize two measures of spatial data quality used to evaluate expert spatial data—positional accuracy and data completeness—and apply them to PPGIS spatial data. The identification of conservation priorities is a traditional expert domain. Significant research effort has been devoted to inventorying species distributions and using spatial modeling to identify areas of high conservation importance. The existence of an expert-derived conservation model for the state of Victoria (NaturePrint v2.0) provides an opportunity to benchmark PPGIS community values for biological conservation with those generated by the expert model. We analyze the spatial concurrence of PPGIS values with conservation priorities identified with the expert-derived model to quantify the quality of spatial data on the metrics of positional accuracy and data completeness.

The value of PPGIS to augment conservation planning is approached by operationalizing and measuring the accuracy and completeness of the spatial data generated by one of the largest PPGIS studies completed to date. Spatial accuracy and completeness have strong implications for whether, and how, PPGIS is to be used for conservation planning. Using an expert-derived model of conservation importance in Victoria as an authoritative reference, we seek answers to the following research questions: (1) what is the spatial accuracy of PPGIS mapped biological/conservation values on public and non-public lands in Victoria; (2) how does the spatial accuracy compare to other mapped PPGIS values and preference that were collected in the same study; (3) how complete are PPGIS mapped biological/conservation values using the largest contiguous areas of high conservation importance in Victoria as reference areas; (4) what conservation areas were missed or over-represented in the PPGIS results compared to the expert derived data, and what are the characteristics of these areas? Following a presentation of results, we discuss the implications of the findings for integrating crowd-sourced conservation values and preferences into conservation planning processes.

Methods

Study location

The study location was the state of Victoria, the sixth largest state or territory in Australia with an area of 237,629 km^2 and an estimated population of 5,768,600 (ABS, 2013). Most of the state's population is concentrated in the area near the capital city of Melbourne, Australia's second most populous city. The public land estate in Victoria, also known as "Crown" lands, comprises approximately 35% of the terrestrial land area (DEPI, 2013a) with the largest contiguous areas located in the mountainous eastern third of the state, and the northwest sector. Parks and conservation reserves make up 3.98 million hectares (approximately 50% of all Crown land), state forests comprise 3.14 million hectares (approximately 40%), and other Crown lands cover 796,000 hectares (10%) including Commonwealth Government land, metropolitan parks, and land held under lease from the Crown (DEPI, 2013a).

PPGIS data collection process

The research team designed, pre-tested, and implemented an internet-based PPGIS for data collection. Details of the study methods are provided in a technical report and related publication (Weber and Brown, 2014; Brown et al., 2014). The study website used a Google® maps interface where participants were requested to place digital markers at locations in Victoria representing 11 landscape values and nine management preferences (see definitions in Table 1). The landscape values were based on a typology originally operationalized by Brown and Reed (2000) and subsequently adapted to multiple PPGIS studies (see Brown and Kyttä, 2014). Management preferences were identified by the research team in consultation with Parks Victoria, the sponsoring agency. Landscape values are an operationalized form of place value used for natural resource and environmental planning applications described by Brown and Donovan (2014) as a "relationship" value that bridges both "held" values (what is personally important) and "assigned" values (relative importance of external objects). In the process of associating values with place, what is personally important to an individual (held value) merges with conceptions of what appears important to the individual in the physical landscape (assigned value). Management preferences represent positive or negative attitudes toward future land use and/or management activities. The different types of markers placed and their spatial locations were recorded for each participant in a web server database. Participants could place as few or as many markers as they deemed necessary to express their values and management preferences.

From December 2013 to February 15, 2014, study participants were recruited using both purposive and convenience sampling methods: (1) visitors to 16 national parks, 5 state parks and 9 metropolitan parks were contacted on site and provided with an

Table 1
Landscape values typology, operational definitions, and expected associations of values with public lands in Victoria.

Values	Operational definition	Expected association by public land type
Scenic/esthetic	These areas are valuable because they contain attractive scenery including sights, smells, and sounds.	National parks, state forests, coastal reserves
Recreation	These areas are valuable because they are where I enjoy spending my leisure time – with family, friends or by myself, participating in outdoor recreation activities (e.g., camping, walking, or fishing).	National parks, state forests, state parks, and community/metro/regional parks
Economic	These areas are valuable because they provide natural resources or tourism opportunities.	State forests, national parks
Life sustaining	These areas are valuable because they help produce, preserve, clean, and renew air, soil, and water.	State forests, reservoirs
Learning/education/research	These areas are valuable because they provide places where we can learn about the environment through observation or study.	National parks, state forests
Biological/conservation	These areas are valuable because they provide a variety of plants, wildlife, and habitat.	National parks, state forests, marine sanctuaries, nature conservation reserves
Heritage/cultural	These areas are valuable because they represent natural and human history or because they allow me or others to continue and pass down the wisdom and knowledge, traditions, and way of life of ancestors.	National parks, heritage/cultural reserves
Therapeutic/health	These places are valuable because they make me feel better, physically and/or mentally.	Community/metro parks, state forests
Spiritual	These areas are valuable because they are sacred, religious, or spiritually special places or because I feel reverence and respect for nature here.	National parks
Intrinsic/existence	These areas are valuable in their own right, no matter what I or others think about them.	National parks, natural features reserves
Wilderness/pristine	These areas are valuable because they are wild, uninhabited, or relatively untouched by European activity.	National parks, wilderness areas

Preferences	Operational definition
Increase conservation/protection	Increase conservation and protection here (e.g., due to encroaching development, feral animals/weeds, illegal use).
Add recreation facilities	Add more recreation facilities (e.g., walking trails, playgrounds, picnic ground) here.
Add tourism services/development	Add new tourism services (e.g., guided tours, signs, brochures, apps) or development (e.g., trail head, toilet block, visitor center) here (Please specify).
Improve access	Improve vehicular access (i.e., from no access to 4WD access or from 4WD road to 2WD road). Note: please map increased walking trail access under the recreation facilities icon.
Improve bushfire protection	Improve bushfire protection here.
Resource extraction	Engage in resource extraction such as logging or mining here.
Resource use	Engage in resource use such as grazing, hydroelectric energy, or wind energy here.
Decrease or limit access	Decrease or limit access here (e.g., close to vehicles or 4WD)
No development or change	No development or change to land use here.

invitation card describing the study; (2) Parks Victoria distributed a press release describing the study, placed a link to the study on the agency's website, and an agency spokesperson promoted the study in an Australian Broadcasting Corporation radio interview; and (3) a recruitment letter was distributed to the Victoria National Parks Association (VNPA), a non-governmental organization (NGO) that promotes nature conservation in Victoria. Participants in the study were also encouraged to refer friends, relatives, and acquaintances to the study website. A total of 1905 participants accessed the study website and placed one or more markers. A total of 35,347 markers were mapped during the data collection period, with 30,194 (85%) of these attributable to public lands in Victoria. Approximately 85% of the markers placed were *value* markers with the remaining 15% *preference* markers.

