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Analysis of ecosystem services provision in the Colombian Amazon using participatory research and mapping techniques

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ABSTRACT

Over the last two decades indigenous peoples in the lower Caquetá River basin in Colombia have experienced detrimental changes in the provision of important ecosystem services in ways that have significant implications for the maintenance of their traditional livelihoods. To assess these changes we conducted eight participatory mapping activities and convened 22 focus group discussions. We focused the analysis on two types of change: (1) changes in the location of ecosystem services provisioning areas and (2) changes in the stock of ecosystem services. The focal ecosystem services include services such as provision of food, raw materials and medicinal resources. Results from the study show that in the past two decades the demand for food and raw materials has intensified and, as a result, locations of provisioning areas and the stocks of ecosystem services have changed. We found anecdotal evidence that these changes correlate well with socio-economic factors such as greater need for income generation, change in livelihood practices and consumption patterns. We discuss the use of participatory mapping techniques in the context of marginalized and data-poor regions. We also show how this kind of information can strengthen existing ecosystem-based management strategies used by indigenous peoples in the Colombian Amazon.

1. Introduction

The Millennium Ecosystem Assessment (MA) (2005) reported that the human use of ecosystem services (ES), particularly provisioning services, has accelerated in the last 50 years and that nearly 60% of the ES globally are being degraded or used unsustainably. This alarming development is attributed to rapid population and economic growth, changes in consumption patterns and to climate change. Moreover, the demand for ES is expected to grow in the foreseeable future, accentuating the current environmental and social challenges. Therefore, there is a need for new approaches to the management of ES provision so that this trend (e.g., declining soil fertility, fish stocks, fresh water) will not have adverse effects on human well-being (e.g., food insecurity, conflicts over access to resources, exposure to infectious diseases) (Carpenter et al., 2009; de Groot et al., 2010; Millennium Ecosystem Assessment (MA), 2005; Sukhdev et al., 2008). In particular, the management of ES needs to be strengthened and tradeoffs between the provision of different services need to be considered, (e.g., enhancing livelihoods in the short-term by exploiting the environment unsustainably may undermine the long-term provision of essential ecosystem services and affect the well-being of future generations) (Bennett et al., 2009; Dearing et al., 2012; Poppy et al., 2014a; Raudsepp-Hearne et al.,

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2010; Tallis et al., 2008). There is mounting scientific evidence that these issues are especially important for the rural poor and marginalized indigenous populations whose livelihoods often depend heavily on the provision of ES and are therefore more vulnerable to environmental change and ecosystem degradation (Butler and Oluoch-Kosura, 2006; Folke et al., 2005).

In this context, approaches that account for ES dynamics (changes in spatial and temporal flows of ES) and tradeoffs between provision of different ES have become a prominent topic of research in many leading environmental and academic institutions (Crossman et al., 2012; Egoh et al., 2012; Schägner et al., 2013). Despites the promising advances in ES modelling, mapping and visualization of ES, a number of important challenges still need to be addressed (Crossman et al., 2013). For example, in some well-studied regions in Amazonia, the mapping of ES dynamics has focused on just a few relatively well-understood ecosystem services such as hydrological services and climate regulation (Grimaldi et al., 2014; Josse et al., 2013; Lima et al., 2014). Other ES mapping studies are often based on secondary data at broad scales (Martínez-Harms and Balvanera, 2012). In marginal areas, where data availability is very limited, the scientific understanding of the importance of ES to the local community has been only poorly addressed (Pagella and Sinclair, 2014).

It has been argued that socio-economic and cultural factors, such as people's domestic and productive roles, are likely to shape how individuals value ES. For instance, McCall and Dunn (2012) documented that rural women in southern countries have specific knowledge of food, medicinal herbs and fibers because they frequently use them for their work. Similarly, large market-oriented landowners are likely to value agro-ecosystem services differently from subsistence-oriented farmers (Daw et al., 2011; Díaz et al., 2011; Poppy et al., 2014a). Unless these different perspectives are integrated in ES assessments, it is unlikely that resulting management decisions will adequately address all the issues and tradeoffs.

For these reasons, we support the 'call to arms' by other researchers (e.g., Chambers, 1994; Cowling et al., 2008; Gilmore and Young, 2012; Jankowski, 2009; King, 2002; Rambaldi et al., 2006; Wang et al., 2008; Wright et al., 2009) that ES research needs to be more relevant to users' needs, to be user-inspired and user-friendly. The growing dependence of conservation science on spatially explicit data for ecosystem-based planning and management has increased the need to integrate the spatial knowledge of local communities with visualization tools (McLain et al., 2013). Dunn (2007) has highlighted that the use of more participatory approaches for mapping ES is essential for good management. This is because top down "technology-based" approaches (e.g., conventional geographic information systems (GIS) and remote sensing) when applied to indigenous territories may delegitimize indigenous knowledge and, in extreme cases, may cause indigenous people to lose control over management of their natural resources. Participatory mapping tools, such as participatory geographic information system (PGIS) techniques, could overcome these problems. PGIS techniques have been demonstrated to be an effective tool for data generation and improved management of natural resources (Dunn, 2007; Rambaldi et al., 2006). Moreover, in many circumstances, maps of the use of natural resources created by the users can be of better quality and more relevant than the "official maps" produced by authorities without local knowledge (Goodchild and Li, 2012).

In this article we extend the use of focus group discussion and PGIS techniques for mapping and qualitatively assessing changes in the provision of multiple ES in the Colombian Amazon. We specifically aim to answer the following research questions: (1) How does the location of ES provisioning areas change over time? (2) What are the changes of stocks of locally important ES? (3) How does this approach contribute to the enhancement of an existing management system? (4) Is this approach useful for marginal areas? The analysis described in this article is part of the first phase of the ASSETS research project[1] which aims at understanding the contribution of ecosystem services to food security and the nutritional status of the rural poor in the forest–agriculture interface (Poppy et al., 2014a). We concentrated on the results of three focus group discussions that addressed local perceptions regarding the source, trajectory and drivers of change of critical ecosystem services that are essential for indigenous people's livelihoods.

We applied the concept of a service provisioning area (SPA) referring to the source of ES (Syrbe and Walz, 2012). We focus on nine provisioning services and one supporting service which were regarded as the most important ES by local people. The provisioning services are supply of timber (for construction of houses and canoes), thatch (woven palm leaves for roofs), resins (tree exudate used as glue or sealant), wild fruits (mainly from palms), bush meat (large animals hunted for meat), fish (caught for commercialization), natural medicines, materials for making crafts and traditional tools (fibers, stems and leaves) and ornamental resources (fibers, trees and tree bark used for making masks and clothes for traditional dances and celebrations). The supporting service is nutrient cycling represented as perceived soil fertility which is defined by local communities as the soil conditions needed for practicing traditional agriculture.

2. Study area

The case study presented here is situated in the *corregimiento* of La Pedrera; a rural administrative unit (smaller than a municipality) located in the Lower Caquetá River Basin, tributary of the Amazon River, in the Department of Amazonas, Colombia. The total area of the *corregimiento* is 394,944 ha. A recent study on land-use change for the country has shown that the area reported non-significant variations in land cover between 2001 and 2010 (Coca-Castro et al., 2013; Sánchez-Cuervo et al., 2012). Official figures show that the population in the Department of Amazonas doubled in the last three decades from 39,937 in 1985 to 80,487 in 2005 (Departamento Administrativo Nacional de Estadística, 2001; Manrique de Llinas, 2009). The Department has experienced economic, technological and cultural changes which have affected the traditional livelihoods of the local indigenous populations (Echeverri, 2009; Reichel-Dolmatoff, 1997).

Administratively, the *corregimiento* of La Pedrera is divided into four indigenous reserves, two non-officially recognized indigenous territories (*veredas*) and two State forest reserves (Fig. 1). The indigenous reserves were recognized by the Colombian government between 1985 and 2002 giving the local indigenous communities a larger degree of sovereignty and autonomy in local resource management. Population has continuously increased in this region for the past two decades: the 1985 census reported 1631 inhabitants and the 2005 census 3267 residents. Official projections estimate that by 2014 the population may stand at 4846 inhabitants (Departamento Administrativo Nacional de Estadistica, 2009; Manrique de Llinas, 2009).

