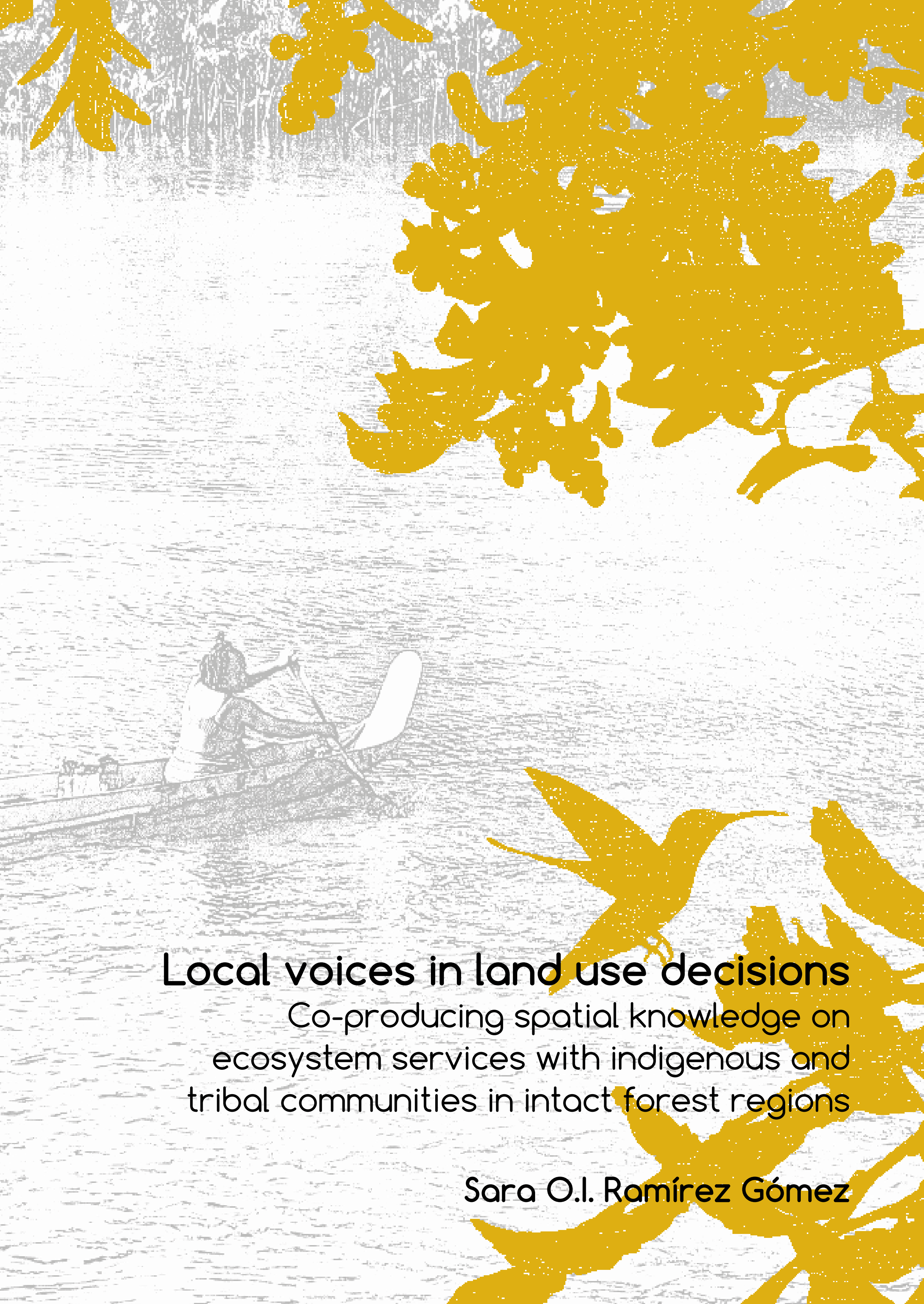

Local voices in land use decisions

Co-producing spatial knowledge on ecosystem services with indigenous and tribal communities in intact forest regions

Sara O.I. Ramírez Gómez

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De lokale stem in besluiten over landgebruik:

Co-productie van ruimtelijke kennis over ecosysteemdiensten
met inheemse en tribale gemeenschappen in intacte bosgebieden

(met een samenvatting in het Nederlands)

Las voces locales en la toma de decisiones sobre el uso de la tierra:

Produciendo conocimiento espacial sobre servicios ecosistémicos en
colaboración con comunidades indígenas y afro-descendientes en
bosques intactos

(Con un resumen en español)

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Chapter 1

General introduction

Intact forest are critical for the provision of ecosystem services, from the local to the global scale. They offer unique opportunities to mitigate two of the greatest environmental problems that the world faces: climate change and the loss of biodiversity (McCauley et al., 2013). However, the expansion of external pressures into intact forest regions, such as roads, logging, agriculture and mining, threatens the maintenance of these high conservation values. Indigenous and tribal communities live, manage and own vast areas of the remaining intact tropical forest regions of the world (Garnett et al., 2018). Their livelihoods also depend on these forests. It is therefore highly relevant and urgent to involve them in land use decision making that affects them, and to consider the entangled social and ecological transformation processes that local communities undergo upon the arrival of external pressures. However, tools and approaches that consistently enable their engagement are not yet available. Our scientific understanding of how external pressures affect the spatial and temporal dynamics of ecosystem service use by local communities and how these dynamics affect the conservation of intact forest areas is still limited. In this context, conservation is understood as a broader concept referring to the safeguarding of both, biodiversity and ecosystem services. This thesis has been designed to address these pressing and urgent research needs in remote and data scarce intact forest regions. This first chapter presents the context and explains why it is needed to co-produce a knowledge base that can be understood by all stakeholders and that can enable a more effective management of these globally important regions.

1.1 Intact tropical forest: global conservation gains and contests

Intact forest landscapes are defined as an unbroken expanse of natural forest having an area of ≥ 500 km^2 that has remained free from industrial and intensive land use activities (Potapov et al., 2008). As such, these regions are critical for harboring biodiversity, maintaining terrestrial carbon stocks and regulating hydrological regimes at planetary scales (Watson et al., 2018; Potapov et al., 2017). Analysis of Global Forest Watch (2018) has shown that 29% of the carbon stored in trees is concentrated in intact forest landscapes across the world. As Balmford et al., (2003) argued, intact forest landscapes should be globally prioritized for conservation, not only for the provision of globally important ecosystem services – the benefits that people obtain from nature – but also because these high environmental values can be maintained at relatively low conservation and opportunity costs. Furthermore, intact forest cover constitutes an important indicator in measuring progress towards achieving Sustainable Development Goal 15 (Life on Land), Aichi target 5 (halve all natural habitat loss, including forest) and the New York Declaration on Forest (stop forest loss)

(Minnemeyer et al., 2017). This doctoral doctoral thesis focuses on tropical forest areas inside intact forest landscapes.

At least 35.8% of the remaining intact forest regions of the world are inhabited and managed by 250 million of indigenous and tribal communities[1] (McFarland, 2018; Watson et al., 2018; Chao, 2012). These communities depend almost exclusively on the direct provision of ecosystem services such as food (fruits, nuts, fish, game, oils), raw materials (resins, fibers, thatch, timber, medicinal plants and other non-timber forest products), shelter (building materials), clean water, clean air, as well as sense of belonging, spirituality and religion (Poppy et al., 2014b). Through their management of these ecosystem services, indigenous and tribal communities have significant and long-lasting impacts on the structure and composition of the forests in which they live. Hence, the maintenance of the conservation values of a significant share of the intact tropical forest areas depends on the partnerships with indigenous and tribal communities across the tropics, policy actors and civil society (Garnett et al., 2018).

Not only have the management practices by indigenous and tribal communities helped to preserve intact forests regions, but many of these regions have also been conserved due to their remoteness, as there are few or no roads enabling access to them (Ibisch et al., 2016). Nevertheless, the continuous expansion of road infrastructure projects in tropical forest areas implies that remote and intact forest areas are no longer intrinsically protected by remoteness (Laurance et al., 2014; McCauley et al., 2013). Some cases in Amazonia illustrate this. In Peru for

[1] Based on Martinez Cobo (1987), indigenous communities are characterized as: 1) communities that maintain a strong attachment to particular geographic locations and ancestral territorial origins; 2) they typically seek to remain culturally, geographically and institutionally distinct from the dominant society, resisting assimilation into the greater national society; 3) they tend to preserve their own socio-cultural, economic and political ways of life; and 4) they specifically and overtly self-identify as indigenous or tribal people.

example, the building and extension of the Manu road strongly enhances accessibility of the core area of Manu National Park (1.5 million hectares of intact forest), exposing uncontacted indigenous tribes and favoring the influx of new colonists to develop logging, mining and illicit extractive and agriculture activities (Gallice et al., 2017). This is in line with what has happened following new road construction elsewhere in Amazonia (e.g. Laurance et al., 2001). Also, in the Guyana Shield region, comprising one of the largest intact blocks of primary forest (circa 270 million hectares) (Hammond, 2005; Ter Steege et al., 2003), the IIRSA[2] project has increased the accessibility of the region. Subsequently, its forests started facing encroachment due to expanding industrial activities such as logging and gold mining (Rahm et al., 2017; van Dijck, 2008; WWF, 2012).

Potapov et al. (2017) estimated a total loss of 720,000 km^2 of intact tropical forests worldwide between 2000 and 2016 because of industrial logging (37.0%), large-scale agriculture expansion (27.7%) and the expansion of the energy and mining industries (12.1%) following the development of road infrastructure. The construction and improvement of roads are explicitly included in the Sustainable Development Goals (SDG 9) for its contribution to economic development (SDG 8) and subsequent enhancement of well-being of the rural poor (SDG 1) (Swamy et al., 2018). However, road proliferation in tropical forest regions is often chaotic and poorly planned (see for example the Nigeria's Cross River Superhighway in Laurance et al., 2017) which implies that in practice, pursuing these international goals conflicts with the unique conservation opportunities offered by intact tropical forest regions (Rockström et al., 2009). Therefore, with the length of paved roads projected to increase by 25 million kilometers towards 2050, extending far into remote and intact tropical forest regions (Laurance et al., 2014), there is an urgent need to conserve these regions and maintain the local

[2] Initiative for the Integration of Regional Infrastructure of Latin America (Sánchez, 2015)

and global provision of ecosystem services that these provide while simultaneously achieving the Sustainable Development Goals and targets.

1.2 Indigenous and tribal communities and the conservation of intact forest regions

Although indigenous and tribal communities represent less than 5% of the global population (The World Bank, 2019), taken together, their forest management practices have proven to be remarkably important in the conservation of intact forest regions (Mistry and Berardi, 2016). For example, Potapov et al., (2017) found that the deforestation rate of intact forest area worldwide was 8.2% smaller in indigenous and tribal communities territories than on other lands. Notorious examples of this also exist in the Brazilian Amazon where indigenous community lands have been effective in halting deforestation in the most dynamic deforestation frontiers (Ricketts et al., 2010; Soares-Filho et al., 2010; Nepstad et al., 2006; Schwartzman and Zimmerman, 2005). In terms of ecosystem services of global importance, it is estimated that indigenous communities manage at least 24% (54,546 MtC) of the above-ground carbon stored in tropical forests globally (Frechette et al., 2016) and 85% of the areas designated for biodiversity conservation worldwide (Schmidt and Peterson, 2009). Finally, a recent land cover study by Garnett et al. (2018) showed that 67% of indigenous lands were classified as natural compared with 44% of other human inhabited lands. Thus, a significant part of the conservation of intact forest regions depends on the institutions and actions of indigenous and tribal communities' worldwide (Brondizio and Tourneau, 2016). Nonetheless, it is not to assume that all indigenous and tribal communities have a desire or willingness to conserve intact forest regions (Garnett et al., 2018). As indigenous and tribal communities are increasingly exposed to Western cultural and economic norms and patterns, their political, social, cultural and economic motivations, aspirations and expectations to manage these lands are also changing (Tengö et al., 2017; Armitage et al., 2012). Therefore, any conservation strategy in intact forest regions needs to consider local needs, expectations and attitudes towards conservation (Kohler and Brondizio, 2017).

The decision making of indigenous and tribal communities is strongly influenced by external pressures (Garnett et al., 2018). These pressures are exerted by industrial drivers of forest conversion, including logging, large-scale agriculture, oil, gas, and other mineral mining projects, which are following the proliferation of roads into forest frontier regions (Laurance and Balmford, 2013). This in turn is driven by increasing economic globalization and rising standards of living (MEA 2005). As these pressures, rapidly advance into remote and intact forest regions, the daily decisions of indigenous and tribal communities increasingly confronted with dilemmas of prioritizing short-term gains over long-term forest conservation (Poppy et al., 2014b). Consequently, their coping response can involve unfavorable trade-offs between provisioning, cultural, regulating, and supporting ecosystem services across space and time scales (Rodríguez et al., 2006). For example, Khundi et al. (2011) found statistically significant correlations between participation in charcoal making (at the cost of forest) and high poverty levels in Uganda. Similarly, Nasi et al., (2011) demonstrated how the need for short-term cash increased unsustainable use of bush meat and fish in the Congo and Amazon Basins. Therefore, a better understanding of the livelihoods constraints that indigenous and tribal communities experience and the role of external pressures is fundamental to inform effective conservation policies.

Thus, external pressures have local impacts on ecosystems and the way indigenous and tribal communities cope with environmental change operates at the local level. Hence, it is through local action that biodiversity and ecosystem services provided by intact forest regions will be preserved or lost (Brooks et al., 2006). Therefore, now that external pressures are rapidly advancing into the most remote and intact forest regions of the world (Potapov et al., 2017), it has been argued that the capacity of local stewards, such as indigenous and tribal communities, needs to be strengthened to continue managing ecosystems sustainably in the face of change (Archer and Dodman, 2015; Díaz et al., 2019). The co-production of a knowledge base that can be accessible to a wide range of stakeholders and a deep understanding of how external pressures affect local communities' needs, priorities and motivations is at the core of this capacity building as has been suggested by the last IPBES Global Assessment of Biodiversity and Ecosystems (Díaz et al., 2019)

1.3 The data scarcity challenge

To date, empirical research on ecosystem services has given scant attention to ecosystem service dynamics in data scarce and intact forest regions (Pandeya et al., 2016). Hence, social and ecological data on local ecosystem services use are often missing in those forests areas. A crucial gap in knowledge concerns the development of indicators that can be used to measure how external pressures affect the spatial and temporal dynamics of ecosystem service use by indigenous and tribal communities and how these dynamics affect the conservation of intact forest areas (Watson et al., 2018, Chazdon 2018, Garnett et al., 2018; Bennett and Chaplin-Kramer, 2016). Without this knowledge, spatial and temporal patterns in those regions tend to be assumed rather than demonstrated (Maes et al., 2012). For instance, there is an implicit assumption that ecosystem services degradation is not a critical issue in intact forest areas (Socolar et al., 2016). However, this is an incorrect interpretation, since these forests while seemingly undisturbed from above (as observed from remote sensing images) can hide serious social and ecological issues beneath the canopy (see Nasi et al., 2011). Judging from "above", policy makers and outsiders neither can perceive the needs of indigenous and tribal communities in intact forest regions. Policy decisions therefore tend to overlook the entangled social and ecological processes that indigenous and tribal communities undergo on the ground upon the arrival of external pressures. This can ultimately lead to conflict and incompatibility between the demands created by livelihood activities and conservation objectives as reported by Salafsky and Wollenberg, (2000).

Some recent studies started addressing these data gaps. For instance, several studies focusing on data scarce regions combined remote sensing techniques with participatory mapping to understand changes in the provision of locally important ecosystem services. These studies showed how the supply of ecosystem services changed under different land use conditions. Paudyal et al., (2015), for example, found that the supply of ecosystem services increased in community forestry areas in Nepal, while Delgado-Aguilar et al., (2019) found that the supply of important ecosystem services was larger in undisturbed than in degraded forest. Other studies in data scarce regions used participatory mapping to complement knowledge that cannot be captured with remote sensing information. For example, Beaudoin et al. (2016) used participatory mapping to understand the drivers of land use change in case studies in Kalimantan and Java. Similalry, Zaehringer et al., (2018) filled temporal data gaps in satellite imagery through participatory mapping in order to be able to map annual land use change over extended periods of time in Laos, Myanmar and Madagascar. While this small but growing body of literature has unveiled a more complex picture of spatial ecosystem service use in data poor intact forest regions, a number of important challenges still need to be addressed (Pandeya et al., 2016). For example, case studies have predominantly been conducted in the agriculture-forest frontier, leaving gaps in knowledge about core areas of tropical primary forest. Furthermore, most studies have covered small areas (<100 km^2), and therefore, results cannot simply be extrapolated to larger regions. Likewise, these studies remain focused on biophysical aspects of ecosystem service provision (e.g. ecosystem services provided by different land uses) whilst ecosystem service dynamics in intact forest regions is usually influenced by more factors including variation in remoteness, land tenure regimes, cultural aspects, population density and the influence of external pressures (Mehring et al., 2018; Lambin and Meyfroidt, 2010).

Importantly, knowledge generation processes in data poor and remote intact tropical forest regions have not yet led to the development of spatial metrics that are needed to measure policy impacts in these regions (Bennett and Chaplin-Kramer, 2016). For example, spatially explicit knowledge is required to demarcate the areas necessary to support the provision of ecosystem services to indigenous and tribal communities. Without this demarcation, the allocation of investment plans for infrastructure, industrial agriculture, mining, and other extractive activities may overlap with important ecosystems and undermine the provision of ecosystem services that are important for indigenous and tribal communities' well-being (Cowling et al., 2008a). Although some participatory spatial approaches have been proposed to delineate areas in use by communities, which can eventually be applied in data scarce environments (Serna-Chavez et al., 2014; Syrbe and Walz, 2012), the applicability and relevance of these approaches need to be tested by collecting empirical data on the ground.

Moreover, differences in access to locations where ecosystem services are produced can have important social equity implications (Fisher et al., 2009) and such differences may largely influence spatial and temporal patterns of ecosystem service use (Elena M. Bennett et al., 2015). In this context, equity relates to the just access opportunities that marginalized social groups may have to ecosystem services (Corbera et al., 2007). This in turn depends on complex mechanisms of access including social relationships, power, institutions, capabilities, rights and various capitals (Ribot and Peluso, 2003). For example, in a local community context, those community members who are more influential might be able to take up larger areas where ecosystem services are generated than other user groups in a disadvantaged position (Rodríguez et al., 2006). Thus, by studying differences in spatial patterns of use of ecosystem services, important equity issues related to their spatial distribution can be unveiled (Bennett et al., 2015; de Groot et al., 2010). However, spatial patterns of equity in access to ecosystem services remain largely unaddressed in data poor regions (Bennett et al., 2015; Bennett and Chaplin-Kramer, 2016; Birkhofer et al., 2015).

Thus, in the same way that policy makers need forest extent metrics to inform conservation prioritization (Brooks et al., 2006), spatial layers of socio-ecological information on different aspects of ecosystem services access and use are needed to gain a better understanding of the needs and priorities of indigenous and tribal communities (McLain et al., 2013). While gaps in current ecosystem service knowledge should not be taken as an excuse for inaction (Balmford and Bond, 2005), a better knowledge base that is co-produced with indigenous and tribal communities and that is accessible to a wider range of stakeholders is needed to assess the impact of external pressures on intact forest regions (Archer and Dodman, 2015). This doctoral thesis has been designed to address this pressing gap in knowledge.

1.4 Knowledge co-production: creating an enabling environment for action

The fact that land use policies and policy making still do not consider ecosystem services patterns that are locally relevant in intact tropical forest regions, does not only stem from the scarcity of empirical data but also from the lack of solution-oriented research approaches (Carmen et al., 2018; Cowling et al., 2008a). With the increasing rate of intact forest loss and external pressures underpinning a rapid cultural and social-ecological change in these regions, the demand for usable and actionable knowledge is quickly outpacing the ability to produce it, using the approaches currently employed (Knight et al., 2008). This calls for a new way of producing knowledge that is explicitly linked to action (Peterson et al., 2018; Bennett et al., 2015; Mauser et al., 2013). One promising way to develop usable knowledge is to coproduce it (Clark et al., 2016b, 2016a; Nel et al., 2016; Lemos and Morehouse, 2005). Knowledge co-production refers to a collaborative and dynamic knowledge generation process involving stakeholders from inside and outside academia, with the explicit intention to create scientific knowledge that can be used to influence decision-making (Schuttenberg and Guth, 2015). It can be described as a governance strategy (Armitage et al., 2012) and as a research approach, in which case it is referred as transdisciplinary research (Miller et al., 2014).

The production of usable scientific knowledge is central to sustainability science (Clark et al., 2016a) and in recent years fields of relevant theory have been blossoming (Miller and Wyborn, 2018). A great deal of scientific research that targets the co-production of usable knowledge focuses on the science-policy interface and seeks to mobilize knowledge that can effectively enable solutions to global environmental problems (Mauser et al., 2013). For instance, international transdisciplinary research programs such as Future Earth (van der Hel, 2016) and the Earth System Governance Project (Biermann et al., 2010) have been designed to this end. Parallel research efforts are urgently needed in view of the 25 million kilometers of projected road infrastructure expansion into intact forest regions by 2050 (Laurence et al., 2014) to produce knowledge that can be easily used in the daily practice of local decision makers in these regions (Tengö et al., 2014). This knowledge can also be used to inform international actors such development banks, which tend to favor large infrastructure projects in forest regions (Laurance et al., 2015).

This thesis addresses the gaps in knowledge highlighted above and seeks to expand existing approaches to sustainability science by enabling the incorporation of local indigenous and tribal communities' knowledge in decision-making processes. This is considered a prerequisite in the development of solutions to local conservation challenges (Sayer et al., 2013). As the majority of intact forest regions are governed by indigenous and tribal communities (Garnett et al., 2018), their knowledge system provides local insights needed to understand the complexity of conservation of these regions (Berkes, 2009a). The inclusion and recognition of indigenous and tribal communities' knowledge in international science-policy arenas such as the Inter-Governmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Díaz et al., 2018, 2019) and the Convention on Biological Diversity (CBD, 2017) have been recognized. However, tools and approaches that consistently enable their engagement towards the production of useable knowledge are not yet available (Cundill et al., 2012; Obermeister, 2017; Tengö et al., 2014). Main gaps include approaches that move from "studies about indigenous and local knowledge systems, to equitable engagement with and among these knowledge systems to support mutual investigations into our shared environmental challenges" (Tengö et al., 2017 pp. 24). This also requires tools that bridge local knowledge system in ways that are useful to indigenous and tribal communities and that do justice to their efforts of conserving intact forest regions (Brondizio and Tourneau, 2016). Finally, important gaps remain about the way to produce usable local indigenous and tribal communities' knowledge, while at the same time producing high quality science. The divide between the two types of knowledge is a complicating factor: local indigenous knowledge tends to be seen by scientists and policy makers as subjective, arbitrary and imprecise, while scientific knowledge is seen as objective and rigorous (Mistry and Berardi 2016).

The participatory creation of maps by scientist and local experts is claimed to play a significant role in transdisciplinary research (Roux et al., 2017), as maps constitute boundary objects through which research communities can "organize relations with new science, other sources of knowledge, and the worlds of action and policymaking" (Clark et al., 2016 pp. 4618). Linked with the role of maps to harness knowledge co-production is the growing dependence on spatially explicit tools for effectively managing the impacts of external pressures on ecosystem services (Pagella and Sinclair, 2014; de Groot et al., 2010; Egoh et al., 2007). Participatory mapping of ecosystem services refers to a set of approaches and techniques that combines the tools of modern cartography with participatory methods to represent spatial knowledge on ecosystem services. Hence, it is argued that participatory mapping of ecosystem services is an example of a transdisciplinary approach to research (Cundill et al., 2015). It provides a tangible cooperation platform that can make knowledge scientifically robust, understandable and accessible to a wider range of stakeholders while enabling local decision-making capacity (Tripathi and Bhattarya, 2004).

