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An enhanced analytical framework of participatory GIS for ecosystem services assessment applied to a Ramsar wetland site in the Vietnam Mekong Delta

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ABSTRACT

Public participation geographic information systems (PPGIS), though proven valuable in ecosystem services (ES) research, is occasionally criticized for being expensive in terms of time, cost and administration efforts in case the post-hoc sophisticated spatial analytics/statistics are targeted. This study, based on the enhancement of the pre-developed PPGIS analytical framework, seeks to address these critiques by introducing an in-expensive effective data collection strategy, while substantially facilitating geo-spatial analytics. The U Minh Thuong National Park (UMTNP) in the Mekong Delta in Vietnam, a world's renowned Ramsar site, was chosen to demonstrate the framework. The respondents participated in the participatory mapping on paper maps, using color markers to hand-draw (as polygons) their self-perceived areas associated with different categories ES. By collecting 2D data, the post-hoc spatial analyses could have utilized more meaningful statistical methods. In this study, we introduced the uses of three methods: Ordinary least squares (OLS), Geographically weighted regression (GWR) and Moran's I to assess the spatial autocorrelation of ES across the landscape. In addition to participatory mapping, the respondents were also engaged in completing a semi-structured questionnaire, which was subsequently analyzed using principal component analysis and hierarchical cluster analysis. These two multivariate analyses serve to reveal the structured diversity of the people's perceptions towards the importance of different ES. It was shown that Provisioning ES was the most highly regarded benefit, followed by Regulating, Supporting and Cultural. Regulating and Supporting ES, the two indirect material services share relatively similar appreciation patterns while Cultural ES was unexpectedly the least credited, a stark contrast lineagainst the government designated eco-tourism and historical functions of UMTNP. Geographically, the core areas of the national park have the most overlaps between Provisioning and Regulating services. Supporting services, on the other hand, were the most associated with Provisioning and Regulating services in peripheral areas. Cultural services were synergized with the other three types of ES in the areas reserved for eco-tourism activities. The revealed spatial synergies can determine the areas where potential conflicts between extractive and non-extractive uses could occur, contributing insights for sustainable management of UMTNP and other protected areas worldwide. In addition, this study also contributes to promoting the PPGIS method in ES research and other human geographical studies, those relying on community participation.

1. Introduction

In Ecosystem Services (ES) research, Public Participation Geographic Information Systems (PPGIS) refers to methods for collecting spatial information from non-professionals (Brown and Fagerholm, 2015). PPGIS differs from empirical mapping methods (i.e. collecting secondary data or maps) in (i) the direct inclusion of stakeholders (can be either experts or members of the public) and (ii) the quantification of ES demand via stated preferences over the space (Sieber, 2006). Notable contributions using PPGIS in ES literatures include, for instance, Palomo

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et al. (2014), who incorporated public knowledge to highlight areas where ES was derived and where risks of ES degradation were perceived in a national park in Spain. Similarly, Pfueller et al. (2009) and Cox et al. (2014) identified specific places on a map where the public would like to set aside for conservation. In the same manner, Canedoli et al. (2017) provided spatially explicit data about perceived cultural ES of a park as well as information about the matching or mismatching patterns between the civilians' view with management strategies. Stakeholder involvement in the mapping process as such can contribute to capture the heterogeneity of their expectations, values and preferences towards different landscape features, i.e. different geomorphological formations of the landscapes, e.g. lakes, rivers, grassland, etc. Moreover, successful implication of PPGIS of ES has proved to be an operational inclusive process that can be embedded in long-term and locally driven spatial decision-making agendas adaptable to multiple institutional and biophysical environments (Corbett and Rambaldi, 2009).

In general, PPGIS and other forms of voluntary mapping studies: participatory GIS or volunteered geographic information are more associated with the western developed countries. For instance, the meta-analysis in the most recent literature review of participatory GIS, includes exclusively studies from western developed countries, e.g. USA, Australia, or Norway (Brown 2017). The applications of PPGIS in ES research, specifically, Brown and Fagerholm's (2015) review could have identified only 2 out of 32 studies that were completed in developing countries, i.e. Tanzania (Fagerholm and Käyhkö, 2009; Fagerholm et al., 2012). The mapping technologies can be roughly classified into two categories: (i) digital mapping utilizing internet mapping services such as "*maptionaire*" (https://maptionnaire.com/ - accessed on 28th of August 2020) (e.g., Brown and Reed, 2012; Brown and Brabyn, 2012ab), and (ii) manual mapping relying on primitive markers such as stickers or beads on cartographical/topographical maps or aerial images (e.g. Fagerholm et al., 2012; Scolozzi et al., 2015; Palomo et al., 2014; Canedoli et al., 2017). Manual mapping can also be done in a quasi manner, such as using cross-tables matrix (Kaiser et al., 2013 or Loc et al., 2018a, b). It should be noted while that manual mapping technologies were employed irrespective of the economic statuses of the studied countries, the internet digital mapping has so far been used in developed countries (Brown and Fagerholm, 2015; Brown, 2017). Admittedly, free digital mapping platforms are increasingly prevalent, yet the applications of such tools in developing countries are critically more challenging because the local communities in these areas are substantially less comfortable using "high-tech" in deliberative assignments, hence the lack of willingness to participate. Instead, paper maps and analogous markers are more intuitive, hence considerably more appropriate to use in the less developed study areas (Fagerholm et al., 2012; Scolozzi et al., 2015). The inevitable trade-offs include the accuracy of the mapping results and the extra burden of post-hoc digitizing (including georeferencing) the responses to facilitate geospatial analyses. This partly explains the overall limited number of inclusive PPGIS studies in the less developed areas of the globe. With specific geographical focus on developing countries in the Southeast Asia region, only a few notable references can be made, for instance to Kaiser et al. (2013)'s evaluation of tsunami impacts on land cover and related ES supply in Thailand. In this study, a cross table of 17 different types of ES versus 10 types of land uses was given to 33 volunteer mappers (village chiefs, governmental organisations, and non-governmental international organizations) to assign scores of importance. The use of cross-tables as such was also employed by Loc et al. (2018a) who sought to measure abundance, richness, and diversity of ES across the UMTNP landscape using the locals' perceptions (N = 94). Another noteworthy PPGIS literature with developing country context is Damastuti and de Groot (2019) who had 325 participating villagers to actually "*map*" their perceptions, also with manual sketching and scale mapping. Referring to the six common stages and methods applied in participatory mapping (Corbett 2009), the authors opted for the methods that the participants found the most comfortable with.

