



Evaluating the role of spatial landscape literacy in public participation processes and opinions on environmental issues and ecosystem services

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Abstract

Little is known about how spatial literacy influences mapping and decision-making related to environmental management and ecosystem services. We assessed the role of spatial landscape literacy in participatory environmental management and ecosystem service assessments in peri-urban Bogota, Colombia. Spatial landscape literacy (SL) was evaluated by testing stakeholder's ability to locate specific landscapes and landmarks. We then assessed if opinions on environmental decisions and ecosystem services were significantly related to SL. We used an online instrument to capture 2,397 respondent's socioeconomic characteristics, SL, ecosystem service perceptions, and opinions concerning relevant environmental issues. We evaluated and measured respondents' self-perceived SL and ability to locate four landscapes in an integrated online map. Positional accuracy was calculated using a Spatial Landscape Literacy Index (SLI). We then tested for effects of socio-demographics on SLI, modeled the relationship between socio-demographics and SL, and tested the relationship between respondents' SL and their opinions on relevant environmental issues and ecosystem services. We found that about 75% of the respondents correctly located 2 of the 4 landscapes. The SLI model was also poorly predicted by socio-demographic variables. However, we found significant relationships between SLI and opinions concerning the environment. No relationship was found between respondents' levels of active participation in local governance and SLI. Overall, SL was little affected by education levels. Participatory processes using maps should ideally measure SL and not assume a priori that participants are spatially literate. Further research is needed to evaluate how spatial technologies and understanding stakeholder's values towards the environment can democratize participatory-based decision-making.

Keywords Public Participatory GIS · Landscape planning · Environmental management · Bogota Colombia · Spatial literacy

Introduction

Participatory environmental management, Geographical Information Systems (GIS), and Public Participatory GIS (PPGIS) studies have assessed the dynamic among landscapes, their processes and ecosystem services, as well as society's needs, perceptions, and values towards these (Brown and Kyttä 2018; Fagerholm et al. 2019b; Hui and Wescoat 2019). Key to these assessments is the use and application of spatially explicit information, primarily maps, and in-person participatory processes with stakeholders to locate, identify, capture and understand people's knowledge of landscapes (Aggrey et al. 2021; Brown and Kyttä 2018). Although most of these studies are from higher income countries in North America, Europe, and Australia, participatory methods are similarly used for landscape planning

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and ecosystem management in middle- and lower-income countries (Hui and Wescoat 2019; Rambaldi et al. 2006). However, there are much fewer studies from such countries, particularly using online technologies in more urban settings. Further, very little is known about the spatial and cognitive abilities of participants in these contexts (Escobedo et al. 2020).

A similar body of literature has begun using PPGIS methods to measure stakeholder's needs or demands for different ecosystem services from landscapes (e.g., Palomo et al. 2014; Burkhardt et al. 2012; Darvill and Lindo 2015; Damastuti and de Groot 2019). These methods generally integrate GIS technology into decision-making processes as well as to study citizen's preferences and demand for nature's ecosystem services and benefits (Brown et al. 2012; Do et al. 2020). Some studies have documented that such a participatory approach, grounded in personal experience, is particularly appropriate for the assessment of provision and cultural ecosystem services (Fagerholm and Käyhkö 2009; Fagerholm et al. 2019a). A characteristic of many of these studies is their focus on rural areas, while fewer are from urban settings and use online technologies. Some of these studies have also indicated participant's inability to cognitively understand complex ecological processes (Bagstad et al. 2016).

Other PPGIS-related literature has also noted participant's inability to precisely locate and map landscapes and points of interest related to ecosystem processes (Escobedo et al. 2020). Such studies regarding people's understanding of landscapes and ecosystem processes also assume a priori that participants have sufficient cartographic or geographic information and knowledge, to make them spatially literate (Aggrey et al. 2021; Do et al. 2020; García-Díez et al. 2020; Reilly et al. 2018). Outside the environmental and resource management literature, other disciplines such as psychology, neurosciences, geography (including cartography), and computer science have also studied the role of spatial cognition and map reading in people's acquisition of spatial knowledge and their ability to navigate or place and locate themselves in space, encode the environment, and their literacy using cartographic images (Golledge 1993; Ramadier and Bronner 2006; Tu Huynh and Doherty 2007). Indeed, this aspect of the role of spatial literacy has been little studied in the ecosystem services and environmental planning literature.

In addition to spatial literacy, conflict and power structure among stakeholders, particularly in small group participatory or deliberative PPGIS exercises and settings, can affect the legitimacy and results of the planning and decision-making process (Ernstson 2013; Brown et al. 2017; Trimble and Lázaro 2014). Indeed, much of the PPGIS literature is based on workshops or group exercises, where facilitators observe and capture information or use