Conservation value modeling

The modeled conservation importance values used in this study were derived from NaturePrint v2.0, a spatial product developed by the Victoria Department of Sustainability and Environment (DEPI, 2013b). The strategic natural values map in NaturePrint integrates information from the spatial distribution and co-location of mammals, birds, amphibians, reptiles, fish and plants while considering rare and threatened species site records in Victoria. The model also considers information on connectivity potential and recoverability of areas. The natural values map was developed using zonation software (http://cbig.it.helsinki.fi/software/zonation/), a spatial optimization program that satisfies a model 'objective' (in this case, maximize the area retained for species assemblages and Victorian rare or threatened species) while maximizing retention of areas of high landscape connectivity and condition. See DEPI (2013c) for a technical explanation of the development of the zonation model.

The strategic natural values map used in our analyses is a GIS raster data layer where each map pixel (cell) has a spatial resolution of 75 m × 75 m. The map indicates areas that contribute most to biodiversity conservation as determined by the relative contribution of each pixel to protecting the full range of biodiversity values found within Victoria. The model produces a continuous surface for Victoria where each cell is ranked between 0 and 100 (higher scores indicate greater conservation importance). This information was simplified in the final map product by converting each pixel score to a scale ranging from zero-to-seven where larger numbers indicate greater importance to conservation. In the final natural values map (Fig. 1), red, pink and dark green colors signify high conservation importance where it is essential to protect existing features while areas of light green, purple, and mauve indicate areas that require re-establishment and improvement of habitat values including revegetation and connectivity. In our analyses, the NaturePrint quantitative data were analyzed using the simplified zero-to-seven pixel scale.

Analyses

Positional accuracy

To assess the positional accuracy of PPGIS mapped biological/conservation values with modeled conservation importance,

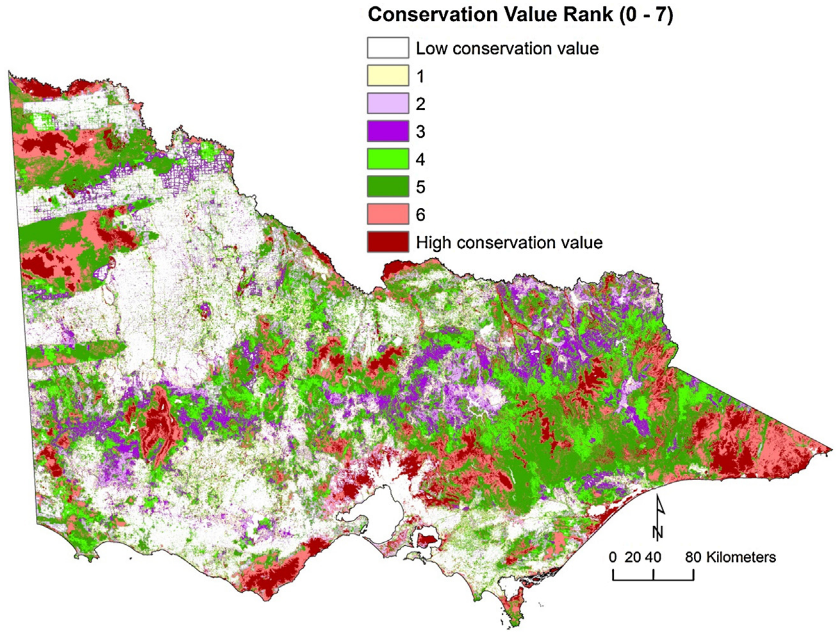

Fig. 1. The distribution of NaturePrint v2.0 conservation values in Victoria ranked from low (0) to high (7). Pixel resolution is 75 m × 75 m. (For interpretation of the references to color in text, the reader is referred to the web version of this article.)

separate analyses were completed for both public and non-public lands. Each PPGIS point was buffered to 250 m (diameter = 500 m) to capture the conservation values in the neighborhood of the point. A mean conservation importance score was calculated from the individual pixels (values range from 0 to 7) located within the buffered areas (approximately 35 pixels were averaged for each point). This process was repeated for all PPGIS values and preferences such that each mapped PPGIS point was assigned a mean conservation importance score derived from the NaturePrint data.

To provide a benchmark for positional accuracy, 1000 random points were generated separately on public and non-public lands. Similar to the procedure for the PPGIS mapped points, a mean conservation importance score was calculated for each random point using the 250 m buffering method. We performed a one-way analysis-of-variance (ANOVA) on the mean conservation scores for all PPGIS values and preferences on public and non-public lands separately to determine whether PPGIS point conservation scores significantly differed from random point conservation scores. Statistically significant differences between each PPGIS attribute type and the random points were identified using a post hoc least significant difference (LSD) test.

We mapped the mean conservation scores for the PPGIS biological/conservation value points on public and non-public lands to visually identify potential differences in spatial accuracy based on location (public vs. non-public) and the potential influence of mapped locations in the Melbourne urban area on the overall results.

In the final analysis, we examined the combined frequency distribution of mean conservation scores from all of the PPGIS biological/conservation points, regardless of location within Victoria, and compared this frequency distribution to the mean conservation scores of the 2000 random points. To benchmark the spatial accuracy, we calculated the percentage of mean conservation scores falling between 0 and 4.99 (lower conservation importance) and 5 to 7 (higher conservation importance). The difference in percentage between the PPGIS points and the random points provided a simple measure of the increased spatial accuracy of mapped biological/conservation points over random points.

Completeness

In GIS terminology, completeness refers to the relationship between the existing objects in the GIS database and the universe of all such objects (Veregin, 1999). To determine completeness, one must define a universe of objects of interest. The completeness of PPGIS biological/conservation values was assessed by establishing a completeness benchmark (universe) for comparison. The benchmark consisted of the largest, contiguous areas of high conservation importance in Victoria derived from NaturePrint. These areas could be located anywhere in Victoria. PPGIS completeness was determined by quantifying how many of these areas of high conservation were also identified by PPGIS participants as having conservation value. High conservation areas were operationalized as contiguous raster cells having a conservation importance score of either 6 or 7. These areas were converted to polygons and the 100 largest areas exceeding 50 km^2 were selected for benchmarking. These irregular-shaped polygons were generalized into minimum convex polygons and dissolved using a tolerance of 500 m, resulting in 54 large, contiguous high value conservation areas (see Fig. 6). These areas provided the completeness benchmark for the PPGIS mapped biological/conservation values wherein completeness was determined by the number and percentage of these areas identified or missed by the PPGIS participants.

The analyses for completeness included PPGIS biological/conservation values, as well as the combined PPGIS mapped preferences for “increased conservation/protection” and “no change/development”. We included PPGIS conservation preferences to compare with the biological/conservation values to test the supposition that areas identified by respondents as having a high conservation value would also be associated with a preference for conservation and no development. The PPGIS values and preference points were spatially intersected with the 54 polygons to determine the number of PPGIS points falling within the polygons. Point frequencies and maps were generated to quantify and visualize how PPGIS participants performed in identifying the 54 polygons. Completeness was calculated as the percentage of areas identified by PPGIS participants.