The *corregimiento* includes a number of ethnic groups, including *Yucuna, Bora, Uitoto, Miraña, Andoke,* among others. Local narratives collected during this study and those documented elsewhere (van der Hammen, 1992; Fontaine, 2001) suggest that most of these ethnicities migrated from other regions of Colombia (upper and mid Caquetá River, the Mirití-Paraná River and some

[1] ⟨http://espa-assets.org/⟩.

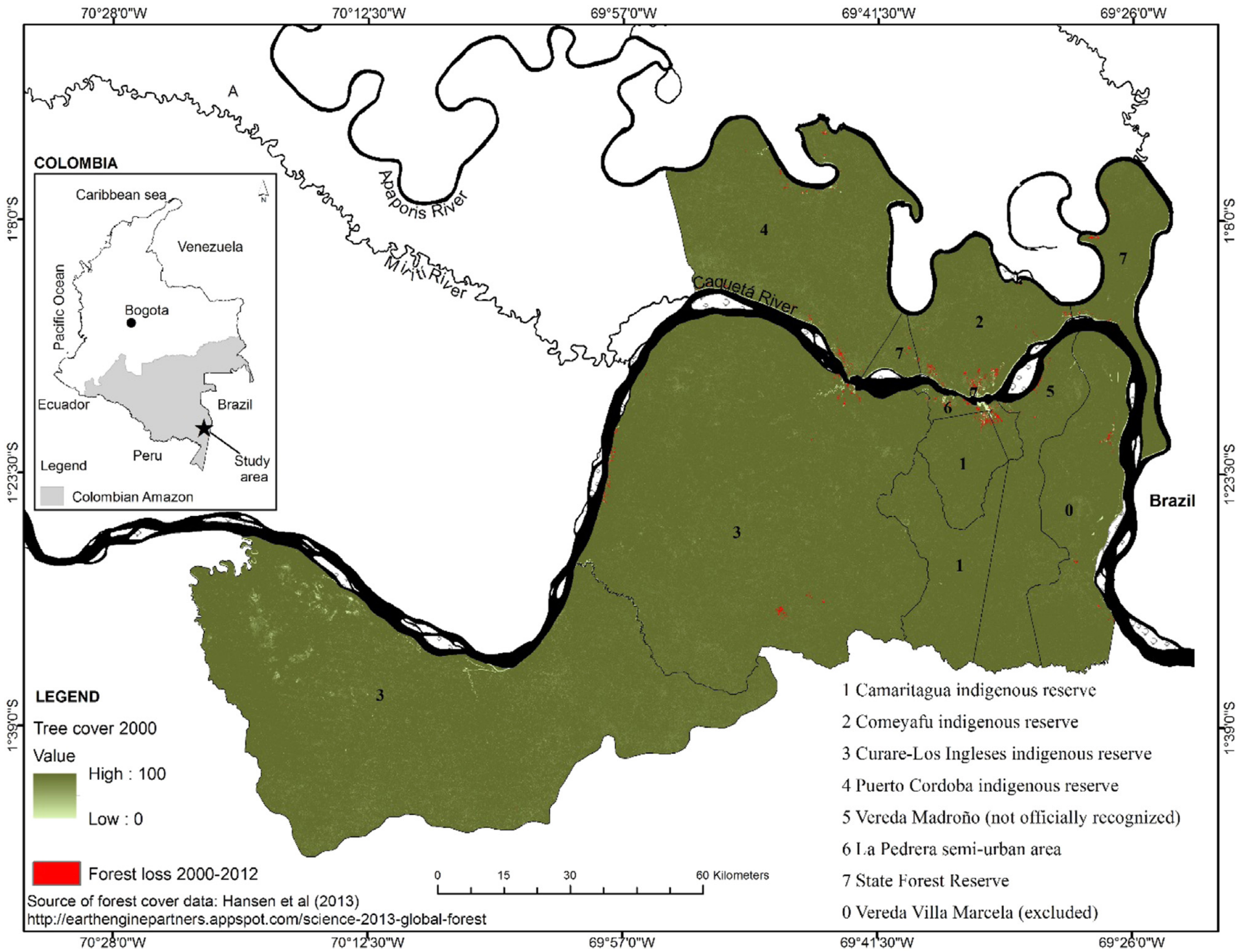

Fig. 1. Location of the study area and forest cover information. The list of indigenous reserves comprise the total area of the *Corregimiento* of La Pedrera (Total area: 394,944 ha).

from the Apaporis River) during the first decades of the 20th century. In the last two decades, indigenous groups have continued to arrive in *La Pedrera* attracted by the education opportunities of local schools, economic opportunities, and access to fertile land, as well as looking for better access to 'western' commodities such as soap, salt, sugar, cooking oil, fish hooks and fuel. *La Pedrera* town has become the most important market place in the lower Caquetá region (Organization of American States (OAS), 1989) and, along with Leticia, it is considered one of the principal sources of several freshwater fish species that are consumed in Colombia's main cities (Lasso et al., 2011; Rodriguez-Fernández, 1992).

The livelihoods of the inhabitants of the study region are based primarily on slash-and-burn agriculture, wild fruit harvesting, fishing and hunting (Gutierrez-Rey et al., 2004). Traditionally, these efforts were oriented to self-consumption; however, there is a growing integration of local households into the market economy (Rodríguez-Celis, 2012). Income is generated primarily from the sale of surplus agricultural products, fish, wild fruits and bush meat. The level of integration of residents into the market economy has fluctuated over time, related to marked economic booms which have had major consequences for the environment and resource availability as follows:

- 1970s: Demand for furs meant that men went hunting instead of practicing subsistence agriculture (Payán and Trujillo, 2006).
- 1970–1980s: The growth of the semi-urban area of *La Pedrera* led to over-exploitation of timber resources, roof thatching materials, fish and bush meat from the areas nearby (Vanegas-Cubillos and ASSET team, 2014).
- 1980s: Men went to work in commercial coca plantations instead of practicing agriculture (Molina-Guerrero, 2007).
- 1970–1990s: Gold mining in neighbouring regions of *La Pedrera* led to mercury pollution (Molina-Guerrero, 2007).
- 1980–1990s: Commercial fishing reduced fish stocks (Rodriguez-Fernández, 1992).

Between the 1990s and the 2000s, communities in *La Pedrera* established indigenous institutions to facilitate administration of the indigenous reserves. This process of community organization included the formulation of environmental management plans for the sustainable management of natural resources in each indigenous reserve. These community-based conservation efforts, which started in the year 2000 and were facilitated by the international NGO, Conservation International, have a strong basis in indigenous ecological knowledge and include community agreements, as well as restrictions and sanctions in order to avoid over-harvesting and over-exploitation (Rodríguez-Celis, 2012). Linked to the management plans, a zoning plan divides each indigenous reserve and *vereda* into use areas and preservation areas. Natural resource use is controlled by social and cultural norms, rules and restrictions in the use areas, whereas all utilization and exploitation activities are forbidden in the preservation areas. The main resources being addressed through the management plans are the palm 'hoja de Pui' (*Lepidocaryum tenue* Mart.), the leaves of which are a preferred thatching material; timber resources (e.g., 'acapú'—*Minquartia guianensis* Aubl.) used for building; and large bush meat such as tapir, deer and wild pigs for which hunting is restricted to a monthly quota per family depending on the environmental management plan of each indigenous reserve.

The *corregimiento* of La Pedrera comprises 13 communities (excluding the communities living in La Pedrera town which were not included in this study). Two of the 13 communities withdrew from participation in the study; the study is, therefore, based on data collected from 11 communities with a total of 1115 inhabitants approximately. To facilitate data collection, five communities were grouped into two clusters based on geographical proximity and socioeconomic profile. The first cluster is formed by the communities of Puerto Córdoba, Loma Linda and Bocas del Miriti (Puerto Córdoba indigenous reserve). The second cluster is composed of Tanimuca and Yucuna communities (Comeyafú indigenous reserve).