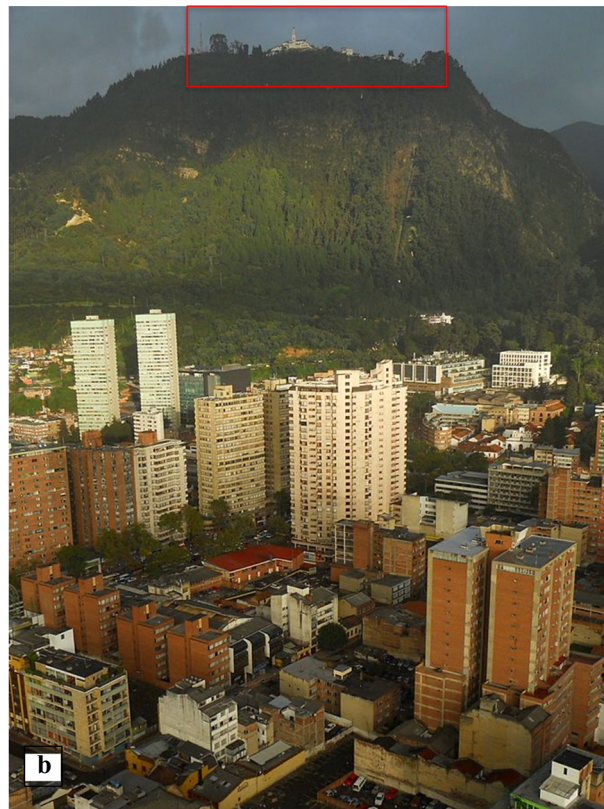
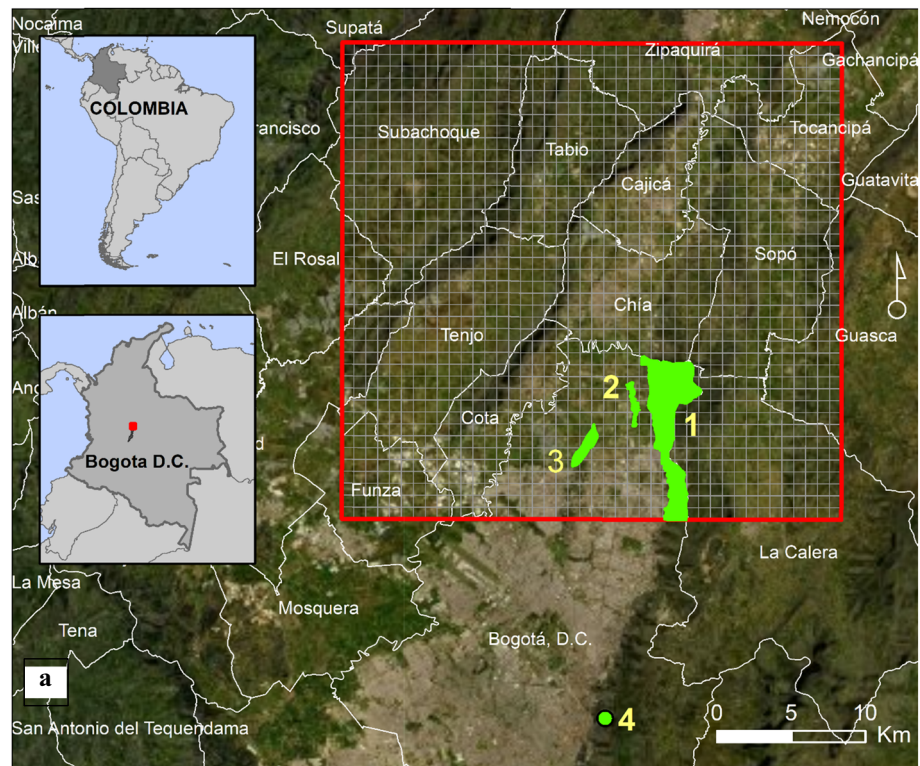
the spatial information that is generated from these (Fagerholm et al. 2019b; Reilly et al. 2018). However, politically active or well-informed stakeholders and more urban educated participants (Liu and Opdam 2014) have been reported to more consistently and actively participate in PPGIS processes using spatially explicit information and often influence decisions, regarding management, planning, and ecosystem services but again, little is known about how spatial literacy might be affecting the PPGIS outcomes (Brown et al. 2017).

More recently, online resources (e.g., web and mapping tools, geo-browsers) and social media are being used as part of these participatory processes to capture information regarding spatial planning and for other decision-making tasks (Mosso et al. 2020). Online surveys are more common, however, their integration with interactive spatially explicit information acquisition options are scarce (Escobedo et al. 2020). The use of these online, web-based surveys with interactive maps and images could potentially be used to: increase sample size, maintain respondent's privacy, minimize influence by other participants, increase respondents participation, and even improve the ability to capture and assess respondent's cognitive recognition of landscape attributes and positional accuracy of features (McCall and Dunn 2012).

A few studies have started using these spatially explicit online instruments to assess and analyze citizen perception of landscapes, sociodemographic variables, and spatial aspects of the environment and ecosystems. Studies such as those of Brown et al. (2012), Brown et al. (2014), and Brown et al. (2014) used online questionnaires with a Google Maps® Application Programming Interface (API) to display an online map where participants were requested to drag-and-drop icons in response to different questions. By additionally accounting for data quality and participant bias, such studies provide several examples of how PPGIS using spatially explicit online surveys can be used to study how landscape characteristics relate to ES supply and demand. Heikinheimo et al. (2020) for example, used georeferenced social media data (e.g., Instagram, Flickr, sport tracking data, mobile phone data) with a survey, to analyze people's use of Helsinki's (Finland) green spaces; thereby measuring preferences, attention spans for certain attributes, hourly use, and areas of interest. On the other hand, Brown and Kyttä (2018) have highlighted the need to evaluate PPGIS results to provide evidence of the effectiveness or success or participatory processes, particularly in the Global South. However, participant's spatial literacy in these approaches or studies has been rarely evaluated, particularly in regions outside the Global North (Trimble and Lázaro 2014).