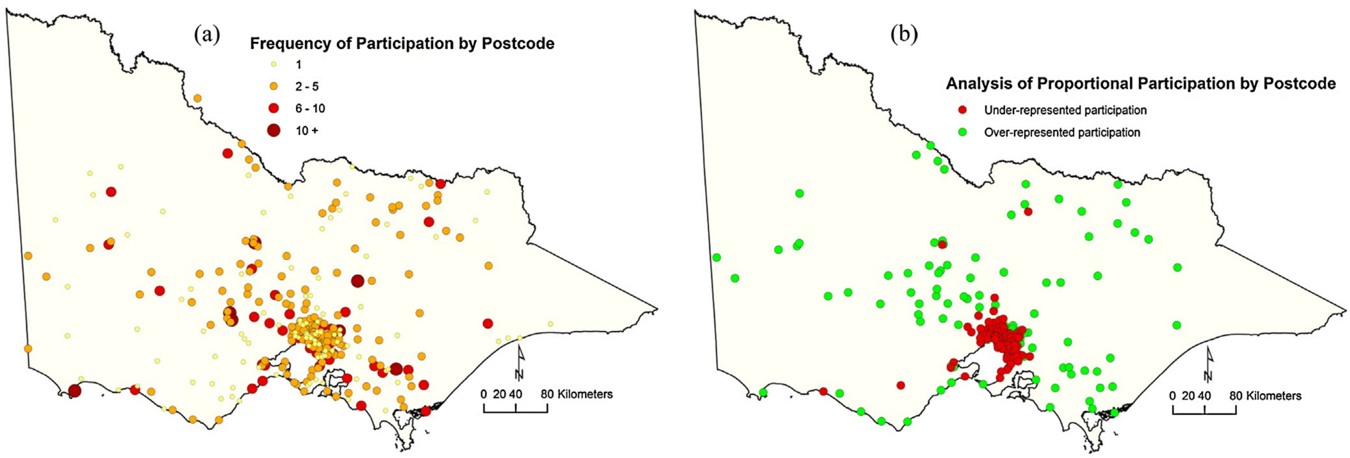

Fig. 2. Maps showing the (a) frequency of participation (number of participants) by postcode, and (b) analysis of participation by postcode indicating those postcodes that had greater or fewer participants than expected based on census population proportions.

Given that some of the conservation areas were "missed" by PPGIS participants, chi-square and residuals analyses were performed to better understand the distribution of PPGIS values and preferences relative to the 54 high value conservation areas. A residual quantifies the difference in the observed frequency and expected frequency, in this case, of PPGIS points located within the polygons. The PPGIS point counts falling within each polygon, expressed as a percentage of the total points, and expected point counts generated from the percent of total area within Victoria occupied by each polygon, were used to calculate the standardized residual scores. Standardized residuals are a normalized score like a *z* score and if greater than 2.0, indicate significantly more PPGIS points than would be expected given the size of the polygon area. On the other hand, standardized residuals less than −2.0 indicate significantly fewer PPGIS points than expected based on the size the area. Standardized residuals falling in the range −2.0 to +2.0 may be suggestive of under- or over-representation, but are not statistically meaningful.

This assessment accounts for polygon size under the assumption that larger areas are more likely to be mapped than smaller areas, as would be the case if points were placed randomly. Of course, this is a simplistic assumption because the frequency of PPGIS mapping is likely related to frequency of use in addition to size of area, but area use statistics were not available for the areas to calculate expected counts, hence the area-based analysis.

In our analyses, one would expect the overall chi-square statistic of association to be statistically significant given the large number of point/area relationships evaluated so the most useful information are the residuals that indicate which areas are significantly over- or under-represented by PPGIS points. Residuals can reveal which types of areas are more likely to be mapped or missed in the PPGIS mapping process by observing the location and types of lands. We generated a map of the areas that were significantly over or under-represented by PPGIS biological/conservation values and conservation preferences to visualize the results.

Results

PPGIS participant characteristics

The median age of participants was 36 (similar to census data), but more participants were male, with higher levels of formal education, and higher self-reported household income than would be expected based on census data. The PPGIS sampling bias toward more highly educated and higher income males is consistent with other reported PPGIS studies in developed countries (Brown and Kyttä, 2014). Almost 80% of participants rated their self-identified knowledge of public lands in Victoria as "good" or "excellent" and about 87% of respondents use public lands more than once a month.

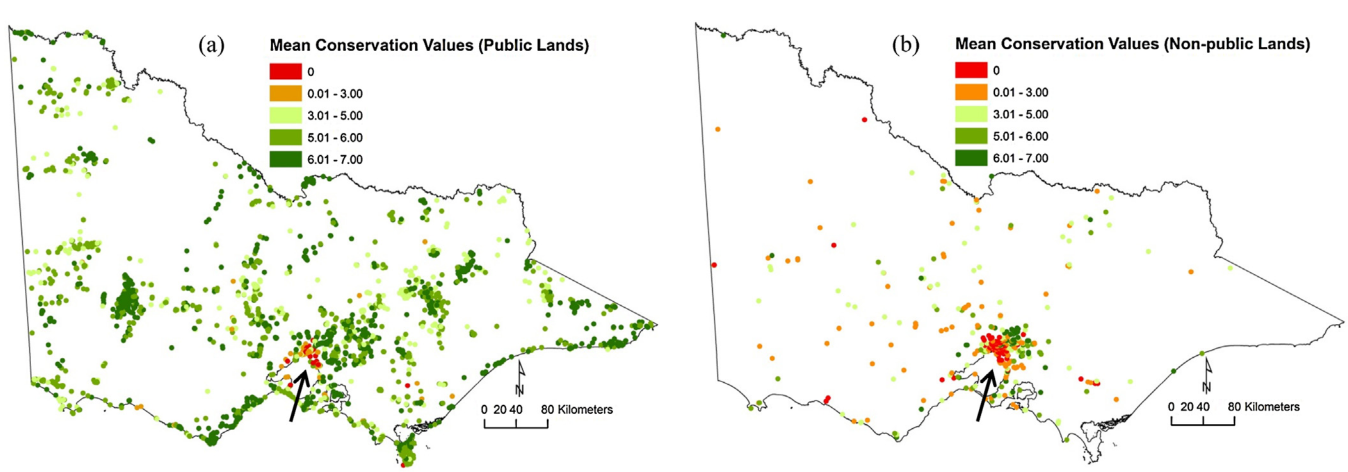

Fig. 3. Maps showing mean NaturePrint v2.0 values within 250 m radius of mapped PPGIS biological/conservation points on public lands (a) and non-public lands (b). Arrow indicates the capital city, Melbourne.

Overall, the study participants appear knowledgeable about the lands in Victoria they mapped.

We assessed the geographic distribution of participants in Victoria by comparing the expected counts of participants per postcode based on census data with the actual number of study participants from each postcode. The largest number of participants lived in the greater Melbourne area, but participation was distributed throughout the state including regional Victoria (see Fig. 2a). The central Melbourne postcode (3000) was significantly over-represented in PPGIS participation compared to census data ($n = 114$ participants), but there were multiple other Melbourne suburbs that were significantly under-represented (see Fig. 2b). The over-representation of central Melbourne was offset by multiple regional postcodes that were also over-represented. Thus, the PPGIS participants represented a reasonable mix of both urban and regional residents.