Unfortunately, there has been little evidence of the influence of participatory mapping of ecosystem services in decision making in remote tropical forests regions (Brown and Fagerholm, 2014). In fact, the research by Sulistyawan et al., (2018) in the Merauke District, Papua, Indonesia, is one of the first (if not the first) studies which outputs are actually incorporated into local spatial planning legislation. Yet, the environmental and social challenges faced by local communities on the ground demand more than this improvement to harness effective decision-making capacity (Reed et al., 2016). Quantitative research has shown that legitimacy of knowledge is more significant in explaining impact in decision making than salience and credibility (Posner et al., 2016). Using the definitions in Cash et al., (2003), legitimacy refers to the unbiased inclusion of the views of stakeholders, salience deals with the relevance of the assessment to decision makers and credibility refers to the scientific rigor of the technical evidence. Although these attributes are tightly coupled, the limited application of participatory mapping in real world issues affecting indigenous and tribal communities territories can be attributed to the credibility of their knowledge systems according to western worldviews (Brown and Fagerholm, 2014). Thus, if researchers want to leverage indigenous knowledge to conserve biodiversity and other ecosystem services in the last intact tropical forests, participatory mapping methods need to be systematic and rigorous to meet Western scientific standards of research, while being implemented in the vernacular of indigenous language and culture (Brondizio and Tourneau, 2016). This is a catch-22. If participatory mapping appears to be too simplified or restricted to particular locations, it will not be accepted within the Western scientific tradition of research. Conversely, if the participatory mapping approach embraces the Western scientific methods that emphasize accuracy and validity, it might alienate indigenous people. A key question is also, whether participatory mapping by indigenous people can achieve sufficient credibility among policy makers to influence ecosystem service outcomes.

1.5 Objective and research questions

Given the importance of intact tropical forest regions as last repositories of biodiversity and ecosystem services of global importance. Similalry, given the rapid expansion of external pressures into these regions as well as the risks posed by the scarcity of empirical data, it is necessary to enhance the capacity of the stewards of these regions, i.e. indigenous and tribal communities, to continue managing ecosystem services sustainably in the face of change. Further, in line with the idea to make science more relevant to the solution of real-world problems, there is an urgent need to increase the likelihood of producing usable research knowledge that can effectively be used by decision makers on the ground while enabling inclusiveness of local communities in the decision making that affects them. This thesis has been designed to address this pressing and urgent research challenge.

The objectives of this doctoral thesis were as follows:

- To assess to what extent external pressures affect the spatial and temporal patterns of ecosystem service provision; and
- To understand how can this knowledge be used to respond to these pressures and support a process of inclusive policy making that recognizes the needs and priorities of indigenous and tribal communities regarding ecosystem service use.

The central research question to address these objectives is: In intact and data scarce forest regions, to what extent do external pressures affect the spatial and temporal patterns of ecosystem service provision and how can this knowledge be used to respond to these pressures and support a process of inclusive policy making that recognizes the needs and priorities of indigenous and tribal communities regarding ecosystem service use?

This central question is answered by responding to the following sub-questions:

I. Can participatory mapping be used to gain insights into the spatial and temporal patterns of ecosystem services provision and use in remote and data scarce forest regions?
II. What factors affect the spatial and temporal patterns of ecosystem services use in remote and intact tropical forest regions under external pressure?
III. If external pressures emerge in a remote and intact forest region, how do does it affect the spatial and temporal aspects of equity in access to important ecosystem service hotspots?
IV. Can a combination of analytical methods and participatory mapping be used to co-produce usable knowledge on ecosystem services in support of inclusive decision-making and policies?

1.6 Study regions

The research leading to this doctoral thesis was carried out in three study regions: one in Colombia and two in Suriname. These areas are located inside the intact forest block of Amazonian and the Guiana Shield according to the intact forest map of the world (Global Forests Watch, 2016) (Fig. 1). I chose these regions based on different degrees of remoteness and differences regarding the status of legal land right recognition. A degree of remoteness (e.g. high, medium, low) was assigned to each study region according to population density (Carver and Fritz, 2016) and the presence or absence of road infrastructure (Ibisch et al., 2016). Table 1 shows these features for each study region. For example, two areas, La Pedrera and South Suriname, inhabited by indigenous communities, are highly remote as these are only accessible by a small plane or a boat trip of several days, crossing rapids and whirlpools.

Table 1 Case study description

	Colombia	**Suriname**	
		South Suriname	**Upper Suriname River**
Study area	La Pedrera district, Department of Caquetá, Amazon region	Brokopondo district, upper watershed of the Marowijne, Tapanahony and Sipaliwini rivers	Brokopondo district, upper watershed of the Suriname river
Type of communities	Indigenous communities	Indigenous communities	Tribal communities
Main livelihoods	Traditional agriculture, fishing, hunting and harvesting non-timber forest products	Traditional agriculture, fishing and, harvesting non-timber forest products	Traditional agriculture, fishing, hunting and harvesting timber
Intact forest area	3,809 km^2	25,000 km^2	1,250 km^2
Road length	0 km	0 km	93 km
Population density	1.2 person per km^2	1 person per km^2	2.4 person per km^2
Remoteness	High	High	Moderate
Legal land rights	Yes	No	No

The contrast between these cases is that La Pedrera has legal recognition of traditional land rights while South Suriname has not. This contrast was important to evaluate whether land rights security play a role in the effect of external pressures on the spatial and temporal patterns of use of ecosystem services. The third study area, the Upper Suriname River, inhabited by tribal communities, is accessible through a paved road after a trip of four hours from the city capital. A few unpaved roads occur inside this region. Communities in this study region do not hold legal land rights. By including this study region, it was possible to compare the effect of external pressures on spatial and temporal patterns of access to ecosystem services in situations with different degrees of remoteness.

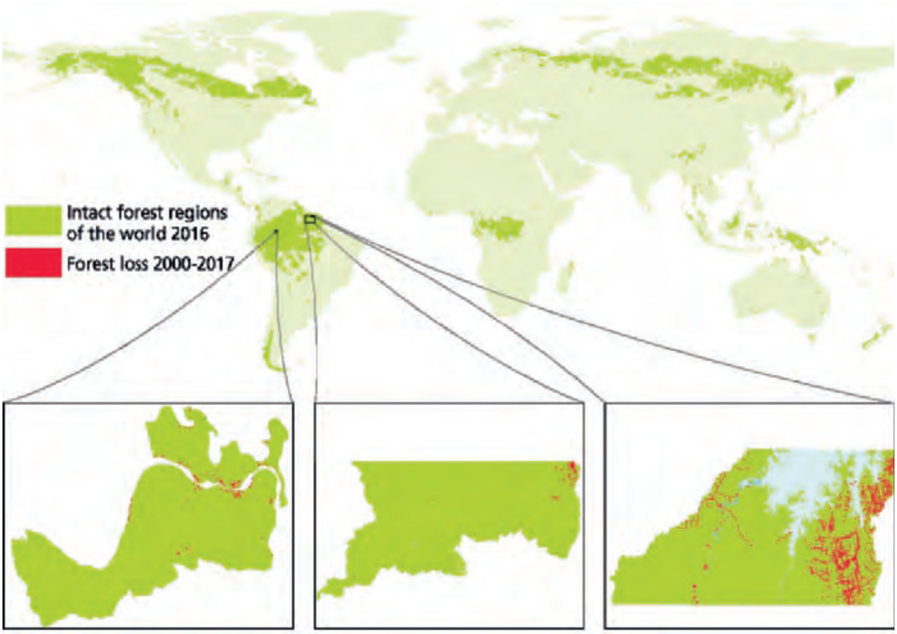

Figure 1 Location of the study areas. Source intact forest regions data: Potapov et al., 2017

1.7 Overview of methodology

This thesis combines an array of participatory methods that have become well established in the field of development studies (Chambers, 2006, 2007, 2012; Desai and Potter, 2006; Rifkin and Pridmore, 2001). 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 (McLain et al., 2013; Giacomo Rambaldi et al., 2006b). The data for each study case were collected between January 2012 and February 2016, through 21 community meetings, 40 focus groups discussions, 32 questionnaires, 24 participatory mapping workshops and 7 participatory mapping surveys with 1108 community participants. A summary of the methods employed in each chapter is summarized in table 2. Data collection was assisted by 13-trained facilitators. Four types of data were produced in the thesis: (i) textual data, based on consolidated notes from facilitators; (ii) images and digital photographs of cause-effect diagrams; (iii) quantitative data derived from trend analysis matrices and, (iv) spatial data derived from the participatory mapping activities. Spatial data were further analyzed and processed into vector layers using a Geographic Information System.

Table 2 Summary of participatory methods employed

Study area	chapter	Community meetings	Focus groups	Questionnaires	PGIS workshops	PGIS surveys	Total participants
La Pedrera, Colombia	2	8	22	-	16	-	158
South Suriname	3	5	-	-	-	191	191
Upper Suriname River	4	6	18	32	8	-	267
Upper Suriname River	5	2	-	-	-	492	492
	Total	21	40	32	24	683	1108

1.8 Outline of the thesis

The four research questions are addressed in the empirical chapters 2 through 5. Chapter 2 analyses the spatial change in the stock of locally important ecosystem services and provides an understanding of the influence of external pressure on changing conditions in highly remote intact forest regions. This chapter addresses research questions I and II. Chapter 3 evaluates an approach to demarcate community use zones in remote intact forest regions where data is scarce and where land use developments threaten the provision of ecosystem services on which local livelihoods depend. This chapter addresses research questions I and IV. Chapter 4 studies the influence of external pressures on spatial and temporal patterns of equity in access to service provisioning hotspots according to clan and authority position.

This chapter addresses research questions I, II and III. Chapter 5 tests the potential of a three-dimensional participatory mapping approach to produce usable knowledge that can foster inclusive decision-making in remote, data scarce and marginalized forest regions under external pressure. This chapter addresses research question IV. The synthesis chapter 6 summarizes the findings in each chapter, followed by the answers to each research question and the main discussion points. This last chapter provides recommendations for further research, as well as for policy makers and practitioners. A summary of the outline of the thesis is presented in table 3.

Table 3 Overview of research questions and chapters in which these are addressed.

Chapter		Research questions			
		I.	II.	III.	IV.
2	*Research paper on the assessment of spatial and temporal changes in stocks of ecosystem services relevant to the livelihoods of indigenous communities in the Colombian Amazon*	●	●		
3	*Research paper on how to use participatory mapping methods to estimate and delineate community use zones in southern Suriname*	●			●
4	*Research paper on how to assess spatial and temporal patterns of equity in access to service provisioning hotspots in forest regions in Suriname undergoing external pressures*	●	●	●	
5	*Research paper on a 3D ecosystem services mapping method to enable trust, co-creation and community ownership of knowledge and inclusive decision making in Suriname*				●

Chapter 2

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

This chapter has been published as:

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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.

Key words: participatory mapping, service provisioning area, ecosystem services, indigenous communities, livelihoods, community based management.

2.1 Introduction

In 2005, the Millennium Ecosystem Assessment (MA) reported that the human use of ecosystem services, particularly provisioning services, has accelerated in the last 50 years and that nearly 60% of the ecosystem services globally are being degraded or used unsustainably (Millennium Ecosystem Assessment, 2005). This alarming development is attributed to rapid population and economic growth, changes in consumption patterns and to climate change. Moreover, the demand for ecosystem services is expected to grow in the near future, accentuating the current environmental and social challenges. Therefore, there is a need for new approaches to the management of ecosystem services 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; MA, 2005; Sukhdev et al., 2008). In particular, the management of ecosystem services 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; Raudsepp-Hearne et al., 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 ecosystem services 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 ecosystem services dynamics (changes in spatial and temporal flows of ecosystem services) and tradeoffs between provision of different ecosystem services 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 ecosystem services modelling, mapping and visualization of ecosystem services, 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 ecosystem services 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 ecosystem services 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 ecosystem services 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 ecosystem services. For instance, (McCall and Dunn, 2012a) 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 ecosystem services 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., Gilmore and Young, 2012; Cowling et al., 2008a; Wang et al., 2008; Wright et al., 2009a; Jankowski, 2009; Giacomo Rambaldi et al., 2006b; King, 2002; Chambers, 1994) that ecosystem services 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 ecosystem services 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). 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 ecosystem services in the Colombian Amazon. We specifically aim to answer the following research questions: (1) how does the location of ecosystem services provisioning areas change over time? (2) what are the changes of stocks of locally important ecosystem services ? (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 project3 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., 2014b). We concentrated on the results of three focus group discussions

[3] http://espa-assets.org/

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 ecosystem services (Syrbe and Walz, 2012). We focus on nine provisioning services and one supporting service that were regarded as the most important ecosystem services 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 that is defined by local communities as the soil conditions needed for practicing traditional agriculture.

2.2 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 (Departamento Administrativo Nacional de Estadística, 2001; Manrique de Llinas, 2009). The Department has experienced economic, technological and cultural changes that 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 2). 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 1,631 inhabitants and the 2005 census 3,267 residents. Official projections estimate that by 2014 the population may stand at 4,846 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 (Fontaine, 2001; van der Hammen, 1992) suggest that most of these ethnicities migrated from other regions in the Amazon (upper and mid Caquetá River, the Mirití-Paraná River and some 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, fishhooks 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 that 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).
- 1970s – 80s: 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 (Cruz-Garcia and ASSET team, 2014).
- 1980s: Men went to work in commercial coca plantations instead of practicing agriculture (Molina-Guerrero, 2007).
- 1970s – 90s: Gold mining in neighboring regions of La Pedrera led to mercury pollution (Molina-Guerrero, 2007).
- 1980s – 90s: 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.

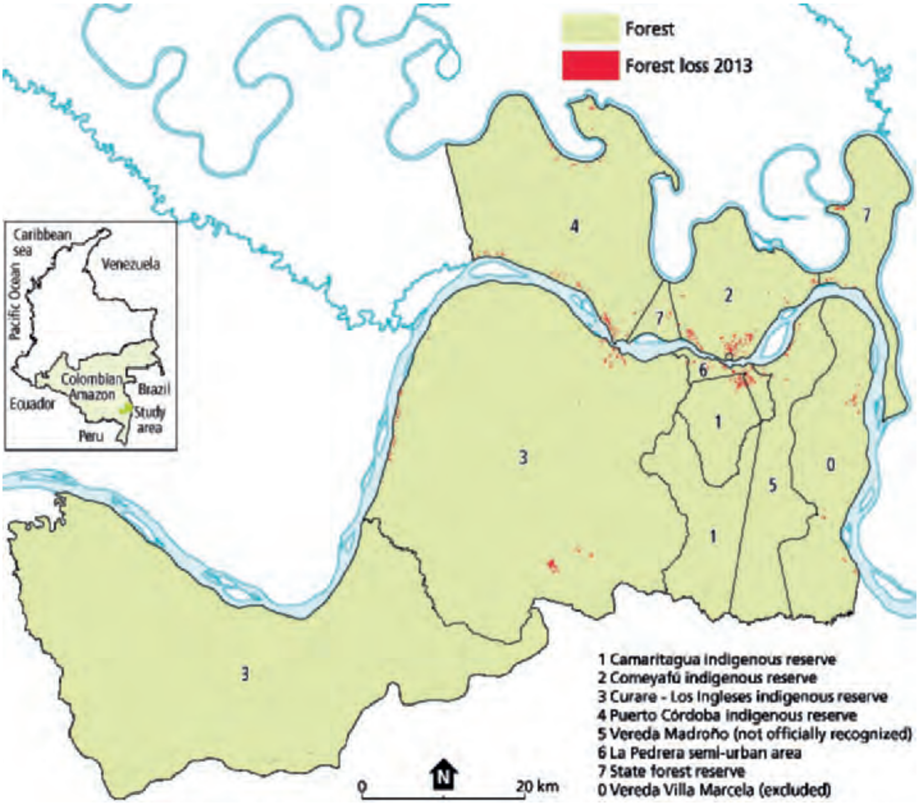

Figure 2 Location of study area and forest cover information. The list of indigenous reserves comprise the total area of the Corregimiento of La Pedrera (Total area 394,944 ha). Source forest cover data: Hansen et al, (2013).

The corregimiento of La Pedrera comprises 13 communities (excluding the communities living in La Pedrera town that were not included in this study). Two of the 13 communities withdrew from participation in the study. Therefore, this study is based on data collected from 11 communities comprising 1,115 inhabitants. 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).

2.3 Methods

This study integrates PGIS activities and focus group (FG) discussions on livelihoods (Fig 3) (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.

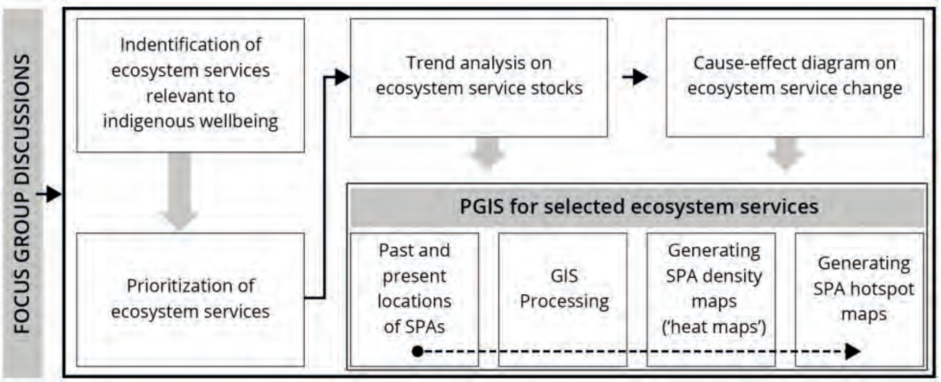

Figure 3 Flow diagram showing the process for analyzing changes in the provision of ecosystem services.

The results of this study are based on information obtained from eight FG discussions on ecosystem services 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). In total, 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 4). 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).

Table 4 Composition of the focus groups on ecosystem services 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**	2	3	7	5	0	6
TOTAL	14	35	30	35	4	40

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

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 ecosystem services stocks and ecosystem services source areas in the corregimiento of La Pedrera and because spatial representations of land use practices and ecosystem services 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 the PGIS activity). The trend analysis FG began by asking informants to identify all the ecosystem services 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 ecosystem services 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 ecosystem services 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 zero 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 three and four hours.

Following the ecosystem services 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 ecosystem services benefits resulting from the negative trends and proceeded to order these impacts depending on whether they were considered 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 two and three hours.

Participatory mapping of SPAs started by asking the participants to review, discuss and agree on the list of ecosystem services identified during the ecosystem services trend analysis. The mapping task focused on those ecosystem services 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 landmarks 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 ecosystem services. 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 three and four hours.

2.3.1. Data analysis of ecosystem services 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). Ecosystem services 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 ecosystem services 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 ecosystem services stocks were consolidated according to ecosystem services 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.

2.3.2. 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.

2.3.3. Polygon density analysis

Each digitized polygon was assigned an ID according to the year and ecosystem services they were representing. Multiple polygons for each ecosystem services were appended and then output into a distinct shapefile. Table 5 shows the total number of SPA polygons generated for each community. Density maps were generated to obtain a 'heat map' of SPAs. This was done using the overlap counter customized tool developed within ArcGIS© as described in Ramírez-Gómez and Martínez (2013) and Ramirez-Gomez et al. (2013).

2.3.4. 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). SPA hotspots indicate areas that are important for providing multiple ecosystem services without explicit mention of the underlying ecosystem processes that generate the services (Palomo et al., 2013) and as such is an important tool in data scarce regions.

2.3.5. 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:

$$\% \text{ change} = ((A2013-A1993)/A1993)*100$$

where A is the total area of a SPA hotspot in a corresponding year.

2.4 Results

2.4.1. Identification of the most important ecosystem services

During the FG discussions, communities identified ten categories of ecosystem services 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 6). The ecosystem services reported during the PGIS activities varied slightly from those discussed in the trend analysis and cause-effect FGs (Fig. 4). 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.

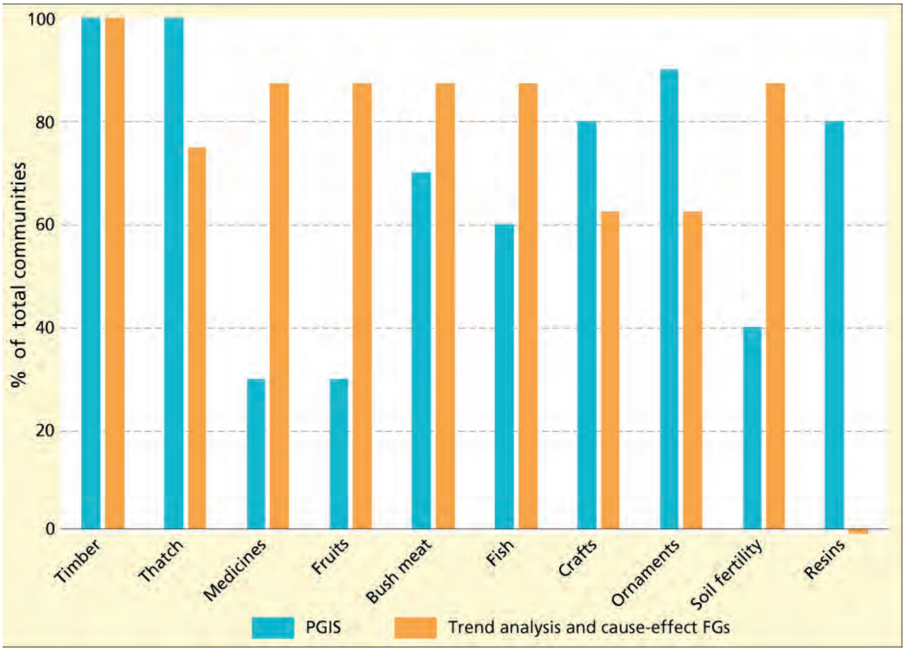

Figure 4 Important provisioning services discussed by communities during focus group

Table 5 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	1993	2013	1993	2013	1993	2013	1993	2013	1993	2013	1993	2013	1993	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 **	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

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

Table 6 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 (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
Resins	Symphonia globulifera L.f.	Breo
	Byrsonima cognata W. R. Anderson	Lana

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

Results of the ecosystem services trend analyses provided information on perceived changes in stocks of ecosystem services between 1993 and 2013 (Table 7). 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 8): (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 8). 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.

Table 7 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

2.4.3. 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 figure 5. 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, figure 5b 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, figure 5c depicts an increase of hotspots (significant concentration of SPAs) towards Curare-Los Ingleses and Puerto Córdoba indigenous reserve.

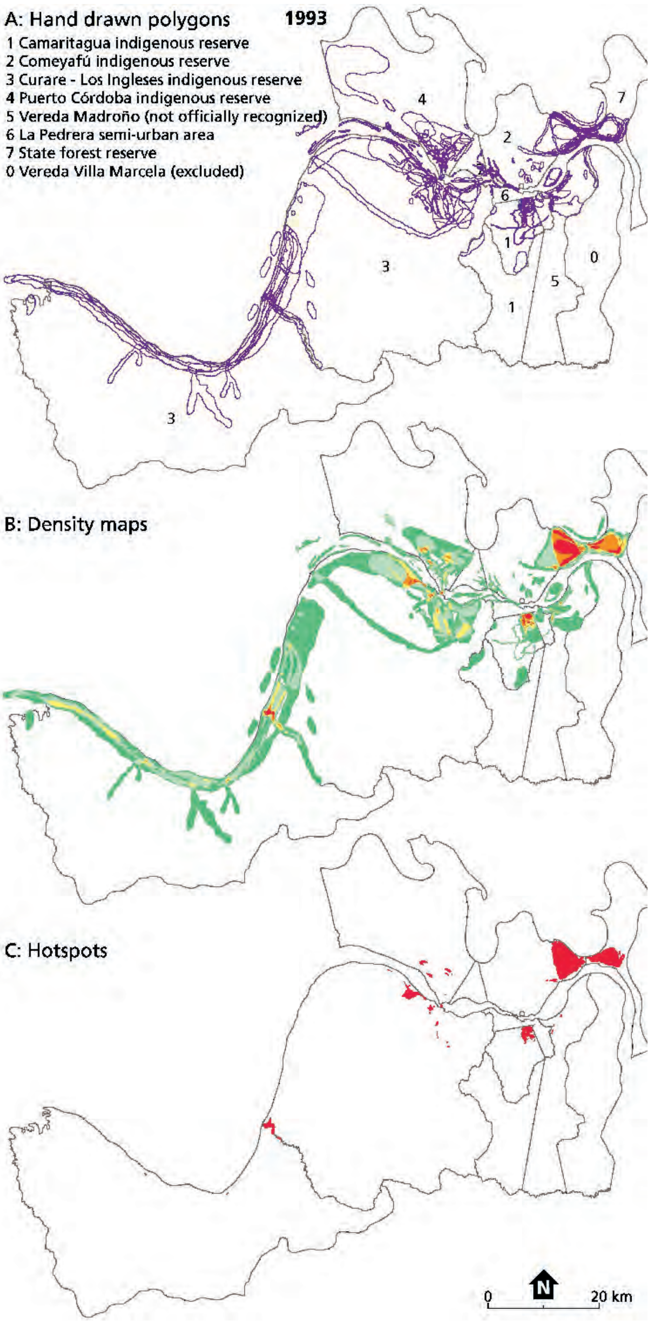

Figure 5 Spatial representations of SPAs for 1993 and 2013 generated from hand-drawn polygons during participatory mapping activities. A. Hand drawn polygons polygons. B. Density maps. C. Hotspots.