However, the PPGIS research design needs to address three critical concerns: (i) time and effort required by the direct inclusion of stakeholders; (ii) the qualifications of invited participants, and (iii) the mapping technologies involved. Within the 32 PPGIS-study literature review by Brown and Fagerholm (2015), the sample sizes ranged from 22 to 1905 with the majority being 125 to 400. The studies reviewed by (Brown and Fagerholm, 2015) also had the median number of samples of approximately 200. With specific examples from Asian developing countries, the sample sizes of Kaiser et al. (2013), Loc et al. (2018a), and Damastuti and de Groot (2019) are 33, 94 and 325, respectively. Budget aside, the sample sizes were essentially driven by the types of spatial analyses needed to generate inferential conclusions. Evidently, those studies with sample sizes of several hundreds data points could have facilitated substantially more sophisticated spatial analyses, such as Nearest Neighbour Analysis (Clement-Potter 2006) or Density-based Cluster Analysis (Nielsen-Pincus 2011). On the other hand, those with smaller sample sizes, i.e. several dozens to less than 50, would perform simple analyses, such as entry aggregation or statistical analyses for cross-tables. Quantity aside, the qualifications of participants also constitute an important concern. In this regard, Brown (2017) remarked that the term "public" in PPGIS includes not only random public, but also decision makers, implementers, affected individuals (i.e. stakeholders), or interested observers. As such, PPGIS sampling designs should take into account who has the spatial knowledge needed for the mapping exercises and the potential for bias when targeting the various "publics" in the process. This is particularly relevant to studies related to protected areas because the information to be mapped is not necessarily intuitive and easily comprehensible for laymen. This partly explains the rarity of PPGIS assessment of ES derived from conservation areas against the bundles of publications using expert-based approaches. Thirdly, the analyses employed by studies on the lower end of the sample size were more straightforward, such as measurement of intensity aggregated by the number of participants' responses on the grids (Klain and Chan 2012). As an illustration for the barrier related to the mapping technologies involved, Brown et al. (2012) estimated that the cost per mapping completion using an online panel was approximately USD $42, substantially higher than the average cost for household surveys. This is even more challenging in developing country contexts due to the tighter budget available for research budget. To offset the costs, other studies often use paper maps combined with manual marking systems. However, this would require the post-hoc digitization of results (Raymond et al. 2009).

This study, therefore, seeks to present an enhanced analytical framework that accommodates sophisticated geo-spatial analysis techniques without requiring a large sample size. Also, to explore opportunities to streamline PPGIS research findings with specific decision-making contexts, this study develops a novel analytical framework and applies it in a Mekong Delta Ramsar site as a showcase. The developed framework could have generated important socio-ecological and geographical findings by adopting an unorthodox participatory mapping strategy to generate two-dimensional data directly from the survey as compared to the one-dimensional data conventionally collected in studies, e.g. Raymond et al. (2009) or Brown and Brabyn (2012). We demonstrate the implementation of our novel framework in U Minh Thuong National Park (UMTNP) in Vietnam Mekong Delta (VMD), the world's third largest river delta. The UMTNP is the country's most important biosphere reserve and also recognized worldwide as a Ramsar site (Matthews, 1993, WWF, 2016, Government' Decision 11/2002/QĐ-TTg - in Vietnamese). "Ramsar" is among the oldest of the modern global environmental agreements, and "Ramsar sites'' refer to the network of approximately 2,000 representative wetlands around the globe that are supporting the habitats for rare species, and housing abundance, and significance of water birds and aquatic fauna. Vietnam joined the convention on January 20th, 1989 and has eight RAMSAR sites, among which UMTNP is the most recent that was successfully recognized on February 22nd, 2015 (From www.ramsar.org/about/

history-of-the-ramsar-convention).

2. The analytical framework

The goal of this paper is to contribute an improved version of the existing PPGIS framework applied by Loc et al. (2017a), (2018a) (Vietnam) and Kaiser et al. 2013 (Indonesia). The first improvement to the existing approaches is the introduction of a more inclusive and spatial explicit participatory mapping exercise. Within the previous PPGIS studies in the Southeast Asia region, by using the cross-tables, the participants did not actually "map" ES across the landscape. Also, by classifying the landscapes according to the land covers, it is assumed that similar land covers should have similar ES, irrespective of the locations. While this might be true biophysically in general, protected areas such UMTNP have strict zoning regulations for biodiversity conservation and forest rejuvenation purposes, which would affect the geographical heterogeneity assumption of the cross-table approach. For example, for the same class of melaleuca forests, extraction is limited to only certain areas where the rest are strictly prohibited. The second improvement relates to the types of data collected, which in turn decide which type of analyses can be performed. With the cross-table approaches, the post-hoc analysis is limited to only numerical statistics. The data collected by the enhanced approach is true spatial data (2-D polygons), hence can facilitate various sophisticated spatial analytical methods, in which three are suggested herewith: Ordinary least squares (OLS), Geographically weighted regression (GWR), and Moran's I. It should be noted that traditional numerical statistics such as Chi-squared tests or Correspondence Analysis are also possible after converting the spatial data into numerical forms, as exemplified in this study.

The enhanced framework introduced in this study could have been an important reference for PPGIS and ES research for developing countries in Asia, which is substantially lacking in the existing literature. In relation to the current geographical bias of PPGIS in Southeast Asia countries, this framework could have contributed to promote the method for ES research in this region. Specifically, it could have contributed to address the technical inaccessibility of internet digital mapping in remote areas, enabling sophisticated spatial data analyses even with manual mapping. The flowchart in Fig. 1, as such makes explicit the methodological steps as well as recommending some of the potential data collection and analysis methods that have been used in the case study. Similar to any methodological/conceptual framework in social sciences, our framework only serves as guidelines and recommendations. Fellow researchers are encouraged to further explore other possibilities. All in all, we have made the efforts to clarify the goal and the sequential relationships of each of the steps, the significance of the associated inputs/outputs as well as the potential knowledge that can be created from the approach.

3. Materials and methods

3.1. Study area: the U Minh Thuong national park

The research was performed at UMTNP in Kien Giang province, covering a total area of 8,038 ha between the Minh Thuan (MT) and An Minh Bac (AMB) communes, and supports one of the country's largest peat-swamp forests (WWF, 2016). The area houses an extensive collection of terrestrial and aquatic fauna ecosystems, including 32 mammal species, 187 bird species, 37 fish species, and 203 insect species (UMTNP, 2013; Bird Life International and MARD, 2004), therefore contributing significantly to preserving the biodiversity of the Vietnam Mekong Delta, and of the whole country as a whole. The rich biodiversity of UMTNP is supported by a full spectrum of ecosystem functions and services, including the provisioning of water and nutrients, the regulating of hydrology and climate regime, and the protection from natural hazards. In addition, the NP had also served as an important Vietcong's military camp during the Vietnam Wars, hence the significant cultural and historical values (Loc et al., 2018a).

3.2. Methods

3.2.1. Phase i - background investigation and questionnaire development

Among the associated literature reviewed, the Ramsar Information Sheet (RIS) is of particular importance as it provides fundamental information regarding natural attributes (e.g. area, hydrological regime) and ecological descriptions (e.g. abundance, representativeness and rarity of species). The RIS of UMTNP was prepared by the Biodiversity Conservation Agency, Environment Protection Administration, Ministry of Natural Resources and Environment of Vietnam. Other notable literatures include the annual reports prepared by UMTN management boards (UMTNP, 2013); technical reports from previous projects (Sage et al., 2004 and Institute of Tropical Biology (2002)); and scientific publications (Hoa, 2000; Nguyen, 2002; and Loc et al. 2018a).