Positional accuracy

Positional accuracy was operationalized as PPGIS mapped locations for biological/conservation values that also contain relatively large mean conservation scores (5.0 or greater) from the NaturePrint data. The PPGIS mapped points and associated 250 m buffers for biological/conservation values appear in Fig. 3a (public lands) and Fig. 3b (non-public lands). Smaller mean NaturePrint conservation scores are indicated using shades of red and higher score using shades of green. From visual inspection of the spatial distribution, the greatest spatial error occurred in mapped areas proximate to the Melbourne urban area on both public and non-public lands. Further, the mapped biological/conservation values associated with non-public land also show higher degrees of inaccuracy vis-à-vis the NaturePrint values.

The mean conservation scores for all mapped PPGIS values and preferences were benchmarked against 1000 random points on public and non-public lands. It was expected that PPGIS biological/conservation values would have the largest mean conservation scores of all mapped values given this attribute most closely matches the underlying basis of the NaturePrint model. This was true with one exception—mapped wilderness/pristine values had a statistically larger (LSD, $p \leq 0.05$) mean value of 5.9 compared to 5.7 for biological/conservation values on public lands, with both means significantly larger than the mean of random points on public lands (5.4) (Fig. 4). Mapped intrinsic/existence values were also significantly larger (5.6) than the random points on public lands. On non-public lands, biological/conservation values had the largest mean scores (2.7) of all PPGIS values and they significantly differed from random points, but these mean biological/conservation scores reflect a much lower level of conservation importance compared to the wilderness scores on public lands (Fig. 5). The PPGIS mapped preferences for increased conservation/protected also had significantly larger mean conservation scores on both public (5.7) and non-public lands (2.8) than random points. Overall, all PPGIS mapped values on public lands had larger mean conservation scores than non-public lands.

To assess the overall positional accuracy of PPGIS mapped biological/conservation values, we plotted the frequency distribution of mean conservation scores of all PPGIS biological/conservation values for all lands in Victoria and the frequency distribution of the combined 2000 random points on public/non-public lands (see Fig. 6). If PPGIS participants simply guessed as to which areas had important conservation values, one would not expect to see significant improvement over the random distribution of points. This was not the case. About 71% of the PPGIS mapped biological/conservation values with mean conservation scores of 5.0 or greater compared with 46% of the random points. This represents an improvement of 25% over the random distribution benchmark. Overall, PPGIS mapped biological/conservation values were

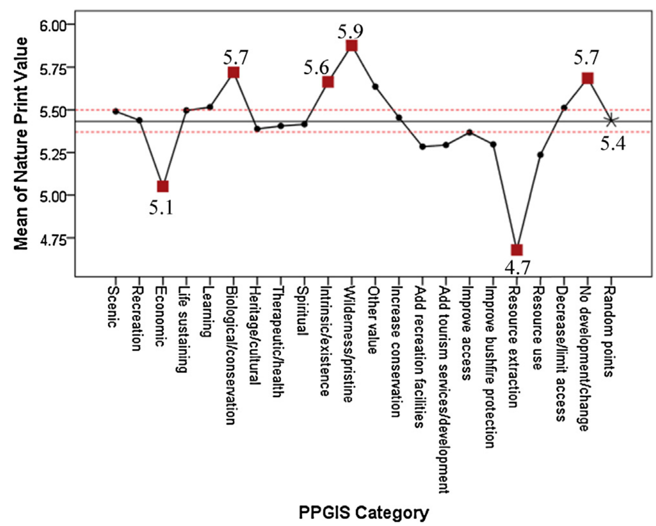

Fig. 4. Plot of mean NaturePrint v2.0 conservation values calculated for buffered areas around PPGIS mapped values and preferences on public lands with 1000 random generated points as benchmark (mean and 95% confidence intervals are indicated in the plot). Statistically significant differences (ANOVA, *LSD* post hoc, $p \leq 0.05$) between PPGIS attribute means and the random point mean appear as red square symbols while non-significant differences appear as black points. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

accurate with the NaturePrint data just over 70% of the time, and differ about 30% of the time.

Completeness

The completeness of the PPGIS data for biological/conservation purposes was assessed by identifying and quantifying the number and percentage of the 54 largest, contiguous areas of high conservation value that were also identified by participants. This analysis was completed for both PPGIS biological/conservation values and preferences. Fig. 7a displays a color-coded frequency distribution of PPGIS biological/conservation value "hits" or "misses" per high

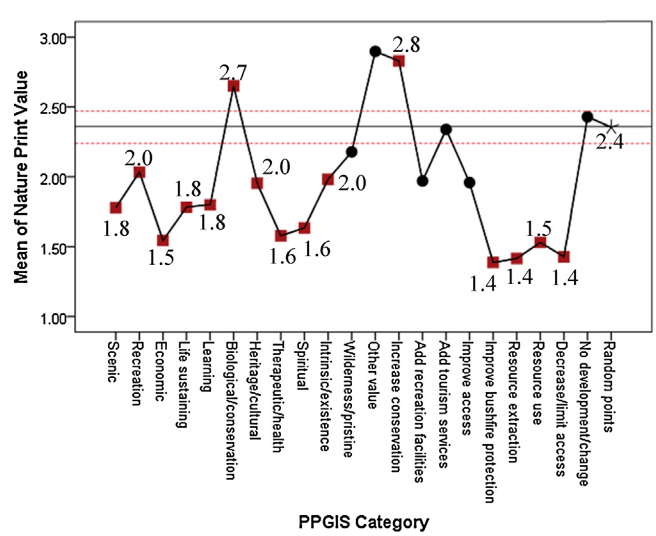

Fig. 5. Plot of mean NaturePrint v2.0 conservation values calculated for buffered area around PPGIS mapped values and preferences on non-public lands with 1000 random points as benchmark (mean and 95% confidence intervals). Statistically significant differences (ANOVA, *LSD* post hoc, $p \leq 0.05$) between PPGIS attribute means and the random point mean appear as red-square symbols while non-significant differences appear as black circles. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