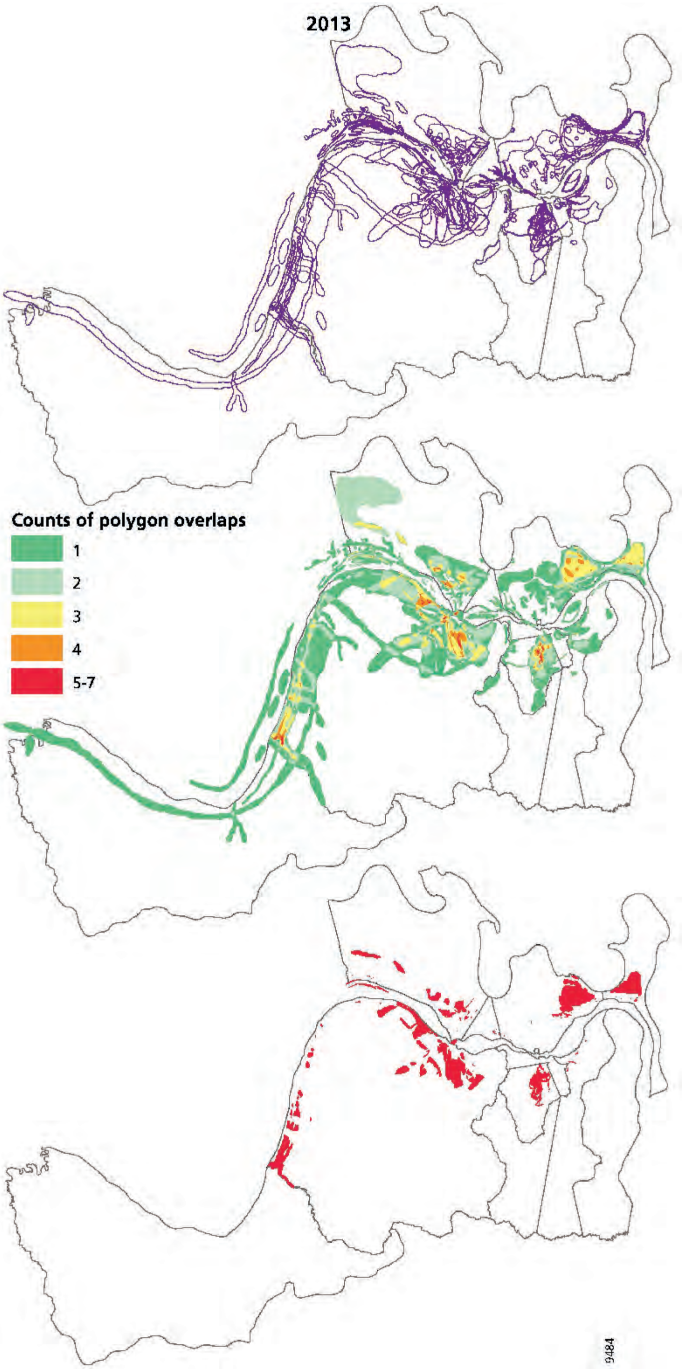
2013
Counts of polygon overlaps
1
2
3
4
5-7
9484

Table 8 Trends in ecosystem service stocks during the last twenty 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[4] 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

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

Medicines	Health	**+/-**
Fruits	Income generation	**+/-**
Crafts materials	Brooms, baskets, kitchen implements, handicrafts	**+/-**
Resins	Glue, sealants and body painting	**+/-**

Legend: ▼▼ Severe decline. ▼ Moderate to severe decline. **+/-** No clear trend.

2.4.4. 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 per commune with an average increase in area of 1,001 ha (Table 9). 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 4,711 hectares 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 9). 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 that was using 3.8% in 1993 and 9.6% in 2013. In terms of spatial distribution, this study finds that the expansion of service provisioning hotspots was higher in the indigenous reserves with the lowest population density (Fig. 6, Table 9).

Table 9 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	2,111	1,932	11.1	10.2
Curare-Los Ingleses (263)	237,643	76	209	662	5,373	0.3	2.3
Puerto Córdoba (212)	46,897	17	78	124	1,169	0.3	2.5
State Forest Reserve (0)	15,417	89	32	1,131	1,063	7.3	6.9
MEAN	57,965	61	94	728	1,729	3.8	5.2

2.4.5. 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 reported the greatest increase in extent of SPA (Fig. 7). 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 10). 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 10).

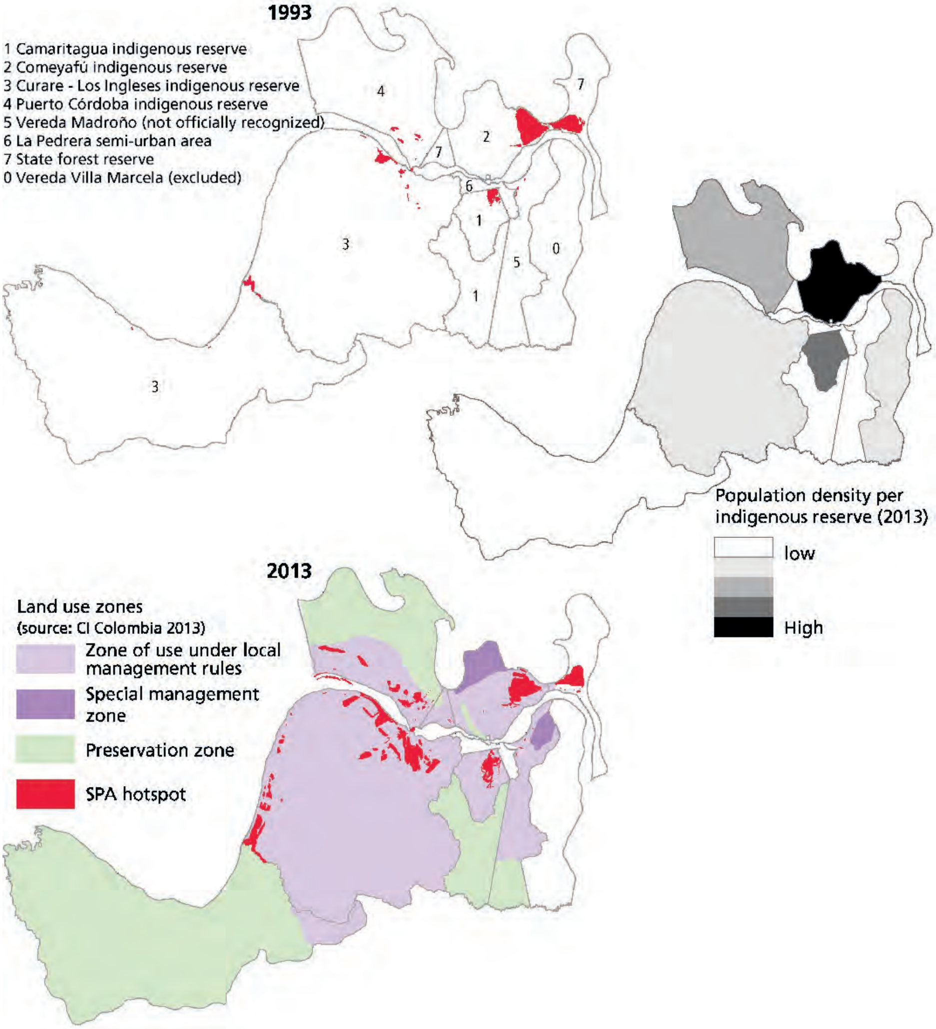

Figure 6 (A). Indigenous reserves with SPA hotspots in 1993. There was no land use zonation in 1993 and no population data were available. (B) Population density per indigenous reserve for 2013. C. Map of indigenous reserves with SPA hotspots (red) and land use.

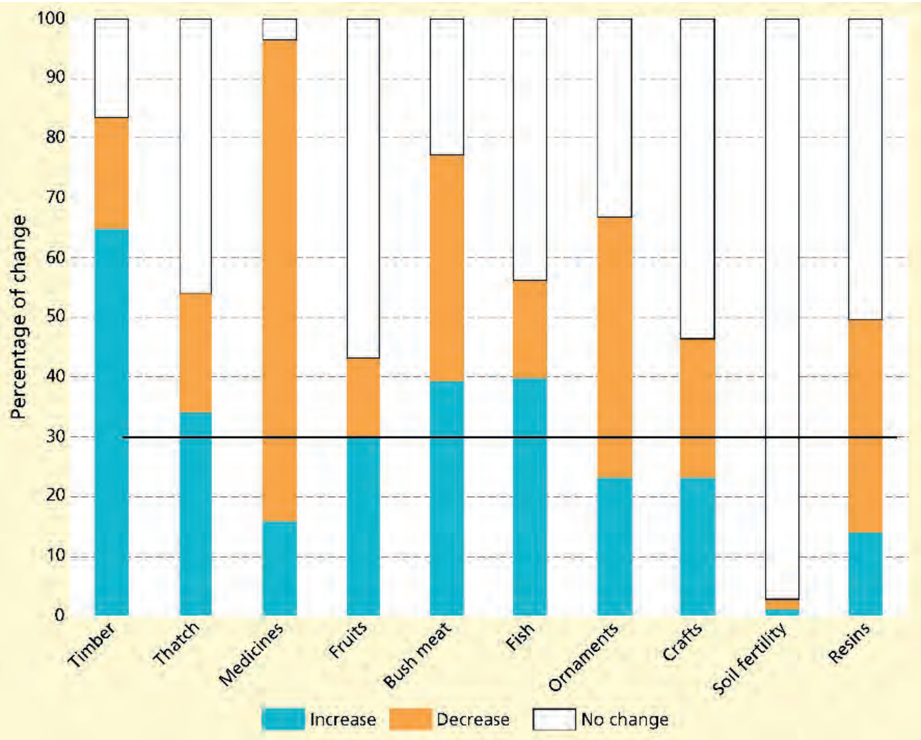

Figure 7 Total change in the area of SPAs between 1993 and 2013. In the case of timber, for example, 64% of the SPAs have increased in size, 18% have decreased in size and 18% have experienced no change in size between 1993 and 2013.

Table 10 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 increase
High decrease	Medium increase
Medium decrease	High increase
Low decrease	very high increase
No change	No data

2.5 Discussion

2.5.1. 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 ecosystem services access restrictions imposed by land use zoning plans within the indigenous reserves have contributed towards the opening of new service provisioning locations 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 ecosystem services provision as the areas of ecosystem services provision may have become overexploited (Biggs, 2004). In contrast, large community use zones and low population density suggest less pressure on the stocks of ecosystem services, as demonstrated in the case of Curare-Los Ingleses indigenous reserve (Fig 6). These findings are similar to findings of previous studies that considered the effect of population density on the supply and demand of ecosystem services 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 ecosystem services research.

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

- 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 that 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.
- 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.

- 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).
- Timber: Timber stocks became scarce from accessible areas 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.
- 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. Consequently, 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 ecosystem services (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.

2.5.2. Contributions to community-based management and institutions

Concerns about the availability of resources in the corregimento 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) 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 (Conservation International Colombia, 2013).

Cowling et al. (2008) describe a pathway to ensure the effective and adaptive management of ecosystem services 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; Poppy et al., 2014b). 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 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).

2.5.3. 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 ecosystem services 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 that 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 ecosystem services locations and use. We consider that this is important to promote, especially because one of the perceived drivers of ecosystem services 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 target sustainable use of ecosystem services in the region.

2.5.4. Limitations of this study

The main constraint of this study is the limited inference power for the whole study region. Visualizations of ecosystem services trends are fundamental to ecosystem services 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 that 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 during both 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 ecosystem services 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 ecosystem services data. Mapping ecosystem services 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., 2009b). 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.

2.6 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 that 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. However, 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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Chapter 3

Participatory mapping to identify indigenous community use zones: Implications for conservation planning in southern Suriname

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Abstract

Large-scale development projects often overlap forest areas that support the livelihoods of indigenous peoples, threatening in situ conservation strategies for the protection of biological and cultural diversity. To address this problem, there is a need to integrate spatially explicit information on ecosystem services into conservation planning. We present an approach for identifying conservation areas necessary to safeguard the provision of important ecosystem services for indigenous communities. “Community use zones" (CUZs) were generated using participatory mapping methods that identify place values indicating significant hotspots for ecosystem services. Using principles from landscape ecology, these areas are buffered to provide connectivity and to delineate areas of ecosystem service delivery. We demonstrate the use of community use zones for five villages in southern Suriname (n=191 participants) to inform the South Suriname Conservation Corridor project. The mapped data reveal overlapping hotspots for different ecosystem services depicting multifunctional landscapes that provide an empirical foundation for delineating community use zones. In the absence of legal and traditional land rights for indigenous people, community use zones based on the provision of ecosystem services provide a defensible, spatially explicit approach for integrating indigenous needs into regional conservation plans in southern Suriname. We discuss the utility of community use zones maps for promoting land tenure and security and as a basis for collaborative governance in indigenous and community-conserved areas (ICCAs).

Key words: participatory mapping; community use zones; landscape ecology; ecosystem services; indigenous conservation

3.1 Introduction

The livelihood and wellbeing of 60 million indigenous people globally depend entirely on forest ecosystem services (Chao, 2012) such as food, water, building materials, non-timber forest products and less tangible ones, often classified as cultural services, such as sense of place and cultural identity (Millennium Ecosystem Assessment, 2005). Because of their interdependency with forests, indigenous people see security of tenure over the forest territories that sustain their lives as a factor determining their existence (Larson et al., 2010). Incomes derived from ecosystem goods, such as wild foods (e.g., fruits, nuts, fish, game) and raw materials (fibers, resins, timber, and non-timber forest products) play a critical role in wellbeing by enabling vulnerable forest-dependent people to obtain food and other important goods and services (Fisher et al., 2014; Poppy et al., 2014a, 2014b). Likewise, areas representing cultural values (e.g., sacred places, areas important for recreation) play a less tangible but important role because they are often safeguarded by local resource management strategies that simultaneously safeguard the supply of other ecosystem services such as pollination, fodder, and biodiversity (Berkes, 2012; Fabricius et al., 2007).

Community management of forests in the tropics can provide for long-term maintenance of forest cover (Porter-Bolland et al., 2012) while local participation in forest governance institutions is strongly associated with positive forest outcomes (Persha et al., 2011). Specifically, the role of indigenous communities in conservation has been acknowledged by international fora such as the UN Convention on Biological Diversity (CBD) (Kothari et al., 2014). Yet, a critical issue in the sustainable management of forest resources in the tropics is the status of land tenure and property rights that enable access to livelihood resources and provide security from outside threats (Bennett and Sierra, 2014; Fisher et al., 2014; Chapin et al., 2010). In the absence of land tenure security, an effective system of stewardship in indigenous peoples' regions can be undermined by both development and conservation efforts (Arnot et al., 2011; Schwartzman and Zimmerman, 2005).

However, long-term conservation outcomes cannot be guaranteed through property rights, community-based conservation, or the establishment of protected areas (Andrade and Rhodes, 2012) alone. In practical terms, conservation has a spatial outcome, and without spatially explicit boundaries, conservation becomes meaningless because there is no baseline to assess the impact of anthropogenic influences or to measure success or failure (Cumming, 2011; Daily et al., 2009). Especially in remote and data scarce regions where indigenous territories are not clearly defined or demarcated, and where there is no spatially-explicit information about the importance of areas to indigenous communities, investment plans for infrastructure, mining, and other extractive activities may conflict and undermine indigenous peoples' well-being. In the absence of adequate information regarding land use needs, nature conservation plans may inadvertently limit access for indigenous peoples to locations with cultural, symbolic, and livelihood value (Willemen et al., 2013; Lele et al., 2010; Daily et al., 2009; Cowling et al., 2008; Chan et al., 2006). New information is required to estimate the shape and size of areas necessary to maintain the livelihoods of indigenous peoples, but the demarcation and zoning of these areas is hindered by gaps in spatial layers of socio-ecological information (Bernard et al., 2011; McLain et al., 2013).

The growing dependence on visualization tools for managing the impacts of land use on ecosystem services (Pagella & Sinclair, 2014) has created the need for maps that communicate conservation and management needs more effectively (De Groot et al., 2010; Egoh et al., 2007). In addition, there is demand for visual tools that had better integrate stakeholder perceptions and values into resource and environmental planning processes (Brown & Fagerholm, 2014; McLain et al., 2013; Schägner et al., 2013; Bryan et al., 2010; Nassauer & Opdam, 2008). The integration of ecosystem services into spatial landscape planning (Crossman et al., 2013; De Groot et al., 2010) is important to safeguard ecosystem services flows (Ban et al., 2013; Reyers et al., 2013; Carpenter et al., 2009; Cowling et al., 2008) and should include areas where ecosystem services are generated (sources), delivered to users (sinks), and connect ecosystem services sources with users (Villa et al., 2014; Syrbe & Walz, 2012; Fisher et al., 2009).

Participatory mapping appears suitable for identifying provisioning and cultural ecosystem services (Brown et al., 2012) that are operationalized through the mapping of place values. The early typologies of place values developed for participatory mapping were called landscape values (Brown and Reed, 2000) and subsequently relabeled as social values for ecosystem services (Sherrouse et al., 2011) because the values represent end-products of ecosystem services at their interface with human well-being. The supporting rationale for linking place values with ecosystem services derive from interpreting place values as part of a 'structure–function–value chain' (Termorshuizen and Opdam, 2009) where ecosystem functions become services when their benefits are valued by humans (Brown, 2013). As an alternative to the concept of ecosystem services, Fagerholm et al., (2012) used the term landscape services, arguing it has more relevance to the way that local stakeholders act and perceive their environment. The terms ecosystem services and landscape services appear largely interchangeable and for the purposes of this study, we adopt the more widely used term ecosystem services as the product identified by the mapping of place values.

In this article, we apply participatory geographic information systems (PGIS) to identify hotspots of place values to inform systematic conservation planning. We apply the concept of service provision hotspots (SPH) developed by Palomo et al., (2013) to indicate areas highly valued for their multi-functional character in providing social and ecological services. Following the conceptual framework of Syrbe and

Walz (2012), we define service-connecting areas (SCA) as the spatial connections between service provisioning hotspots and indigenous village locations. The outer perimeter of these areas is considered the minimum area needed for managing multiple ecosystem services on which local livelihoods depend (Serna-Chavez et al., 2014). We define these areas as community use zones. To describe these zones and provide a foundation for their management, we use landscape metrics to identify the spatial structure and distributional patterns of the service provisioning hotspots components (Brown and Reed, 2012), and we apply landscape ecology principles relevant to reserve design (i.e., connectivity of landscape elements) (Bennett, 2003; Dramstad et al., 1996) (Bennett, 2003; Dramstad et al., 1996) to operationalize functional service connections (Syrbe and Walz, 2012).

3.1.1. The Conservation Context

This participatory GIS (PGIS) study was conceived in 2011 by Conservation International Suriname (CIS) to provide empirical data for the proposed South Suriname Conservation Corridor whose purpose is to protect and sustainably manage circa 2 million hectares of tropical forests and the headwaters of Suriname's major rivers. The South Suriname Conservation Corridor is at the heart of the largest connected block of forests in the world and would link protected areas in Guyana, Suriname, French Guiana and northern Brazil. Southern Suriname is inhabited by indigenous peoples, the Trio and Wayana, who directly depend on the forests for their livelihoods. The PGIS project was designed to engage with local communities to co-produce knowledge about indigenous values and to identify conservation management approaches that meet the needs of indigenous communities located in the South Suriname Conservation Corridor.

The study addresses two research questions: 1) how can we delineate areas needed to maintain the delivery of ecosystem services that support livelihoods and wellbeing of indigenous communities in southern

Suriname, a remote region where data are scarce. 2) Can multifunctional areas serve as the basis for spatial zoning that maximizes and protects the delivery of those services? The diversity of indigenous communities and ecosystems within the study area provide a good opportunity to demonstrate community use zones methods that can be applied to a range of social and ecological conditions. Further, traditional land rights are not officially recognized by the Suriname law and therefore indigenous communities lack both tenure security and secure access to life-sustaining resources. In southern Suriname, access to ecosystem services that contribute to indigenous wellbeing has been favored by the remoteness of the region, but these services are threatened by land uses such as gold mining (CANASUR Gold, 2014) and planned infrastructure investments (Suriname Business Forum, 2010). In the absence of spatially explicit information on the needs and aspirations of indigenous communities, the goals of the South Suriname Conservation Corridor may be compromised. The identification of indigenous community use zones presented in this study can provide information for land use and conservation interventions that secure access to livelihood resources while supporting the selection of participatory governance approaches that account for spatial use territories.

3.2 Study area

Southern Suriname is defined here as the region in the southeast of the country between 56ºW and 54ºW longitude and 4ºN and 2ºN latitude (Figure 8). The area is predominantly under high tropical forest with patches of seasonally inundated forest, savanna forest on rocky soil, and savanna with cerrado vegetation (Bánki & Aguirre, 2011). The region is inhabited by Trio and Wayana indigenous communities, who live in the five villages of Sipaliwini, Pelelutepu, Palumeu, Apetina, and Kawemhakan. Their livelihoods are based on shifting cultivation, fishing, hunting and harvesting timber and non-timber forest products for subsistence and cash exchange. Some income is also derived from the small number of tourists visiting the communities. There are no accurate data on the population size of these villages, but unofficial reports estimate 1,311 people in the study area (Heemskerk et al., 2007; Heemskerk et al., 2006). These remote villages, located 300 km from the country's capital Paramaribo, are accessible only by plane or boat trip of several days along and across rivers, rapids, and small creeks. Within the study area, there is one protected area, the Sipaliwini Nature Reserve, an area of 77,500 ha.

3.3 Methods

3.3.1. Place values

The attributes to be mapped were developed together with the participants based on their personal experience and knowledge. The respondents were asked to make a list of the place features that were important to them, which developed into a comprehensive list including several species of birds, frogs, and turtles that they sell. The list also included fisheries, agricultural products, wild fruits, firewood, drinking water sources, materials to build houses and boats, fibers to make hammocks and kitchen utensils, places with traditional and spiritual value, sense of place, tourism, and recreation opportunities. These items were grouped by the participants into income generation, food, building materials, culture, recreation, drinking water (see Ramirez-Gomez et al., 2013 for full details). Another place attribute was added by participants at a later stage in the mapping process to describe areas that are needed to support future generations.

The attributes identified by the participants were interpreted as a subset of place values in the typology developed by Brown and Reed (2000). This typology included 13 values: aesthetic; economic; recreation; life sustaining; learning; biological; spiritual; intrinsic; historic; future; subsistence; therapeutic; and cultural value. For this study, only future, cultural, economic, and subsistence values were used for mapping because we believed they best matched the perceptions of the participants (Table 11). The need for flexibility to tailor the mapping categories and terminology to the specific study context and population is a well-recognized principle in participatory GIS methods. Cultural value was locally adjusted to contain areas with traditional, spiritual and recreation values such that the operational definition contained multiple cultural categories from the Millennium Ecosystem Assessment (MA, 2005). The aggregation of values under the cultural label emerged during validation of the typology with participants indicating that areas with traditional, spiritual, and recreation value were often the same. For example, *Akïjo Ituro* rapids is a sacred site and a place to share food and drinks when traveling on a holiday trip. Participants indicated that combining separate cultural values into one category would make it easier for them to create and use the maps. The combined categories also constitute tacit recognition by the indigenous participants that some ecosystem services are spatially “bundled” in the landscape (Raudsepp-Hearne et al., 2010).