In June, 2018 during the recce to UMNTP, we conducted a key informant interview (KII) with the national park management board. The objective of this KII is to collect the background information of the history, the management strategies and important milestones, including key international collaborations and the recognition of UMTNP by the Ramsar Convention. During the KII, we were also informed of the

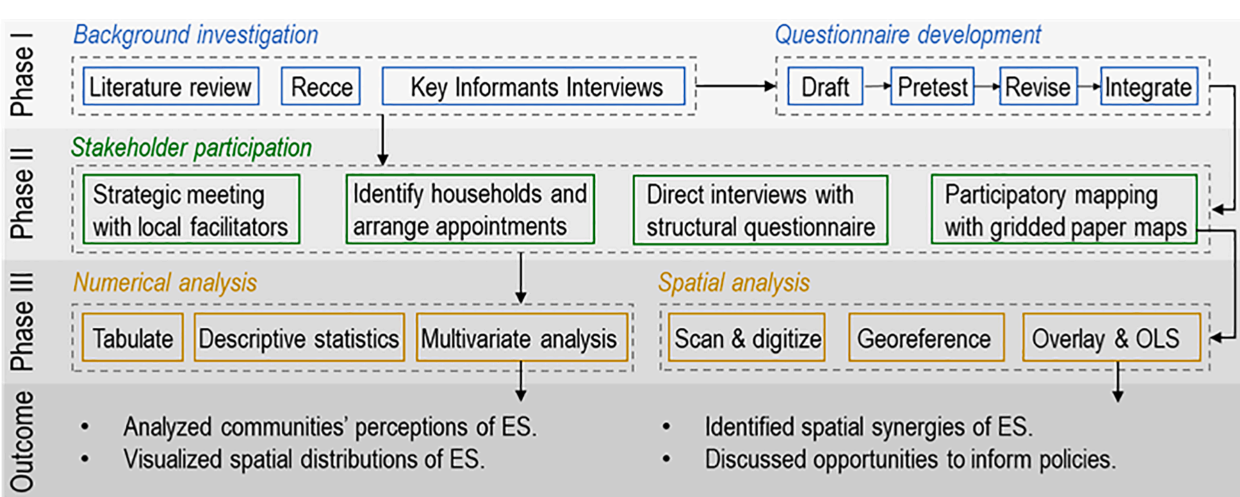


Fig.1. Analytical Framework. Phase I includes the gathering and background information and development of questionnaires. Phase II includes both the preparatory tasks and the stakeholder's PPGIS exercise. Phase III provides good practices for analyzing data, including both questionnaire and participatory mapping results.

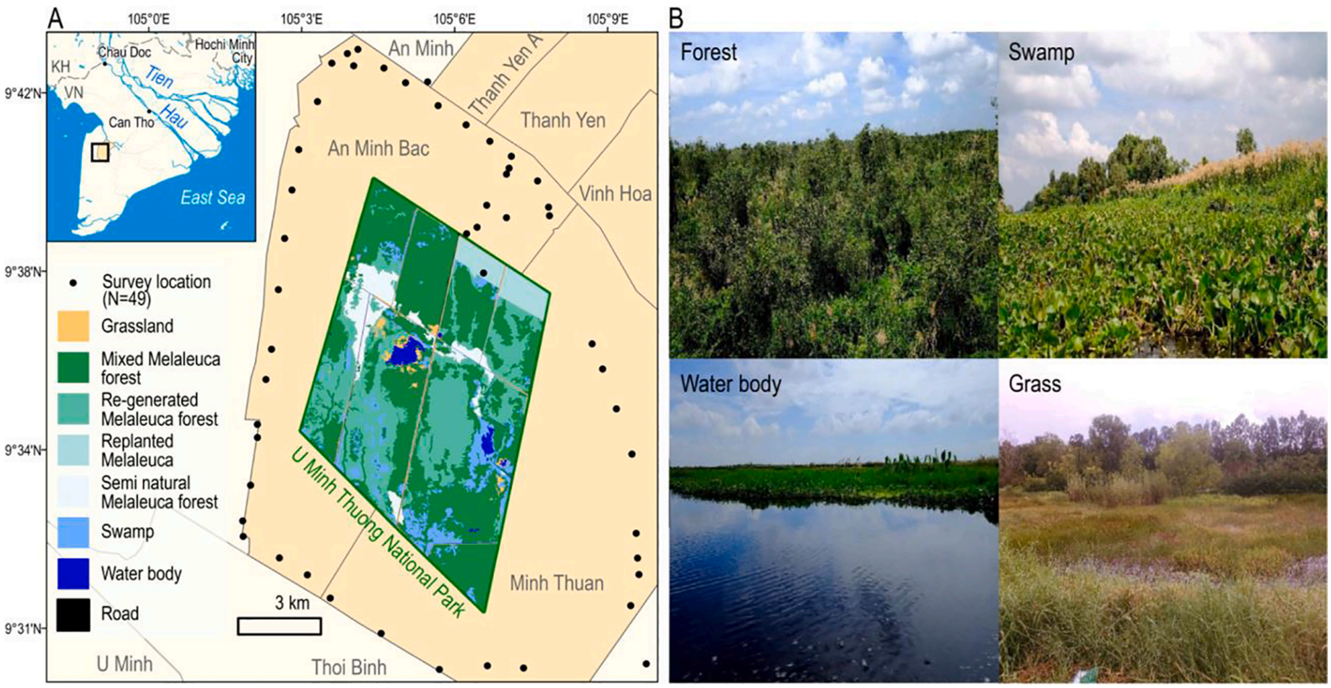


Fig. 2. Study area. A: UMTNP Land Covers. The small map on the top left corner depicts the location of the study site within the Vietnam Mekong Delta. B: Photos of land covers in UMTNP taken by Loc. H.H.

concerns regarding the threats of detrimental actions from the locals, for instance, illegal poaching and trapping of wild animals, fishing and extraction of timber and other food products. These illegal penetrations can pose numerous severe harms to the national park, including forest fires (Triet, 2002). All of these background information constitutes an overall picture of the significance of UMTNP. The management board referred us to a gentleman living in Minh Thuan commune to help facilitate the social-surveys.

The information gathered through the preliminary investigations were incorporated into the questionnaire that was subsequently pre-tested and revised. In social sciences, a field pretest is a rehearsal for the real survey, which is very useful to identify potential problems with survey items and/or data collection protocols prior to fielding a study. In our study, during the pretest, much attention was paid to make sure that the language is understandable to laymen, as well as the mapping practices can be conducted effectively. The final version of the

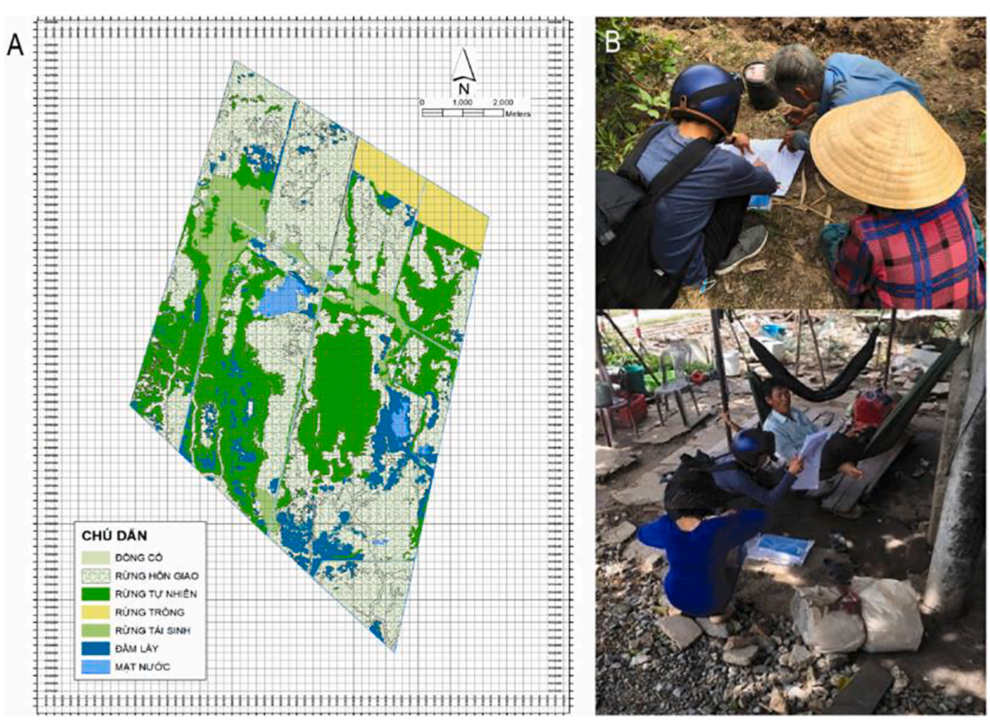


Fig. 3. Materials prepared for stakeholders' participation. A: map used for people to indicate the locations of ES using color markers (in Vietnamese). B: facilitators conducting a field interview survey on date 10 November 2019.