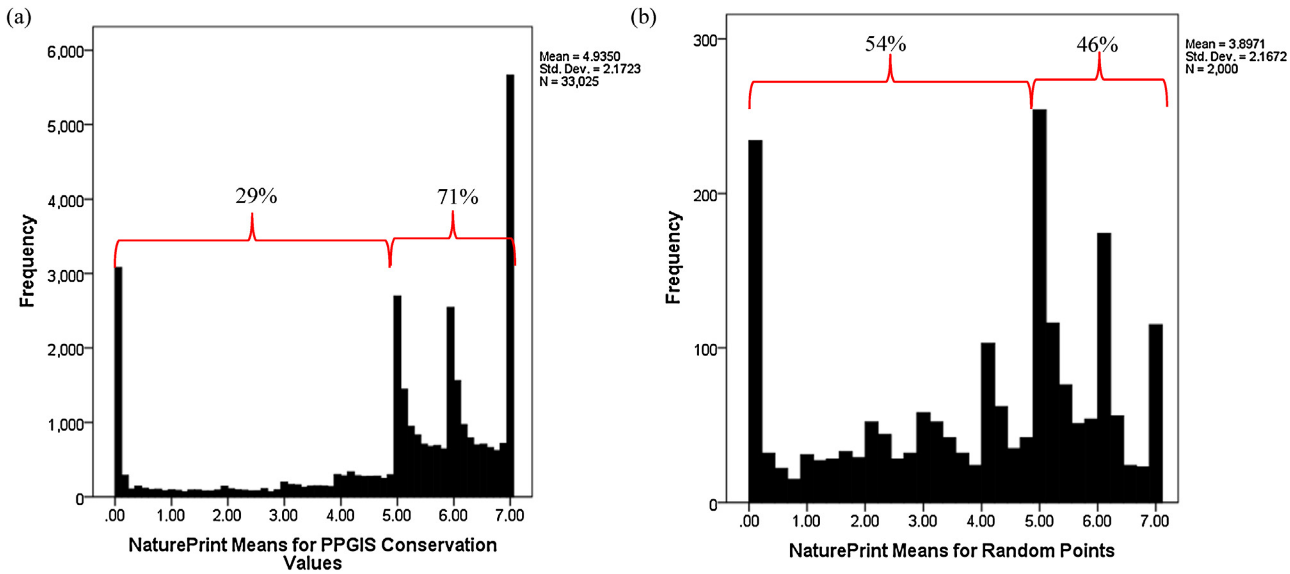

Fig. 6. Frequency distributions of NaturePrint v2.0 means for (a) buffered PPGIS conservation value points, and (b) buffered 2000 random points. Brackets show cumulative percentage of mean values in the ranges from 0 to 4.99 and 5.0 to 7.0.

conservation value polygon. Ten of the 54 polygons (19%) were not identified at all by PPGIS participants. These complete "misses" comprised small area polygons located in central Victoria (areas 17, 28, and 32) associated with state forests, and Murray River lands (areas 9, 19, 20, and 22) that form Victoria's northern border. The number of complete "misses" for conservation preferences (Fig. 7b) was somewhat larger (14 of 54 or 26%) and included many of the same areas that were missed for biological/conservation values.

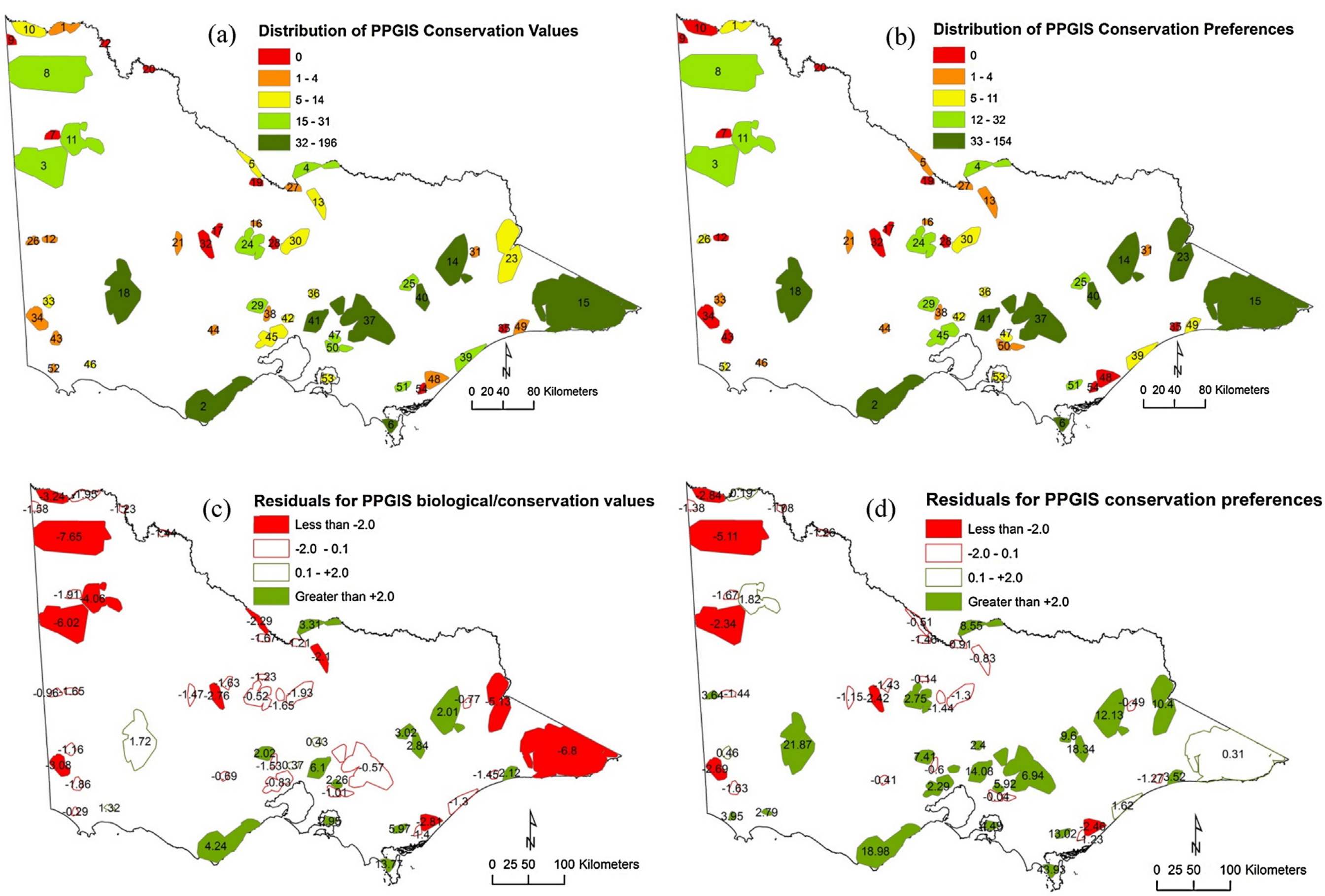

Fig. 7. Maps showing (a) the distribution of the quantity of PPGIS biological/conservation value points; (b) PPGIS conservation preference points (right) in the 54 largest contiguous areas of highly ranked conservation values derived from NaturePrint v2.0; (c) standardized residuals from chi-square proportional analysis of PPGIS conservation values; (d) standardized residuals of PPGIS conservation preferences. (For interpretation of the references to color in text, the reader is referred to the web version of this article.)

The standardized residuals provide a scaled assessment of hits/misses by indicating the extent to which the 54 polygon areas appear over- or under-represented by the number of PPGIS points mapped. For biological/conservation values, 11 of 54 polygons (20%) contained significantly fewer PPGIS value points than would be expected (residuals less than −2.0) given the size of the polygon areas (see Fig. 7c). With this analysis, larger polygon conservation areas appear under-represented in the results and include national parks in the eastern mountains (areas 15 and 23) and western mallee lands (areas 3, 8, and 11). For conservation preferences (Fig. 7d), six of 54 polygons (11%) were significantly under-represented in the PPGIS results. While large national park areas in the northwest (areas 3 and 8) remained significantly under-represented in conservation preferences, the two larger national park areas in the east were either proportional (area 15) or significantly over-represented (area 23). As a general spatial pattern, mountainous areas in the eastern half of Victoria were over-represented by conservation preferences while western areas were under-represented. Highly disproportionate conservation preferences (as indicated by large standardized residuals of 19 and 22) were mapped for areas 2 and 18 that match the Great Otways National Park and Grampians National Park respectively.