3. Methods

This study integrates PGIS activities and focus group (FG) discussions on livelihoods (Fig. 2) (Schreckenberg et al., 2012). We used the combination of these methods because they have been well-established in the field of development studies (Rifkin and Pridmore, 2001; Chambers, 2008; Desai and Potter, 2006). The use of these techniques is an efficient way of capturing group perspectives whilst providing reliable data on topics that are of particular relevance to marginalized communities (Bernard, 2006; Brown and Pullar, 2012; McLain et al., 2013; Rambaldi et al., 2006).

Given the context of the study area and drawing on the experience of similar studies (Lowery and Morse, 2013; Ramirez-Gomez et al., 2013) we used hand-drawn polygons rather than points to represent locations of ecosystem services provisioning areas (SPA). The use of polygon areas is better suited for workshop methods with small sampling size as "spatially significant areas can be determined with fewer polygon observations and thus less participant recruitment" (Brown and Pullar, 2012: 244). Drawing polygons was also easier to implement for the PGIS participants, as no particular technical or rhetorical skills were necessary. Focus group discussions, in turn, help to generate rich descriptions of the topics in question as well as a more in-depth understanding of local historical narratives, perceptions and meanings (Bauer and Gaskell, 2000; Esterberg, 2002). We piloted these methods in an indigenous community in the municipality of Leticia, Department of Amazonas, in February 2013. Data collection in the *corregimiento* of La Pedrera took place between March and June 2013 using amended versions of these exercises.

The results of this study are based on information obtained from eight FG discussions on ES trend analyses (one in each community or community cluster), 14 cause-effect FGs (at least one in each community/cluster) and eight PGIS mapping activities (separately for each community or community cluster). A total of 158 participants took part in the above activities. A purposive sampling approach was used to select the FG participants (Bauer and Gaskell, 2000; Chambers, 2008), based on two main criteria: (i) participants had to be actively engaged in hunting, fishing as well as forest collection activities, and (ii) they had to have been residents of the region for the last 20 years. In addition, for PGIS mapping activities, facilitators were instructed to gather informants from dispersed areas of the community to minimize spatial bias. While each trend analysis FG was, on average, composed of six informants, cause-effect FGs were composed of five informants (see Table 1). Each PGIS activity was carried out with between five and seven participants. Female involvement in mapping activities was limited due to the selection criteria implemented: fishing, hunting, house building and handicrafts are predominantly male activities in the *corregimiento* of La Pedrera (Fontaine, 2001). Following standard ethical guidelines, participation was voluntary (ESRC, 2012).

The methods implemented did not aim to achieve a precise valuation, quantification or spatial representation of the subject. Rather, we aimed to provide an adequate assessment of local circumstances, changes and perceived causes that are not directly translatable into traditional scientific knowledge (Chambers, 2008; Dunn, 2007; Kumar, 2002). The data inputs obtained are not suitable for statistical estimations of "accuracy", nor for generalization to larger populations (Brown and Kyttä, 2014; Brown et al., 2014). However, our preference for this approach was driven partially by the lack of historical data on ES stocks and ES source areas in the *corregimiento* of La Pedrera and because spatial representations of land use practices and ES use could not be pinpointed precisely using land cover maps available for the study area.

Data collection was undertaken by five trained facilitators (two for the trend analysis FG, two for the cause-effect FG and one for

Table 1
Composition of the focus groups on ES stocks and of the PGIS activity groups.

Community	FG trend analysis on ES stocks		FG cause-effect on stock change		PGIS activity	
	Female	Male	Female	Male	Female	Male
Camaritagua	0	5	2	2	0	6
Vereda Madroño	3	3	5	5	0	5
Tanimuca/Yucuna	2	4	4	7	0	5
Angosturas	1	6	-	-	1	6
Bacurí	0	5	5	5	3	2
Borikada	5	6	6	5	0	5
Curare	1	3	1	6	0	5
Puerto Córdoba[a]	2	3	7	5	0	6
Total	**14**	**35**	**30**	**35**	**4**	**40**

[a] Cluster of communities comprising Puerto Córdoba, Loma Linda and Bocas del Mirití.

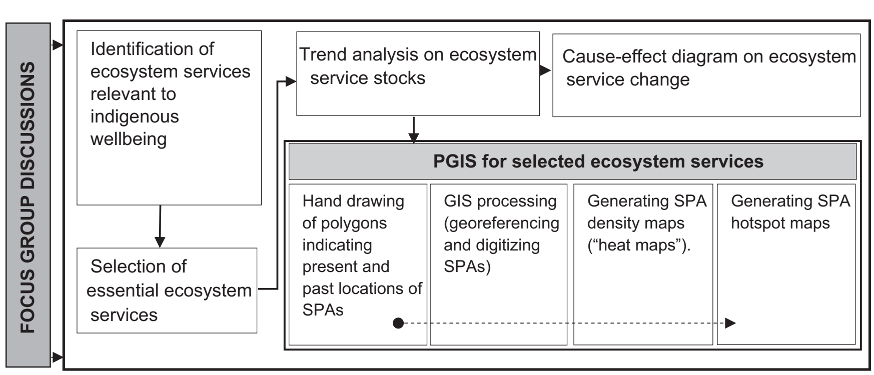

Fig. 2. Flow diagram showing the process for analyzing changes in the provision of ecosystem services. SPA=Service Provisioning Area.

the PGIS activity). The trend analysis FG began by asking informants to identify all the ES considered relevant for housing, domestic chores, health, income generation and local cultural features (e.g., celebrations and handicrafts). Once the list was completed and revised, participants were asked to select those ES that they considered essential for their well-being. Participants then developed a matrix in which they quantified changes in the stocks of each of the selected ES for the past two decades or more according to a timeline they considered relevant in their community history. The quantification of changes was achieved by assigning scores (shown with counters) that ranged from 0 to 10 where 10 represented a period of abundance and lower scores different degrees of scarcity. When the matrix was finished, informants discussed which factors they perceived as causing the reported changes, the impacts they had on local livelihoods and well-being as well as the existing and potential measures that could help manage or redress any negative changes. These discussions lasted between 3 and 4 h.

Following the ES trend analysis FGs, further FGs were conducted to develop cause-effect diagrams on issues identified by participants as being most relevant to their material well-being. The issues selected were (i) decreasing fish stocks (seven groups), (ii) decreasing bush meat stocks (five groups), and (iii) decreasing stocks of timber and thatch construction materials (two groups). Participants first listed – in no particular order – all potential causes contributing to the process being discussed and then sorted them according to whether they were considered direct or indirect drivers of change. Finally, participants identified all impacts on ES benefits resulting from the negative trends and proceeded to order these impacts depending on whether they were considered to be direct or indirect. The FGs further identified the most important drivers and impacts as well as reporting on any preventive and mitigating measures adopted. These FG discussions lasted between 2 and 3 h.

Participatory mapping of SPAs started by asking the participants to review, discuss and agree on the list of ecosystem services identified during the ES trend analysis. The mapping task focused on those ES perceived as essential by participants. Each group of participants received a printed map (A1 size at 1:50,000 scale) of a digital elevation model (DEM) of 30 m, overlaid with layers of administrative boundaries, rivers, creeks, river islands and location of communities. Participants began by locating their communities and other land marks to help them understand the base map. Transparencies were then placed on top of the map to record discussions about the location of SPAs. One map was produced by each PGIS group. Typically one group representative drew polygons using a different colored marker for each ES. First they indicated the present location (in 2013) and then, using the same color marker but a dashed line, they drew a polygon for the historical location (in 1993). When the past and present locations were the same it was noted by a corresponding mark at the bottom of the map. These PGIS activities lasted between 3 and 4 h.