questionnaire then had to be cleared by the Research Office at Can Tho University for ethical standards before being used in the large-scale surveys. In addition, the UMTNP land cover map obtained from the management board was re-projected into UTM Zone 48 N (geodetic datum WGS84) projected coordinate system with a reference grid with the 200 m × 200 m resolution. The grid size was suitable for printing on A4 sized papers without compromising too much the information of the landscape features of the study area (Fig. 3A). Prior to deploying to full-scale PPGIS in the community, we conducted another KII with the gentlemen whom we were referred to by the UMTNP management board to discuss the survey plans and his inputs for the questionnaire.

3.2.2. Phase II - stakeholder's participations

The presence of a local facilitator plays an (lesser known) important methodological step, especially for ethnological or social studies in developing countries such as Vietnam. Even though the rural communities in these countries might show hospitality to visitors, they could become more skeptical and resistant to recorded discussions, such as interviews with questionnaires. In such cases, researchers can (i) spend more time with the locals to gain their trust (Damastuti and de Groot, 2019) or find a local facilitator for ice-breaking (Loc et al., 2017a). This is even more important in those communities whose demographics consist of several ethinic groups. In investigating the social values of ES associated with multiple touristic sites in Kien Giang Province, Loc et al. (2017a) also highlighted the need of a local tour guide to help introduce the research team to the indigenous communities to conduct the social surveys. This research, as such, have successfully collected 123 face-to-face questionnaires from the local households, which could have facilitated the hot-spot analysis to evaluate the social values of ES across the landscape. As mentioned above, we were fortunate that the management board of UMTNP had us introduced to such a local facilitator, whom we subsequently met to explain the research activities and plan for the community surveys.

UMT itself is a district of Kien Giang province located on the west coast of the Vietnamese Mekong Delta. The total population of UMT is 68,076 divided into six rural hamlets. Similar to Loc et al. (2018a), the targeted populations of this study were the local settlements of approximately 3,500 households inhabiting the 38 km boundary of UMTNP. These are the residents of two hamlets of UMT district: An Minh bac and Minh Thuan hamlets. A substantial portion of this community are disadvantaged farmers without lands from different areas re-settled by the government under the "New Economy" programs (from http://nhandan.com.vn - in Vietnamese). Their livelihoods include cultivation of annual crops (rice, vegetables, sugar cane) and extraction of forest products from UMTNP (animals, timber, honey). It should be noted that the research design of PPGIS should only involve those with the spatial knowledge of the study site needed for the mapping process, of course in addition to being willing to participate (Brown 2017). In the case of the UMTNP, the biophysical conditions of the park are complicated, combined with the research objective that seeks to compare all four separate categories of ES, entries from participants with limited understanding of the parks therefore would have been irrelevant. Plus, the diversity in the perceptions of ES among different social groups is not within the scope of our study. Therefore, the data collection method chosen for this study is purposive sampling, including only those with sufficient acknowledgement of UMTNP ecological significance and the whereabouts of the national park landscapes. Specifically, the participants are selected from the local residents living in the peripheral areas of UMTNP, who have developed close relationships with the parks, both material: extracting of natural resources and metal: sense of place. Before initiating the questionnaire, we asked the participants about the livelihoods and the experiences associated with the national park. During the conversation, we looked out for keywords in their responses to decide whether or not to invite them to participate. These keywords include, for instance, *biodiversity, ecological conservation or protection for long term uses*. Admittedly, our judgements could have been qualitative, yet sufficiently objective to identify the qualified participants for the PPGIS exercises.

The survey questionnaire consists of three sections: (i) respondent's demographic information, (ii) assessment of the UMTNP's ecosystems and the derived services, and (iii) participatory mapping exercise. After the first part, each respondent was asked "what do you think the park is important for?". Then the keywords from their answers were picked up and classified into two main themes, i.e. natural conservation (including biodiversity, melaleuca forests, and peatlands) and cultural values (ecotourism and historical sites). Each questionnaire is paired with a supplementary information sheet explaining the research objectives, as well as a brief introduction of Ecosystem Services, the typologies and its relevance to the study site. In this study, the ES categories suggested The Economics of Ecosystems and Biodiversity (TEEB, 2010) is adopted. In this study, the ES categories include Provisioning (water, timber and non-timber forest products), Regulating (flood protection, climate regulation, pollination, pest control), Supporting (soil formation, water and nutrients cycling), and Cultural (historical and tourism). The respondents were subsequently asked to evaluate the importance of each type of ES using a 4-level Likert scale, in which, 1 and 4 represent the least and most important, respectively.

Fig. 3A depicts the paper map representing the landscape features of UMTNP prepared for section (III) - Participatory Mapping. First, the interviewers will help the respondents to navigate across the map by identifying key landmarks within the park, e.g. entrance gates, observation towers, bird-observing locations, etc. We also made efforts to encourage the respondents to associate the locations with their daily activities, such as fishing, picking up woods, extracting honey, etc. Second, the participants were asked to draw polygons on the provided map to highlight the areas where specific ES typologies are the most relevant using markers of different colours, i.e. blue, black, green and red for Provisioning, Supporting, Regulating and Cultural ES, respectively. There were no limits to the number of polygons a participant can draw on a map, and all drawn features were assumed to be equally important. Each respondent, therefore, contributed in total four hand-drawn paper maps plus one hand-filled questionnaire. Upon completion, the total number of 49 such contributed responses were collected.

3.2.3. Phase III (1) - numerical data analyses

In this study, the response ratio was 100% because we only conducted the survey after obtaining the consent to participate from the respondents. With 49 questionnaire answers obtained, we first performed descriptive statistics to report on the characteristics of the respondents. For the inferential statistics, we performed three different statistical methods. First, 1-way Analysis of Variance (ANOVA) was conducted to verify if the importance of four types of ES differently are perceived differently from one another. Next, we performed the Principal Components Analysis (PCA) to project the vector representing the importance of different types of ES on a 2D plane (from the two most important principal components), on which the associations, i.e. positive/negative correlations can be explored. As a technical note, prior to PCA, the data has been verified with Bartlett's Test for Homogeneity of Variances (Bartlett, 1937; Tabachnick and Fidell, 2001). Finally we applied a Hierarchical Cluster Analysis (HCA), an algorithm that groups similar objects into different groups called clusters, whereby each cluster is distinct from each other cluster, and the objects within each cluster are broadly similar to each other. As such, we used HCA to identify within the community groups of similar perceptions towards the different values of UMTNP. From PCA, each data point (individual response record) was projected on the 2D plan made up from the two most important principal components, thereupon, they can be clustered through Euclidean distance and Ward's Agglomerative Methods. The use of multivariate analyses in social-based ES studies have been adopted by multiple previous studies, see for instance, Plieninger et al., (2013); Loc et al. (2017a), Loc et al., (2017b), (2018a,b). All of the analyses above were completed with the aid of FactomineR (Le et al., 2008; R Core Team, 2015).