Therefore, our study aim is to evaluate the role of spatial landscape literacy in participatory environmental management and ecosystem service assessment processes as well as

Fig. 1 Study area displayed in the survey instrument. **a** Municipality boundaries and grid used in the on-line survey (red rectangle) and selected landscapes of interest (light green polygons): (1) Cerros Orientales (portion inside the grid); (2) Humedal Torca Guaymaral; (3) Cerro de la Conejera; (4) Cerro de Monserrate. **b** Photos of the Monserrate landmark (Indicated by the red square) and Cerros Orientales landscape visible from most sectors in Bogotá, Colombia (Source Felipe Restrepo Acosta- Creative Commons License in: https://es.wikipedia.org/wiki/Archivo:Cerro_de_Monserrate_en_Bogot%C3%A1.JPG).



survey instruments based on maps and digital geographical representations. The specific objectives of this research are threefold. First, we assess if the use of on-line spatial

information influences the decision-making process of stakeholders involved in landscape-scale ecosystem management and planning. Second, we evaluate spatial landscape

literacy by testing different stakeholder's ability to identify and precisely locate specific landscapes. And finally, we explore if different stakeholder's opinions about ecosystem services and the environment are significantly related to measured spatial landscape literacy.

Material and methods

Study area

The study area is located in peri-urban Bogota within the “Sabana de Bogotá”, a high elevation plain in the Department of Cundinamarca, Colombia (Fig. 1). The region is a mountain plateau in the eastern Andean Cordillera with an average elevation of 2600 m a.s.l., with mountain peaks reaching 3500 m. Precipitation varies from ~600 to ~1200 mm/year in its western slopes, and the yearly average temperature is around 14 °C (Mendoza and Etter 2002). Mountainous vegetation to an elevation of 3300 m is dominated by high-Andean shrubs and trees of the *Weinmannia*, *Clusia*, and *Cedrela* genera (Cortés et al. 1999). Above ~3500 m, *paramo* tropical highland grasslands dominate the landscape. The region is characterized by a highly disturbed, fragmented, and urbanized landscapes, with widespread presence of secondary forests and *Pinus* spp. and *Eucalyptus* spp. plantations (Clerici et al. 2019).

The socio-ecological dynamics of the region are largely influenced by the economic activities in Bogotá, home to over 7.5 million inhabitants (DANE 2018). The peri-urban study area is an important center of Colombia's economic activities and is characterized by agricultural production (with dominant crops of potatoes, vegetables, sugarcane), livestock, industrial activities such as leather processing, and urban development (CAR 2017; Rubiano et al. 2017). The area used for the online survey instrument is rectangular and extends from coordinates −74.21 Latitude (Lat), 5.02 Longitude (Long) to −73.91 Lat, 4.73 Long; it covers around 1075 km² and intersects the northern limits of Bogotá and several other ex-urban municipalities (grid in Fig. 1). The four landscapes in the analysis are: the “Cerros Orientales”, an elongated periurban forested reserve with some touristic trekking paths; the “Cerro de la Conejera” and “Humedal Torca Guaymaral”; two accessible and smaller sized protected areas in the north of Bogotá, and the “Cerro de Montserrate”, an iconic touristic location close to the Bogotá's city center (Fig. 1b). The latter is located outside the grid (Fig. 1, point 4).

Survey design and implementation

The approaches used by Brown (2012), Fagerholm et al. (2019a), and Escobedo et al. (2020) were used to design the

survey instrument and to select subsequent variables for analyses. We used an online Qualtrics instrument to capture the respondent's socioeconomic characteristics, spatial landscape literacy (as defined in the following section), ecosystem service perceptions, and opinions concerning key environmental issues in the study area. Additional information regarding respondent's opinions on potential land-use activities, resource allocation for ecosystems services and willingness to pay questions were not included in this analysis as they were not relevant to our study objectives. We developed some specific response items to capture locally relevant environmental issues related to land use planning in northern Bogota related to wetlands, green spaces, and urban development. Then based on Hunt (2015) and Ernst's (2019), respondents were asked their opinion concerning these issues regarding ecosystem benefits and environmental planning related to landscapes in the study area, and their participation in environmental decision making. Specifically, their responses regarding the following seven issues were recorded using a 5-point Likert scale (1: “I totally disagree” to 5: “I totally agree”): “Cities are the opposite of nature”, “It is possible to use forests and wetlands as public spaces”, “Healthy and protected forests mitigate floods”, “Local authorities are adopting suitable measures to protect forests”, “I actively participate in decision-making concerning my community”, “Local community action groups allow me to effectively participate in environmental policies”, and “Local forests are well protected”.