3.3.2. Data collection

Data collection was organized in participatory mapping (PGIS) workshops between January and November 2012 with 191 community members from five indigenous villages located in southern Suriname (Table 12). Respondents were selected on a volunteer basis balancing local knowledge of the territory, gender, and age. Older people with detailed knowledge of the study area participated in the mapping activity with the assistance of a younger person. In the process we used a base map (size A1) that contained a digital elevation model (DEM) with 90 meters resolution obtained from the Shuttle Radar Topography Mission (http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp) and reclassified for two elevations: above and below 400 m to highlight mountain ranges and inselbergs which are important spatial referents for the indigenous communities in southern Suriname. The base map also included river, creeks, and village locations. The scale of the base maps varied from 1:100,000 to 1:250,000 depending on the area each community decided to map. One map was given per participant in each of the villages and using a different color for each place value, each villager drew polygons to indicate important locations on the map. Informants were allowed to mark as many places as they wanted, allowing overlap between areas.

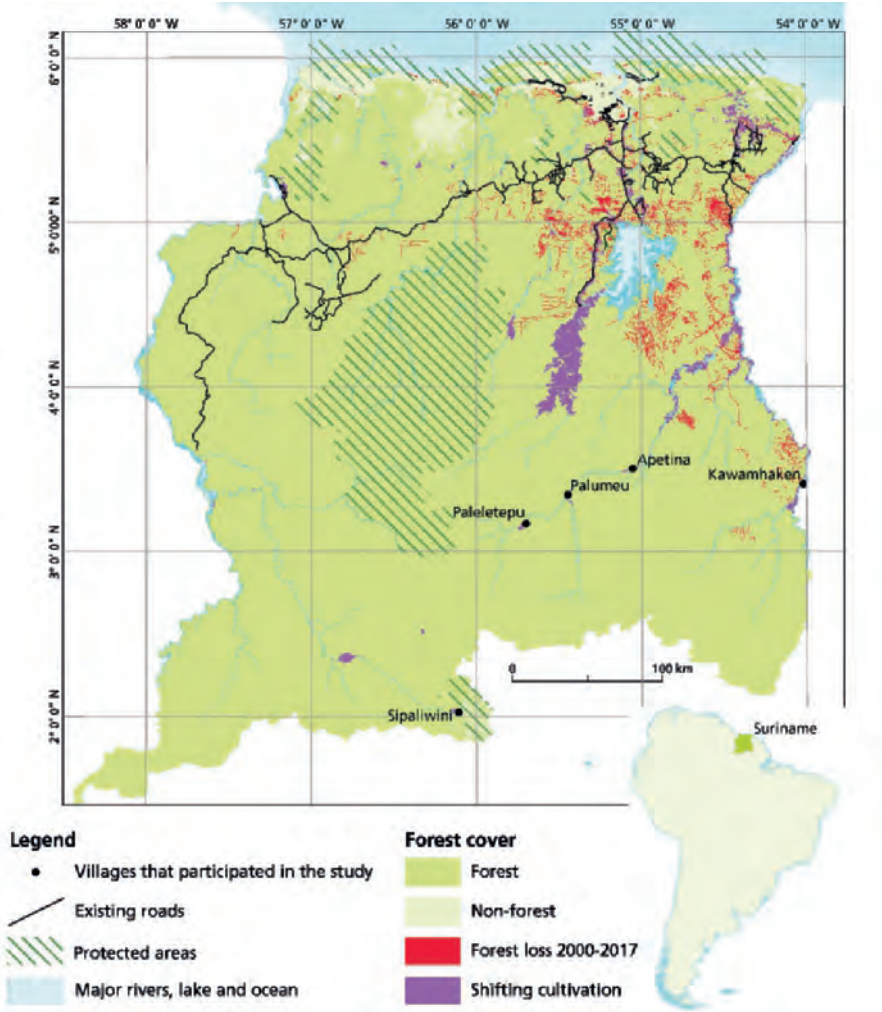


Figure 8 Location and geographic context of the communities that participated in this study. Source of forest cover data: SBB 2017.

Table 11 Typology of place values as perceived by indigenous communities in southern Suriname.

Place value	Description	Local activity/indicator
Future	Areas valued because they allow future generations to know and experience the area as it is now.	Mainly freshwater sources and fishing grounds.
Cultural	Areas valued because they hold spiritual value, because they are meaningful to their traditions, because they have aesthetic value and because they are a good place to swim.	River rapids, mountains, ancestral settlements, caves, inselbergs.
Economic	Areas valued because they provide income opportunities for local indigenous communities from timber, fisheries, minerals or tourism activities.	Handicrafts made from Oenocarpus bacaba, Didimopanax morototoni), selling of birds (such as Oryzoborus crassirostris, Oryzoborus angolensis, Cotinga spp.), selling of reptiles (Corallus caninus, Boa constrictor) and amphibians (Dendrobatus tinctorius, Ceratophrys varia, Bufo marinus).
Subsistence	Areas valued because they provide drinking water, food, raw materials and fuel to sustain the lives of local indigenous communities.	Shifting cultivation, collection of firewood, wild fruits, timber and thatch. Hunting areas, fishing grounds.

Table 12 Characteristics of the PGIS participants per community.

Community	No. of participants	Population estimate
Sipaliwini	22	214
Pelelutepu	58	393
Palumeu	23	360
Apetina	69	262
Kawemhakan	19	82

3.3.3. Hotspots of place values

The mapping activities resulted in 191 individual participant maps containing multiple locations for four place values (cultural, economic, subsistence, future). These maps were digitized and stored as vector data in a geographic information system (GIS) (ArcGIS v.10) using a geographic grid as a reference. Layers of values were overlaid by applying a customized GIS tool (Ramirez-Gomez & Martinez, 2013) that counts the number of overlapping polygons, resulting in density maps for each place value. For each value density map, we identified high concentrations of values that we defined as service provisioning hotspots by applying a cut-off value equal to the upper third of the polygon density distribution, a cut-off heuristic implemented in other studies (e.g., Brown & Pullar, 2012; Ramirez-Gomez et al., 2015). The final hotspot maps were validated with participants in community meetings and two copies of the final maps, as well as a digital version incorporating their comments, were returned to the communities (see Ramirez-Gomez et al., 2013 for more details).

3.3.4. Analysis of spatial patterns of service provisioning hotspots

To examine the spatial characteristics of service provisioning hotspots as landscape patches, we generated social landscape metrics as described by Brown and Reed (2012). These authors adapted landscape ecology metrics to social data to quantify the spatial attributes of human perception of place. In our study, we used Patch Analyst for ArcGIS (Rempel & Carr, 2012) to calculate six social landscape metrics that measure the size, shape, number, and relative isolation of service provisioning hotspots (Table 13). These metrics were selected to assist in the identification of appropriate buffer distances to achieve connectivity among service provisioning hotspots and to assist in the delineation of community use zones that combine core service provisioning hotspots with connectivity buffer zones.

3.3.5. Spatial concurrence of service provisioning hotspots

To identify areas within the community use zones that have multifunctional qualities, we spatially intersected the service provisioning hotspots maps. Areas where more than one service provisioning hotspots spatially overlap were assumed multifunctional areas because ecosystem services that co-occur within an area are considered a surrogate for multiple ecosystem functions (Raudsepp-Hearne et al., 2010). To quantify and measure the degree of spatial association, we applied Jaccard's coefficient to the spatial data for each community. The coefficient was calculated for each pair of hotspots for each community as follows:

$$J_{SPH1,2} = \frac{SPH1 \cap SPH2}{((SPH1 \cup SPH2) - (SPH1 \cap SPH2))}$$

where SPH1 is the hotspot for a given place value (e.g., subsistence) and SPH2 is the hotspot for a different place value (e.g., culture). The numerator indicates the area of intersection between the pair of service provisioning hotspots and the denominator indicates the difference between the union (sum) and intersection of the service provisioning hotspots areas.

3.3.6. Identification of service connecting areas (SCA) and delineation of community use zones

Although community use zones can be identified simply as the service provisioning hotspots multifunctional areas, we added additional buffers to service provisioning hotspots multifunctional zones, the justification being the need to provide linkages between the service provisioning hotspots multifunctional areas (Syrbe and Walz, 2012). Thus, community use zones consist of two landscape components: (1) core multifunctional areas and (2) connectivity linkages. Core multifunctional areas were operationalized by examining the number of service provisioning hotspots polygon overlaps and then selecting the top 50% as a cut-off to delineate core areas. To determine an appropriate spatial arrangement that serves the connectivity function of a community use zones, we considered the following landscape ecological principles related to connectivity and corridors (Bennett, 2003; Dramstad et al., 1996):

- Landscape ecological functionality is dependent on an effective network of corridors connecting important nodes (core zones).
- Continuous corridors are better than fragmented corridors (nearness is better than separation). Although not an optimal configuration, a series of small patches between large patches can serve as stepping stones in corridors if the distance between them is not too large.
- Wide corridors are better than narrow corridors, so wherever possible, the width of linkages should be maximized to increase effectiveness.
- Two or more corridor connections are better than one.
- Additionally, connectivity can be achieved by creating a single compact or larger contiguous patch from small individual patches (Williams et al., 2005; Tischendorf & Fahrig, 2000).

Table 13 Landscape metrics applied (Farina, 2000).

Landscape metrics	**Abbreviation**	**Description**
Number of patches	NumP	The total number of patches of an ES value type.
Mean Patch Size	MPS	The total size of the area covered by patches of ES values, calculated as a simple arithmetical mean.
Mean patch shape index	MSI	A standardized measure of patch shape, calculated for each patch of an ES value type, then summed across all patches of the same type as a simple arithmetical mean. It equals 1 when patches approach a circular shape.
Mean Nearest Neighbor	MNN	The Euclidean distance between patches of an ES value and its nearest neighbor summed across all patches of the same ES value type, as a simple arithmetical mean.
Percentage of landscape	ZLand	The proportion of the landscape comprising a particular ES value type. We applied it to estimate the proportion of the ES value within the CUZ.
Total landscape area	TLA	The sum of areas of all patches of an ES value type in the landscape.

For the application of these principles in this study, we examined the mean nearest neighbor metric (MNN) of the patches to estimate the degree of isolation and to identify potential buffer distances that would ensure structural connectivity that minimizes gaps in patch linkages (Bennett, 2003). Accordingly, if the MNN was relatively large, we experimented with larger buffer distances. We visually inspected the results of multiple trials on buffer distances to determine whether the buffer resulted in compact linkage areas. A similar buffering method was implemented by Serna-Chavez et al., (2014) who delineated spatial ecosystem services flow areas by applying the maximum threshold distance from the outer perimeter of the provisioning area.

Community use zones were operationalized as consisting of three management zones. Zone 1 contains the core multifunctional areas (or nodes) while Zone 2 corresponds to the buffer distance needed to create compact linkages for the connectivity function. A third zone (Zone 3) was added to provide an area to protect the function of the network system (Baker, 1992; Batisse, 1982). This third zone was identified based on the "nearness" landscape ecology principle (principle (b) above) to ensure that isolated patches (i.e., stepping-stones) were included in the connectivity network. The total size of each community use zones was determined by the total area contained within the perimeter of Zone 3. We call these zones core multifunctional areas, critical linkage areas, and service connecting areas respectively.

3.4 Results

3.4.1. Spatial patterns of service providing hotspots by community

The community use zones in the southern Suriname study region cover a total area of approximately 2.7 million ha. Their average size is 532,410 ha. The landscape metrics for different communities show significant spatial variability, with some service provisioning hotspots comprising a larger proportion of the total community use zones (Table 14). For example, in three villages, the most important service provisioning hotspots in terms of percentage of community use zones coverage were those for future value, covering 21% of Pelelutepu community use zones, 15.6% of Palumeu community use zones, and 14.9% of Apetina community use zones. In the other two villages, proportionally the largest service provisioning hotspots were the service provisioning hotspots for culture in Kawemhakan community use zones (11.6%) and the service provisioning hotspots for subsistence value in Sipaliwini community use zones (9.3%). At the other extreme, the smallest service provisioning hotspots in terms of proportion of area of the community use zones was for economic value, except for Sipaliwini community use zones, where it was culture. The size and number of service provisioning hotspots also varied by community. On average, service provisioning hotspots of future value were the largest, while subsistence hotspots were the smallest and most numerous (n=380). Service provisioning hotspots for economic value were fewest in number (n=110).

3.4.2. Spatial association between place values by community

The spatial association between the different place values mapped by each community in the study area was quantified with Jaccard's coefficient (Table 15). In Apetina, Pelelutepu, and Palumeu, cultural and economic value had the highest degree of spatial association (J = 0.56, 0.51, and 0.42 respectively). In Apetina, future and subsistence values were moderately associated (J = 0.34), while in the other four villages, this spatial association was much lower. In Pelelutepu and Palumeu, cultural and subsistence had a moderate degree of spatial association (J = 0.37 and 0.34 respectively) whereas in Apetina, this spatial association was weak (J = 0.13). In Sipaliwini, the level of spatial association was weak, with cultural and subsistence having the highest level of spatial association (J = 0.18). With the exception of Apetina, future value areas had the lowest spatial concurrence with other place values throughout the study area.

Table 14 Social landscape metrics applied for service provisioning hotspot values within each community

Community	Typology of place values											
	Future			Culture			Economic			Subsistence		
	No. Hotspots	Mean hotspot size (ha)	Percent of CUZ*	No. Hotspots	Mean hotspot size (ha)	Percent of CUZ	No. Hotspots	Mean hotspot size (ha)	Percent of CUZ	No. Hotspots	Mean hotspot size (ha)	Percent of CUZ
Apetina	34	1,308	14.9	24	296	2.4	20	223	1.5	44	507	7.2
Pelelutepu	88	1,731	21.6	34	1,680	8.1	31	1,034	4.6	160	514	11.7
Palumeu	83	1,138	15.6	32	697	3.7	10	970	1.6	90	485	7.2
Kawemhakan	88	856	8.5	38	2,695	11.6	32	1,900	6.9	53	1,516	9.1
Sipaliwini	-	-	-	7	897	3.7	17	530	5.2	33	484	9.3

*CUZ: Community use zone

Table 15 Jaccard's coefficients for measuring spatial overlap of place value hotspots for the five villages in Suriname.

Apetina	**Economic**	**Subsistence**	**Future**	**Cultural**
Economic	-			
Subsistence	0.12	-		
Future	0.06	0.34	-	
Culture	0.56	0.13	0.07	-
Sipaliwini	**Economic**	**Subsistence**	**Future**	**Cultural**
Economic	-			
Subsistence	0.21	-		
Future	N/A	N/A	-	
Culture	0.17	0.18	N/A	-
Kawemhakan	**Economic**	**Subsistence**	**Future**	**Cultural**
Economic	-			
Subsistence	0.24	-		
Future	0.07	0.12	-	
Culture	0.16	0.28	0.06	-
Pelelutepu	**Economic**	**Subsistence**	**Future**	**Cultural**
Economic	-			
Subsistence	0.30	-		
Future	0.05	0.12	-	
Culture	0.51	0.37	0.06	-
Palumeu	**Economic**	**Subsistence**	**Future**	**Cultural**
Economic	-			
Subsistence	0.19	-		
Future	0.03	0.20	-	
Culture	0.42	0.34	0.07	-

3.4.3. Community use zones landscape metrics

The number of core multifunctional patches (NumP) was largest in Kawemhakan (n=25) and smallest in Sipaliwini (n=1). There was relative uniformity in the mean patch size (MPS) of core multifunctional areas across the five communities, with an average patch size of about 2,500 hectares. However, the core areas in all communities were irregularly shaped patches (MSI), with the most elongated patches found in Apetina. Rivers and waterways strongly influenced the shape of mapped areas in all communities except Sipaliwini (Figure 9). The mean nearest neighborhood statistic (MNN) shows that core areas were most isolated in Pelelutepu and Palumeu, and proximate in Kawemhakan. The MNN statistic in the connectivity zone reveals that Sipaliwini had the most distant patches and hence need for a larger buffer to connect the multifunctional areas (Figure 9e), while Palumeu and Kawemhakan require moderate size buffers to connect core areas (Figures 9d and 9e). After buffering the core areas to attain a linkage area (Zone 2), some patches remained isolated, especially in Apetina, Palumeu and Kawemhakan. These patches may be considered “stepping stones” (Bennett, 2003), so extending the buffer over longer distances was required to connect these areas (Zone 3) to form the community use zones (Table 16).

Table 16 Social landscape metrics applied to landscape components within the Community use Zones (CUZs).

Community	Zone 1: Core multifunctional areas					Zone 2: Critical linkage area						Zone 3: Service connectivity area	
	$NumP_a$	MPS_b (ha)	MSI_c	MNN_d (m)	Total core area (ha)	NumP	MPS (ha)	MSI	MNN (m)	Buffer distance (m)	Buffer area (ha)	Buffer distance(m)	Total CUZ area
Apetina	7	2,759	2.76	3,041	11,311	502	69	1.68	165	1,000	159,160	3,000	297,819
Pelelutepu	22	2,608	1.83	4,500	57,369	466	508	1.76	158	1,200	563,323	1,000	704,122
Palumeu	9	2,464	1.71	5,86z7	22,173	474	208	1.66	465	2,000	428,144	2,000	606,816
Kawemhakan	25	2,592	1.74	1,479	64,796	438	355	1.60	395	2,000	546,700	2,600	881,512
Sipaliwini	1	2,277	1.25	1	22,173	92	224	1.58	9.89	4,000	155,909	500	171,781

a Number of patches

b Mean patch size

c Mean shape index

d Mean nearest neighbor

3.5 Discussion

This case study has demonstrated how the participatory mapping of place values can be used to estimate the area needed to provide the ecosystem services on which local livelihoods depend. Mapped place values were analyzed and assembled into landscape components called core provisioning areas, linkage, and connectivity areas as suggested by Serna-Chavez et al. (2014) and Syrbe and Walz (2012). The delineation of these zones can guide development and planning for indigenous communities and conservation initiatives such as the South Suriname Conservation Corridor. The novel application of landscape ecological principles to indigenous settlements and patterns of land use operationalizes a multifunctional landscape planning approach (Reyers et al., 2013) that accounts for the spatial extent of local livelihoods and areas of concern for the mitigation of negative impacts from encroaching human activities (Williams et al., 2005). For example, the use of patch connectivity as a guiding community use zones principle prevents spatial disconnection that can hamper spatial flow paths for ecosystem service delivery (Serna-Chavez et al., 2014; Bagstad et al., 2013; Syrbe & Walz, 2012).

The spatial association between place values mapped in this study (i.e., subsistence, cultural, future, and economic) revealed that some values exhibit bundling, i.e., are spatially coincident and frequently appear together (Raudsepp-Hearne et al., 2010). For example, economic and subsistence values showed modest levels of spatial concurrence in all villages and may be attributed to livelihood activities such as fishing that are done for subsistence as well as income generation (Ramirez-Gomez et al., 2013). Economic and cultural value showed the largest spatial concurrence in the three villages of Apetina, Palumeu and Pelelutepu. This can be attributable to common livelihoods in these villages. For example, villagers in Palumeu and Apetina derive an important part of their livelihood from income related to tourism and attractions located

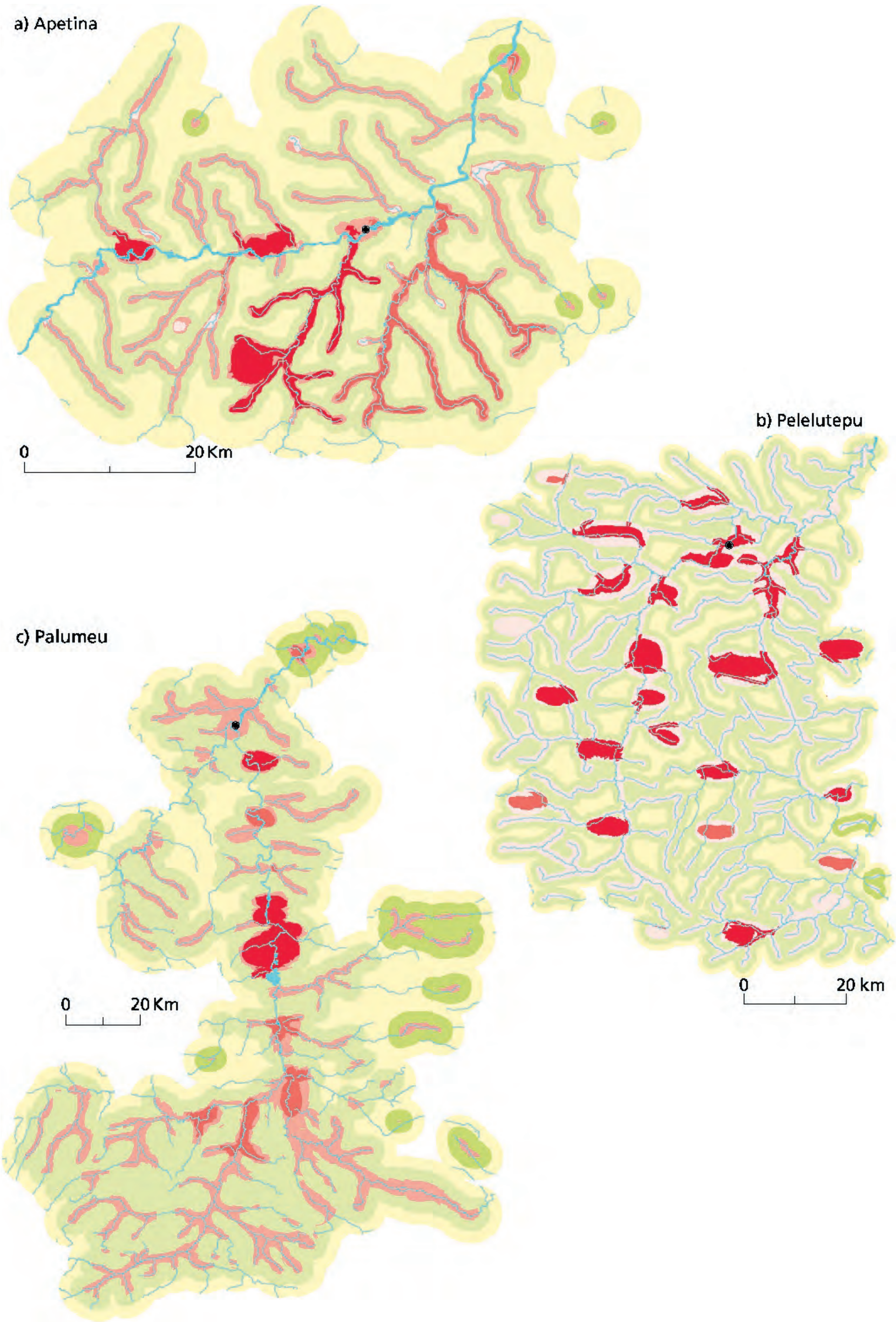
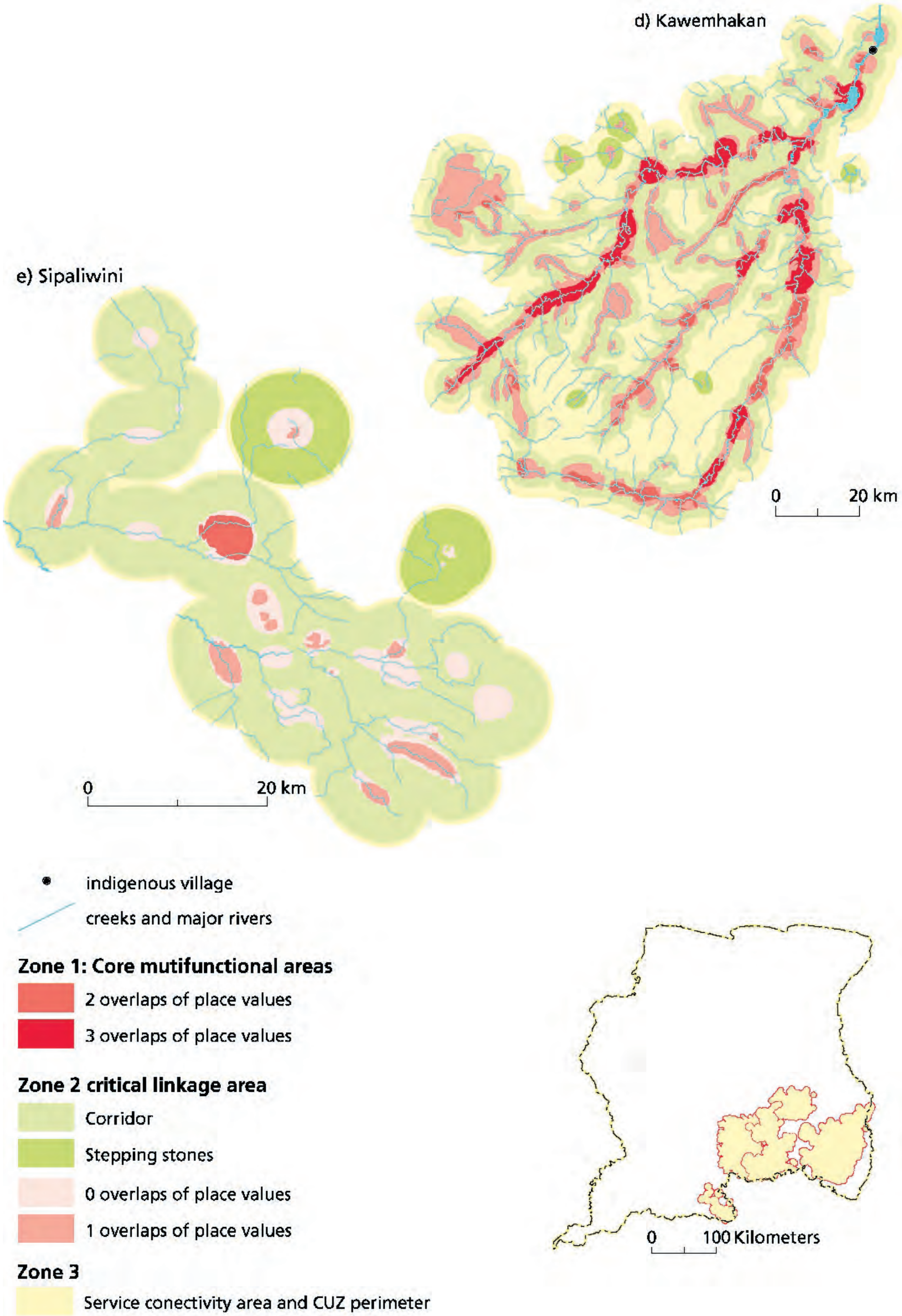


Figure 9. Overlap of hotspot values for ecosystem service representing core multifunctional areas, critical linkage areas, and connectivity areas. Sipaliwini has a maximum of two overlapping ecosystem services values, hence no dark red areas.


d) Kawemhakan
0
20 km
e) Sipaliwini
0
20 km
indigenous village
creeks and major rivers
Zone 1: Core mutifunctional areas
2 overlaps of place values
3 overlaps of place values
Zone 2 critical linkage area
Corridor
Stepping stones
0 overlaps of place values
1 overlaps of place values
Zone 3
Service conectivity area and CUZ perimeter
0
100 Kilometers

in areas with significant cultural values. Similarly, in Pelelutepu, areas with high cultural value, described as special places by the local community, overlap with areas where wildlife provide local sources of income (Ramirez-Gomez et al., 2013). In contrast, future values were not significantly spatially concurrent with the other mapped values. Local narratives about places with future value indicate current low use, but the indigenous communities view these areas as functional “reserves” for subsistence and income-related resources that will support future livelihoods.