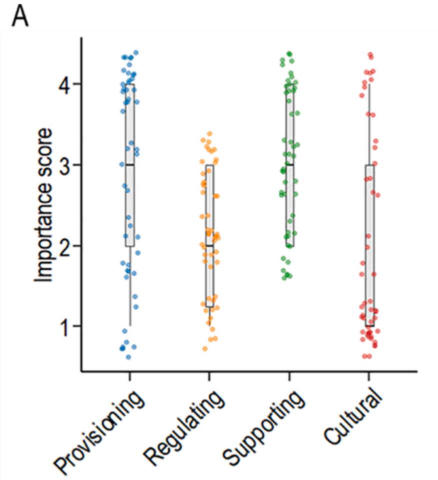
3.2.4. Phase III (2) - spatial data analyses

3.2.4.1. Digitizing and (pre-) processing.. We first scanned the individual's hand-drawn maps (N = 49) and then georeferenced them using the UTM Zone 48 N (geodetic datum WGS84) projected coordinate system. On the GIS platform, each of them were digitized into a separate vector polygon layer as binary data, i.e. 1 within polygons drawn by respondents, otherwise 0. This process was done for the four types of ecosystem services assessed in this study. All digitized maps were spatially added (therefore 49 as the possible maximum value), and ecosystem services density distribution maps (richness) were generated for each type (diversity) (Fig. 4A). Lastly, the maps were converted into the rasters, and a low-pass filter (at 50 × 50 m window) was applied to smooth the data before normalizing into a percentage (%) scale using five equal intervals.

3.2.4.2. Spatial statistical analysis across the services.. We performed spatial statistical analysis using the four ES density distribution maps, mainly to assess their spatial distribution patterns and inter-relations among different types, and also the dependency on land cover. For this purpose, we used three sequential statistics, 1) Ordinary least squares (OLS), 2) Geographically weighted regression (GWR) and 3) Moran's I to assess the spatial autocorrelation of investigated variables across the space. This process chain is to first identify numerical relationships between ES variables, then incorporate spatial dependency among variables (how location of each type affects the values of ES), and finally assess if there is spatial autocorrelation (clustering) among variables in relation to land cover types.

We first used a pair-wise OLS linear regression to identify the relationships between each ES type with others (hence four cases in total).

A



B

	Importance Scores			
	1	3	3	4
Provisioning	8	11	7	23
Supporting	14	17	18	N/A
Regulating	N/A	13	18	18
Cultural	27	5	6	11

Fig 4. Descriptive statistics of the responses. A. Box-whisker plot summarizing the distribution of the perceived importance of four types of ES. The difference between the mean scores is statistically significant with $p < 0.05$ (ANOVA f-test). B. Contingency table of the respondent's evaluation of ES importance.

In specific, OLS is used to characterize how each ES type factor explains other types. Either one of the variables of ES types were used as independent (and dependent) variables. The result from each pair-wise OLS, i.e. the coefficient of determination R2 ranges between 0 and 1, in which those closer to 1 depict greater correlations between the two types of ES. Mathematically, OLS follows the formula $y_i = \alpha x_i + \varepsilon_i$, in which, y_i is the best-fitted estimation of the dependent variable via linear regression mode; x_i is the explanatory variable; α is the slope of the linear regression model and ε_i is the un-observed random error which theoretically fluctuates around zero.

Since the OLS is a regression model that identifies the numerical relationship between the selected variables, however not in a spatial context. Therefore, to see the effect of spatial dependency of the ES variables, we further integrated local coefficient estimates and performed GWR, which is a global spatial regression model (Fotheringham et al., 2003). User-defined weighted matrices (moving window/kernel) in terms of distance (bandwidth) to the center of variables, are used to delimit the local boundary of influences. Since we performed GWR after converting to a gridded data, a fixed bandwidth of 400 m was used, which was determined as the distance across the adjacent grids with the lowest Akaike Information Criterion. The Following formula is used for the GWR analysis:

$$y_i = \beta_0(u_i, v_i) + \sum_k \beta_k(u_i, v_i) x_{ik} + \varepsilon_i$$

where y_i and x_{ik} denotes the response and independent variables respectively, while k is the k^{th} independent variable across the space. u_i and v_i are the coordinates at i, thereby β_k is defined as a spatial dependency term at the location i. ε denotes the error term that is assumed to fluctuate around zero.

The Local R^2 (ranging from 0-1) after the GWR analysis shows the spatial distribution patterns of the model performance, in addition to the spatial dependency between the ES types in the UMTNP. To further investigate the clustering patterns or possible auto-regressive relationships of these by identifying hotspots/coldspots, we used Moran's I that is a global measure of spatial autocorrelation (i.e. degrees of spatial dependency) (O'sullivan and Unwin, 2014) that is formally written as the formula below:

$$I = \frac{\frac{n}{\sum_{i=1}^{n}(X_i - \overline{X})^2} \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}\left(X_i - \overline{X}\right)\left(X_j - \overline{X}\right)}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}}$$

where X_i and X_j denotes the ES density values at the location $_i$ and $_j$. X_{-} is the mean density value across the park while W_{ij} is the weight matrix. Since we calculated Moran's I based on a 30-m grid dataset, we used eight nearest neighbors as the cutoff limit. This means that if the neighboring grid falls within the limit, $W_{ij} = 1$ (otherwise 0). Moran's I is an index to measure the spatial autocorrelation that ranges from −1 to1, with positive I when both X_i and X_j fall below or above the global mean (and vice versa for negative I). I = 0 indicates spatially random. GWR and Moran's I were conducted in ArcGIS.

3.2.4.3. Correspondence analyses of ES across the land covers.. We constructed a matrix containing the area information of each ES type coverage on the land cover in the UMTNP. First, the ES density map (vector format prior to raster conversion) was intersected with the land cover map. This intersected layer generated new records of all the spatially intersected polygons in the attribute table. Then, the table was dissolved by using the land cover column, since we intended to compute how much area for each ES type falls under different land covers. Finally, the spatially dissolved layer was exported as a tabular file (.dbf) as shown in Table 1 for further analysis.

The cross-tabulation data in Table 1 was first validated with a Chi-squared test for variable independence, then analyzed with correspondence analysis (CA) to investigate the spatial statistics between ES and

Table 1
Spatial Coverage of ES across the land covers of UMTNP in km^2.

Land Covers	Provisioning	Supporting	Regulating	Cultural
Mixed Forest	24.457	18.026	25.750	14.562
Regenerated Forest	17.722	8.891	17.635	3.965
Replanted Melaleuca	5.421	1.637	4.868	1.891
Semi Natural Forest	1.913	1.131	2.088	0.505
Grassland	1.732	0.916	2.512	0.808
Swamp	1.329	0.559	1.321	1.154
Water body	1.339	0.194	1.344	1.147

land cover typologies. CA, sometimes referred to as reciprocal averaging, is a multivariate statistical technique proposed by Herman Otto Hartley and later developed by Jean-Paul Benzécri (Greenacre 1983, 2007). Although conceptually similar to PCA, this technique applies to categorical data and has the capability of summarizing and displaying a set of cross-tabulated data in two-dimensional graphical form. Thereupon, the distribution of ES across the different land covers of UMTNP can be efficiently investigated (Plieninger et al., 2013, Loc et al. 2017a, 2018a,b).