With regard to such questions, we were especially interested in three main aspects: perception of nature by the respondents (Kahriman-Ozturk et al. 2012; Yu-Jen 2010), their measured perception about the utility of ecosystem service benefits (Priego et al. 2008) and the perception of the respondents on the usefulness of the participatory process related to environmental decisions (Willock et al. 1999). The survey instrument also integrated a spatially explicit, interactive map. Specifically, we used the Qualtrics platform to program a map of the study area with a superimposed digital grid with 1,800 sixty-ha squared cells (45 × 40 cell grid) over a high-resolution satellite image (100 m × 100 m). With this gridded map, respondents could locate and identify the selected landscapes and landmarks related to the items in the survey. The survey instrument was initially pre-tested with 14 experts. Once issues identified by experts were addressed, an E-mail address list from Bogotá's District Secretariat for Planning was compiled and a link to the Qualtrics survey was sent via E-mail during November 2018–February 2019. Reminders to complete the survey were sent in mid-December and early January. We collected a total of 4,532 responses, and of these 2,397 respondents answered all the questions directly related to our three study objectives. Once data were checked for

quality (e.g., complete answers, same individual responded to all relevant questions), we used a sample of 1,132 respondents for subsequent analyses. We used two different data tables: one concerning the spatial landscape literacy and socio-demographic variables, and the other one regarding opinions on environmental issues and ecosystem services.

Spatial landscape literacy

As part of the survey instrument we described in the previous section, we evaluated a respondent's spatial landscape literacy, or their familiarity and ability to identify and accurately locate landscapes and their inherent processes on a digital image-based map. This definition integrated concepts of both *spatial literacy* as defined by Xie et al. (2018) and Escobedo et al. (2020) and *landscape literacy* (Whiston Spirn 2005; Perez 2019). Specifically, we evaluated spatial landscape literacy using three steps and the spatially explicit on-line, satellite image-based map overlaid with the 1,800 individual cells grid. First, we asked respondents about their self-perceived ability to locate sites and landscapes on the map (i.e., assessing spatial landscape literacy), using a 5-point Likert scale. Second, we asked them if a well-known landmark in Bogota was located on the study area map- which it was not. Specifically, we asked them if the Cerro de Monserrate (Monserrate hereafter) located 13.5 km south and well outside the study area, was visible on the study area map or not. Monserrate was included as it is one of the most recognized landmarks in Bogota and is visible from most areas in the city (Fig. 1b; at the time of writing, its Instagram® hashtag “#monserratebogota” had more than 20 thousand posts). This specific question and landmark were used to assess if respondents could discern the specific study area and exclude spatial information outside the area of interest.

We then asked respondents to identify and locate three well-known landscapes inside the study area (Fig. 1; Appendix A). The respondents could select 1 of the 1,800 cells on the map as the location of each landscape. Landscapes were selected because of their visibility (e.g., Cerros Orientales), references in social media (over 11,000 hashtag photos just in Instagram), and—at the time of writing—recent controversies and news coverage related to proposed urbanization and infrastructure projects, and subsequent protests by environmental organizations, in the “Thomas Van der Hammen” protected area close to these three landscapes. Again, the “Monserrate” location was not displayed on the map (Fig. 1), but respondents were asked if the location was actually located in the study area or not. Conversely, the other three landscapes were physically visible on the on-line map. After being asked about their self-reported mapping ability using a 5-point Likert scale

Table 1 Socio-demographic variables used in the statistical analyses

Variable	Type of variable	Summary
Age of the respondent	Numeric	Median: 30 min: 13 Max: 94
Gender of the respondent	Categorical: male or female	Male: 1093 Female: 1304
Proportion of lifetime lived in the study zone	Numeric (proportion between 0 and 1)	Median: 0.9 min: 0 Max: 1
Has the respondent lived in the study zone during the last five years?	Logical (Yes or No)	Yes: 1790 No: 607
Current activity of the respondent	Categorical: employee, unemployed, independent or student	Employee: 854 Unemployed: 170 Independent: 395 Student 978
Education level	Ranked categorical: Primary < Secondary < Undergraduate < Specialization < Master < Doctorate	Primary: 4 Secondary: 529 Undergraduate: 1333 Specialization: 327 Master: 149 Doctorate: 22
Developed settlement	Categorical: rural, suburban, or urban	Rural: 132 Suburban: 126 Urban: 2139
Wage levels	Numeric: number of minimum wage earned (here from 1 to 10)	Median: 5 min: 1 Max: 10

(1 = low, 5 = high), the respondents were instructed to locate: “Cerros Orientales”, “Cerro de la Conejera” and “Humedal Torca Guaymaral” on the grid overlaid on to the map (Fig. 1; Appendix A). In order to measure the actual positional accuracy of the three landscapes identified by the respondents, we used Eq. 1 to calculate accuracy (A) for each landscape (x) as:

$$A_x = 1 - \frac{d}{d_{\max}} \quad (1)$$

Where d is the distance between (1) the cell identified by the respondent for the landscape in question and (2) the closest limit of the georeferenced polygon depicting the actual and official boundaries of each landscape. Whereas the distance between the most distant cell to the actual boundary of each landscape was $d_{\max}$. Using Eq. 2 we calculated spatial accuracy across the four landscapes of interest, and we integrated them into a Spatial Landscape Literacy Index (SLI);

$$SLI = \frac{C_{\text{Monserrate}} + A_{\text{CerroConejera}} + A_{\text{CerrosOrientales}} + A_{\text{HumedalTorca}}}{4} \quad (2)$$

where $C_{\text{Monserrate}}$

{1 if the respondent answered that Monserrate was not on the map(correct)}

{0 if the respondent answered that Monserrate was on the map(correct)}.