Discussion

The large number of PPGIS participants and volume of spatial data in this study provided the best opportunity to date to examine the spatial accuracy and completeness of crowd-sourced spatial data for potential use in conservation planning. Collectively, participants were about 70% accurate in identifying areas having high conservation importance and they identified about 80% of the largest contiguous areas of high conservation importance (54 areas). Given the size of the study area (almost 240,000 km^2) and the number of participants (1905), this degree of accuracy seems quite impressive. By way of comparison, in a smaller geographic area (England) with a more tangible construct (road networks), Haklay et al. (2010) found between 80% and 86% positional accuracy in an evaluation of VGI contributions to OpenStreetMap (OSM) and a positive, but not statistically significant relationship between the number of contributors and completeness. Our results beg the question of how accurate and complete crowd-sourced spatial data need to be for conservation planning and decision support.

In this study, the spatial error in identifying biological/conservation importance occurred disproportionately near urban areas and on non-public lands, while the missed conservation areas were smaller areas further from major population centers. The phenomenon of spatial discounting in which people identify more values near their home and fewer values at greater distance has been well-documented in multiple PPGIS studies (e.g., Brown et al., 2002; Pocewicz and Nielsen-Pincus, 2013). The large number of PPGIS participants from the greater Melbourne area resulted in disproportionate mapping of values in urban areas with less conservation importance (Fig. 3). This reflects a conundrum of the process. These urban parks and green spaces have considerable social value. The relative scarcity of these areas in an urban environment makes them significant on a local scale and appears to heighten their perceived conservation value to residents. In contrast, the expert conservation model, whose purpose is to evaluate conservation significance at a statewide level, discounts the conservation importance of urban green spaces due to fragmentation, the presence of common species, and the dominating influence of human activity. While urban areas may indeed hold lower values for wildlife, they play an important role in connecting people to nature, fostering conservation attitudes through direct experience, and educating youth about the environment. Thus, although urban areas may be viewed as a source of crowd bias in mapping biological value at a statewide scale, the spatial results may also reflect a broader perspective of the value of urban green spaces.

We further speculate that the results may have been somewhat different if the primary purpose of the PPGIS study was more narrowly focused on the mapping of biological/conservation values rather than a diverse range of landscape values and preferences. Non-public lands and smaller, geographically isolated areas that receive less public use represent “blind spots” for the crowd on the map. The lower public use of such areas may help explain the results. Spatial accuracy metrics for this study would be significantly improved by eliminating urban areas and non-public lands from the PPGIS results. Future studies aiming to identify conservation areas would benefit from a separate mapping exercise for major urban areas and/or options to select local versus statewide significant values, and a more exclusive focus on conservation (i.e., fewer PPGIS marker options).

The large spatial scale of the study area (Victoria) would seem to make full completeness an unlikely outcome under the best of conditions. The results indicate that the degree of completeness is not spatially homogenous across the state with the northwest region, in particular, having lower completeness than other regions. One possible strategy for improving completeness in the PPGIS process would be to over-sample rural, regional residents who may have greater experience and knowledge of the biological features of regional landscapes by virtue of their proximity. This strategy is consistent with one of the pre-conditions for achieving crowd wisdom—decentralization—where people are able to draw on local knowledge (Surowiecki, 2005). It would also appear advisable to spatially partition the state into smaller regions to assess completeness at a scale that would actually be used for conservation planning initiatives. The level of completeness found in this study would suggest that crowd-sourced spatial data for public lands is sufficient for conservation planning where the aim is to reduce conflict and produce socially acceptable conservation outcomes (Redpath et al., 2013; Whitehead et al., 2014).

The PPGIS mapping of wilderness/pristine value was somewhat more accurate than biological value in identifying modeled areas of high conservation importance. In the Victorian context, this result appears logical because the wilderness areas mapped contain larger areas of native vegetation that are associated with greater conservation importance. Further, a higher percentage of wilderness markers (but smaller absolute number) were placed on public lands compared to biological/conservation markers (91% vs. 83%) thus increasing the spatial accuracy because public lands have significantly higher conservation importance than non-public lands in Victoria. To fully record the public’s perception of important conservations areas, it would be defensible to include both wilderness and biological/conservation markers in the analysis, at least in an Australian context, due to the conceptual overlap in the public interpretation of these values.

In Victoria, most public lands have relatively strong legal protection so future enhancements to conservation would likely focus on conservation importance located on non-public lands. But spatial error in identifying conservation importance on non-public lands was relatively high (Fig. 3b). Areas of high conservation importance on non-public lands tend to be small and fragmented. Using crowd-sourced PPGIS to identify the biological value of these smaller conservation areas on non-public lands, at least on a statewide scale, appears to be of questionable value for conservation planning compared to an expert-based assessment such as NaturePrint. An important research question is whether the spatial accuracy of biological value on non-public lands would improve with a smaller study area or with fewer marker options for people to map—remembering that respondents actually had 20 different constructs they were asked to map.

A further question concerns the value of using PPGIS to identify non-public land conservation *preferences*, rather than biological values. The spatial accuracy of mapped preferences on non-public lands was only slightly better, on average (Fig. 5). Conservation preferences, as a type of spatial opinion, need not be associated with areas of high conservation importance. For example, some preferences could be expressing support for restoration of biologically degraded areas, an important aspect of conservation planning. Indeed the definition provided to respondents was "increase conservation and protection here (e.g., due to encroaching development, feral animals/weeds, illegal use). This definition meant we were unable to distinguish between preferences to preserve high, but inaccurately identified biological values, or preferences to restore acknowledged low value biological areas. If the former, the crowd-sourced spatial information would reflect low quality public opinion rather than informed public judgment on future land use. Overall, our results suggest that using PPGIS to identify conservation target areas on non-public lands for systematic conservation planning that seeks to integrate social opportunities for conservation, has limited benefit without methodological improvement. Smaller-scale approaches that identify private land conservation opportunities targeting properties or individual landholders (Knight et al., 2010, 2011; Raymond and Brown, 2011) or that identify gaps in private land legal protection for conservation (Kamal et al., 2013) appear more beneficial to conservation planning for non-public lands. However, we regard our conclusion about the limited benefit of PPGIS preference data to identify conservation opportunities on non-public lands to be tentative because only 15% (about 5000 markers) of the total spatial data were preference data, a volume that is not adequate at a statewide scale.