4. Results

4.1. Descriptive statistics of the participants

The locations of the households interviewed are shown in Fig. 1A (N = 49), among which, 35 were at An Minh Bac commune and 14 were from Minh Thuan commune. Gender wise, 39 respondents were male. Regarding the age groups, the majority of participants were between 40 to 50, while the youngest was 25 and the most senior was 73. As typical for rural families, only two participants out of 49 had ever been enrolled in a university, nine dropped during high school. All of them, however, were able to read and write fluently. 47 participants said that they had known the ecosystem services concept before through various sources of information, which was a pleasant surprise to us. While asked to describe the importance of UMTNP, 23 participants mentioned only the ecological benefits, 20 gave mixed responses of different combinations while 6 mentioned only the cultural values of the park. As for the quantitative evaluation of four different types of ES, Fig. 4 compare the scores across the different categories, in which Supporting ES has the highest mean, followed by Provisioning, Regulating and Cultural (ANOVA F-test for the means, $p < 0.05$). More specifically, Fig. 4A presents a box-whisker plot summarizing the distribution of the perceived importance of the ES while Fig. 4B. summarizes the respondent's evaluation of ES importance via a contingency table.

4.2. Multivariate analyses

Bartlett's Test of Sphericity resulted in the *p*-value of 7×10^{-4} verifying the applicability of the PCA method for the collected data. Findings from PCA and HCA are summarized in Fig. 5A, in which the arrows or vectors represent the variables (ES scores of perceived importance) and the colored dots represent the observations (individual responses). Firstly, we relied on the Ward's Agglomerative Methods to decide on the optimum number of clusters from the original data set, which resulted in 6 cluster as illustrated in Fig. 5B. The first two principal components of PCA account for 95.58% of the total inertia, revealing the strong structured relationships of the data set. Firstly, the *indirect benefits* (regulating and supporting) have similar homogenous scoring distributions; hence the closely projected vectors. It should also be noted that even though the scores are similarly distributed, supporting ES is more highly regarded than regulating ES as illustrated in Fig. 4 The most direct benefit, Provisioning ES, on the other hand, stand out the most for having the highest number of "*the most important*" responses in the survey (23) while the lowest number of "the least important" responses (8). On the other side of the spectrum, the figures

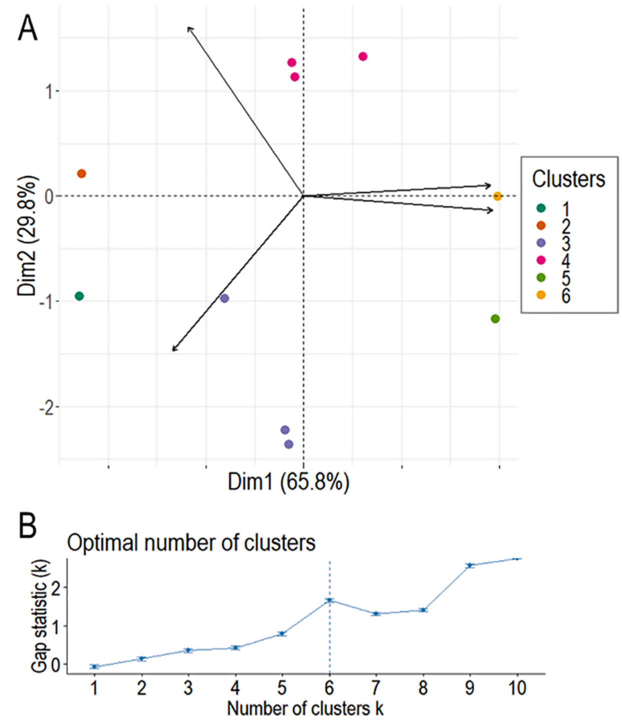


Fig. 5. Multivariate Analysis. A. Two-Dimensional graphical display of PCA and HCA. B. Identification of the optimal number of clusters.

of "the most important" and "the least important" of Cultural ES were 27 and 11, respectively. The discrepancy between Provisioning and Cultural was captured by the separation of their respective projecting vectors in Fig. 5A.

The diversified scoring distribution between the ES types was further explored with the HCA results as projected by the colored dots in Fig. 4B. More specifically, each color represents a cluster of individuals that share similar scoring distributions for the ES typologies. In total, we were able to determine six different clusters following the k-means method and gap statistics criterion as summarized in Fig. 4D. Characteristics of each cluster are summarized in Table 2. It should be noted that since the importance of ES was represented via an exclusive ordinal variable, hence there are cases of identical inputs from several respondents. In such situations, their respective projected data points on Fig. 4D are overlapped, i.e., there are fewer data points than the actual sample size (n = 49).

4.3. Spatial analyses

The distributions of ES classes across the landscapes show distinctive patterns geographically Fig. 6 (A-D). With the exception of cultural services, most ES substantially cover the entire UMTNP area, which can be attributed to the intuitive difference of the two groups, i.e. tangible vs intangible nature-derived benefits. To simplify the comparison, we have combined all different types of forests in Table 1 into one single Forests class. Fig. 6E, henceforth summarizes the spatial distribution of ES

Table 2
Hierarchical Cluster Analysis Results.

Clusters	Provisioning	Supporting	Regulating	Cultural
1 (n = 6)	Neutral	Low	Low	High
2 (n = 7)	High	Low	Low	High
3 (n = 5)	Low	Neutral	Neutral	High
4 (n = 16)	High	Neutral	Neutral	Low
5 (n = 5)	Low	High	High	Neutral
6 (n = 10)	Low	High	High	Low