Statistical analyses

The initial part of the instrument asked for respondent’s socio-demographics including: Age, Gender, Number of years of living in the Bogota area, Residence in the study area (yes/no), Type of employment, Education level, Urban or rural residence, and Income (see Table 1 in Section 3.1). Significant differences were tested using pairwise Mann–Whitney tests with a confidence level of 95% and a Holm method p -value correction for multiple tests. We then tested for the effect of socio-demographic determinants on the SLI index using a Generalized Linear Model (GLM) with a gamma distribution of errors and an “identity” model link function, since we observed strongly skewed residuals from an initial simple linear Analysis of Covariance (ANCOVA). We calculated the 95% confidence interval of each coefficient by profiling the likelihood function used for estimating the parameters of the model. Variables with coefficient confidence intervals that did not cross 0 were considered significant.

We modeled the relationship between a respondent’s socio-demographics and their self-reported level of spatial landscape literacy. For this analysis, we used an ordinal logistic regression (Agresti 2012), which allows us to predict ordinal response and to attribute coefficient to the dependent input variables. We also calculated odd-ratios associated with the different socio-demographic variables and their confidence intervals by profiling the likelihood function used for estimating the parameters of the model. Odd-ratios represent the change in odds for a unit of increase in a continuous predictor, or for a level of a categorical ratio (e.g., a odd-ratio of value 2 means that there is twice the probability of a higher level in the categorical response variable of the model). Variables with odd-ratio confidence intervals that did not cross 1 were considered significant.

In the analyzed models, the different levels of the non-ordinal categorical variables (see Table 1 Section 3.1) were compared using a “treatment” contrast where each variable’s level was compared to a reference level (i.e., “female” for the gender; “employed” for the activity; “rural” for the urban/rural residence). Ordinal variables were compared using a Helmert contrast where each level was compared to the lower levels. Because some socio-demographic variables may be dependent on each other, some collinearity problems may emerge in the linear models. However, all the variables analyzed showed a Variance Inflation Factor (VIF) below 5.0 (a VIF of 10 is considered a threshold in these types of models; Hair et al. 2010). Finally, we tested the relationship between respondent spatial landscape literacy and their opinions on environmental issues using the Kruskal–Wallis rank test and Likert scale values for each of the seven statements and their SLI. All statistical analyses were run using R version 3.6.1 (R Core Team 2019).

Results

Descriptive statistics

Table 1 below describes the socio-demographic variables that were used in the study, as well as basic information about the respondents. Overall, respondents were mostly urban, had higher levels of education, and lived in the study area. However, because of the large number of responses, we were able to analyze the effects of different demographics.

Evaluating the spatial landscape literacy of the respondents

Table 2 shows two metrics of respondent spatial landscape literacy for each of the four sites: number of incorrect answers and the average distance between measured and

incorrect self-reported locations. About 75% of the respondents could correctly locate 2 of the 4 landscapes. The proportion of incorrect answers differed depending on the specific landscape (Table 2). For example, only 17.31% of the respondents incorrectly reported that Monserrate was on the map, while 89.53% of the respondents incorrectly located the smaller and less well-known wetland Humedal Torca-Guaymaral.

Our SLI index model was generally found to be poorly predicted by the socio-demographic variables (pseudo-R squared based on likelihood ratio of 0.02). But, respondents who positively and significantly influenced the SLI index were those with: an independent professional activity, (as compared to those from other employment categories), living in an urban development (as compared to a rural settlement) and with higher wages. Neither the proportion of lifetime lived in the study region, whether they had lived in the study area for the last five years, or their education level were significant in the model.

Evaluating perceived versus measured spatial landscape literacy

The relationship between self-reported spatial landscape literacy and the measured SLI was significant (Kruskal–Wallis statistic: $\chi = 117.61$, p -value < 0.0001). However, the relationship described in Fig. 2a, shows that the different levels of self-reported spatial landscape literacy correspond to largely overlapping ranges of SLI, demonstrating its very low predictability for SLI. The model predicting self-reported spatial landscape literacy according to socio-demographic variables, showed a higher quality of prediction (Likelihood ratio based pseudo square of 0.14) than the model predicting the measured SLI index (Likelihood ratio based pseudo R-squared of 0.02). Eight odd-ratio coefficients were significantly different to 1 in the models (Fig. 2c): male, people having lived a larger proportion of their lifetime in the study area, people who lived in the study area for the last five years, with graduate or master education levels, urban and higher wage, showed a significant positive effect on the orientation abilities, while unemployed people showed lower levels of orientation abilities.