One overriding assumption of this study is the accuracy of the NaturePrint conservation model. This model should be evaluated for spatial data quality and the validity of its assumptions. Expert spatial models and maps embody a set of assumptions about ecological patterns and processes (e.g., the use of corridors by wildlife) that are not always substantiated with empirical evidence. In this study, we treated the NaturePrint model as accurate and authoritative to benchmark the PPGIS spatial data, but in reality, the model is subject to revision based on new biological data, inventories, and understanding of ecological processes. Updated versions of the model can be evaluated with the same PPGIS data to determine how sensitive the accuracy and completeness results are to changes in the model. Further, the thresholds for determining spatial accuracy merit further consideration given the NaturePrint data is essentially rank data rather than ratio data on an absolute scale. For example, if the spatial accuracy threshold for the PPGIS data were set at 4.0 (or higher) for mean NaturePrint scores rather than 5.0, PPGIS spatial accuracy increases to almost 80%, while a cut-off of 6.0 yields spatial accuracy of about 62%.

Researchers have suggested that the benefit of PPGIS in conservation planning is to complement and strengthen scientific biological assessments by incorporating multiple sources of knowledge (systematic study, system-wide observations, and discrete local experiences) that provide for iterative adjustment of conservation priorities in the planning process (Brown et al., 2004). Whitehead et al. (2014) found that PPGIS mapped biological values and preferences can be integrated into a zonation model to produce conservation solutions with approximately equivalent biological value to biological data only models. However, our results suggest that integration of PPGIS data into spatial models for actual (not academic) conservation planning activities should first account for the spatial accuracy and completeness limitations identified in this study. At a minimum, PPGIS spatial model inputs should be modified (e.g., using weighting or exclusion) to adjust for the sources of spatial error (e.g., urban areas, non-public lands, and smaller, remote locations) that would potentially influence the modeled outcomes.

While the intended purpose and use of PPGIS data determines the required spatial accuracy and completeness, it is important to acknowledge that the PPGIS process can benefit conservation planning even with lower spatial data quality. PPGIS provides a convenient method that encourages public engagement in conservation issues. Public involvement in public land decisions, which is mandated in many countries, can lead to increased trust in management, increased support for management, and increased cooperation and compliance (Cox et al., in press). While PPGIS can't replace the need for expert knowledge, the process of having respondents address conservation issues serves important roles as identified by Cox et al. (in press). First, it provides a vehicle to increase capacity and engagement in conservation. The data generated can increase managers understanding of community perceptions of place-based ecosystem services to identify public information and communication needs. The apparent gaps in awareness indicated by the completeness results can provide a substantive basis for information campaigns to increase public appreciation and support for those areas that provide ecosystem services such as biological diversity that promote human well-being, but appear socially under-valued. Second, PPGIS data can identify strategic conservation opportunities that are likely to receive strong community support. For example, locations proximate to urban areas were perceived as more important by participants than experts and would likely receive strong community support for conservation initiatives. Finally, PPGIS data allow planners to predict areas of likely conflict (see Brown et al., 2014) which is valuable for the development of adaptive strategies and alternatives that are socially acceptable. Without discounting the importance of these significant participatory benefits, PPGIS data will need to demonstrate good spatial data quality to achieve widespread adoption for conservation planning and decision support given the prevailing social disposition that favors the use of experts over crowd-sourced information (Surowiecki, 2005).

Conclusion

In their future research agenda for PPGIS, Brown and Kyttä (2014) highlighted the need to identify and control threats to spatial data quality. The research described herein contributes to this objective within the context of conservation planning by quantifying and describing the spatial accuracy and completeness of PPGIS mapped biological/conservation values and preferences. As a limitation, the spatial error and completeness findings may not be directly transferable to other PPGIS spatial attributes in other types of land use planning. A further limitation is that use of PPGIS for conservation planning has yet to be field-tested in a real-world, conservation planning application. PPGIS is intended to provide valuable information for integration into planning processes and yet, PPGIS remains largely driven by academics who are seldom directly engaged in real-world planning applications. Although this PPGIS research was sponsored by a public land management agency, it remains to be seen if, and how the results will be used. Brown (2012a) described the multiple barriers that limit agencies from using PPGIS research including the expert/lay divide in which crowd-sourced knowledge is not trusted. Will these findings of 70% spatial accuracy and 80% completeness confirm or allay fears?

We return to the question posed in the study, "how accurate and complete does crowd-sourced spatial data need to be for conservation planning and decision support"? This is a judgment call without a definitive answer. In the case of planning for protected areas, we argue this data is likely "good enough" but we have highlighted several areas that require further refinement to enhance the use of PPGIS crowd-sourcing methods. The spatial accuracy and completeness of data for public lands, particularly protected areas, was noteworthy. PPGIS data is not intended as a substitute for expert opinion or conservation modeling. Its purpose is to identify potential solutions to complex socio-ecological planning problems through the spatial integration of conservation planning objectives with social values and development preferences. Our results are encouraging but the PPGIS methods will require further evaluation. Our key recommendations include implementing PPGIS at a spatial scale that is appropriate to the conservation planning area, narrow the scope of the PPGIS activity to focus on conservation to increase the mapping of conservation *preferences*, and provide for separate PPGIS processes for identifying conservation values and preferences that are tailored for urban areas. Further, as identified by Brown (2005), future research should be directed at better understanding the participants' state-of-mind when engaged in PPGIS mapping activity. For example, why were markers placed in some locations but not others, and to what extent does the absence of markers reflect an absence of value, a lack of familiarity with the area, or simply the inability to comprehensively identify all values and preferences in the operationalized PPGIS process? This type of research would provide important context for future PPGIS accuracy and completeness assessments.

References

Australian Bureau of Statistics, 2013. QuickStats, Available from http://www.censusdata.abs.gov.au/census_services/getproduct/census/2011/quickstat/2?opendocument&navpos=220 (accessed 27.04.14).

Bonn, A., Gaston, K., 2005. Capturing biodiversity: selecting priority areas for conservation using different criteria. Biodivers. Conserv. 14 (5), 1083–1100.

Brown, G., Reed, P., 2000. Validation of a forest values typology for use in national forest planning. Forest Sci. 46 (2), 240–247.

Brown, G., 2005. Mapping spatial attributes in survey research for natural resource management: methods and applications. Soc. Nat. Resour. 18 (1), 1–23.

Brown, G., 2012a. Public Participation GIS (PPGIS) for regional and environmental planning: reflections on a decade of empirical research. URISA J. 25 (2), 5–16.

Brown, G., 2012b. An empirical evaluation of the spatial accuracy of public participation GIS (PPGIS) data. Appl. Geogr. 34, 289–294.

Brown, G., 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. Soc. Nat. Resour. 27 (1), 36–54.

Brown, G., Fagerholm, N., 2014. Empirical PPGIS/PGIS mapping of ecosystem services: a review and evaluation. Ecosyst. Serv., http://dx.doi.org/10.1016/j.ecoser.2014.10.007 (in press).

Brown, G., Kyttä, M., 2014. Key issues and research priorities for public participation GIS (PPGIS): a synthesis based on empirical research. Appl. Geogr. 46, 122–136.

Brown, G., Reed, P., Harris, C., 2002. Testing a place-based theory for environmental evaluation: an Alaska case study. Appl. Geogr. 22 (1), 49–77.

Brown, G., Smith, C., Alessa, L., Kliskey, A., 2004. A comparison of perceptions of biological value with scientific assessment of biological importance? Appl. Geogr. 24 (2), 161–180.