3.1. Data analysis

3.1.1. Data analysis of ES trend analysis and cause-effect focus groups

Three types of data were produced by these exercises: (i) textual data, based on consolidated notes from FG facilitators; (ii) images, digital photographs of cause-effect diagrams; and (iii) quantitative data derived from trend analysis matrices. Textual and image data were analyzed using a thematic analysis framework by means of descriptive coding techniques which assign a code (a word or a short phrase) that summarizes their content (Esterberg, 2002; Saldaña, 2009). ES were then grouped according to goods and benefits they provide (e.g., thatch, fish, game, etc.). The qualitative data analysis software Atlas.ti (Muhr and Friesse, 2004) was used throughout this process. In addition, an independent manual coding process identified drivers of change for each listed ES benefit. This double coding exercise was conducted in order to guarantee a greater reliability of the findings (Bauer and Gaskell, 2000; Esterberg, 2002). The matrices quantifying perceived changes in ES stocks were consolidated according to ES and the relevant assigned scores added and averaged for two historical periods: two decades ago and the present. The results were used as an illustration device since they summarize the main change narratives described in the textual data.

3.1.2. Spatial analysis following PGIS activities

The PGIS activities generated eight annotated maps showing SPAs for each service in two community clusters and six individual communities. These maps were scanned and georeferenced to MAGNA-SIRGAS/Colombia Bogota Zone as spatial reference system. Polygons were digitized into vector layers using ESRI's ArcGIS 10.1.

Table 2
Total number of polygons (representing service provisioning areas) generated for each ecosystem service in each community or community cluster.

Community	PGIS group size	Number of polygons per ecosystem service																			
		Timber		Thatch		Medicines		Fruits		Bush meat		Fish		Crafts		Ornaments		Soil fertility		Resins	
		1993	2013	11993	2013	191993	2013	1993	22013	1993	2013	1993	2013	11993	22013	11993	2013	1993	2013	1993	2013
Camaritagua	6	4	10	4	6	–	–	2	2	3	3	–	–	8	8	1	4	1	1	2	2
Vereda Madroño	5	12	11	3	2	9	9	1	4	–	–	–	–	–	–	–	–	5	5	–	–
Tanimuca/ Yucuna	5	2	3	1	1	–	–	–	–	9	9	–	–	5	4	2	2	–	–	–	–
Angosturas	7	13	18	9	7	–	–	–	–	–	–	14	14	–	–	3	3	4	9	2	2
Bacurí	5	5	4	9	3	7	14	–	–	–	–	–	–	3	3	7	4	–	–	5	1
Borikada	5	12	12	3	3	–	–	1	1	7	9	–	–	2	2	1	1	–	–	1	1
Curare	5	7	10	3	4	8	8	–	–	6	9	3	4	3	4	3	6	4	4	2	2
Puerto Córdoba[a]	6	8	19	9	21	–	–	–	–	19	29	23	27	5	8	6	12	–	–	2	5
Total	44	63	87	41	47	24	31	4	7	44	59	40	45	26	29	23	32	14	19	14	13

[a] Cluster of communities comprising Puerto Córdoba, Loma Linda and Bocas del Miriti.

Table 3
List of ecosystem services identified as most essential in this study.

Ecosystem Services	Species name	Local name
Timber	*Anaueria brasiliensis* Kosterm.	Aguacatillo
	Copaifera reticulata Ducke	Copai
	Iriartea deltoidea Ruiz & Pav.	Palma barrigona, bombona
	Minquartia guianensis Aubl.	Acapu
	Socratea exorrhiza H.Wendl	Palma zancona
Thatch	*Lepidocaryum tenue* Mart.	Pui
	Philodendron solimoesense A.C.Sm.	Bejuco burro
Medicine	*Aspidosperma* sp.—*Neea obovata* Spruce	Costillo
	Triplaris americana L.	Vara Santa
Food: fruits	*Euterpe precatoria* Mart.	Asai
	Mauritiella armata Burret	Cananguchillo
Food: bush meat	*Cuniculus paca* (Linnaeus, 1766)	Borugo
	Mazama americana (Erxleben, 1777) *and M. gouazoubira* (G. Fischer, 1814)	Venado
	Tapirus terrestris (Linnaeus, 1758)	Danta
	Pecari tajacu (Linnaeus, 1758)	Puerco de monte
Food: fish	*Brachyplatystoma filamentosum* (Lichtenstein, 1819)	Lechero
	Zungaro zungaro (Humboldt, 1821)	Pejenegro
	Phractocephalus hemioliopterus (Bloch and Schneider, 1801)	Cajaro
	Piaractus brachypomus (Cuvier, 1818)	Paco
	Pseudoplatystoma sp. (Bleeker, 1862)	Pintadillo
Crafts: material for making handicrafts and traditional tools	*Brosimum rubescens* Taub.	Palo de sangre, granadillo
	Cecropia spp. Loefl.	Guarumo
	Heteropsis sp. Adans.	Bejuco Yaré
	Ficus obtusifolia Kunth	Higueron
Ornaments: ornamental resources for dances and celebrations	*Brosimum utile* Pettier	Marimá, yanchama
	Eschweilera sp.	Carguero
	Iriartea deltoidea Ruiz & Pav.	Pona
	Ochroma pyramidale (Cav. ex Lam.) Urb.	Balso
Soil fertility		
Resins	*Symphonia globulifera* L.f.	Breo
	Byrsonima cognata W. R. Anderson	Lana

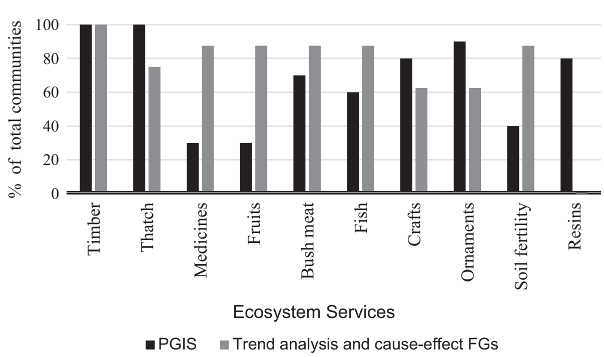

Fig. 3. Important goods and benefits discussed by communities during the PGIS activities and focus groups.

Table 4
Reported trends of the provision of goods and benefits for the past 20 years.

Ecosystems services	No. of focus groups discussing ES	Perceived change (no. of focus groups)			Average score (out of 10)	
		Decrease	Increase	No change	20 Years ago	Present
Timber	8	5	1	2	9.0	7.3
Thatch	6	4	1	1	8.7	7.2
Medicines	7	1	0	6	8.8	8.3
Fruits	7	4	1	2	9.1	8.2
Bush meat	7	6	1	0	8.6	5.9
Fish	7	7	0	0	8.1	4.6
Ornaments	5	5	0	0	9.0	5.6
Soil fertility	7	5	0	2	9.4	6.7
Great otters	4	0	4	0	2.0	7.8

3.1.2.1. Polygon density analysis. Each digitized polygon was assigned an ID according to the year and ES they were representing. Multiple polygons for each ES were appended and then output into a distinct shapefile. Fig. 4A shows all polygons generated for the study area representing SPAs in 1993 and 2013, respectively. Table 2 shows the total number of SPA polygons generated for each community. Density maps were generated to obtain a 'heat map' of SPAs (Fig. 4B). This was done using the *overlap counter* customized tool developed within ArcGIS (Martínez, 2012) as described in Ramírez-Gómez and Martínez (2013) and Ramirez-Gomez et al. (2013).

3.1.2.2. Hotspot analysis. We defined SPA hotspots as areas that exhibit high densities of overlapping polygons. They were determined by applying a cut-off value which corresponds to the upper third rule of the polygon density distribution as has been done in other studies (e.g., Alessa et al., 2008; Brown and Pullar, 2012). Fig. 4C shows SPA hotspots that indicate which areas are important for providing multiple ecosystem services without explicit mention of the underlying ecosystem processes that generate the services (Palomo et al., 2013).

3.1.2.3. Spatial change. To analyze the change in the location of SPAs we utilized ESRI's ArcGIS 10.1 Change Detector tool. This tool compares two feature classes and creates three new classes: (1) newly generated areas, (2) areas lost, and (3) areas that remained unchanged. We use these outputs to estimate the total change in area of SPAs. To estimate the percentage change in SPAs per community, we used the following formula:

$$\%\ \text{change} = \left(\frac{(A_{2013} - A_{1993})}{A_{1993}}\right) \times 100$$

where A is the total area of a SPA hotspot in a corresponding year (Table 7).