Both a higher wage and living in an urban settlement had a positive effect on the SLI and self-reported spatial landscape literacy, but otherwise the socio-demographic variables that affect the SLI are not the same as the one having an effect on self-reported spatial landscape literacy (Fig. 2b, c). An independent activity as employment resulted in a significantly higher SLI for the respondent, but not a significantly higher level of self-reported spatial landscape literacy. Respondents living close to the sites, with an undergraduate and master level of education resulted in respondents with higher self-reported spatial landscape literacy without significantly improving their SLI. Finally, unemployed respondents had a

Table 2 Respondent's spatial landscape literacy in terms of: (A) number of correct answers and average distance between exact location and incorrect answers. An answer is considered incorrect when the selected grid cell does not intersect the specific green area, and (B) cross table of number of respondents and number of overall correct answers

(A)		
Studied landscapes	Number of incorrect answers	Mean distance of incorrect locations (m)
Monserrate	415 (17.31 %)	N/A ^a
Cerros Orientales	840 (35.04 %)	6452.25
Cerro de la Conejera	1852 (77.26 %)	6804.62
Humedal Torca-Guaymaral	2146 (89.53 %)	5322.21
(B)		
Number of overall correct answers	Number of respondents	Percentage
0	113	4.71 %
1	813	33.92%
2	991	41.34%
3	380	15.85%
4	100	4.17%

^aRespondents were only asked whether Monserrate was in the map, not to locate it; thus mean distances could not be calculated

lower self-reported spatial landscape literacy, but their SLI was not significantly lower than those of employed respondents in the model.

Relationships between spatial landscape literacy, stakeholder opinions, and participation in policy processes

Overall, we found significant relationships between SLI and different opinions concerning the environment and issues related to ecosystem services (see Table 3). However, no relationship was found between the levels of active participation of the respondents in local governance and policies and their spatial landscape literacy (i.e., the last 2 items in Table 3).

Discussion and conclusion

Although deliberative and open participation is key for PPGIS, in this study we used a spatially explicit online survey instrument, with an interactive on-line map, to evaluate an individual respondent's self-reported (i.e., perceived) spatial landscape literacy versus the actual and measured ability using a SLI. Different demographic variables were then tested against the SLI. Additionally, we evaluated if spatial landscape literacy influenced stakeholder's opinions and participation in