Service provisioning hotspots with two or more overlapping ecosystem services (red areas in Figure 9) represent a relatively small proportion of the total area used and valued by the five communities. The delineation of community use zones based exclusively on service provisioning hotspots (i.e., Zone 1 core areas) would greatly underestimate the geographic area used by the indigenous communities. Expanding service provisioning hotspots areas through linkage buffers (i.e., Zone 2 critical linkage areas) provides a more realistic assessment of the actual area needed by the communities to sustain their livelihoods and important cultural areas. Heuristic approaches to determine buffer distances can enhance the level of connectivity (Fahrig, 2001; Opdam & Wascher, 2004; Tischendorf & Fahrig, 2000) and we therefore trialed a number of buffer distances in this study.

The delineation of community use zones based on core and connectivity zones was insufficient to capture the geographic complexity of community needs in the region. The mapped areas in Figure 9 reveal distinctive spatial patterns of land use by different communities, with the communities of Apetina, Palumeu, Pelelutepu, and Kawamhaken being highly dependent on riverine systems, as shown by service provisioning hotspots located along rivers, while the community of Sipaliwini was much more dependent on the savanna environment. The service connecting areas (Zone 3) fill the spatial gaps between the network of rivers and waterways. Although these areas are not used intensively by the communities, largely because of the difficulty of access and transport in the study region, they nonetheless provide supporting ecosystem functions (e.g., soil retention, water purification) that help sustain the biological productivity of the riparian areas. Zone 3 areas can be described as “indirect” community use areas. Thus, the community use zones mapping approach described in this study is best characterized as providing an estimate of the areas needed by indigenous people in the region.

3.5.1. Implications for conservation planning in southern Suriname

Pragmatically, having delineations of community use zones in the southern Suriname region increases the likelihood that land use and conservation plans will reflect indigenous peoples’ needs. The identification of community use zones is a modest step toward providing decision makers in Suriname with information that may help integrate protection of indigenous livelihoods, the promotion of appropriate economic development, and the identification of conservation opportunities in a region characterized by weak institutions and a need for capacity building. In the absence of legal traditional land rights for indigenous people in Suriname, community use zones derived from place values that identify important ecosystem services provide a defensible, spatially explicit approach for integrating indigenous needs into regional conservation plans in southern Suriname. Based on the results, we suggest three major implications of the community use zones approach for conservation planning: 1) as an empirical foundation for promoting and advocating land tenure and security; 2) as a basis for a collaborative governance approach to indigenous and community-conserved areas (ICCAs) and, in the specific context of the South Suriname Conservation Corridor; and 3) a tool for allowing a sensible zonation plan that considers multiple stakeholders needs.

The community use zones represent an important communication tool for indigenous communities in the study area on issues related to their territory. For example, during the Multi-stakeholders Dialogue on the Protection of South Suriname[5], the indigenous communities used the maps produced during the first part of the study (see Ramirez-Gomez et al., 2013) to show the audience the areas that are important to them and that should be considered when designing the South Suriname Conservation Corridor (Fig 10). Thus, identification of community use zones can facilitate involvement that is more effective and compliance with indigenous people's right to free prior informed consent (FPIC) vis á vis proposed conservation interventions and exploitative concessions in indigenous territories. This is very important in contexts like Suriname where indigenous communities lack national level legal recognition and support.

Community use zones can also provide the basis for a management approach grounded in sound governance principles and participation that encourages resource stewardship, nature protection, sustainable land use, and a right based approach to conservation (Campese, 2009). Specifically, information about community use zones in southern Suriname can support ongoing national dialogues about ICCAs (VIDS, 2012) or other collaborative governance systems by providing estimates of the areas used by indigenous communities to maintain traditional ways of life (Bernard et al., 2011). In other countries (e.g., Bolivia), this information is less urgent in ongoing ICCA dialogues because indigenous communities have clearly defined the extent of their territories (Miranda and Vadillo, 2012).

[5] http://www.conservation.org/NewsRoom/pressreleases/Pages/Guardians-of-the-Forest-Indigenous-Peoples-Take-Action-to-Conserve-Nearly-Half-of-Suriname.aspx.

Figure 10 Indigenous communities from south Suriname during the 9 days of multi-stakeholder dialogue on the protection of South Suriname. In the picture, indigenous peoples from the village of Apetina are showing the audience the areas that are important to them (using in the maps produced in this study) during the dialogue's session on "What needs to be conserved and where" held in Paramaribo on February 23, 2015. Photo by Sara Ramirez-Gomez.

Currently, de facto ICCAs exist in southern Suriname (VIDS, 2012) because of customary laws, traditions, and spirituality, while other de facto ICCAs have been designated as an incentive for earning income from ecotourism. The identification of community use zones can help leverage co-management agreements, such as ICCAs, although these agreements will require supporting legislation (Kothari et al., 2014; Oviedo, 2006; VIDS, 2012). Similarly, current conservation planning projects, like the South Suriname Conservation Corridor, should incorporate the expectations of indigenous communities for their livelihoods and cultural well-being. As noted by (Colchester, 1998), conservation should not rely on state bureaucracies to defend isolated, protected areas of high biodiversity. Conservation and biodiversity protection must occur within larger landscapes occupied by human beings that care about the environment and the wellbeing of future generations (Colchester, 2000).

3.5.2. Limitations of the community use zones approach

There is a tendency for spatial analysis to over simplify the complexity of real-world application. For example, in the case of Kawemhakan, the resulting community use zones is the largest in area, but has the smallest population. This complexity exists in other indigenous territories across the Amazon where indigenous peoples, especially the young, are migrating to cities or frontier zones where they can better access education, health care, and commodities (Alexiades, 2013; Pérez-Llorente et al., 2013). Therefore, when determining the size, management, and characteristics of proposed community use zones, data on population size, growth, and out-migration should be incorporated, although this could prove difficult in resource and data-scarce regions like southern Suriname.

Effective conservation requires consideration of both ecological priorities and the needs of human communities. The identification of community use zones is clearly focused on the latter, but they should not be interpreted as limiting conservation outcomes. There is also a need for more comprehensive biodiversity assessments in southern Suriname to complement the data produced through community mapping. The most effective conservation outcomes will protect biodiversity while meeting the needs of indigenous communities in the region. Large-scale resource development projects in the region pose a risk to both. An in-situ conservation strategy, operationalized through community use zones mapping, can provide a pragmatic pathway to achieve biodiversity protection while maintaining human well-being.

Acknowledgements

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Chapter 4

Assessing spatial equity in access to service provisioning hotspots in tropical forest under external pressure

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Abstract

Equity is an essential element in the implementation of policies related to ecosystem services. With the rapid expansion of commercial land use into tropical forest regions, the urgency and importance to integrate equity issues in space and time in decisions and actions stand without doubt. However, data scarcity in these regions limits the understanding of how land use affect spatial and temporal aspects of equity. This again emphasizes the need of rapid and robust ways to address spatio-temporal patterns of equity that are especially suited for data-scarce regions. This study addresses this gap. We assess the impact of land use interventions on spatial equity through an empirical study that compares two sub-regions in the Upper Suriname River Basin. In the first sub-region, some logging and road building occur; the other, however, is more remote and such interventions are not yet developed but merely planned. We collected spatial data for 1995 and 2015 using a participatory GIS survey (n= 493), registering provisioning service hotspots. We then explored different dimensions of spatial equity, according to clan and authority position, by analyzing variation over time and across regions. In the region with roads and logging, spatial equity concerns emerged over time regarding the provision of timber and fish. In the remote region, spatial inequity in access to hotspots of ecosystem services appeared early, ahead of the economic opportunities posed by new roads in nearby forests areas. Our analysis made spatially explicit the places where conflict between users of ecosystem services, associated to asymmetries in access to hotspots of ecosystem services, is most likely. In outlining these concerns, we argue that spatial equity analysis unveils an essential social dimension in the use of the space that is integral in spatial planning processes.

Key words: external pressures, ecosystem services, service provisioning hotspots, spatial equity, conflicted space, participatory GIS.

4.1 Introduction

Tropical forests provide a variety of goods that form the base of rural livelihoods, such as food, water, timber, fibers, medicine and fuel. These goods, commonly referred to as provisioning ecosystem services, are used for both subsistence and commercial purposes (Shackleton and Shackleton, 2004) by different social groups (henceforth, 'user groups'). In common pool resources, the degree to which any individual, including traditional resource users, can use and benefit from these ecosystem services depends on complex mechanisms of access including social relationships, power, institutions, capabilities, rights and various capitals (Ribot and Peluso, 2003). Thus, depending on these differences, there is a certain degree of inequity implied within traditional resource use systems (Fisher et al., 2013). Inequity in access to ecosystem services occurs when not all user groups accessing the same ecosystem service can obtain what they need to sustain their livelihoods (Daw et al., 2011). For example, some user groups might obtain more benefits from ecosystem services because they have better access capabilities because of their high social status related to lineage, while other users belonging to a lower ethnic group might obtain less benefits (Lakerveld et al., 2015).

Inequity in access to provisioning services, according to the different access capabilities of users, is often studied in the context of social power dynamics that emerge in the flow of benefits from ecosystem services (Anderson et al., 2015; Barnaud and Van Paassen, 2013; Felipe-Lucia et al., 2015). However, since the production and use of ecosystem services has a strong spatial component (Syrbe and Walz, 2012), differences in access to locations where ecosystem services are produced can have important equity implications (Fisher et al., 2009). For example, in a local community context, those community members who are more influential, might be able to access larger areas where ecosystem services are generated than other more marginalized user groups in a disadvantaged position (Rodríguez et al., 2006). Thus, by studying differences in spatial patterns of use of ecosystem services, other equity issues related to their spatial distribution can be unveiled (Bennett et al., 2015; de Groot et al., 2010). However, spatial patterns of equity in access to ecosystem services have remained largely unaddressed (Bennett and Chaplin-Kramer, 2016; Bennett et al., 2015; Birkhofer et al., 2015). This study aims at addressing that gap by focusing on equity in access to the locations where ecosystem services are produced. We refer to this as spatial equity.

The study of spatial equity relies on the immediate need to bring equity analysis closer to the real-world problems and practice of land use planners and policy makers (Turkelboom et al., 2018). Land use policies aimed at opening up remote forest areas – e.g. in the form of infrastructure projects (roads, dams) or the promotion of commercial logging and mining – are often intended to ultimately have a net positive effect on the economy of a region. However, policy makers' focus on overall economic development seems to make them blind to the effects of these interventions on equity, in particular on spatial equity. This can be more acute in forest regions characterized by data scarcity. Without baseline data to inform decisions, it is likely that the impact of land use policies and the unequal distribution of its benefits may reinforce structural inequities within user groups. In particular in tropical forest regions affected by such commercial land use interventions, where inequity in access to ecosystem services can be pronounced, scarcity of trustworthy and affordable data constraints the assessment and understanding of spatial equity the most (Palomo et al., 2018). Therefore, a rapid, but also robust approach to study spatial equity is urgent in these regions. This study responds to this pressing call.

Participatory GIS of ecosystem services refers to a set of approaches and techniques combining the tools of modern cartography with participatory methods to represent spatial knowledge on ecosystem services (Jankowski, 2009). It is increasingly used to address gaps in spatial layers of social data (McLain et al., 2013). As such, the aim of this paper is to develop and apply a participatory mapping methodology to assess spatial equity in data-scarce regions. We specifically address the question: what is the effect of external pressures, such as roads and logging, on spatial equity?

We studied the nature and extent of the impact of external pressures on spatial equity by means of an empirical study that makes a comparison between two traditional communities in the Upper Suriname River Basin – one community affected by external pressures in the form of road infrastructure developments and logging, and the other being affected to a much lesser extent. We operationalized our central research question and the assessment of spatial equity in this remote, data-scarce forest region in four steps. First, we disaggregated user groups in a manner that reflects different capabilities to access ecosystem services. In this study, we disaggregated according to ethnicity and authority position (e.g. chief, assistant chief or a regular ecosystem service user), which are social divisions suggested in exploratory equity approaches (Daw et al., 2011). Second, we identified, through participatory mapping, spatial units that are collectively valued as highly important locations for ecosystem service provision. These are termed service-provisioning hotspots (Palomo et al., 2013), which authors usually define without explicitly mentioning the ecological functions underlying the production of services (Syrbe and Walz, 2012). These service-provisioning hotspots were found to be particularly useful in studies characterized by data scarcity (Alessa et al., 2008). Third, we made a comparison over time (between 1995 and 2015), of the general spatial patterns (e.g. size, quantity) of service-provisioning hotspots. Fourth, we explored overall spatial equity over time, across users and cases by developing a novel service-provisioning hotspots distribution index. In the discussion, we reflect on how the findings can support spatial planners and practitioners to consider spatial equity issues arising from the use of space among traditional communities.

4.2 Methods

4.2.3. Study area

This study took place in the Upper Suriname River Basin that is located south from the Brokopondo reservoir, approximately 315 km south of Paramaribo, the capital of Suriname (Fig. 11). Afro-descendent people belonging to the Saamaka tribe, who are living in 62 villages along the river, inhabit the area. Traditionally, their livelihoods have been based on shifting cultivation, the collection of non-timber forest products, fishing and hunting.

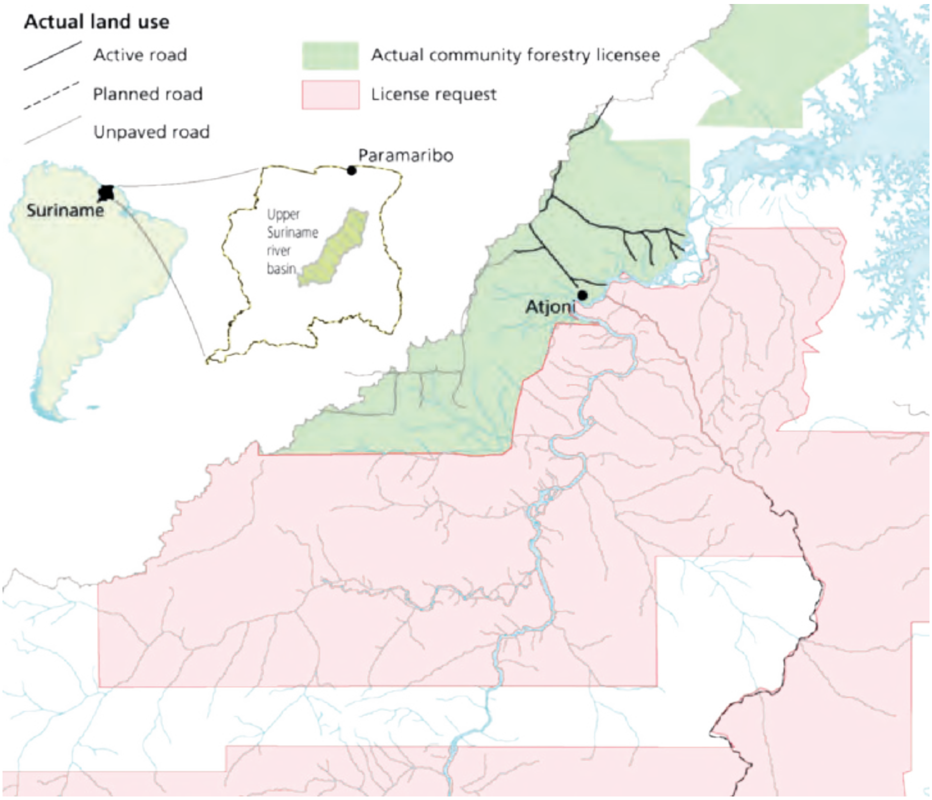


Figure 11 a Location of the study area and overview of land use activities. Sources: Stichting voor Bosbeheer en Bostoezicht, (2019, 2016, 2011).

Since the construction of a major road in 2010, local communities have been increasingly involved in economic activities such as trade of timber and non-timber forests products, craft making and ecotourism. This study focuses on the basin area above the 4° latitude, which is the

Southern limit up to which timber concessions can be granted in Suriname (Stichting voor Bosbeheer en Bostoezicht, 2016).

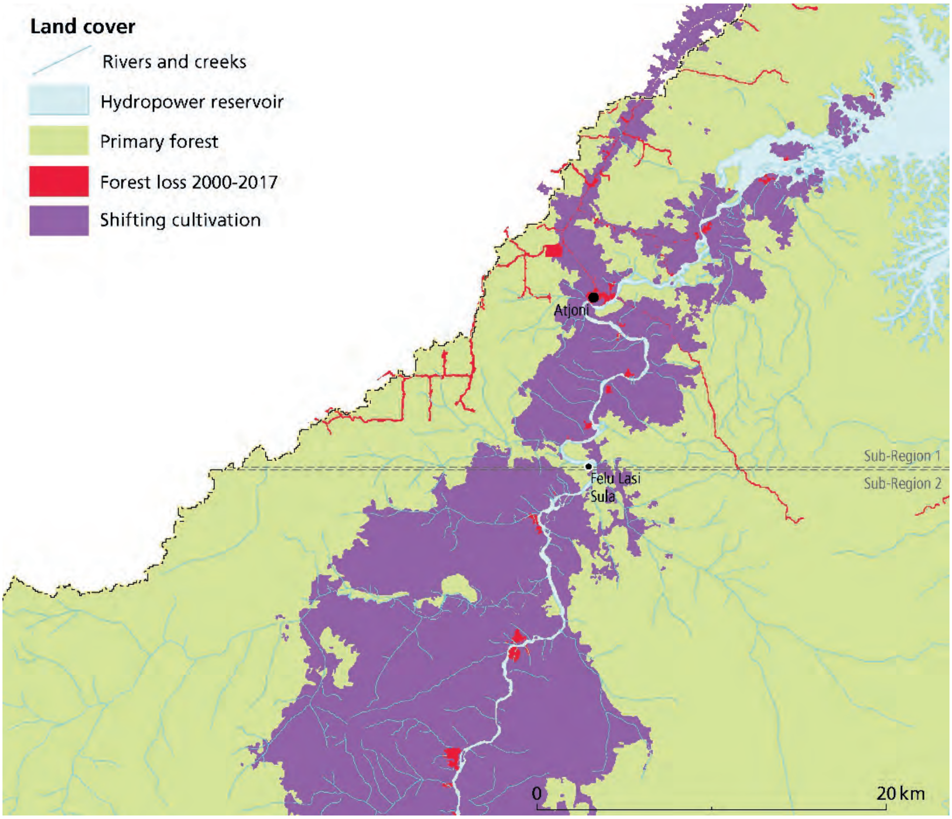


Figure 11 b Land cover in the study area. Source: Stichting voor Bosbeheer en Bostoezicht, (2017).

Within that region, we selected two study sub-regions (Fig. 11). Sub-region 1 is characterized by the presence of roads and active community forestry concessions. These are areas where communal property rights are granted to manage timber and non-timber forest products (Bocci et al., 2018). Currently there is a community concession area of 39,000 ha in sub-region 1, which is used in liaison with outsiders. According to official reports, the round wood production increased 90% between 2010 and 2016 (Stichting voor Bosbeheer en Bostoezicht, 2016). This increase coincides with the pavement of the Atjoni road in 2010. By contrast, sub-region 2 is more remote and has no road infrastructure nor granted community forest concessions, although community forestry applications covering 92,200 ha have been submitted (Stichting voor Bosbeheer en Bostoezicht, 2019). A large rapid - the Felu Lasi Sula that makes access to sub-region 2 difficult - marks the division between the regions. This de facto division of the basin is also made by local communities when working with outsiders, as the rapid functions as the gate to the most remote communities in the basin. Table 17 shows the general demographic aspects of the study area and the size of the sub-regions. Information about population size in each village of the Upper Suriname River Basin is only available from 2010 onwards (Centraal Bureau voor Burgerzaken (CBB), 2019).

Table 17 General characteristics of the study sub-regions.

Study case	**Population size***			**Total area (ha)**	**Total number of respondents**
	1997	2010	2015		
Upper Suriname River Basin	13,045	17,254	18,502	1,267,557	
Sub-region 1	-	2,444	2,553	177,231	238
Sub-region 2	-	6,221	6,517	203,635	254

*Source: Centraal Bureau voor Burgerzaken –CBB-, (2019); Algemeen Bureau voor de Statistiek in Suriname, (2017).

Sub-region 1 and sub-region 2 include 124,989 ha of tropical primary forest and a fringe of 75,906 ha of secondary forest along the river, originated because of regeneration after shifting cultivation (Fig 11b). In the entire watershed, forest management has been traditionally based on customary laws that distribute forest lands over clans and according to which the individuals belonging to a particular clan enjoy subsidiary use and occupation rights (Price, 1975). In the basin, there are 12 clans: Awana, Abaisa, Bakapau, Biitu, Dombi, Fandaaki, Langu, Matjau, Nasi, Nyafai, Paputu and Watambii. In addition, there are a few people from the Matawaii tribe, who are originally from the Western neighboring basin. Therefore, in total, this study had responses from 13 clans.

Some clans tend to have more influence than other depending on the perceived spiritual relations with ancestors, the land and kinship structures (Price, 2002). The formal socio-political structure of the Saamaka tribe includes a Granman (tribal chief) and village chiefs (*Kapiteins*) who are assisted by several assistant chiefs and elderly people locally known as Dresimen. The government appoints the chiefs and the assistant chiefs; their position is for life and they receive a wage. None of the communities in the entire watershed hold legally recognized land rights. All land is formally owned by the state.