Brown, G., Weber, D., de Bie, K., 2014. Assessing the value of public lands using public participation GIS (PPGIS) and social landscape metrics. Appl. Geogr. 53, 77–89.

Cox, C., Morse, W., Anderson, C., Marzen, L., 2014. Applying public participation geographic information systems to wildlife management. Hum. Dimen. Wildl. 19 (2), 200–214.

Cox, C., Morse, W., Anderson, C., Marzen, L., (in press) 2014. Using public participation geographic information systems to identify places of watershed service provisioning. J. Am. Water Resour. Assoc.

DEPI—Department of Environmental and Primary Industries, 2013a. Victorian Crown Land Area Statement, Available from http://www.depi.vic.gov.au/__data/assets/pdf_file/0006/199068/FactSheet_CrownLandVictoria_20130821FINAL.pdf (accessed 08.01.14).

DEPI—Department of Environmental and Primary Industries, 2013b. Introduction to NaturePrint: A Blueprint for Nature Conservation, Available from http://www.depi.vic.gov.au/__data/assets/pdf_file/0012/220404/NaturePrint-v2-Introduction-facts-sheet.pdf (accessed 08.01.14).

DEPI—Department of Environmental and Primary Industries, 2013c. NaturePrint v2.0: Elements and Integration, Available from http://www.depi.vic.gov.au/__data/assets/pdf_file/0011/220403/NaturePrint-v2-Explanation-of-elements-and-integration-facts-sheet.pdf (accessed 08.01.14).

Girres, J., Touya, G., 2010. Quality assessment of the French OpenStreetMap dataset. Trans. GIS 12 (4), 435–459.

Goodchild, M.F., 2007. Citizens as sensors: the world of volunteered geography. GeoJournal 69 (4), 211–221.

Haklay, M., 2010. How good is volunteered geographical information? A comparative study of OpenStreetMap and ordnance survey datasets. Environ. Plan. B 37, 682–703.

Haklay, M., Basiouka, S., Antoniou, V., Ather, A., 2010. How many volunteers does it take to map an area well? The validity of Linus' law to volunteered geographic information. Cartogr. J. 47 (4), 315–322.

Kamal, S., Grodzinska-Jurczak, M., Brown, G., 2013. Conservation on private land: a review of global strategies with a proposed classification system. J. Environ. Plan. Manage., Available from http://www.tandfonline.com/doi/full/10.1080/09640568.2013.875463

Knight, A.T., Cowling, R.M., 2007. Embracing opportunism in the selection of priority conservation areas. Conserv. Biol. 21 (4), 1124–1126.

Knight, A.T., Cowling, R.M., 2008. Clearing the mud from the conservation opportunity debate: reply to Pressey and Bottrill. Conserv. Biol. 22 (5), 1346–1348.

Knight, A.T., Cowling, R.M., Difford, M., Campbell, B.M., 2010. Mapping human and social dimensions of conservation opportunity for the scheduling of conservation action on private land. Conserv. Biol. 24 (5), 1348–1358.

Knight, A.T., Grantham, H.S., Smith, R.J., McGregor, G.K., Possingham, H.P., Cowling, R.M., 2011. Land managers' willingness-to-sell defines conservation opportunity for protected area expansion. Biol. Conserv. 144 (11), 2623–2630.

Lechner, A., Brown, G., Raymond, C., (in press) Modeling the impact of future development and public conservation orientation on landscape connectivity for conservation planning. Landscape Ecol.

Margules, C.R., Nicholls, A.O., Pressey, R.L., 1988. Selecting networks of reserves to maximise biological diversity. Biol. Conserv. 43 (1), 63–76.

Margules, C.R., Pressey, R.L., 2000. Systematic conservation planning. Nature 405 (6783), 243–253.

Moilanen, A., Possingham, H.P., Wilson, K.A., 2009. Spatial Conservation Prioritization: Quantitative Methods and Computational Tools. Oxford University Press, Oxford, UK.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., Da Fonseca, G.A., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403 (6772), 853–858.

Pocewicz, A., Nielsen-Pincus, M., 2013. Preferences of Wyoming residents for siting of energy and residential development. Appl. Geogr. 43, 45–55.

Pressey, R.L., Johnson, I.R., Wilson, P.D., 1994. Shades of irreplaceability: towards a measure of the contribution of sites to a reservation goal. Biodivers. Conserv. 3 (3), 242–262.

Pressey, R.L., Humphries, C.J., Margules, C.R., Vane-Wright, R.I., Williams, P.H., 1993. Beyond opportunism: key principles for systematic reserve selection. Trends Ecol. Evol. 8 (4), 124–128.

Pressey, R.L., Bottrill, M.C., 2008. Opportunism, threats, and the evolution of systematic conservation planning. Conserv. Biol. 22 (5), 1340–1345.

Raymond, C.M., Brown, G., 2011. Assessing conservation opportunity on private land: socio-economic, behavioral, and spatial dimensions. J. Environ. Manage. 92 (10), 2513–2523.

Redpath, S.M., Young, J., Evely, A., Adams, W.M., Sutherland, W.J., Whitehouse, A., Amar, A., Lambert, R., Linnell, J., Watt, A., Gutiérrez, R.J., 2013. Understanding and managing conservation conflicts. Trends Ecol. Evol. 28 (2), 100–109.

Sherrouse, B.C., Clement, J.M., Semmens, D.J., 2011. A GIS application for assessing, mapping, and quantifying the social values of ecosystem services. Appl. Geogr. 31 (2), 748–760.

Sieber, R., 2006. Public participation geographic information systems: a literature review and framework. Ann. Assoc. Am. Geogr. 96, 491–507.

Smith, P.G., Theberge, J.B., 1986. A review of criteria for evaluating natural areas. Environ. Manage. 10 (6), 715–734.

Spielman, S.E., 2014. Spatial collective intelligence? Credibility, accuracy, and volunteered geographic information. Cartogr. Geogr. Inform. Sci. 41 (2), 115–124.

Surowiecki, J., 2005. The Wisdom of Crowds. Anchor, New York.

Veregin, H., 1999. Data quality parameters. In: Longley, P.A., Goodchild, M.F., Maguire, D.J., Rhind, D.W. (Eds.), Geographical information systems, Vol. 1, 2nd Ed. Wiley, New York, NY, pp. 177–189, Chap. 12.

Weber, D., Brown, G., 2014. Identifying and Mapping the Values of Victorian Public Lands. University of Queensland and University of South Australia, Available from http://www.landscapemap2.org/publications/StatewidePVreport2014.pdf (accessed 08.01.14).

Whitehead, A.L., Kujala, H., Ives, C.D., Gordon, A., Lentini, P.E., Wintle, B.A., Nicholson, E., Raymond, C.M., 2014. Integrating biological and social values when prioritizing places for biodiversity conservation. Conserv. Biol. 28, 992–1003.

Zielstra, D., Zipf, A., 2010, May. A comparative study of proprietary geodata and volunteered geographic information for Germany. In: 13th AGILE International Conference on Geographic Information Science, Guimarães, Portugal, Available from http://agile2010.dsi.uminho.pt/pen/ShortPapers_PDF%5C142_DOC.pdf (accessed 08.01.14).