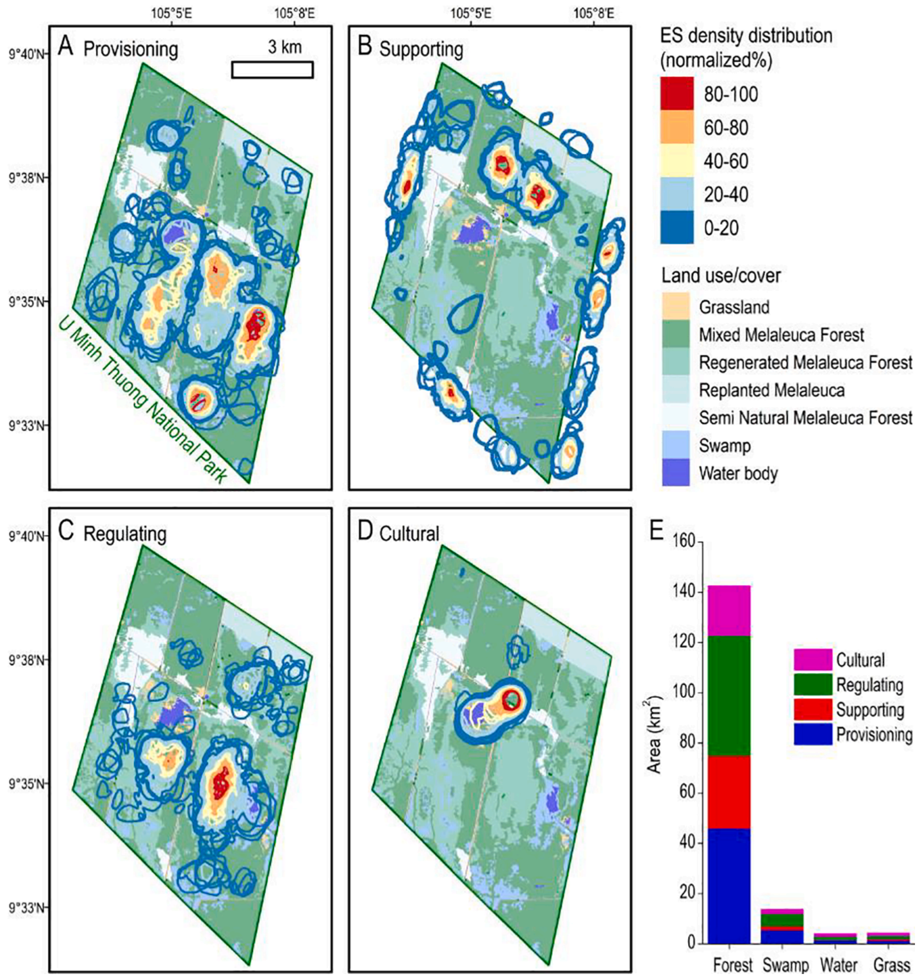


Fig. 6. A-D. Spatial density of four categories (49 each) respondents. Maps are to the same extent, and the value scales are the same since they are all normalized into % scale. Background land use/cover map is 40% transparency. People just marked location by drawing polygons (not the value). A: Provisioning, B: Supporting, C: Regulating and D: Cultural. E: mosaic-plot summarizing the distribution of ES typologies (rows) on different land covers (columns).

across the four main categories of UMTNP land covers. In general, Forests areas have the most entries, followed by Swamp, Water and Grassland. Within the Forests, Replanted and *Mixed Forests* had the highest perceived ES values, which corresponds to its dominance across the park, both area and ecological function wise (Table 1). Other types of Forest, i.e. *Replanted Forests*, *Semi-natural Forests* are under protection and off-limit, hence substantially less associated with ES. Likewise, Swamps and Water Bodies are also substantially less connected with ES. The Provisioning and Regulating services are concentrated the most in the core areas of the park covered by Mixed and Regenerated Melaleuca Forests. The distribution of Supporting services, on the other hand, is scattered along the periphery of UMTNP on Semi-natural Forests.

Results from CA (Fig. 7) help to explain the spatial correlations between ES and different landscape features. The projection results confirm the spatial synergies which were previously explored, i.e. Provisioning and Regulating services on the Forests and Swamp, supporting ES being the most associated with the Mixed Forests areas; and Grassland and Waterbody landscape features are the most distinguishable for their Cultural benefits. Subsequently, findings from the pair-wise OLS and GWR analysis identified on the map the synergies of hot spots as depicted in Fig. 8. More specifically, the core areas having the most synergization for Provisioning and Regulating, signifying its ecological importance. Supporting services were the most synergized with provisioning and regulating services at the periphery of the natural park where its non-extractive material benefits are the most prevalent. Cultural ES, on the other hand, are synergized with the other services at the

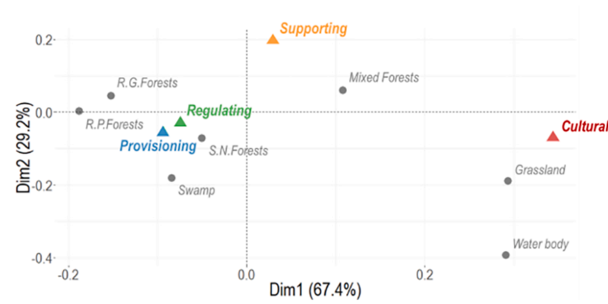


Fig. 7. Correspondence Analysis (CA) between ES and Landscape features. A: Correspondence Analysis. All forests are melaleuca tree predominant. Abbreviations: R.G. - Regenerated, R.P. - Replanted, S.N. – Semi-natural.

areas distinguished by recreational activities (bird-viewing yard, recreational fishing pond, and historical sites) and are associated with grassland or water bodies.

5. Discussions

5.1. PPGIS findings to inform decision making

First of all, the revealed clusters from the multivariate analyses essentially confirms the diversified perceptions regarding the

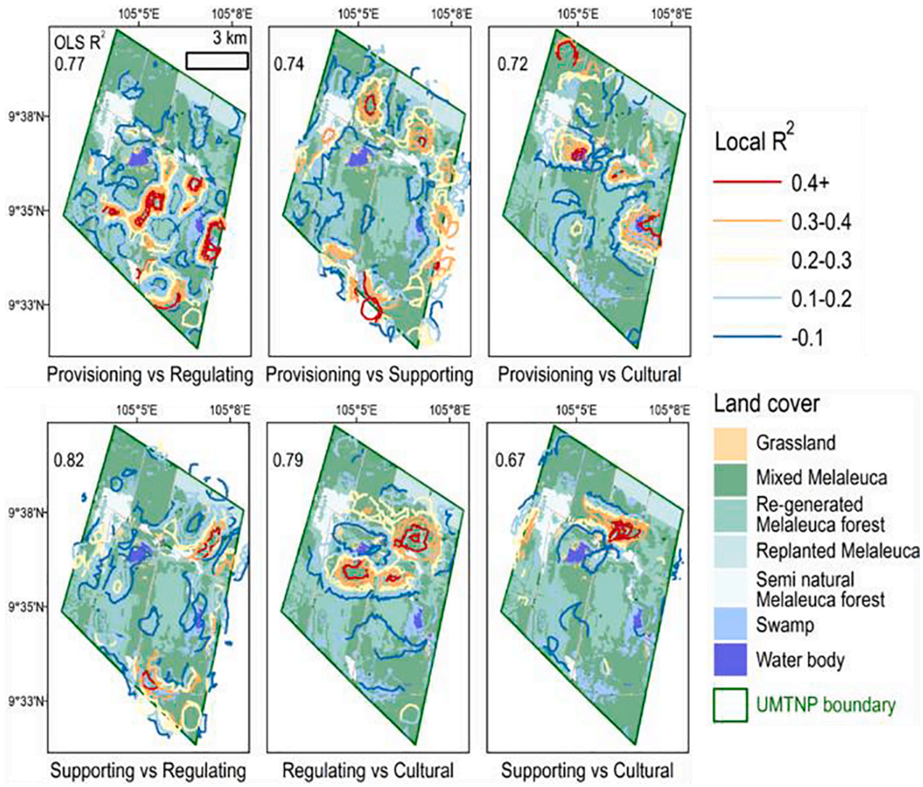


Fig. 8. Spatial Statistics between ES and Landscape features. ADigitized survey results were rasterized to generate a contour map using 0.5 as an interval. All OLS results are given in each map as global R^2 which are all statistically significant at 95% confidence level. Background map is the land use/cover map.

importance of different ecological and cultural benefits within the community. Acknowledging these imbalance perceptions is henceforth important for the management of natural resources and environment of the conservation areas (Loc et al. 2018a, Loc et al. 2020). Admittedly, in-depth inferences of each cluster's characteristics could have been further explored with larger sample sizes and/or more socio-economic background information. Nonetheless, this is beyond the scope of this study. Readers with an interest in such analytical results can refer to various published works, for instance Loc et al. (2017a,b), (2018a,b), Nguyen et al. (2019).

Secondly, the results from the hotspot analysis essentially reflect the zoning regulatory strategy of the park managers to balance between conservation and development, in which certain forest plots still allow for regulated resource extractions or non-extractive activities whereas the others are strictly protected for conservation. In UMNTP, daily tours are offered for various genres of visits, e.g. educational field trips, outing activities, and more importantly, bird watching. The park has some of the most renowned sites for bird watchers and photographers in the region. These benefits are essentially regulated by the management board, hence concentrated on designated areas, i.e. fishing ponds (water body), and bird viewing sites (grassland).