Table 5
Trends in ecosystem service stocks during the last 20 years based on communities' views and drivers of change recorded during ES trend analysis FGs, cause-effect FGs and PGIS activities.

Ecosystem Service	Benefit	Perceived stock change trend	Perceived drivers	
			Direct	Indirect
Timber	Building material for houses, *malokas*[a] and canoes, income generation	▾	Unsuitable logging practices, illegal logging	Population growth, change in practices and consumption patterns
Thatch	Building material for houses and *malokas*	▾	Unsustainable harvesting practices	Population growth, change in practices and consumption patterns
Bush meat	Income generation	▾	Unsuitable practices	Population growth, change in practices and consumption patterns
Fish	Income generation	▾▾	Unsuitable practices, pollution, giant otters	Population growth, change in practices and consumption patterns, expanding trading networks, climate change and seasonality.
Ornaments	Dresses and masks for traditional dances	▾▾	Unsuitable practices	Population growth
Soil fertility	Traditional shifting agriculture	▾	Unsustainable practices	Population growth, loss or lack of traditional knowledge
Medicines	Health	±		
Fruits	Income generation	±		
Crafts materials	Brooms, baskets, kitchen implements, handicrafts	±		
Resins	Glue, sealants and body painting	±		

▾▾ Severe decline. ▾ Moderate to severe decline. ± No clear trend.

[a] Maloka is a traditional round house with high cultural value among the indigenous communities in the Colombian Amazon and home to the traditional authority.

4. Results

4.1. Identification of the most important ecosystem services

During the FG discussions, communities identified ten categories of ES related to provision of food and materials important for their livelihoods and culture as well as one supporting service—soil fertility, which was identified as essential for agricultural activities (Table 3). The ES reported during the PGIS activities varied slightly from those discussed in the trend analysis and cause-effect FGs (Fig. 3). This may be explained by the fact that the mapping activities focused on forest areas whilst trend analysis and cause-effect FGs were more generic, encompassing both forest, farmland and home gardens. Furthermore, constraints related to representing spatial scale meant that the PGIS activities could not capture all the reported list of essential ecosystem goods and services, such as medicines and fruits found in home gardens.

4.2. Trend analysis in the stock of selected ecosystem services and drivers of change

Results of the ES trend analyses provided information on perceived changes in stocks of ES between 1993 and 2013 (Table 4). Fish and ornamental resources are amongst the ecosystem services perceived to have declined the most, followed by bush meat. Based on the results of this analysis, we recorded three different tendencies in the change of the service provision (Table 5): (i) *Severe decline* refers to a resource that has become increasingly scarce; (ii) *Moderate to severe decline* refers to resources that have become rare in traditional areas of use as compared with 20 years ago; (iii) *No clear trend or no change.* In this study, fish and ornamental resources for traditional dances were identified as suffering from *severe decline*. Bush meat, timber, roof thatching materials and soil fertility are among the goods and services with moderate to severe decline, with no clear trend reported for wild fruits and medicinal plants.

Based on the cause-effect FGs, a number of drivers of change in ecosystem service provision were identified and summarized (Table 5). The participants recognized population growth as the most salient indirect driver. According to their perception, it has increased the demand for goods and benefits and therefore it has intensified natural resource extraction (e.g., timber and thatch for building, fishing and hunting for market). By contrast, the abandonment of traditional natural resource use practices and the adoption of unsuitable practices were identified as direct drivers of change that have led to over-exploitation of important resources such as thatch, fish and timber. This change has been the result, on the one hand, of an expansion of trading networks (e.g., establishment of weekly flights to Leticia and regular visits of commercial boats from Brazil) which has improved the access to markets and intensified extractive operations. On the other hand, change in consumption patterns associated with improved education and means of communication are responsible for changes in practices and preferences, particularly among the younger generation. Therefore, there is an increase in the use of 'modern' extractive equipment (e.g., shotguns to hunt or chainsaws to fell trees) and a growing preference for 'imported' products (e.g., salt, rice, cooking oil) stimulating commercial activity of the local population.

4.3. Spatial distribution of service provisioning areas

The spatial representations of SPAs and the process to generate density maps from digitized hand-drawn polygons is presented in Fig. 4. Density maps display areas where several SPAs overlap and therefore represent areas perceived by PGIS activity participants to be of collective importance in the *corregimiento* of La Pedrera. They can also be interpreted as areas with high and low intensity of use. From visual inspection, Fig. 4B shows that in 1993 the highest intensity of use was inside Comeyafú indigenous reserve, followed by Camaritagua. By contrast, in 2013 the highest concentration of SPAs shifted to Curare-Los Ingleses indigenous reserves and to a lesser extent to Puerto Córdoba. Likewise, Fig. 4C depicts an increase of hotspots (significant concentration of SPAs) towards Curare-Los Ingleses and Puerto Córdoba indigenous reserve. A more detailed explanation of the distribution of SPAs hotspots is presented below.

4.3.1. Distribution of SPA hotspots in relation to administrative land use units

Our analysis shows that over the past 20 years the number of SPA hotspots in the indigenous reserves rose by an average of 33