4.2.4. Selected ecosystem services and their users

The ecosystem services included in this study are the provision of fish, timber and crops. We made this selection based on a prioritization exercise within the scope of the overall research project in which the present study is embedded (see Ramirez-Gomez et al., 2017 for details). Furthermore, we define ecosystem service users as individuals or groups of people who benefit from using specific services that ecosystems provide (Plieninger et al., 2013). In this study we made a distinction by ethnical clans and by authority position according to four levels: 1) chiefs, 2) assistant chiefs, 3) elderly people (or Dresimen) and 4) regular community members. This distinction was based on the result of focus groups and community discussions (for details see Ramirez-Gomez et al., 2017). According to local communities, the allocation of benefits from ecosystem services to individuals is often determined according to membership of certain clans or according to their authority level in the communities.

4.2.5. Data collection

Data was collected through a participatory GIS (PGIS) survey among community members, which was conducted between November 2015 and February 2016 by a team of three interviewers and one field coordinator. The sample population was selected using a snowball approach (Newing et al., 2010). First, the field coordinator asked the village authority to provide a list of 20 names trying to balance gender (50:50 if possible) and age (≥31 years). The people selected were interviewed first and subsequently, interviewers asked each respondent to nominate additional respondents. In total, 492 responses were collected, 238 in sub-region 1 and 254 in sub-region 2. The PGIS survey built on previous participatory mapping activities described in detail in Ramirez-Gomez et al., (2017). The map produced during that study was used as the base map during the PGIS survey. The base map was printed in A3 format and overlaid with transparent sheets having a geographical grid as a reference. Respondents were asked to first draw polygons indicating the location of the selected ecosystem services in the past (20 years ago), using different color markers. Only the past locations for the provision of fish and timber were identified. Since the respondents indicated that the most important locations for the provision of crops had been semi-permanent over the last 20 years and remained within walking distance from the main village, there is no crop data preceding 2015.

Ethic statement

Data collection methods were in line with the Code of Conduct for working with Indigenous and Local Communities of Tropenbos International (Persoon and Minter, 2011). Before beginning the survey, potential respondents were informed of the goal of the interviews through a statement read by the interviewers who assured that the data would be analyzed anonymously. Interviews were conducted with voluntary respondents following a verbal and written consent from the potential respondents who also indicated whether they would like to be contacted for the presentation of the results of the analysis.

4.2.6. Data analysis

a. Disaggregation of ecosystem service users

PGIS survey respondents were divided according to 13 clans and 4 authority positions mentioned above. For ethical reasons, we refrain from naming the clans in this study but provide a number to identify them. Table 18 presents the number of respondents per clan and authority position in each sub-region. The exact size of each clan is unknown. However, the number of respondents are indicative of estimated clan sizes. For example, clan 1 and clan 5 are the largest common clans in the entire basin (Price, 2002) and as such, they have the largest representation in the responses.

b. Identification of service provisioning hotspots

The transparent sheets containing the raw PGIS information were scanned; georeferenced and polygons indicating locations where ecosystem services are provided to individual respondents were digitized and stored in ArcGIS®. To identify service-provisioning hotspots, the polygons where overlapped using a customized GIS tool (Ramirez-Gomez and Martínez, 2013) that counts the number of overlapping areas. This resulted in polygon density maps for each ecosystem service. For each density map, we identified hotspot locations by applying a heuristic cut-off value equal to the third quartile of the polygon density distribution. This was in line with procedures applied in other studies (e.g. Ramirez-Gomez et al., 2016, 2015; Brown and Pullar, 2012). Service provisioning hotspots were mapped and classified for the past (1995) and present (2015), except for crops (only for 2015). However, to address the lack of primary historic data for crop provisioning, we compared our data from 2015 to the size of the areas in crops derived from the available forest cover map of 2000 (Stichting voor Bosbeheer en Bostoezicht, 2019). For both 1995 and 2015, an attribute table was built for each service provisioning hotspot containing information about size in ha, as well as clan membership and authority position of the respective users (respondents). To gain insight in the development of the intensity of use over time, we compared the increase in number and size of the service provisioning hotspots in each sub-region.

Table 18 Number of respondents per clan and per authority position.

Clan ID	Sub-region 1	Sub-region 2
1	4	142
2	2	35
3	19	25
4	13	8
5	121	5
6	3	4
7	26	4
*8**	9	n/a
*9**	20	n/a
*10**	3	n/a
11	15	19
*12***	n/a	3
*13***	n/a	3
Authority position		
Chief	4	3
Assistant chief	13	10
Dresimen	n/a	4
Regular ecosystem service user	221	237

* Respondents belonging to these clans were only present in sub-region 1

** Respondents belonging to these clans were only present in sub-region 2

c. Calculation of spatial equity in access to service provisioning hotspots

- Service provisioning hotspots distribution index

To address spatial equity, we first calculated an index that measures how the total area of service provisioning hotspots per ecosystem service was distributed across clans and authority position in 1995 and in 2015 in each sub-region (SPH distribution index). The index is based on the following formula:

$$SPH\ \ distribution\ index_{\ [clan,authority]} = \frac{Total\ SPH\ area\ accessed\ per\ ES\ user\ (group)}{\#\ of\ respondents\ in\ each\ category}$$

where ES is ecosystem services and SPH is service-provisioning hotspots.

The index was calculated individually for each clan and authority position.

- Spatial equity according to clan membership

To assess spatial equity according to clan membership, we first identified those clans having a high degree of access versus clans with a lower degree of access to service-provisioning hotspots. To identify high degree of access, we set a heuristic upper limit of 50% above the aggregated value of the service-provisioning hotspots distribution index. To identify those users having a low degree of access, we set a heuristic limit of 50% below the aggregated value. This analysis was completed for two periods corresponding to the years 1995 and 2015 for the provision of fish and timber and 2015 for the provision of crops.

Additionally, to understand spatial equity concerns among clans and between sub-regions, we calculated the Gini coefficient index. The Gini coefficient is a commonly used summary measure of inequity of income. It can also be applied to measure inequities in other resource distributions (Druckman and Jackson, 2008). In this study, we applied it to measure the extent of spatial inequity in the provision of fish, timber and crops among clans in each sub-region. We calculated it for 1995 and 2015 using the results of the SPH distribution index per clan, based on the following formula:

$$\mathrm{GC} = \frac{1}{2\mathrm{n}^2\mu}\sum_{j=1}^{n}\sum_{i=1}^{n}|y_j - y_i|$$

where n is the number of clans in the sample, y_i is the SPH extent of clan $_i$ (clan 1, 2, 3, …, n) and μ is the arithmetic mean of SPH extent among all clans.

The value of the Gini Coefficient varies from 0 to 1. According to general international standards, a Gini Coefficient that is smaller than 0.3

represents a particularly equitable situation, values from 0.3-0.4 a common situation, while values greater than 0.4 raise concern, and a value greater than 0.6 indicates a problematic state (Jin et al., 2015). Details of the calculation are presented in Table A3-A12

- Spatial equity according to authority position

To calculate spatial equity across authority position, we plotted the service provisioning hotspot distribution index to compare how service provisioning hotspots areas are distributed among chiefs, assistant chiefs, and Dresimen, compared to regular ecosystem service users.

d. Locations with potential conflict among users groups with different access to hotspot locations

The overlap between users perceiving high access versus users perceiving low access to the same hotspots locations can be indicative of that area being subject to conflict (Daw et al., 2011). To identify these locations, we completed a spatial overlap between users with high versus low access to service provisioning hotspots assessed in session b. For this purpose we used the intersect tool in ArcMap®.

4.3 Results

4.3.1. Intensity of use of ecosystem services over time

In this study, service-provisioning hotspots represent areas of collective importance where ecosystem services (i.e. fish, timber and crops) are used more intensively than in other areas. We therefore consider these areas as locations of high-intensity use. Table 19 provides a summary of the amount of hotspots and their respective sizes for 1995 and 2015 in each of the study regions. Figure 12 depicts the locations of service provisioning hotspots for all three ecosystem services. An expansion over time, from 1995 to 2015, for fish and timber provisioning hotspots can be observed, next to the development of road infrastructure and expansion of forestry concessions.

Table19 Intensification of use over time of ecosystems service in both sub-regions. Sub-region 1 is under the effect of roads and commercial logging while sub-region 2 is influenced to a much lesser extent. SPH refers to service provisioning hotspots; Total area mapped refers to the sum of the provisioning areas reported by all individual respondents before aggregating them into hotspots.

Service Provisioning Hotspots	Attribute	Sub-region 1		Sub-region 2	
		1995	2015	1995	2015
Fish	Number of SPH	1	5	5	9
	Total SPH area (ha)	1033	1382	3357	3427
	Total area mapped (ha)	48,788	55,353	87,852	139,848
Timber	Number of SPH	8	34	2	10
	Total SPH area (ha)	1231	2811	2772	3570
	Total area mapped (ha)	33,251	44,484	85,604	132,953
Crop	Number of SPH	-	19	-	25
	Total SPH area (ha)	-	1319	-	2580
	Total area (ha, 2000)*	12,767	27,295	31,459	101,085

* Based on the forest cover map of the year 2000. Source: Stichting voor Bosbeheer en Bostoezicht, (2019).

- Fish provision

Table 19 shows that, according to the number and area of service provisioning hotspots, the intensity of use of fish ecosystem services was larger in sub-region 2. In terms of change in intensity over time, the findings show that the areas of service provisioning hotspots for fish increased in both sub-regions.

- Timber provision

According to the number and area of timber provisioning hotspots in 2015, the actual intensity of use of timber provisioning services was higher in sub-region 1 than in sub-region 2 (Table 19). The analysis over time showed that in sub-region 1, the number of service provisioning hotspots increased from eight in 1995 to 34 in 2015 and their area doubled in the period analyzed. In sub-region 2, the number of timber provisioning hotspots increased from two in 1995 to 10 in 2015, while the total hotspots area had a less pronounced increase over time than in sub-region 1. Based on these results, the overall intensification in use of timber provisioning hotspots was stronger in sub-region 1 than in sub-region 2.

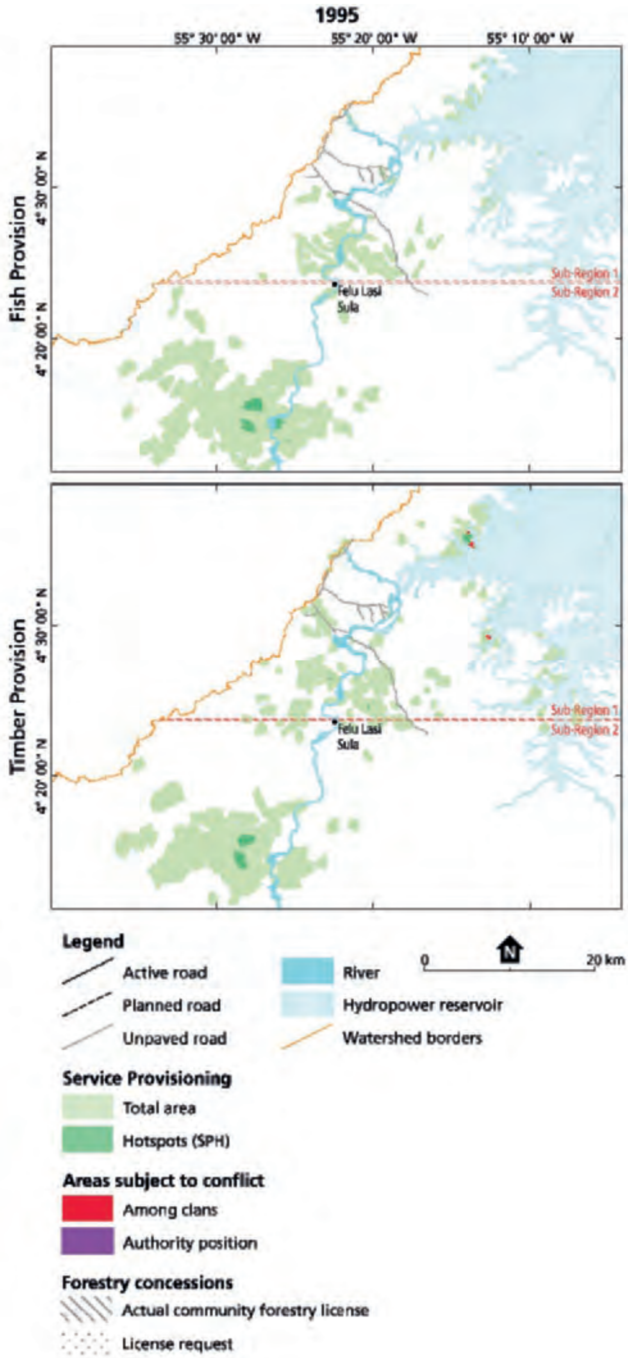
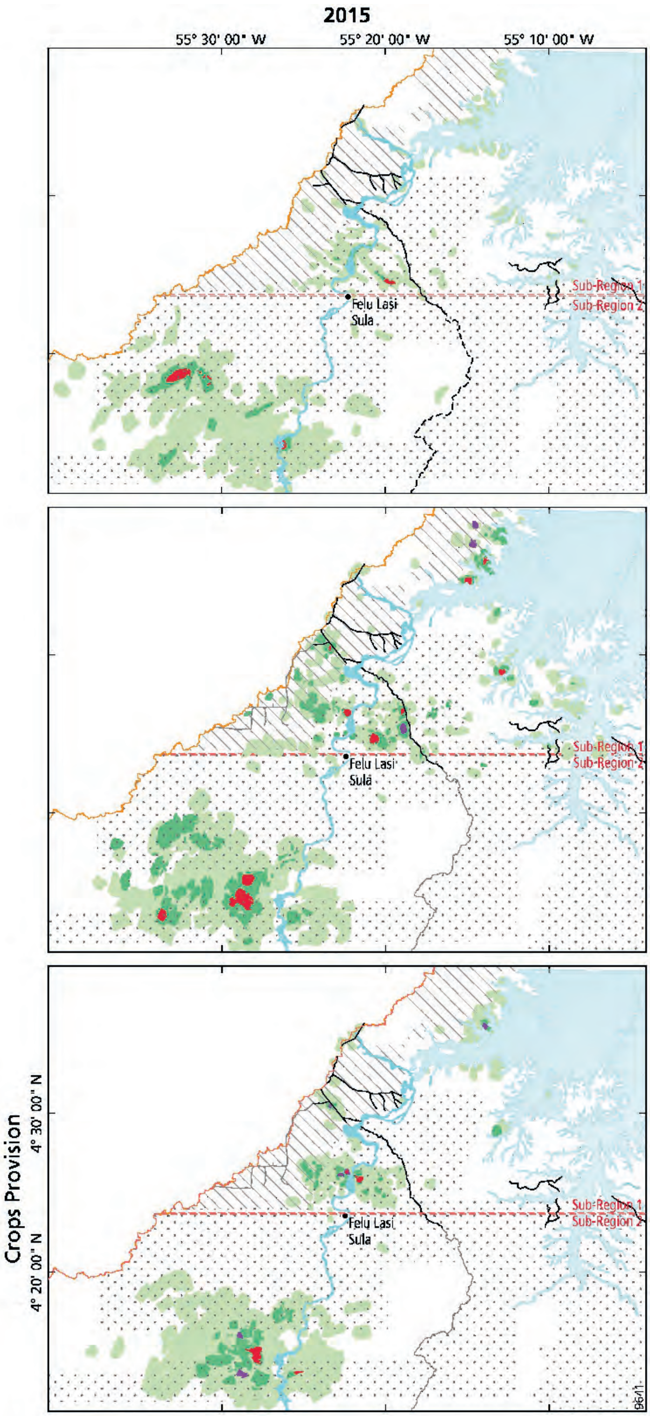


Figure 12 Maps depicting the location and the change in service provisioning hotspots, the emergence of areas subject to (potential) conflict from 1995 to 2015, and the expansion of road infrastructure and forestry concessions.



2015
55° 30' 00" W
55° 20' 00" W
55° 10' 00" W
Sub-Region 1
Sub-Region 2
Felu Lasi
Sula
Crops Provision
4° 30' 00" N
4° 20' 00" N
9641

- Crop provision

According to the area of service provisioning hotspots for crops in 2015, the use of this ecosystem service in sub-region 2 was almost twice as large as that of sub-region 1 (Table 19). Based on the total area in crops derived from the 2000 forest cover map and comparing it with the total area mapped by the participants for the year 2015, we observed that the size of crop provisioning areas has doubled in sub-region 1 and tripled in sub-region 2. Based on these results, the overall intensification in the use of crop provisioning areas was stronger in sub-region 2 than in sub-region 1.

4.3.2. Spatial equity according to clan membership

The results in table 20 and 21 show the patterns and trend in the access attained by the different user groups. Asymmetries in access to service provisioning hotspots according to clan membership can be noted in both sub-regions during the period analyzed.

- Fish provision

The findings show asymmetries in access to fish provisioning hotspots in both sub-regions. For example, table 20 shows that clan 6 in sub-region 1 was represented by 1% of the total responses, but had 24% of the total access to these important locations in 2015. The table also shows a three times increase the access reported by this clan in 1995. By contrast, clan 5, with 50% of the responses, appeared to attain less than 2% of the total access to fish provisioning hotspots. Similarly, in sub-region 2 clan 13, represented by 1% of the total responses, appeared to have 26% of the total access to fish provisioning hotspots in this sub-region, with access having increased two times over time. Clan 1 in sub-region 2, represented by 55% of the responses, reported less than 2% of the total access to these hotspots and this access had decreased over time (Table 21).

- Timber provision

The analysis of access to timber provisioning hotspots shows that in sub-region 1, clan 6, represented by 1% of the responses, appeared to have 15% of the total access to these locations, while access doubled over time (Table 20). By contrast, clan 5, with the largest number of responses (50%) reported about 2% of the total access to these important hotspots locations. Likewise, in sub-region 2, clan 4, represented by 4% of the responses, reported 24% of the total access to timber provisioning hotspots in 2015 with access increasing over time. Clan 1 in this sub-region, represented by 55% of the responses, reported less than 2% of the total access to these hotspots (Table 21).

- Crop provision

Asymmetries regarding crop provision were also reported. For example, clan 8 in sub-region 1, represented by 3% of the responses, had 23% of the total access to these areas. By contrast, clan 13 in sub-region 2, represented by 1% of the responses, had 34% of the total access to these service-provisioning hotspots. For crop provisioning hotspots there are no primary data preceding 2015 (see section 4.2.6).

Table 20 Service-provision hotspots distribution index and access according to clan membership in sub-region 1 in the years 1995 and 2015. Cells are shaded pink based on a threshold of 50% below the aggregate value for decrease in access. These thresholds in 1995 are 2.2 and 2.6 for fish and timber provision respectively. In 2015, threshold values are 2.9, 5.9 and 2.8 for fish, timber and crop provision respectively. Cells are shaded green based on a threshold of 50% above the aggregate value for increase in access. These thresholds in 1995 are 6.6 and 7.8 for fish and timber provision respectively. In 2015, threshold values are 8.7, 17.7 and 8.3 for fish, timber and crop provision respectively. Values falling within the range marked by these thresholds are left blank.

User category	ES provision	N	Total SPH (ha)		SPH distribution index	
			1995	2015	1995	2015
All clans	Fish	238	1033	1382	4.4	5.8
	Timber		1231	2811	5.2	11.8
	Crops		-	1319	-	5.6
Clan 1	Fish	4	4	7	1.0	1.8
	Timber		12	28	3.0	7.0
	Crops		-	32	-	8.0
Clan 2	Fish	2	2	2	1.0	1.0
	Timber		6	2	3.0	1.0
	Crops		-	15	-	8.0
Clan 3	Fish	19	124	171	6.5	9.0
	Timber		282	535	14.8	28.2
	Crops		-	195	-	10.3
Clan 4	Fish	13	124	143	9.5	11.0
	Timber		50	158	3.8	12.2
	Crops		-	145	-	11.2
Clan 5	Fish	121	212	254	1.8	2.1
	Timber		198	438	1.6	3.6
	Crops		-	228	-	1.9
Clan 6	Fish	3	30	88	10.0	29.3
	Timber		31	75	10.3	25.0
	Crops		-	19	-	6.3
Clan 7	Fish	26	106	107	4.0	4.0
	Timber		254	958	9.8	36.8
	Crops		-	150	-	5.8
*Clan 8**	Fish	9	137	185	15.2	20.6
	Timber		88	257	9.8	28.6
	Crops		-	199	-	22.1
*Clan 9**	Fish	20	96	106	4.8	5.3
	Timber		259	260	13.0	13.0
	Crops		-	86	-	4.3
*Clan 10**	Fish	3	33	56	11.0	18.7
	Timber		6	15	2.0	5.0
	Crops		-	7	-	2.3
Clan 11	Fish	15	165	263	11.0	17.5
	Timber		45	85	3.0	5.7
	Crops		-	243	-	16.2

Table 21 Service-provision hotspots distribution index and access according to clan membership in sub-region 2 in the years 1995 and 2015. Cells are shaded pink based on a threshold of 50% below the aggregate value for decrease in access. These thresholds in 1995 are 6.6 and 5.5 for fish and timber provision respectively. In 2015, threshold values are 6.8, 7.0 and 5.1 for fish, timber and crop provision respectively. Cells are shaded green based on a threshold of 50% above the aggregate value for increase in access. These thresholds in 1995 are 19.8 and 16.4 for fish and timber provisioning respectively. In 2015, threshold values are 20.2, 21.1 and 15.2 for fish, timber and crop provision respectively. Values falling within the range marked by these thresholds are left blank.

User category	ES provision	N	Total SPH (ha)		SPH distribution index	
			1995	2015	1995	2015
All clans	Fish	254	3357	3427	13.2	13.5
	Timber		2772	3570	10.9	14.1
	Crops		-	2580	-	10.2
Clan 1	Fish	142	604	416	4.3	2.9
	Timber		450	606	3.2	4.3
	Crops		-	222	-	1.6
Clan 2	Fish	35	822	301	23.5	8.6
	Timber		273	624	8.0	18.0
	Crops		-	1124	-	32.1
Clan 3	Fish	25	625	350	25.0	14.0
	Timber		466	380	18.6	15.2
	Crops		-	242	-	9.7
Clan 4	Fish	8	287	643	35.9	80.4
	Timber		506	672	63.3	84.0
	Crops		·	71	-	8.9
Clan 5	Fish	5	322	254	64.4	50.8
	Timber		140	203	28.0	40.6
	Crops		-	125	-	25.0
Clan 6	Fish	4	94	110	23.5	27.5
	Timber		33	251	8.3	62.8
	Crops		-	41	-	10.3
Clan 7	Fish	4	20	388	5.0	97.0
	Timber		20	24	5.0	6.0
	Crops		-	6	-	1.5
Clan 11	Fish	19	356	569	18.7	29.9
	Timber		567	542	29.8	28.5
	Crops		-	455	-	23.9
*Clan 12***	Fish	3	52	43	17.3	14.3
	Timber		76	92	25.3	30.7
	Crops		-	82	-	27.0
*Clan 13***	Fish	3	175	353	58.3	117.7
	Timber		241	174	80.3	58.0
	Crops		-	212	-	70.7

4.3.3. Spatial equity among users depending on their authority position

The results on spatial equity across different levels of authority in each sub-region are presented in figure 13. A first overview of these graphs shows that the extent of the area claimed by each of the users in this category was on average 22 ha in sub-region 1 while in sub-region 2 this was 72 ha.

- Fish provision

The analysis shows that in sub-region 1, chiefs attained the highest access to service provisioning hotspots whereas the access to these areas by regular community users was the lowest. The data do not show significant changes in access during the period analyzed. Similarly, in sub-region 2, the trend over time shows that members of the community with high-authority position such as chiefs and Dresimen have maintained the highest access to important fish provisioning locations over time. Thus, there were large asymmetries in the access to fish provisioning hotspots in both study cases, although this appeared to be larger in sub-region 2.

- Timber provision

The analysis shows that chiefs attained the highest access to service provisioning hotspots in both sub-regions. This asymmetric access pattern has become more pronounced over time for sub-region 2. By contrast, access to these important provisioning locations by regular community members remained low in both sub-regions.