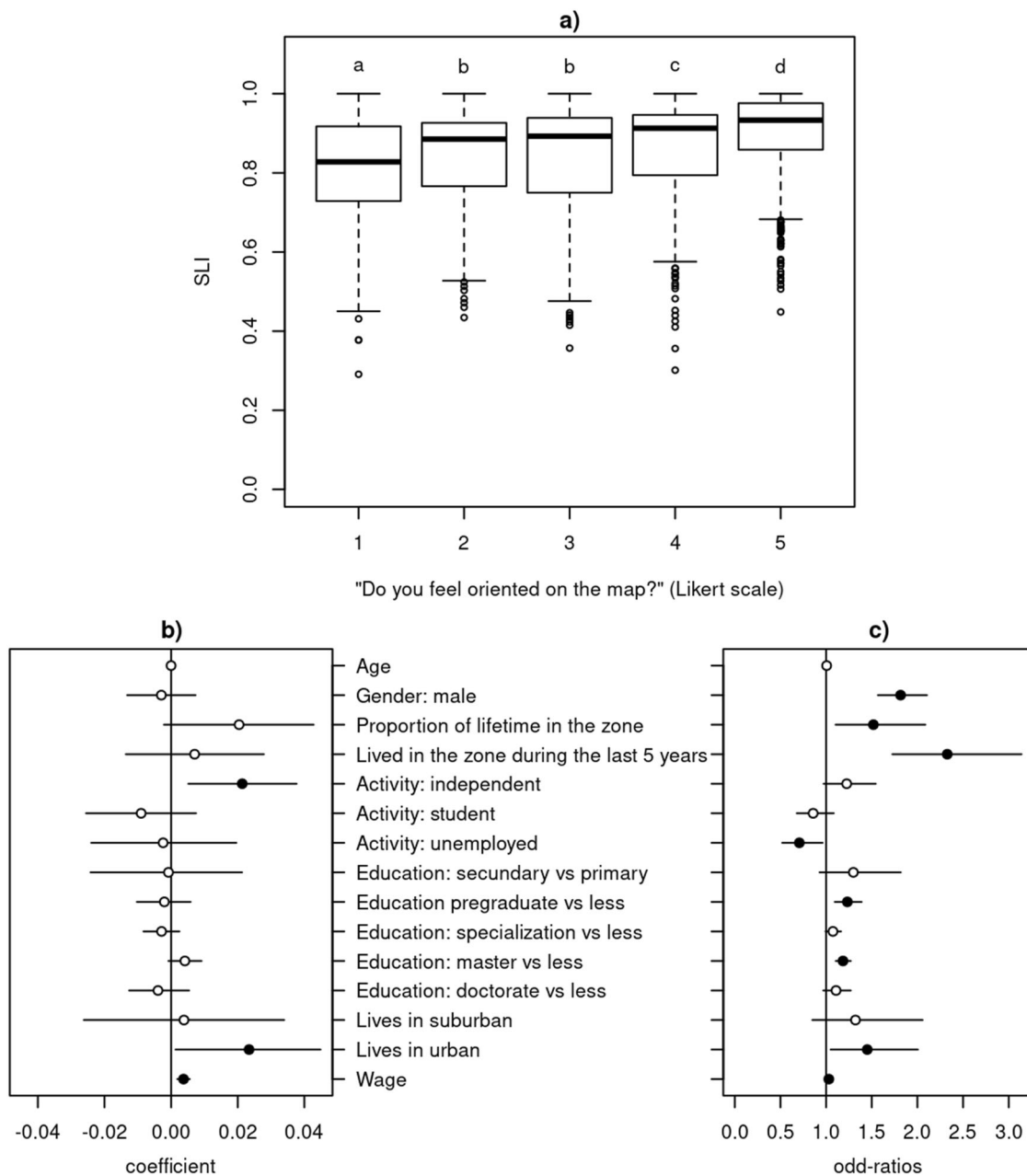


Fig. 2 Relationships between self-reported perceived level of spatial literacy on a scale of 1–5 (1 being a low level of spatial literacy and 5 a high level of spatial literacy) and the actual measured Spatial Literacy Index (SLI). **a** Self-reported spatial literacy versus the actual SLI; Significant differences are shown by different letters. **b** The

relationship between sociodemographic variables and SLI as well as their 95% confidence interval in the Generalized Linear Model. **c** Variable odds ratios for the sociodemographic variables and their 95% confidence interval in the ordinal Logistic Regression with self-reported orientation as the dependent variable.

management, environmental issues, and ecosystem service-related decisions involving Neotropical, peri-urban landscapes. We did so using a series of on-line response items to rank opinions about currently relevant environmental issues in a socio-ecologically complex (i.e., urban to rural land uses, mountains, wetlands, agriculture disparate socioeconomic strata) study area in peri-urban Bogotá, Colombia.

Overall, we found that most respondent's (~80%) were not able to accurately locate more than 2 of the 4 landscapes. In general, self-reported sites were incorrectly located by an average of 5–6 km from their actual locations. The inability of participants to identify and locate points of interest during public participatory exercises was already noted by Escobedo et al. (2020).

Table 3 Kruskal–Wallis tests showing relationships between a respondent's spatial landscape literacy index SLI and their opinions regarding environmental issues and ecosystem services

Environmental issues and ecosystem services	Kruskal–Wallis χ statistic	<i>p</i> -value
A city is the opposite of nature.	17.2484	0.0017
It is possible to use forests and wetlands as public green spaces.	12.6678	0.013
If our forests are protected and healthy, they can help mitigate floods.	50.6325	<0.0001
Local authorities are adopting suitable measures to protect forests	26.2108	<0.0001
Local forests are well protected.	17.8995	0.0013
I participate actively in the decisions concerning my community	0.8978	0.9249
Community action boards (" <i>Juntas de acción comunal y locales</i> ") allow for my effective participation in environmental policies.	1.9961	0.7365

Therefore, although assessment and studies regularly ask respondents to locate specific sites on maps, it is important such methods should consider evaluating the actual positional accuracy of a respondent's self-reported locations. For such succinct information on relevant socio-ecological features of the area of interest can be provided during participatory-based assessments (Hui and Wescoat 2019). Similarly, as part of the deliberative mapping exercise, facilitators could assist respondents (Aggrey et al. 2021). Alternatively, other spatially explicit tools and information such as 3-Dimensional landscape models can possibly better help translate stakeholder's spatial knowledge (Gaillard et al. 2013).

We also found mixed results regarding the socio-demographic correlates of spatial landscape literacy. In general, urban, higher income, independently employed respondents were related to higher SLI index levels. However, the level of education was not significant in the model and, therefore, spatial landscape literacy seems not to be affected by education or residence in the study area as has been noted in some recent literature (Ooms et al. 2016; Escobedo et al. 2020). Research in spatial cognition has also found that such measures of spatial literacy are subject to a person's overall spatial knowledge and familiarity with maps and images (Golledge. 1993; Tu Huynh and Doherty 2007).

In terms of self-reported or *perceived* versus measured and *objective* spatial landscape literacy, the relationship was significant but weak. We found that self-reported spatial landscape literacy was significant and positive in respondent's who were: male, lived a larger proportion of their lifetime or the last five years in the study area, had a graduate or master education levels, were urban, and with a higher income. While urban or higher wage respondents had a higher self-reported spatial landscape literacy which corresponded to a higher *objective* spatial landscape literacy, the higher *perceived* self-literacy from males, higher education and respondents who lived a larger proportion of their life in the study area did not correspond to higher levels of objective spatial landscape literacy. Similarly, unemployed respondents had a lower perceived spatial landscape literacy while objective spatial landscape literacy was not significantly different to the employed respondents. Also, independent workers had no perceived

spatial landscape literacy differences relative to the other workers while their objective spatial landscape literacy was significantly higher.

Thus, as shown by Fagerholm et al. (2019a), even though maps and satellite images are powerful tools for PPGIS, based on our findings, one's perceived spatial landscape literacy during mapping exercises does not necessarily correspond to an actual spatial landscape literacy as measured by our study. Accordingly, our findings show that certain socio-demographic profiles perceive they have high spatial landscape literacy (i.e., urban, male, well educated, etc.) which is not necessarily related with their actual literacy (Table 2; Fig. 2). Thus PPGIS should ideally measure actual spatial literacy and thus not just assume that participants are spatially literate. Indeed as pointed out by Brown and Kytä (2018) and Brown (2012), PPGIS needs to be evaluated and this can include accounting for the capacity and constraints of the participants involved in elicitation-based spatial exercises (Liu and Opdam 2014).