Finally, the results from HCA combined with spatial statistics reveal important synergies of different types of ES cross UMTNP landscape as illustrated in Fig. 6. The spatial synergies result essentially point to the areas where the contrasted perceptions from the inhabitants potentially emerge. This, in turn, implies potential conflicts among different uses; for instance, especially between extractive and non-extractive uses, material vs mental benefits. This mismatch is noteworthy because UMTNP is a duo-functional site regulated by the central government, i.e. biodiversity conservation vs ecotourism development (Decision 11/ 2002/QĐ-TTg - in Vietnamese).

5.2. Policy relevance of the PPGIS findings

When it comes to policy relevance of the mapping results, most of the studies referred to herewith are skeptical, thus modestly suggesting potential implications or pathways otherwise. For example, Cox et al. (2014) states that *"PPGIS offers a practical toolset for efficiently capturing and analyzing stakeholder management preferences, allowing managers to make informed decisions and understand tradeoffs"*. In the same manner, Van Riper and Kyle (2012) or Loc et al. (2018a,b) highlighted the mismatches in the density of social values imply the potential conflicts amongst user groups that decision-makers should anticipate. In essence, information on ES mapped via PPGIS or empirical methods, has been rarely applied in actual decision making or landscape planning agendas so far. Perhaps, as Opdam (2013) writes, "*ES research does not provide the type of science that is required to support sustainable, community-based landscape planning*" and that "*there is a strong demand for approaches that are able to involve local governance networks and move the ecosystem services research of the static mapping and evaluation approaches*".

So how can we generate the science that is actually meaningful for decision makers? And in return, how can we communicate to them the results from our research, including the mapped more effectively? The analytical framework as presented in Fig. 2 may address these questions as the information gathered from the research is essentially a fusion of knowledge from both decision makers and local communities, with the PPGIS of ES being the vehicles. The proactive interactions with the decision makers prior to conducting the survey have allowed for the acknowledgment of their expectations, mandates and planning visions, thus the findings become more relevant to their agendas. In essence, it is highly recommended that scientists to take the extra miles to bring their technical findings closer to the decision-making agendas of the government (Loc et al., 2018b, 2020).

Accordingly, we purposely made use of the land cover maps developed for the conservation management purposes instead of the generic aerial photos or satellite images. In doing so, the results become more associated with the managers of UMTNP. Secondly, the contrasted perceptions of the UMTNP multiple ES within the local communities is confirmed and further investigated. Not only did we acknowledge the existence of the contrasted judgments using the questionnaires, but we also identified those areas where ES are recognized differently on the land cover map of the park. For instance, even though the majority of the participatory mapping results concentrate on the mixed forests, there are several entries connecting provisioning ES with semi-natural forests, i.e. protected areas. In other words, the mismatches between the natural parks' regulations and the local residents' perceptions might lead to the ignorant detrimental impacts to the protected areas. For example, even though certain areas are designated as *protected*, there are still illegal penetrations by the locals to extract the resources, such as timber and other non-timber forest products (honey, ornaments, animals).

Finally, this study took note of the limited appreciation of the community for the non-material benefits of the park. Cultural values, in fact, should have been the second highest ES regarded given the UMTNP's designated position as both a biosphere reserve and a site for eco-friendly and educational/historical tourism (Decision 11/2002/QĐ-TTg - in Vietnamese). This critical discrepancy between the community's responses and the government's planning highlights the imbalanced cognitions in public awareness potentially lurking among the community. Evidently, in the future, the management board is advised to highlight the cultural values of the park better, in addition to the ecological functions. In essence, the intentionally limited sample would not allow for more detailed inferences to be made without critical statistical caveats. The methods presented, nonetheless, lay important foundations for future studies, for example, human geographers can investigate the community's sense of place in relation to their ethnography backgrounds.

6. Conclusions

The analytical framework and its associated methods presented in this study contribute to move the PPGIS of ES forward in three aspects: (i) more efficient participatory mapping strategy, (ii) more meaningful data analyses, and (iii) more decision-maker friendly results. In the first aspect, the data collection method has taken a step forward from Loc et al. (2018a), and adopted a genuine participatory mapping approach. The presented method also provides important evidence to re-examine a point raised by Brown and Fagerholm, 2015 regarding the use of polygons or points as a marking system. Using polygons has the capability to generate primary two-dimensional data sets as compared to the one-dimensional data. Thereupon, having an additional spatial dimension of the collected data constitutes an important methodological advantage as it can open the door to several powerful analytical tools, which could have been impossible otherwise. Secondly this study showcases the merits of two important spatial statistics tools, i.e. OLS and GWR, combined with two multivariate analysis methods, i.e. PCA and CA. The combinations and cross-validations of these advanced data analytical methods have made the hidden information from the data available, for instance, the identified clusters of different perceptions within the community or the spatial synergies across different natural benefits. Concerning cost-effectiveness, the ability to reveal multidimensional information as such is even more important given the limited sample data of the study. Finally, the entire analytical framework is developed with the ultimate target to generate new knowledge that is not only scientifically sound but also practical for decision makers. More specifically, from the acknowledgment of decision maker's expectations, to incorporating their advisory inputs and materials during the survey design, each step contributes to delivering more policy relevant research outcomes. In essence, the analytical framework itself suggests an operational pathway to streamline ES research findings into decision making agendas.

The topic of ES is especially pertinent to the UMT conservation area for its ecological and cultural significance in Vietnam. This was clearly reflected in the Prime Minister's decision in converting the park from a provincial biosphere reserve to one of the national parks in 2002. The development strategy has been shifted towards balancing between biodiversity conservation and eco-tourism development. This study applied the novel analytical framework to craft meaningful information to support the decision making in two specific accounts. Firstly, we confirm the existence of the contrasted perceptions regarding the UMTNP resources among the communities and identify those areas where these possibly emerge. By associating this information with their conservation and developing strategies, actions can be taken to address the potential threats. Secondly, the results could have highlighted the limited appreciation of the locals for intangible benefits, cultural ES compared to tangible benefits, provisioning, regulating and supporting ES. This could have led to the erroneous actions that might affect the unique biophysical features of the park, for instance, illegal poaching or trapping of protected animals and birds that are the key attractions to the parks' visitors. Even though this study sample size is admittedly small, the results generated from the qualified (purposely selected) participants could have suggested important questions regarding the contested uses of the natural resources around and within UMTNP for future studies. From the findings generated by this study, decision makers are suggested to revisit their education and public awareness campaigns to alleviate this mismatch. As the final note to Vietnam Mekong Delta, the environments are constantly changing under a full spectrum of natural and anthropogenic threats (Park et al. 2020; Binh et al., 2020; Loc et al., 2020), people's perceptions towards the nature-derived benefits will no longer be the same as before. For instance, this study was able to document the recognitions of the local people regarding the ES concept, one of the most interconnected concepts of sustainable development. This is essentially a welcomed signal for UMTNP, laying important grounds to realize the sustainable management of natural resources in harmony with the local people's livelihoods. The PPGIS analytical framework contributed by this study, henceforth, can be efficient in identifying the mismatches: e.g. between governments and residents; or between conservation and livelihoods purposes, hence facilitating better informed policy planning and decision making processes.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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