- Crop provision

Although an asymmetry in crop provisioning hotspots was present in sub-region 1, it was not pronounced. By contrast, the asymmetry in access to crop provisioning hotpots was large in sub-region 2, with assistant chiefs and Dresimen having the largest claims. For crop provisioning hotspots there are no primary data preceding 2015 (see section 4.2.6).

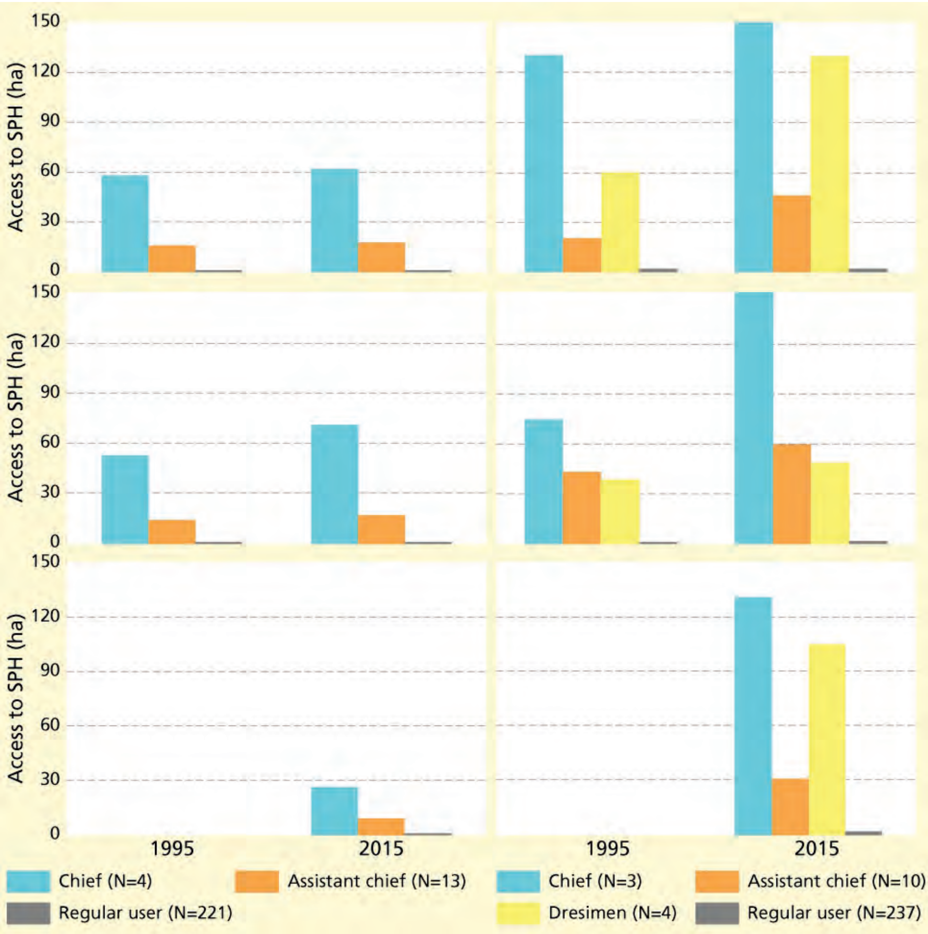


Figure 13 Spatial equity in access to service provisioning hotspots according to different authority positions, expressed in terms of access to service provisioning hotpots per user. Sub-region 1 is under the influence of external pressures i.e. logging and road development, while sub-region 2 is influenced to a lesser extent.

4.3.4. Spatial equity between sub-regions

The results of the Gini coefficient are presented in table 22. According to these values, spatial equity concerns regarding access to fish and timber provisioning hotspots did not exist in 1995 in sub-region 1, but emerged in 2015. Similarly, spatial equity concerns emerged for fish provision in sub-region 2, while equity concerns for timber provisioning pre-existed in 1995 and had decreased by 2015.

Table 22 Trend in the Gini coefficient in 1995 and 2015 for access to ecosystem service provisioning hotspots in both sub-regions among clans. A value ≥0.4 is indicative of spatial inequity. Sub-region 1 is under the influence of external pressure i.e. logging and road development while sub-region 2 is influenced to a lesser extent.

Sub-watershed	Number of clans	Ecosystem service	Gini coefficient	
			1995	2015
Sub-region 1	11	Fish provision	0.37	0.45
		Timber provision	0.34	0.43
		Crop provision	-	0.31
Sub-region 2	10	Fish provision	0.37	0.47
		Timber provision	0.47	0.40
		Crop provisioning	-	0.47

4.3.5. Locations subject to conflicting claims

Overlapping the access to service provisioning hotspots for different users resulted in the identification of areas of potential conflict between ecosystem service users (see Figure 12). These areas emerged in both regions over the period analyzed, however the amount and size of such conflict areas vary (Table 23).

Table 23 Summary of areas subject to conflicting claims between ecosystem service users. These areas are the result of the overlap between users with high vs. low degree of access to service provisioning hotspots. Sub-region 1 is under the influence of logging and roads; sub-region 2 to a lesser extent as these interventions are not yet developed in this region.

Service Provisioning Hotspots	Attribute	Sub-region 1		Sub-region 2	
		1995	2015	1995	2015
Fish	Number of areas of potential conflict	0	1	0	4
	Total size (ha)	0	36	0	602
Timber	Number of areas of potential conflict	2	10	0	3
	Total size (ha)	44	287	0	376
Crop	Number of areas of potential conflict	-	1	-	2
	Total size (ha)	-	44	-	57

For example, fish provisioning hotspots subject to potential conflicting were more numerous and larger in sub-region 2. By contrast, in sub-region 1 the number of timber provisioning hotspots subject to potential conflicting was larger (and had increased by a factor five in the period analyzed), whereas the extent of these areas was larger in sub-region 2 in the year 2015. For crop provisioning hotspots there are no primary data preceding 2015 (see section 4.2.6). The results for 2015 show that crop-provisioning hotspots subject to conflicting claims were larger in sub-region 2.

4.4 Discussion

4.4.1. Intensification of service provisioning hotspots

The consideration of the spatial configuration of access to ecosystem services, such as the extent and number of ecosystem service hotspots is important to express the intensity of ecosystem service provision (De Vreese et al., 2016). The results of this study have shown that the provision of fish and crop is more intense in sub-region 2, while the intensification of timber provision has been larger in sub-region 1. Overall, the total sizes of service provisioning hotspots are larger in sub-region 2 than in sub-region 1 for all studied ecosystem services. The stronger intensity of fish and crop provision in sub-region 2 is in line with the subsistence economy in this sub-region. Crops and fish are mainly used for subsistence and the surplus, if any, is either sold or bartered to provide for other basic needs (Amazon Conservation Team, 2010).

Similarly, the large areas of service provisioning hotspots in sub-region 2 can be related to population pressure, as this is the sub-region with the highest population size of the entire Upper Suriname River basin (Table 18). Local narratives have also suggested that population from more remote places in the basin have been migrating to sub-region 2 in order to be closer to the economic and education opportunities offered by the pavement, in 2010, of a major road in sub-region 1 (the so-called Atjoni highway). It is possible that internal migrants do not settle in sub-region 1, which is closer to the road and to local markets than sub-region 2, because of a scarcity of land for shifting agriculture in that region (Fleskens and Jorritsma, 2010). Thus, an increase in inhabitants implies an increase in the local areas of use.

The larger intensification of timber provision in sub-region 1 over time is probably related to the pavement of the Atjoni highway and the emergence of forestry concessions. For example, a report of the Forest Service shows an increase by 45% in the production of round wood in the area between 2010 and 2016 (Stichting voor Bosbeheer en Bostoezicht, 2016). Wood production may currently have further increased with the completion, in 2017, of 48 km of road running from the Atjoni highway deep into the forest (the so-called Pusugrunu road). Forestry concessions are not yet developed in sub-region 2, but these are planned. Traditionally, in this sub-region, timber is locally used on a small scale for the construction of houses, boats and crafts. However, a request for timber exploitation of 92,200 ha of forest has been made to the official authority by local community members (Stichting voor Bosbeheer en Bostoezicht, 2019). These facts give us reasons to believe that the actual intensification in the provision of timber in sub-region 2 is to be delayed until roads expand into the area. Such intensification could become stronger in sub-region 2 than actually is the case in sub-region 1, because of the higher population density in the former.

4.4.2. Spatial equity among clans and between sub-regions

The findings in this study show asymmetry in access to service provisioning hotspots among clans (Tables 20 and 21). In the study area, property rights associated to clan structure only apply to forest areas, thus the interpretation of these results for timber and crop provisioning hotpots can be associated. The asymmetries found regarding access to timber and crop service provisioning areas are actually reflecting existing customary patterns of use of ecosystem services among the Saamaka people, which are presumably related to pre-established ethnic hierarchies mediating de facto harvesting rights of forest areas (Price, 1975). These results are in line with findings in (Torpey-Saboe et al., 2015), who showed that inequity in benefit sharing from forestry activities among castes in Nepal is mainly determined by underlying social disparities associated with ethnic cleavages within communities. In terms of access to fish provisioning hotspots in the study area, as in many community-based fisheries, there are unwritten regulations or customary laws that prevent individuals from maximizing their private gains. Thus, we suggest that the asymmetries we found for this ecosystem service, reflect differential capabilities (e.g. access to capital or fishing gear) of individuals belonging to these clans, to take advantage of fishing grounds as pointed out by (Kibria et al., 2018).

Our findings around the Gini coefficient present a general picture of spatial equity patterns between sub-regions. The results of table 23 show that inequity in access to service provisioning hotspots emerged for fish and timber in sub-region 1, while it increased in sub-region 2. An inspection of the land use information in figure 11, suggests that the emergence of spatial inequity in sub-region 1 by 2015 coincides with the emergence of roads and forestry concessions. This can be expected as these developments may increase the value of ecosystem services that are subject to local elite capture as noted by (Iversen et al., 2006a). Our data provide some evidence for some of the ecosystem services. For example, in relation to the inequity found in access to timber provisioning hotspots in sub-region 1, the findings in tables 20 show that clan 3 and 6, which are influential clans (Price, 1975), experienced, respectively, a two and three-fold increase in their access to timber provisioning hotspots during the period analyzed. By contrast, the increase in the Gini coefficient for sub-region 2 is likely related to population growth because of internal migration triggered by the allure of timber in nearby areas and by the proximity to western goods, as indicated during the focus groups discussions. With newcomers, competition within ethnic groups can increase as noted by Torpey-Saboe et al. (2015) for ethnically diverse groups in Nepal. Thus, it is feasible that the spatial inequity patterns found in sub-region 1 are anticipating in sub-region 2 due to the expectations created by the foreseeable expansion of economic land use developments in this sub-region (Stichting voor Bosbeheer en Bostoezicht, 2019). Deriving from this conclusion, we suggest that existing spatial inequity within traditional resource use systems may be exacerbated as soon as economic opportunities get within reach. Due to these complex access dynamics, the effect of external pressures on spatial equity at the clan level is complex and analysis that is more comprehensive is needed to obtain detailed patterns of access. Yet, the importance of these findings is that they make, for the first time, differences in spatial patterns of access visible to outsiders i.e. land use planners, policy makers and NGOs. Thus, this knowledge cautions outside actors not to apply blueprints to the access that local communities exercise to ecosystem services.

4.4.3. Spatial equity assessment across authority positions

The asymmetries reported in this study showed that despite the depletion of fish in 2015, as discussed in session 4.3.1, and the consequent shifting of hotspots of fish provision further away, those with a high authority position have been able to maintain access to fish provisioning hotspots while regular community members have not. Thus, from our findings and drawing on the copious literature linking access to livelihoods with capabilities and capitals (Bebbington, 1999; Chambers and Conway, 1992; Haan and Zoomers, 2005; Lienert and Burger, 2015), it appears that access to fishing grounds in the study area is determined by the material resources that user groups have. This was also observed for the clan user groups as discussed in section 4.4.2.

Furthermore, the asymmetries found in the access of chiefs and assistant chiefs to timber provisioning hotspots were to be expected. Customary laws enable these authorities to manage and exploit community forests on behalf of the community (Amazon Conservation Team (ACT), 2010), and to formally apply for logging permits. Currently such permits have been granted only in sub-region 1. Our findings have shown that access of local authorities to timber provisioning hotspots doubled in sub-region 1. It was reported during focus groups discussions that since logging permits have been granted to local traditional authorities in sub-region 1, there are big concerns regarding the distribution of benefits derived from logging on lands that have the status of community forests. It has created windows of opportunity for local authorities to increase their power and to exert a significant influence and control over important forest areas. Hence, these findings demonstrate that external pressures actually exacerbate the influence of some elites within the community. This is in line with (Sikor and Lund, 2009), who argued that access and property regarding ecosystem services are intimately associated with the exercise of power and authority, which is in turn influenced by large political economic forces. In sub-region 2, the increase in access of local authorities to timber provisioning hotspots may be interpreted as early claims on forest areas by local authorities ahead of the economic opportunities posed by the paved road in sub-region 1 and the construction of a new road into the forest. In fact, multiple traditional chiefs have requested the entire area of sub-region 2 as forestry concession (see Figure 11a).

4.4.4. Areas subject to potential conflicts

In this study, areas with potential conflict were driven by the spatial overlap between users perceiving high access to service provisioning hotspots and users whose access to these important locations was perceived low (Table 20 and 21). Thus, the mapping process reported herein explicitly visualizes the places where conflict between users having access to ecosystem service provisioning hotspots is most likely. It also shows the influence of external pressures in underpinning conflicted space. For example, the larger areas of potential conflict concerned access to timber hotspots in both study regions. Their emergence in sub-region 1 coincides mainly with the improvement of roads and the appearance of commercial forestry. In sub-region 2, we found that the largest timber provisioning hotspots had more than three quarters of its area under potential conflict. The increasing population in this region and the proximity of these hotspots to the human settlement give us reasons to believe that conflict locations are underpinned by demographic pressure. Other studies across tropical forest found similar conflicts associated to access to timber ecosystem services (Dasgupta and Beard, 2007; Iversen et al., 2006a; Pacheco et al., 2010). However, without the spatially explicitly identification of areas of potential conflict, some incompatibilities between ecosystem service users might remain invisible. For example, some areas of potential conflict identified for fish and timber provision were remote from settlements (see Figure 12). This means that forests areas should not be assumed be free from conflict in virtue of their remoteness. Mediating potential conflicts is an important aim at both local and higher land use planning scales, and findings of differential access capabilities such as those reported here underscore the need to integrate and account for spatial equity in the planning of commercial logging activities.

Lastly, the identification and mapping of areas subject to potential conflict between ecosystem service users represent locations with an essential social dimension, which is key in spatial planning processes (De Vreese et al., 2016). The use of participatory mapping methodology was an effective means for assessing potential conflict areas in a region characterized by data scarcity. Hence, it provided a method for the inclusion and consideration of asymmetries in the use of space by different ecosystem services users, by means of relatively little data and straightforward analysis. Although the use of participatory mapping does not bring solutions regarding potential conflicts, the delineation of these locations could be seen as a starting point for understanding the complexity of relationships between ecosystem service users in space, as well as the role of external pressures in underpinning potential conflicts.

4.4.5. Caveats

We acknowledge a number caveats in the implementation of the present study. First, we add a note of methodological caution regarding our temporal analysis. Since the 1995 datasets were based on perception, it relied on the memory of the respondents, which affects the spatial accuracy of our findings. The effect of bias in our data was partly redressed by using a threshold to define consistent spatial aggregations of service provisioning locations based on 492 responses, both for 1995 and 2015, similar to the hotspot approach used in Brown and Pullar (2012) and Ramirez-Gomez and Martinez (2013). Moreover, our analysis over time was done according to two snapshots in time (1995 and 2015) which could limit our understanding of the facts influencing service provision and ultimately spatial equity. For example, precious wood had probably been removed from sub-region 1 in the period between these years. Furthermore, participants suggested during focus groups discussions that some people from the area had become wealthy and migrated to Paramaribo. Therefore, part of the process of elite capture is probably not visible in the dataset. Related to this, we suggest including people who out-migrated to cities in the group of respondents in future research.

4.5 Conclusion

Equity is an important element in the implementation of policies related to ecosystem services. However, equity aspects and complex human interactions in the use of space are often overlooked in land use policy processes, in particular in data scarce and remote tropical forest regions where traditional communities are living and external pressures are expanding into forests. These processes can have important implications for equity in access to ecosystem services, which emphasizes the importance of a rapid, but also robust way to operationalize the study of spatial equity issues in these data-scarce regions. This study proposes a participatory mapping methodology to unveil equity issues that might be otherwise hidden, by means of relatively little data and straightforward analysis. The spatial equity analysis implemented in this study revealed asymmetries in access to ecosystem services hotspots for fish, timber and crops based on clan membership and authority position of community members. Spatial equity concerns already existed in the most remote sub-region in this study, which was affected to a much lesser extent by external pressures. However, roads, logging and mining activities were likely to have exacerbated some of these asymmetries in the other sub-region. Potential conflict areas were also identified and mapped. The resulting spatial equity patterns and indicators can be used to support a proactive land use planning process guided by principles of participation, recognition of local concerns, and equity regarding access to ecosystem services. This makes the methodology suited for data-scarce remote forest regions under external pressure. A challenge is to explore the utility of this methodological approach to spatial equity assessments for other social contexts across tropical forest regions. Yet, its application in this study demonstrates how participatory mapping can link science to practice: by functioning as a scientific field that brings different assessment approaches together, and supporting contributions to sound ecosystem service management and conservation of remaining tropical forest regions by local communities.

Acknowledgments

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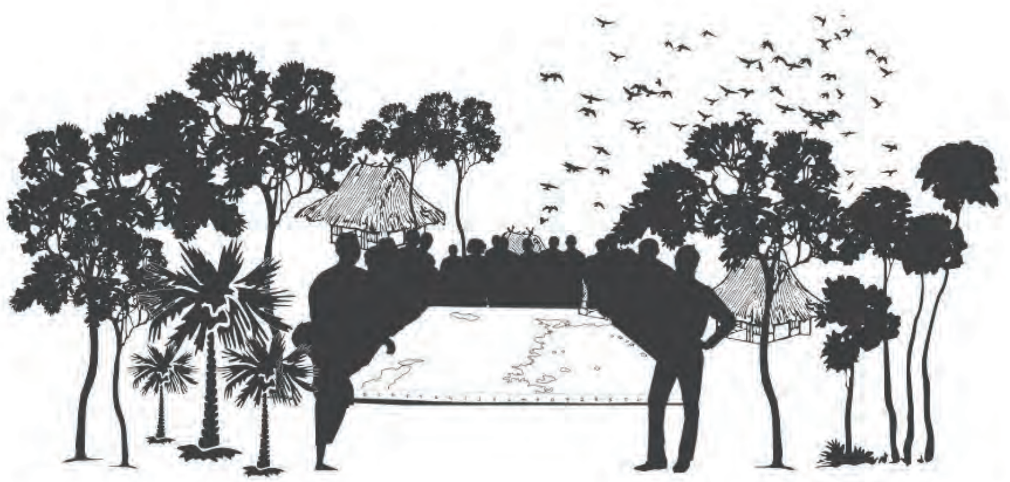

Chapter 5

Participatory 3D modelling as a socially engaging and user-useful approach in ecosystem service assessments among marginalized communities

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Abstract

Land use decision making in the Upper Suriname River area knows a history of disempowerment and marginalization of the Saamaka communities. Non-recognition of land rights is at the origin of this problem. This is aggravated by the increasing over-exploitation of timber resources by powerful stakeholders and the unfair distribution of timber benefits. This has left Saramakaans marginalized and distrustful. Further, deforestation in the region has caused detrimental changes in the ecosystem services that support local traditional livelihoods, with important effects in their wellbeing. A distrustful environment has made difficult the assessment of these concerns by external actors. Hence, an assessment approach that would generate relevant ecosystem services knowledge while generating trust and enabling communication among stakeholders was needed. In this paper, we evaluate whether Participatory 3D modelling (P3DM) is an effective approach for ecosystem services assessments in disenabling environments. Results show the efficient identification and evaluation of 36 ecosystem services representing provisioning, cultural and regulating service categories with crops, fish, wild meat, timber and forest medicines identified as most important. We found a decrease in the demand and supply of crops, fish and wild meat associated with ecosystem degradation, out-migration and changes in lifestyles. Further, our findings show an increasing demand and decreasing supply for timber related to over-exploitation. We provide evidence of the utility of P3DM in the assessment of ecosystem services among wary communities. We discuss the necessary conditions needed for P3DM process to tackle the needs of the local communities as well as the need for a broader P3DM implementation strategy beyond the engagement, screening, and diagnostic phases of ecosystem services assessments when the aim is to enhance ecosystem services outcomes for marginalized communities.

Key words: ecosystem services; disempowerment; distrust; local livelihoods; logging; participatory 3D modelling.

5.1 Introduction

More than 50 million people live in remote regions and depend entirely on functioning forest landscapes for the provision of food, medicines and shelter (Newton et al., 2016; Sunderlin et al., 2008). Infrastructure investments such as roads and dams, as well as extractive industries like gold mining and logging, are changing forest landscapes in profound and uncertain ways (Lambin and Meyfroidt, 2010). These activities have differential impacts on localities and communities across regions in the form of changing consumption patterns, transformation of traditional land use practices, among others (Nelson et al., 2006). In some cases, they trigger forced migration and consequently marginalization and disempowerment (Terminski, 2014). Indigenous communities living in remote and poorly governed regions tend to endure the most of the negative effects of these developments while benefiting little of the prosperity they generate (O'Faircheallaigh, 2013). They are vulnerable because their livelihood means rely on the ecosystem services that are susceptible to the impacts of these economic activities (Willemen et al., 2013b).

In some cases, top-down, expert driven land use decision making has left rural communities feeling marginalized and disempowered, leading to distrust and opposition towards outsiders (Ban et al., 2013; Kumar and Kumar, 2008). Distrust has been recognized as an important obstacle to effective natural resource management (Hahn et al., 2006). Hence, researchers and practitioners identify trust as essential to effective natural resource management and implementation (Fazey et al., 2013; Reed, 2008; Stern and Baird, 2015). Despite the increasing research efforts, information on how to generate salient, credible and legitimate knowledge (for a definition see Cash et al., 2003) for the integrated management of natural resources among wary communities in remote regions, promoting empowerment and enabling local ownership and trust, remain key challenging issues (Chaffin et al., 2014; McCall, 2003; Olsson et al., 2006).

By the same token, several scholars have pointed out the gaps towards a science-policy-practice interface in ways that enhance ecosystem services outcomes for marginalized communities: First, turning science and technology into action in a manner that enhances a collaboration of local stakeholders in the co-production of ecosystem services information while creating capacity among local communities so that they can better participate in decision making (Cash et al., 2003; Fischer et al., 2015; Miller et al., 2014). Second, attaining a fair distribution of the benefits from ecosystem services (Elena M. Bennett et al., 2015; Daw et al., 2011; Pascual et al., 2014) (e.g. access to provisioning services such as food, water, fertile soil, timber). Third, identifying alternative livelihood sources for the rural poor that avoid compromising environmental sustainability (Dawson et al., 2010; Poppy et al., 2014b; Sayer et al., 2013) (e.g. alternatives to the involvement of poor rural communities in illegal timber and mining activities in order to make a living). Lastly, procure appropriate communication channels between experts, local people and policy makers, in a language that is understood by all in order to deal with conflicts between actors, increase transparency, bring all perspectives into the negotiation table and establish criteria for decision making (Elena M. Bennett et al., 2015; de Groot et al., 2010; García-Nieto et al., 2015; Palomo et al., 2016).

It is only through the engagement of the end users of the knowledge generated by research that science on ecosystem services can pursue transformative interventions and render an important contribution towards a fair and more equitable sustainable development (Fischer et al., 2015; Reyers et al., 2015; Sitas et al., 2014). This implies that, in marginalized regions, ecosystem services assessments should apply user-friendly methods that can be understood by all (Fischer et al., 2015; Ostrom, 2009). A more friendly and inclusive ecosystem services assessment approach might enhance the quality and likelihood of durability of ecosystem services management interventions (Bohensky and Maru, 2011; McLain et al., 2013; Ostrom, 2007, 2009).