We also found that in most cases there was a strong relationship between spatial landscape literacy and opinion on environmental issues and those related to the provision of ecosystem services (Table 3). Conversely, we found that a respondent's opinion concerning their active participation in decision making and policy process was not related to their spatial landscape literacy. This finding has potential implication in that PPGIS assessments and studies can yield inaccuracies in responses from certain participants: since some opinions are associated with lower spatial literacy, the respondents holding these opinions may result in being overlooked in such participatory processes. This can also be compounded by many non-expert respondent's inability to understand complex ecological processes (Bagstad et al. 2016). Another interpretation for this finding is that we found no relationship between local participation in governance related processes and a participant's level of spatial landscape literacy. We note that our results are based on online spatially explicit maps used in this study and that participatory deliberative processes are key for most PPGIS (Brown and Kytä 2018). Nevertheless, the use of 3-D maps or information (Escobedo et al. 2020) or actual site visits to familiarize participants with the area of study can be useful (Damastuti and de Groot 2019).

We do note some limitations in our study. First, responses were from specific socio-demographic groups that have access to computer and consistent internet access, something which is often not possible in some Global South contexts (Graham 2014). Second, although we measured and tested respondent's residence in the study area, we did not directly measure for mobility or activity in the study area or overall experience with map use. As pointed out by a reviewer, differences in spatial learning can be a result of a person's familiarity or experience with the actual study area (i.e., spatial cognition and knowledge) versus those who are not as active and unfamiliar with the study area or others how have previously or regularly used visual media such as maps (Ramadier and Bronner 2006; Whiston Spirn 2005; Vlami et al. 2019). That said, our findings do support that demographics such as age and whether respondents lived in the study area, influence spatial literacy.

Similarly, the experimental design used in our study, limits our ability to draw conclusions outside our study context and we also did not incorporate measures of spatial cognition. For example, the nature of the environmental and ecosystem service opinion statements were specific to the Bogota region at the time of writing. The use of other landscapes in the study area could also lead to potentially different results (e.g., urban parks, agro-ecosystems; Liu and Opdam 2014). In terms of spatial cognition other measures of spatial knowledge, learning, and familiarity could have been included in our survey (Golledge 1993; Tu Huynh and Doherty 2007). Likewise, the use of Likert-scale levels, specific preference elicitation methods, and the time of survey implementation (December–January is a holiday season in Colombia) can have an influence on response rates and the statistical results (Sironen et al. 2014). Finally, such response rates can be an indication of not only survey exhaustion or protest responses, but also respondent's lack of spatial knowledge and abilities to read a satellite image and maps. This can possibly have an effect on their participation in this study or other participatory processes. Research has pointed out that satellite-based imagery can represent or shape impartial geographical information and lead to “spatial imaginaries” (Shim 2014).

That said, this is one of the few studies that integrates technology and a large sample size to better understand the role of spatial literacy in public participation processes and opinions regarding environmental perceptions in a Global South context (Aggrey et al. 2021; Do et al. 2020; Hui and Wescoat 2019). The increasing use and dependence of cartographic information, on-line technologies, and social media now presents an opportunity for improved democratization, social learning, and access to the environmental

decision-making process. Their application is opportune particularly in complex and rapidly urbanizing fringes of cities in low and middle-income countries. Similarly, this also presents as opportunity to study the role and influence of technologies, such as 3-D landscape models and georeferenced social media data, on PPGIS and other participatory-based assessments and typically underrepresented participants (non-experts, marginalized communities, those with less power and influence over environmental matters).

We caution, however, that the potential dominant focus on technology can come at the expense of the participatory processes, which remain the core foundation for participatory environmental management (Brown and Kyttä 2018). Accordingly, further research is needed to evaluate how different contexts and participant's spatial knowledge (i.e., spatial cognition) and their attitudes and values towards the environment can influence the decision-making outcomes that use PPGIS or other cartographic information (Do et al. 2020; Liu and Opdam 2014). Similarly, our results might indicate opportunities for improving education learning goals that deal with spatial information and knowledge. Specifically, our findings can be highlighting other possible socio-cultural factors associated with a higher spatial literacy in low and middle-income countries, i.e., access to quality geographic education, a priori assumptions by regarding the need and ability for spatial literacy by researchers from the Global South.

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Compliance with Ethical Standards

Conflict of Interest The authors declare no competing interests.

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Appendix A. Aerial and on site photos of Cerro La Conejera (A1 and A2) and Humedal Torca Guaymaral (A3 and A4). Note: in Spanish “Cerro” means mount or hill while “Humedal” means wetland

Figures 3–6

Fig. 3 Cerro de la Conejera
(Photo: Google Earth)



Fig. 4 Cerro de la Conejera
(With permission from
Humedalesbogota.com; Photo:
J.E.Escobar)



Fig. 5 Humedal Torca Guaymaral (Photo: Google Earth)



Fig. 6 Humedal Torca Guaymaral (Photo: With permission from Humedalesbogota.com; Photo: J.E.Escobar)



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