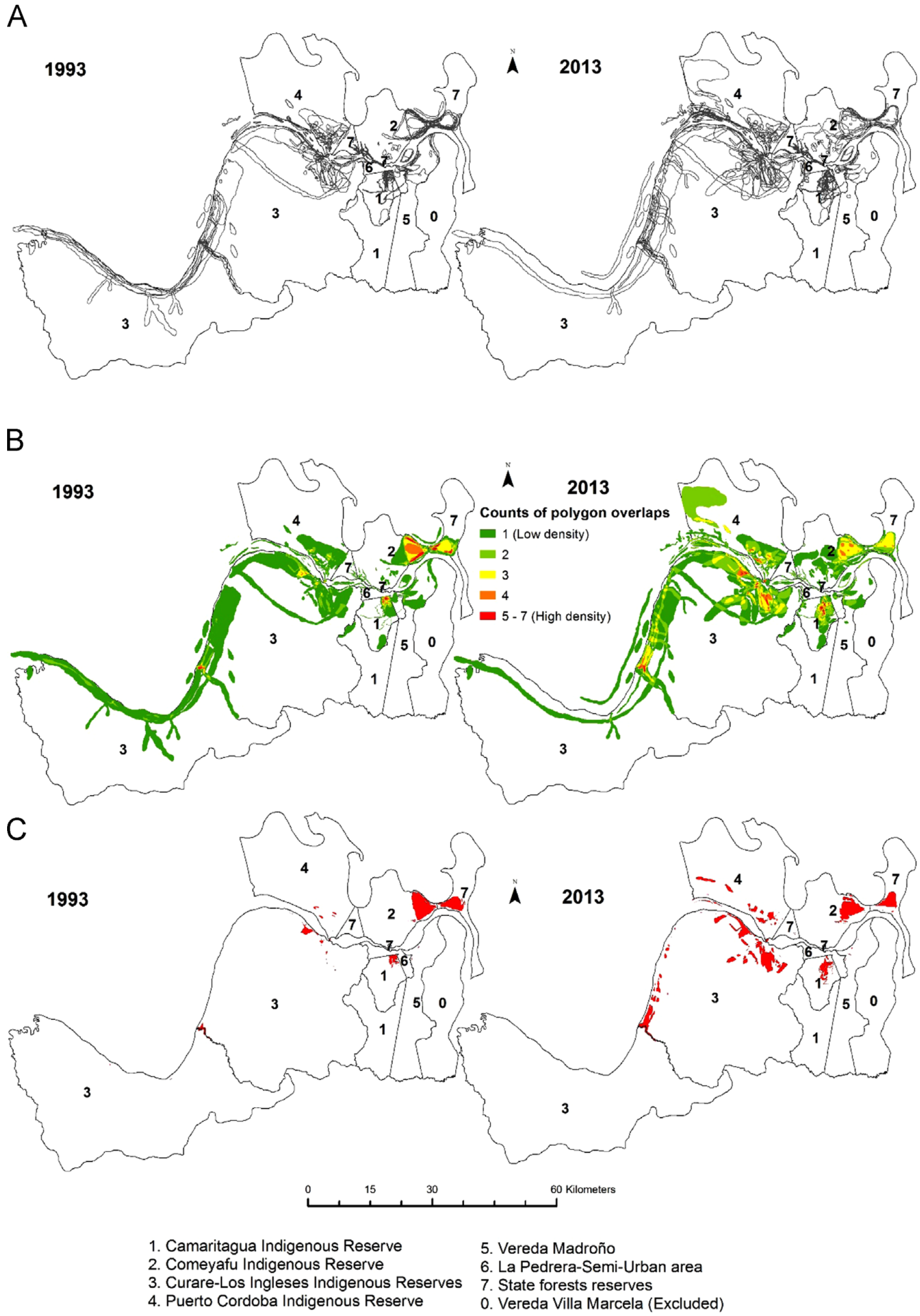

Fig. 4. Spatial representations of SPAs for 1993 and 2013 generated from hand-drawn polygons during participatory mapping activities. (A) Digitized polygons. (B) Density maps. (C) Hotspots.

per commune with an average increase in area of 1001 ha (Table 6). The pattern of increase in the number of hotspots shows the largest variability range of 132 for the community of Curare-Los Ingleses. In terms of hectares, participants from Curare-Los Ingleses reported experiencing an increase of 4711 ha in SPA hotspot area. In contrast, total hotspot area in Comeyafú indigenous reserve and the State Forest Reserves were reported to decrease by 179 and 68 ha, respectively. Moreover, the proportion of indigenous reserve covered by SPA hotspots indicates that, relative to the size of the administrative unit, Comeyafú had the highest proportion of SPA in 1993 (11.1%) and 2013 (10.2%) (Table 6). This relatively high intensity of use correlates well with population size—Comeyafú is the most populous community in the study area. The highest increase in the use of the reserve was recorded for Camaritagua which was using 3.8% in 1993 and 9.6% in 2013. In terms of spatial distribution, this study finds that the expansion of SPA hotspots was higher in the indigenous reserves with the lowest population density (Fig. 5, Table 6).

4.4. Changes in SPAs

The spatial comparison of SPAs for 1993 and 2013 provides an indication of the extent of spatial change detected during this period. Our results show that timber, bush meat, fish and thatching materials

Table 6
Change in SPA hotspots between 1993 and 2013 in the indigenous reserves of La Pedrera corregimiento.

Indigenous reserve (no. of inhabitants)	Indigenous reserve total area (ha)	Number of SPA hotspots		Total SPA hotspot area (ha)		Proportion of indigenous reserve occupied by SPA hotspots (%)	
		1993	2013	1993	2013	1993	2013
Camaritagua (64)	8,456	100	202	324	809	3.8	9.6
Vereda Madroño (56)	20,351	6	7	14	25	0.1	0.1
Comeyafú (520)	19,023	79	33	2111	1932	11.1	10.2
Curare-Los Ingleses (263)	237,643	76	209	662	5373	0.3	2.3
Puerto Córdoba (212)	46,897	17	78	124	1169	0.3	2.5
State Forest Reserve (0)	15,417	89	32	1131	1063	7.3	6.9
Mean	57,965	61	94	728	1729	3.8	5.2

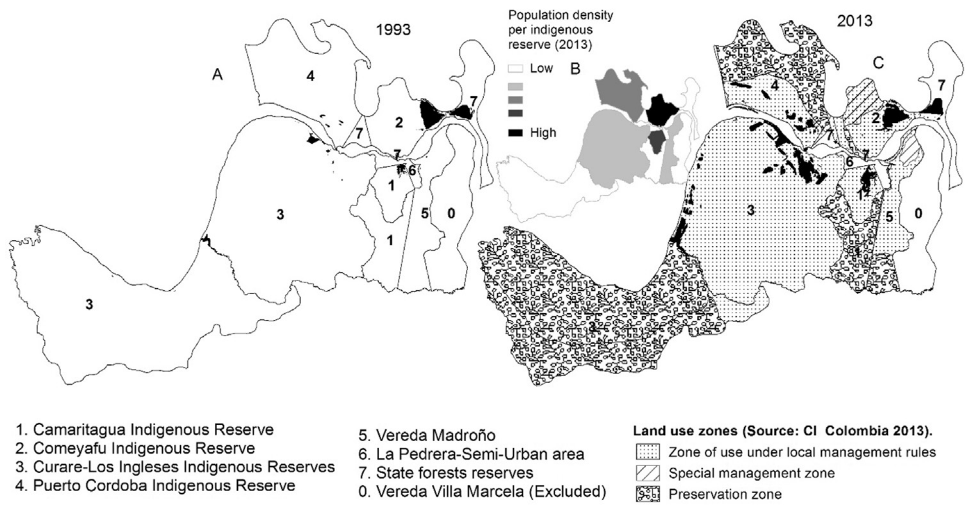

Fig. 5. (A) Indigenous reserves with SPA hotspots in 1993. There was no land use zonation in 1993 and no population data are available. (B) Population density per indigenous reserve for 2013. (C) Map of indigenous reserves with SPA hotspots (black) and land use zones for 2013.

reported the greatest increase in extent of SPA (Fig. 6). In contrast, the extent of SPAs for medicines and ornaments for traditional dances showed the greatest decline. Finally, soil fertility, fruits, crafts and resins had the greatest area of SPAs that remained unchanged. These results vary by community (Table 7). For example Camaritagua, Tanimuca/Yucuna, Bacuri and Curare show the largest increase (between +100% and +693%) for timber, roof thatching materials, ornamental resources and crafts. By contrast, Bacurí and Angosturas had the largest decrease (between −20% and −90%) for timber, thatch, crafts, ornaments, soil fertility and resins. Overall, Borikada, Loma Linda and Puerto Córdoba were the sites with the smallest amount of SPA area change, except for a moderate decrease in the SPA area for bush meat in Borikada and a moderate increase for timber in Puerto Córdoba and Loma Linda (Table 7).

5. Discussion

5.1. Change in ecosystem service provision

Our spatial analysis of SPAs shows that between 1993 and 2013 there was a significant shift of SPAs from Comeyafú to Curare-Los Ingleses, Puerto Córdoba and Camaritagua Indigenous reserves. It seems that the ES access restrictions imposed by land use zoning plans within the indigenous reserves have contributed towards the opening of new SPA locations in areas where it was permitted. In the case of Comeyafú, for example, a combination of a relatively restricted community use area and high population density may have caused a decline in ES provision as the areas of ES provision may have become overexploited (Biggs, 2004). In contrast, large community use zones and low population density suggest less pressure on the stocks of ES, as demonstrated in the case of Curare-Los Ingleses indigenous reserve (Fig. 5). These findings are similar to findings of previous studies that considered the effect of population density on the supply and demand of ES in the region (Albert and Le Tourneau, 2007; Sirén, 2007). Another possible interpretation of decreases in SPA could be that the ecosystem service concerned is no longer very valuable (e.g. natural medicines are being replaced by purchased one) and therefore only a few people continue to collect them. These figures however should not be interpreted as a complete analysis of SPA change. Our findings are presented here to demonstrate the type of data and advantages of using this methodology in data poor regions.

SPA change in the *corregimiento* of La Pedrera does not correspond with information from the available land cover maps of the area. This can be explained by two factors. First the resolution of these maps is too coarse to detect SPA changes. Second, SPA change has an impact on land use without a detectable impact on forest cover. For example, all palms used for thatching can be removed from the forest and still leave an apparently high forest cover, or large mammals – bush meat – can become extinct from forest areas that still appear intact (Redford, 1992). Therefore, the limitation of remote sensing data and other conventional GIS approaches to detect change in SPAs strengthen our preference for PGIS approaches as a more effective method to produce land use maps in the context of ES research.

The ES trend analysis is an indication of which ES need to be targeted by conservation management actions in order to restore ES

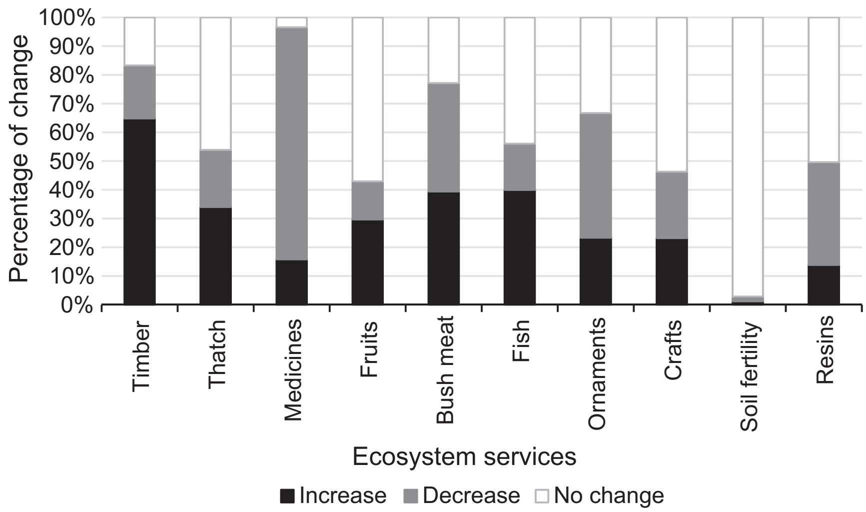

Fig. 6. Total change in the area of SPAs between 1993 and 2013. In the case of timber, for example, 64% of the SPAs have increased in size, 18% have decreased in size and 18% have experienced no change in size between 1993 and 2013.

provision. Some of the most salient reasons that explain the decline in provision of the most important goods and benefits in our study area include:

i. *Provision of fish*: Cold storage units established in La Pedrera town have increased demand for fish, promoting commercial forms of fishing that are often unsustainable. Other threats perceived by participants included river pollution, resulting from upstream gold mining, and changes in river seasonality due to climate change. Studies from other places have documented that overexploitation of fish for commercial purposes may result in a complete collapse of fish stocks, for example in the Lower Amazon floodplains (Castello et al., 2011), in the upper Amazon region (Petrere et al., 2004) and in the Colombian Amazon (Córdoba et al., 2000). Another perceived reason for this decline was the increase in the number of giant otters which were considered to be in direct competition for fish with the local fishermen. A similar conflict between fishermen and giant otter was found by Recharte et al. (2008) in the Peruvian Amazon and by Rosas-Ribeiro et al. (2012) in western Brazil.
ii. *Provision of ornaments for traditional dances*: Stocks of these resources (such as tree trunks to make face masks and tree bark and fibers to make traditional costumes) were perceived to be declining due to the increasing number of traditional festivals. This was linked to population growth because, although festivities are usually communal, there is a recent trend for them to be conducted by individual households, resulting in an increased demand for these resources.
iii. *Bush meat*: Participants reported that more time and effort were needed to hunt for bush meat. They perceived that the animals had moved to more remote forest areas. Main threats included indiscriminate hunting, misuse of sacred places (e.g., 'salados' or salt-licks), habitat degradation due to the expansion of shifting cultivation, unsuitable hunting techniques (e.g., use of shotguns) and intensification of commercial hunting. Similar unsustainable bush meat hunting practices have been documented in Africa and Amazonia (Fa et al., 2002; Peres and Palacios, 2007), Ecuador (Oldekop et al., 2012; Sirén et al., 2006) and Nicaragua (Godoy et al., 1995).
iv. *Timber*: Timber stocks became scarce from accessible areas in the communities near to La Pedrera town due to the demand for building materials during the expansion of this semi-urban center. The population growth continues to increase the demand for timber resources in the *corregimiento* of La Pedrera.
v. *Thatch material*: Roof thatching materials were perceived to have declined in a similar way to timber resources. Local population growth increased the demand for building materials and unsustainable harvesting practices depleted thatching resources near to the communities, especially those in closer proximity to La Pedrera town. As a consequence, communities have to travel longer distances or, in some cases, communities have looked for alternative roof materials that turn out to be less resistant and less durable. Those who could afford it started using zinc roofing. These factors explaining depletion of thatch materials have also been reported in Peru (Flores and Ashton, 2000), Ecuador (Svenning and Macía, 2002) and across the Amazonian region (Kahn and Granville, 1992).

From our observations we suggest that the decrease of important provisioning ES (e.g., provision of fish and bush meat) may be causing profound changes in the economic income of indigenous communities. Access to new technologies and markets gradually leads to abandonment of traditional practices of natural resource use (e.g., the use of shotguns for hunting; the use of nets and poison for fishing). This is congruent with research findings in other indigenous regions in the Amazon, for example by Lu (2007) in Ecuador and by Pérez-Llorente et al. (2013) in Bolivia who found that economic needs changed the manner in which indigenous people use natural resources, often in an unsustainable way. More and more income-generating activities used by traditional communities are less benign and may undermine the capacity of ecosystems to generate services (Fabricius et al., 2007). More in-depth and quantitative assessments of these interplays are needed in the *corregimiento* of La Pedrera so that conservation programs have the necessary information for the design and implementation of actions that contribute to the improvement of life quality and income-generating sources among indigenous populations without undermining traditional forms of natural resource use.

5.2. Contributions to community-based management and institutions

Concerns about the availability of resources in the *corregimiento* of La Pedrera led to the formulation and implementation of management plans that regulate the sustainable use of the land and resources among indigenous communities in the study area. Restriction on the use of natural resources is a common practice in traditional management systems (Berkes, 1999; Berkes et al., 2000)

Table 7
Percentage change between 1993 and 2013 in the total and mean SPA size (ha) for different ecosystem services in each community of the study area.

Community	Type of change	Timber	Thatch	Medicines	Fruits	Bush meat	Fish	Crafts	Ornaments	Soil fertility	Resins
Camaritagua	Counts of SPA change	+6	+2		0	0		0	+3	0	0
	Total SPA area	+153%	+113%		+64%	0%		-7%	+498%	0%	0%
	Mean SPA size	+1%	+42%		+64%	0%		-7%	+49%	0%	0%
Vereda Madroño	Counts of SPA change	-1	-1		+3					0	
	Total SPA area	-2%	-23%		+224%					0%	
	Mean SPA size	-7%	0%		-19%					0%	
Tanimucha/ Yucuna	Counts of SPA change	+1	0			0		-1	0		
	Total SPA area	+586%	0%			0%		+10%	+111%		
	Mean SPA size	+357%	0%			0%		+38%	+40%		
Angosturas	Counts of SPA change	+5	-2				0		0	+5	0
	Total SPA area	-38%	-37%				0%		0%	-27%	0%
	Mean SPA size	0%	-19%				0%		0%	-68%	0%
Bacurí	Counts of SPA change	-1	-6	+7				0	-3		-4
	Total SPA area	+319%	19%	-80%				-57%	-64%		-86%
	Mean SPA size	+424%	+258%	-90%				-57%	-37%		-29%
Borikada	Counts of SPA change	0	0		0	+2		0	0		0
	Total SPA area	0%	0%		0%	-33%		0%	0%		0%
	Mean SPA size	0%	0%		0%	-48%		0%	0%		0%
Curare	Counts of SPA change	+3	+1	0		+3	+1	+1	+3	0	0
	Total SPA area	+77%	+85%	0%		+93%	+32%	+276%	+693%	0%	0%
	Mean SPA size	+24%	+39%	0%		+28%	-1%	+182%	+296%	0%	0%
Puerto Cordoba*	Counts of SPA change	+11	+12			+10	+4	+3	+6		+3
	Total SPA area	+81%	0%			0%	0%	0%	+37%		0%
	Mean SPA size	+45%	0%			0%	0%	0%	+10%		0%

* Cluster of communities comprising Puerto Córdoba, Loma Linde and Bocas del Miriti

Very high decrease	Low decrease	High increase
High decrease	No change	very high increase
Medium decrease	Low increase	No data
	Medium increase	

and it plays a fundamental role in the regulation and distribution of common pool resources (Ostrom, 1990). In Camaritagua indigenous reserve for example, the implementation of the management plan has had a positive effect on the recovery of thatch resources which were heavily affected by the growth of La Pedrera town three decades ago (Conservación Internacional Colombia, 2013).

Cowling et al. (2008) describe a pathway to ensure the effective and adaptive management of ES in a dynamic but resilient socio-ecological system. This pathway includes three phases: (i) assessment, (ii) planning, and (iii) management. In addition to contributing to resource management discussions within the study communities, the analysis of change provided by this study will be integrated into a modelling framework that seeks to identify how dynamic stocks and flows of ecosystem services at the landscape scale translate to environmental securities of marginalized rural communities (Poppy et al., 2014a,b). In this sense, the main contribution of these findings, and especially the SPA maps, is that they go beyond static representation of the location of resources; instead the output maps show hotspot locations and SPAs that have increased and decreased between 1993 and 2013. Furthermore, the identification of such dynamic patterns may add to local conservation measures oriented to spatial zoning and to improve and update the standards for the existing sustainable use practices and regulations. Additionally, we feel that these maps are a concrete product from the community which directly contributes to knowledge building and bridging which are key for strengthening community adaptive responses to change (Fabricius et al., 2007; Folke et al., 2002).

5.3. Usefulness of this approach in marginalized regions with poor data availability

We identified five reasons why our approach is useful with marginalized indigenous communities: (i) The combination of methods provides land use data enabling ES studies to be holistically traced from biophysical production studies to a more data-efficient and land-user friendly approach. (ii) The mapping process generates conversations of political importance which ultimately can have a community empowerment effect. For example, in the *corregimiento* of La Pedrera, participants in the focus groups repeatedly discussed what was being mapped, access to natural resources, local organizational issues, institutional matters, management actions and traditional authority. (iii) The PGIS approach helps to legitimate traditional knowledge within scientific and policy-making forums. In our case, communities reflected on the possibilities that they had to spatialize some aspects of their local knowledge in a manner that could be understood and accepted by outsiders ("lenguaje de blanco"). (iv) This participatory mapping approach supports the transfer of ecological knowledge within (and among) the communities and between generations. For example, in some focus group sessions there were teenagers listening attentively to the discussions, narratives and traditional stories as well as observing the mapping process, occasionally helping the elders and asking questions about ES locations and use. We consider that this is important to promote, especially because one of the perceived drivers of ES change in La Pedrera was associated with the loss of traditional knowledge about natural resource practices, which participants partly related to the lack of interest in traditions by young people. (v) The (spatial) analysis of change is key to achieving a better understanding of past and present trends in stocks and for visualizing shifting SPAs as it allows communities to effectively target sustainable use of ES in the region.

5.4. Limitations of this study

The main constraint of this study is the limited inference power for the whole study region. Visualizations of ES trends are fundamental to ES management and implementation (Pagella and Sinclair, 2014) but our study shows that the utility of these findings for decision support are constrained by insufficient spatial data for regional generalizations (Brown and Kyttä, 2014) associated with the sampling method that we used (Brown et al., 2014). Furthermore, an important limitation of participatory methods, including PGIS, relying on indigenous knowledge, is that their outputs do not automatically meet "scientific" requirements for technical accuracy and statistical estimation (Chambers, 2008; Dunn, 2007). Further work is still needed to integrate these findings into the assessment of key issues related to environmental securities of the rural communities in marginalized regions (Poppy et al., 2014b; Villa et al., 2014). We are aware that data obtained through participatory workshops in initial phases of ecosystem services assessments should not constitute the endpoint for decision-support processes (Brown and Pullar, 2012) but should rather constitute the early, exploratory and hypothesis-generating stages of science-based projects (Brown and Kyttä, 2014; Goodchild and Li, 2012). Therefore, despite the consistency observed in most key findings reported here, at present the accuracy and generalizability of *La Pedrera* indigenous peoples' perceptions and representations remains uncertain.

In a similar manner, the suitability of the presented PGIS outputs for an effective natural-resource management programme in *La Pedrera* region is yet to be established. Although the successful use of PGIS to this effect is well-documented (McLain et al., 2013; Rambaldi et al., 2006; Wright et al., 2009), in a context of rapid transition – as observed in the study area – local interests may differ from those intended by the research team (e.g., some community authorities are as interested in identifying potential areas for exploitation as for conservation). A transparent process of negotiation, dialogue and external technical, if not economic, support is needed to achieve natural resource management which takes into consideration the interests of all stakeholders. As mentioned earlier, the particular issue of gendered use of resources needs to be given more consideration both during the mapping process and ensuing discussions about resource management.

Acknowledging these limitations, we nevertheless think that our study's findings provide understanding of critical ecosystem services under pressure in *La Pedrera* region and, like the studies by Lowery and Morse (2013), Ramirez-Gomez et al. (2013) and Ricaurte et al. (2014), demonstrate the benefits of this methodology in ES research by enabling meaningful descriptions of important areas and a better understanding of human–environmental interactions. The use of mixed-method approaches is considered necessary for generating quality local ES data. Mapping ES does not constitute an isolated factual data-collection exercise but is embedded in the social practices, worldviews and power relations that shape a given community, which need to be understood in order to interpret those visual representations satisfactorily (Elwood, 2006; McLain et al., 2013; Rambaldi et al., 2006). Furthermore, a ground-based mixed-method approach also serves to generate a greater sense of ownership of research outputs among informants and is a critical step for using PGIS outputs for management and planning initiatives from the bottom-up (Chambers, 2008; McLain et al., 2013; Rambaldi et al., 2006; Wright et al., 2009).

The social embeddedness of participatory data-collection techniques can make them susceptible to biases like gender, education, wealth and geographical location (Chambers, 2008; McLain et al., 2013; Rambaldi et al., 2006; Wright et al., 2009). The sequential use of participatory data-elicitation techniques and their combination with focus group methodologies, however, sets in place different quality measures to attain reliable and valid results. The successive implementation of focus groups and related participatory mapping methods has been shown to increase awareness and reflectivity among participants. It constitutes a learning process that leads to more critical and precise responses from informants as well as more discernment from researchers to phrase questions and interpret answers, thereby improving data reliability (Chambers, 2008; Kumar, 2002; Rifkin and Pridmore, 2001). The research design adopted also facilitated diverse forms of triangulation (Bauer and Gaskell, 2000; Flick, 2004; Kumar, 2002): (i) data triangulation, by gathering the same type of information from different informants; (ii) investigator triangulation, by relying on different facilitators to gather similar data as well as different researchers to interpret similar outputs; and (iii) methodological triangulation, by addressing the same topic using different methods.

6. Conclusion

As populations increase and the demand for multiple ecosystem services increases, there is a growing need to integrate both local and scientific knowledge about ecosystem services in a way that is accessible to decision-makers at all levels. We have shown that PGIS can be a useful means for helping indigenous communities visualize perceived changes in the provisioning areas and overall stocks of ecosystem services over time. Local perceptions can be represented on maps which can more easily convey this local understanding to external decision-makers. In our case study area of La Pedrera in the Colombian Amazon, PGIS activities and associated focus groups were useful in identifying ecosystem services of key importance to local people, mapping how the sources and stocks of these ecosystem services had changed over the past 20 years, and identifying the key direct and indirect drivers of the perceived changes. These methods have great potential to fill information gaps in areas with poor data availability. By improving the information base for environmental planning, a combination of participatory assessment methods can make an important contribution to enhancing the adaptive capacity of local communities to manage ecosystem service provision more sustainably. The methods used had advantages in terms of relatively low cost, efficiency and local expert knowledge, although they are of limited inference power. Though, the methods are appropriate in scoping phases and hypothesis-generating stages of research, the benefits would be maximized if data quality could be improved and assured through results validation processes.

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