Participatory Geographic Information Systems (PGIS) comprise an array of methods based on place-based mapping by local communities, seeking to democratize spatial information and technology (Brown and Fagerholm, 2014). PGIS have been proposed as an important tool to strengthen the capacity of the end users to engage and participate effectively in decision making by legitimizing local peoples knowledge, by enabling ownership and by preparing local stakeholders to judge and respond to changing environmental conditions (Jankowski, 2009; McCall and Minang, 2005; Giacomo Rambaldi et al., 2006b; Sayer et al., 2013; Talen, 2000). Refutably, compared to conventional GIS, PGIS may lack cartographic precision (McCall, 2006), yet PGIS can be a powerful method to produce social outcomes (i.e. social learning and social capital) (Brown and Fagerholm, 2014) which "…are arguably equally important objectives in the achievement of sustainable future land use" (Brown and Kyttä, 2014, pp 13).

In this article we use a PGIS tool centered on a community-based process which integrates local knowledge on ecosystem services with data on elevation of the land to produce physical 3D models known as Participatory 3D Modelling (P3DM) (Rambaldi and Callosa-Tarr, 2001). We adopted P3DM as the means to engage with local stakeholders in a collaborative, spatially explicit research on ecosystem services, with a view to contribute to informed and participatory decision making in the Upper Suriname River area where people, belonging to the Saamaka tribe, have lived for centuries. By using P3DM, we wanted to research the social engagement and user-usefulness of the P3DM approach in collaborative ecosystem service assessment in a remote forest landscape undergoing land use pressures, in order to enhance ecosystem services outcomes for marginalized local communities that show distrust and opposition towards outsiders. We answered this question based on empirical findings that specifically: 1) identified and mapped ecosystem services that Saramakaans people value most for their contribution to local livelihoods, 2) ranked ecosystem services that are more important for their income and subsistence, 3) explored local perceptions of change in the supply and demand of those prioritized services, 4) assessed the opinion of local and external stakeholders regarding the usefulness of the P3DM in the context of the study area and 5) gauged the main concerns of local community regarding the flow of important ecosystem services .

The socio-economic and cultural context of the Saamaka territory pose the need for a more user-friendly and socially engaging approach (Cowling, 2014; Cowling et al., 2008a). The Saamaka people have a history of marginalization and disempowerment, both during the colonial period as well as after the independence of the country in 1975 and for this reason they have been wary towards outsiders. Some of the major causes of community disempowerment in the context of this study include:

- The building of the Brokopondo reservoir in 1960's to supply the demands of the bauxite industry and the city capital: Over 300,000 hectares of Saamaka territory was flooded causing the transmigration of more than 4,000 villagers which triggered the loss of burial grounds, sacred places and agricultural fields (Price, 2012a). Paradoxically, until today, 62 villages (approximately 17,000 people), including those that were transmigrated lack access to electricity.
- Absence of de jure land rights: Although de facto rights exist (Schlager and Ostrom, 1992), traditional land right are not legally recognized by the national law and therefore Saamaka communities lack both tenure security and secure access to livelihood resources.
- Lack of consultation and participation: Logging activities that have taken place in the Saamaka territory, damaging agriculture fields and other important places, without proper consultations nor

implementation of free prior informed consent (Inter-American Court of Human Rights, 2007; Price, 2012b).

We used the typology for the classification of ecosystem services of Vallés-Planells et al., (2014) because in our study context it provided more flexibility to include a broader range of functions valued in economic, socio-cultural and ecological sense (Termorshuizen and Opdam, 2009) as well as the consideration of the carrier function for basic every day human activities referred in de Groot, (2006). For example, the consideration of spaces for daily activities such residential space, communication paths, places to work as provisioning services of the landscape. This study made part of the diagnostic phase of the broader ongoing program Towards Productive Management of Transformed Forest Landscapes of Tropenbos International Suriname in the hinterland of Suriname.

5.2 Methods

5.2.1. Study area

The Upper Suriname River Basin (USRB) is located south from the Brokopondo reservoir between the 56ºW and 54ºW longitude and 4ºN and 3ºN latitude (Fig. 14), approximately 315 km south of Paramaribo. There is a paved road to Atjoni, the landing place, from where outboard motor boats are taken to reach to the villages up-streams. The area is covered with 124,989 hectares of primary forests and a fringe of 75,906 hectares of secondary forests along the Suriname River created as the result of shifting cultivation. The average annual rainfall is 2,700 mm (Nurmohamed et al., 2008). The region is inhabited by Afro-Surinamese people belonging to the Saamaka tribe. Their livelihoods have been traditionally based on shifting cultivation, fishing, hunting and harvesting of timber and non-timber forest products, mainly for subsistence. Since the construction and paving of the Atjoni road in 2010, the people have been increasingly involved in economic activities such as trade in non-timber forests products, craft making, boat transport, and ecotourism.

The total population in the entire study area is 18,502 people according to the latest census (Algemeen Bureau voor de Statistiek in Suriname, 2017). Inhabitants are distributed in 62 villages along the Suriname River.

In our study, we focus on 24 villages located in the northern part of the study area. These were divided in two groups of 14 and 10 villages that we labeled as sub-region 1 and sub-region 2 respectively (Fig. 14). Such division was suggested by local traditional authorities who explained that although they all belong to the same tribe and have similar culture and land use traditions, yet there are some differences between these two groups. For example, nine of the 14 villages in sub-region 1 are of transmigrated origin due to the construction of the Brokopondo reservoir whereas in sub-region 2 there is only one transmigration village. Additionally, sub-region 1 is influenced by roads and commercial logging while sub-region 2 is still remote and no commercial logging activities have yet taken place. Additionally, the local traditional authorities explained that such division is the same as applied in projects with external organizations. Regarding population size, there are 2,553 and 6,517 inhabitants in sub-region 1 and 2 respectively. None of the 24 communities in the two sub-regions holds legally recognized land titles.

5.2.2. The stakeholders in the study area

We identified in the Upper Suriname River area two stakeholders' groups namely internal and external stakeholders. Local stakeholders are members of the Saramakaan community who are affected by land use management decisions or actions. External stakeholders are defined as those who can influence decisions that affect those internal stakeholders. Within the context of this study, the most relevant external stakeholders are the Ministry of Regional Development and the Forest Service who are in charge of forest management. Similarly, the Ministry of Public Works in charge of infrastructure investments as well as extractive industries such as the State Oil Company of Suriname and the mining industry. Other include the University of Suriname, civil society organizations and NGO's in Suriname whose work is to observe and produce information for sound decision-making.

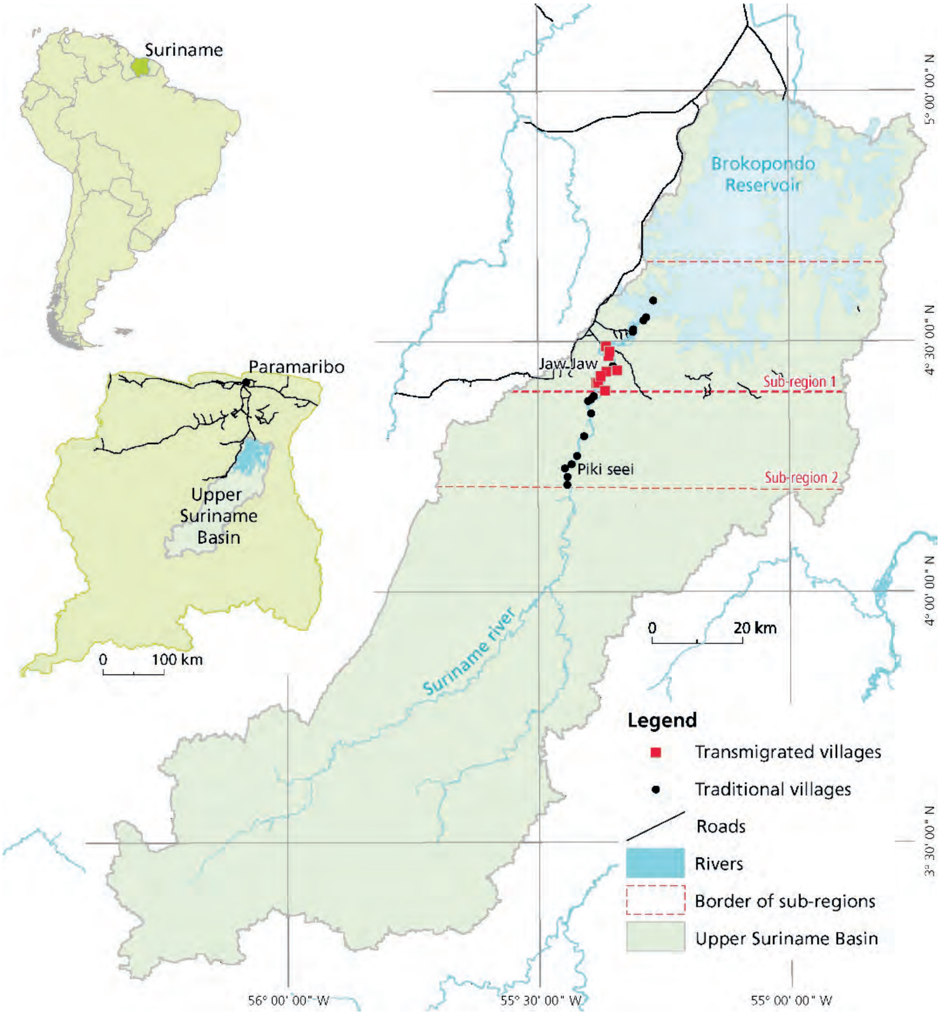

Figure 14 Location of the study area. Jaw Jaw and Pikien Slee were the central villages in sub-region 1 and sub-region 2 of the Upper Suriname River Basin where most of the P3DM activities took place.

5.2.3. Data collection

This study integrates an array of participatory methods commonly used to gather reliable landscape information that is relevant to marginalized communities living in remote tropical regions (Chambers, 2007; Lynam et al., 2007; Villamor et al., 2014). Data were collected from multiple sources such as participatory mapping, focus groups discussions (FGs), workshops, semi-structured interviews, in situ conversations, participant observations, notes from the field and sound recordings. The summary of the methods used and the aim are summarized in table 24. Participants from the study area were selected on a volunteer basis (Goodchild and Li, 2012). Both men and women were informed about the activities and were free to participate.

Before the implementation of project activities, an informed consent procedure was followed (Schreckenberg et al., 2014). First, a general consultation meeting was organized to inform local communities about the project aims and to ask for their oral consent. Subsequently, before every workshop or interview, written informed consent was asked from each participant. A separate consultation meeting was held with traditional local authorities to define and agree on the extent of the study area. Creating trust and interest in collaboration on behalf of potential participants was crucial for the engagement process because of the many doubts about data usability, benefit sharing and tangible outputs among these communities.

– Identification of important landscape features

We implemented six workshops (three in each sub-region) to gather the list of landscape features. In order to get meaningful interaction and greater in depth discussions, participants were divided into focus groups of four to five people, men and women separately. Elders were assisted by younger persons who helped writing. Metacards and markers were distributed per group. At the start, we asked to the whole group: "What are the most essential features in the area that serve the needs of the

Saamaka people? Please write an item per card and include a short description". When the groups were ready, written metacards were placed on a board, presented and discussed with all the participants to ensure that the list of features was agreed by all. Repeated items were left apart and descriptions of commonly identified items were enriched. The same procedure was completed in each workshop carried out in sub-region 1 and 2.

– The map legend

We grouped the list of landscape features identified into legend items. Symbols were chosen to represent points, lines or polygons. The final legend was presented to all participants and approved prior to the map-making activities in each sub-region. The agreed list of landscape features to be mapped was visualized on a board and used as a guide during the P3DM activity (Fig. 15).

Figure 15 Map legend in Saamaka and Dutch language used by communities of sub-region 1 during P3DM activities.

Table 6 Summary of the methods implemented to gather landscape and ecosystem services information during the P3DM process.

Activity	Aim	No. of activities	Who was involved?	No. of participants		Methods	Date
				Female	Men		
Inception meeting	Obtain consent for the project Decide about the extent of the study area	2	Board of traditional Saamaka authorities	3	6	Community consultation meeting (Schreckenberg et al., 2014)	April 2014/June 2015
Community meeting	Obtain informed consent	4	Local authorities, village committees, local community members	39	90	Community consultation meeting (Schreckenberg et al., 2014)	May 2014/July 2015
Participatory GIS	Building blank relief model	2	Children and youngsters from Saamaka villages	32	18	Participatory 3D Modelling (P3DM) (Rambaldi and Callosa-Tarr, 2001)	July 2014/ August 2015
	Actual mapping activities	2	Elderly and adults from various Saamaka villages	21	84		
Focus groups discussions	Elucidate map legend items	6	Elderly and adults from various Saamaka villages	30	80	Free listing (Schreckenberg et al., 2014)	July 2014/ July 2015
	Cross-check and validate information	6	Elderly and adults from various Saamaka villages	22	78	Free interaction organized in groups (Schreckenberg et al., 2014)	July 2014/ October 2015

	Gather perception of change in supply and demand of ecosystem services Prioritize ecosystem services Gather information about land use, natural resource management	6	Elderly and adults from various Saamaka villages	8	52	A mixture of Multidisciplinary Landscape Assessment (MLA) methods (Liswanti and Basuki, 2009)	July 2014- Dec 2015
Interviews	Explore the views of external stakeholders regarding the utility of the P3DM approach in the socio-economic context of the study area	32	Ministry of Regional Development, District commissioner, Forest service, NGO's, University, Private sector	-	-	Self-administered questionnaires	February 2016

– Participatory 3D mapping of landscape features

Two mapping activities took place in each sub-region using P3DM methods as derived from Rambaldi and Callosa-Tarr, (2001). The base map for the P3DM was created from a Digital Elevation Model (DEM) of 30 m spatial resolution obtained from the Shuttle Radar Topographic Mission (USGS, 2014) from which we conveniently generated 20 m contour line with the desired size and spatial scale of the model. A spatial scale of 1:15,000 was selected to ensure the coverage of the entire area as selected by the local traditional authorities during the inception stages. This resulted in two P3DMs constructed in foam board of 4 mm thick. They measured 4.8 m x 2 m for sub-region 1 and 6 m x 1.6 m for sub-region 2. We split the models in four and five units of 1.2 m x 2 m and 1.22 m x 1.60 m each respectively for sub-region 1 and sub-region 2.

The P3DM activity started with the constructions of a blank model by children and youngsters and continued with local knowledge holders (i.e. elders and adults) who mapped the legend items using a color-coded system consisting of pushpins to represent point features (Fig. 16). Water-based color paint was used to represent land cover types and to draw line features (roads, trails and creeks). Once the P3DM was completed, a sequence of high-resolution digital photographs was taken from the model following the guidelines specified in Rambaldi, (2010) taking care of minimizing radial and relief displacement. These photographs were entered as TIFF raster images in a GIS system where these were first geo-referenced and then digitized using ArcMap®. The images were geo-referenced to the UTM projected coordinate system, Zone 21N with an average of 32 ground control points per map piece.

– Validation of the information by P3DM participants

We carried out six additional workshops (three in each sub-region) to crosscheck and validate, together with the participants, the information contained in the P3DM. During these workshops, we presented the digitized maps with the landscape features mapped and asked the participants to check for missing or wrong information, misplaced features and misspelled words. This was an important step to reinforce the ownership of the P3DM outputs by local communities and to engage them in the following up stages of the assessment described below.

Figure 16 Group of community participants from sub-region 1 (left) and sub-region 2 (right) mapping landscape features on the 3D map in progress.

5.2.4. Typology of ecosystem services

We classified the identified landscape features into ecosystem services according to the typology of the Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin, 2011; Vallés-Planells et al., 2014). The original typology contains three broader ecosystem services categories: provisioning, regulation and maintenance, cultural and social. These categories are divided into 13 ecosystem services classes: nutrition, material, energy, daily activities, regulation of waste, flow regulation, regulation of physical environment, regulation of biotic environment, regulation of spatial structure, health, enjoyment, self-fulfillment and social fulfillment. For this study, we included 11 classes (Table 25) as these were considered relevant by the participants.

Table 25. Typology of ecosystem services adjusted to match the ES identified during this study.

Theme	Ecosystem service class	Description
Provisioning (P)	Nutrition	Plant and animal food sources found in terrestrial, freshwater and marine ecosystems. Includes potable drinking water.
	Material	Biotic and abiotic materials.
	Energy	Renewable fuel sources.
	Daily activities	Residential space, space where people develop a job and spatial communication paths that allow people to commute, travel or just access other services.
Regulation and maintenance (R)	Flow regulation	Water flow regulation.
	Regulation of the biotic environment	Ecosystem maintenance and habitat protection
	Regulation of the spatial structure	Refers to the ways that landscape configurations ensure the provision of other services for present and future generations. For example connectivity between habitats and ecosystems.
Cultural and social (C&S)	Health	Contribution to the enhancement of mental and physical health.
	Enjoyment	Opportunities for aesthetic appreciation and recreation. Commensurate with tourism opportunities.
	Self-fulfillment	Includes: 1) landscape referents that enhance spatial orientation. 2) Provision of sites that have learning opportunities. 3) Spiritual experience through the provision of sacred places for religious practices or sites connected to legends or myths. 4) Landscape elements that are source of inspiration for culture.
	Social fulfillment	Includes: 1) Places in the landscape, different from home and work that provide opportunities for social interactions. 2) Places in the landscape that contribute to shaping of community's cultural identity. 3) Provision of stable referent points through the life course.

5.2.5. Prioritization of ecosystem services

The participants discussed the list of classified ecosystem services during six FGs (three in each sub-region). Once they agreed with the classification, we asked them to start with the prioritization by means of the Pebble-Distribution method (Colfer et al., 1999). Using a panel of illustrations for each ecosystem services, the participants were prompted to distribute 100 pebbles among the illustrations based on their perception of importance for their ways of life. The more pebbles an ecosystem service illustration would get, the more important it was perceived to be. Participants explained the reasoning behind the final scores, the different opinions were discussed by the entire participants group, and the relative scores were averaged from all groups of participants in each of the sub-regions.

5.2.6. Perception of change in the supply of important ecosystem services

We also asked the participants to discuss their perceptions of change in the supply of those prioritized ecosystem services over the last three decades or more depending on the timeline that participants remembered. Opinions were rated from 0 to 10 where 10 represented a period of abundance while lower rates represented different degrees of scarcity. During the exercise, informants discussed which were the factors underlying change and the implications for their traditional livelihoods and wellbeing.

5.2.7. Change in the demand of ecosystem service use

Similarly, the use of certain ecosystem services has changed over time according to different factors. To assess these changes, respondents indicated during FGs, the current use of those prioritized ecosystem services as compared to the past (to refer to the past we ask them to think back to the time when their grown up children were small) using a scale of five categories: not used anymore, rarely used, occasionally used, regularly used and used often.

5.2.8. Assessment of the usefulness of the approach in the context of the study area

We collected the views of both external and local stakeholders regarding the usefulness of the P3DM approach to an ecosystem services assessment among the Saamaka communities. To appraise the opinion of external stakeholders, we conducted 32 interviews among civil society organizations, governmental institutions, community-based organizations, extractive industries and NGOs by asking the following questions: 1) Comparing P3DM with other methods implemented, what is, in your opinion, the main value of the P3DM process and outcomes in Suriname? 2) Could you please select a maximum of three situations in which the P3DM is useful in the context of the Upper Suriname River Basin? By contrast, the views of local stakeholders were appraised through anecdotal evidence, in situ conversations, field notes and sound recordings.

5.3 Results

5.3.1. Identification of landscape units

The P3DM mapping process resulted in two local communities-vetted maps for each sub-region (Fig. 17). The total landscape area is 176,860 hectares and 198,910 hectares for sub-region 1 and 2 respectively. The maps contain 11 landscape units that are described in table 26. These units were identified by the community participants reflecting both their landscape knowledge and their use of the area. For example, Pu (swamp) might exist in more locations across the study area but only those that are actually known or are in use have been mapped. In terms of extent, the largest area is occupied by primary forest in both sub-regions covering 45% in sub-region 1 and 73% in sub-region 2. One contrasting difference among sub-regions is the extent of the field in fallow (kapeë) where local communities harvest palm oils. The extent of this landscape unit per inhabitant is estimated at 0.07 and 6.6 hectares for sub-region 1 and 2 respectively.

Table 26 Landscape units digitized from the P3DM both in sub-region 1 (S1) and sub-region 2 (S2).

Local name	English name	Brief description (based on local narratives)	%	
			S1	**S2**
Paw Matu	Primary forest	Forest with big trees where there has not been shifting cultivation.	45	73
Kapëe matu	Secondary forest	Forest that was cleared for shifting cultivation in the past and that has regenerated into forest.	20	18
Kapëe	Fallow field	Abandoned shifting cultivation sites were palm fruits are continuously harvested.	0,2	3
Mäsiä	Grassland	Area around the lake where only grassy vegetation grows.	1	0,3
Via	Home garden	Area around houses with some perennial crops and fruit trees.	2	1
Pu	Swamp	A place in the forest that collects rainfall water that flows to creeks.	0,1	0,2
Savanna	Savanna	A natural place in the forest with no big trees.	0	0,2
Sandu bangi	Sand bank	Places in the river where sand is accumulated.	0,1	0,1
Meer	Brokopondo reservoir	Artificial lake for hydropower generation	29	2
Lio	River	River and river arms	1	0,4
Gowtu baakoe	Gold mining areas	Areas where gold mining activities take place	2	2

5.3.2. Identification of landscape features and classification into ecosystem services

The landscape features reported by the communities varied slightly among sub-regions. In total, 36 landscape features were identified during the P3DM process and further classified into ecosystem services. Most differences among sub-regions are related to cultural services under the category of self and social fulfillment (Table 27).

Table 27 List of landscape features per sub-region and classification into ecosystem services (ES). S1: sub-region 1, S2: sub-region 2 P: Provisioning, C: Cultural. ★ Intrinsic irreplaceable value, ■ intrinsic traditional value, ● intrinsic daily life value, ▲ intrinsic leisure value.

No.	Landscape features	Local name	Description (based on local narratives)	Relative importance (No. of pebbles).	
P Nutrition				**S1**	**S2**
1	*Crops*	Njang njang goön	Crops under shifting cultivation both in primary and secondary forest	10	9
2	*Wild meat*	Matu gwamba	Animals hunted in the forest for food and for income generation	9	6
3	*Palm oils*	Fatu (u boï sondi)	Oils extracted from palm fruits and used for cooking and other uses such as ceremonies/ rituals	6	7
4	*Fish*	Fisi	Fish found in rivers, creeks and swamps and used for subsistence and income generation	6	6
5	*Wild fruits*	Matu fuuta	Fruits found in the forests	5	5
6	*Spices*	Uwii / son di boï	Herbs and spices used for cooking	3	4
7	*Drinking water*	Wata u bebe	Drinking water sources from creeks and rivers	★	★
P Material					
8	*Timber*	Paw u wöoko	For construction of houses, boats and kitchen utensil, crafts and for income generation purposes	25	9
9	*Thatching materials*	Tasi	Woven palm leaves used for roofing	3	5
10	*Binding materials*	Tatai mbei wosu	Liana used as a binding material in the construction of houses	2	-
11	*Fibers*	Uwiï u mbei sondi	Gourds, reeds, wild cotton and palm leaves used for making clothes, rope, hand crafts, kitchen utensils and elements for rituals	5	8

12	*Quarry*	Tjatja/Sandu	Sand and gravel for the construction of houses and for income generation purposes	5	5
13	*Soil*	Doti	Type of soil used in construction of houses	2	5
14	*Resins*	Paw kandea	Type of resins from certain tree used to light fires	1	-
P Energy					
15	*Firewood*	Faja udu	Firewood for cooking	4	7
P Daily activities					
16	*Place to live: Village*	Konde	Village	●	●
17	*Place to move: Trails*	Pasi	Includes walking trails between villages, hunting trails and trail to the river	●	●
18	*Place to move: Roads*	Wagi pasi	Roads where cars can drive	●	●
19	*Place to move: tractor ways*	Koni pasi	Trails were a tractor can go	●	●
20	*Place to move: Rivers*	Lio	Main transport hub in the area	●	●
R Water flow regulation					
21	*Swamps*	Pu	Areas in the primary forest were water accumulates	★	★
R Regulation of the biotic environment					
22	*Biodiversity reservoirs*	Mbeti liba	Areas in the primary forest that are important for wildlife and for the protection of other resources	★	★
R Regulation of the spatial structure					
23	*Primary forest*	Paw matu	Large tracts of connected primary forests providing connectivity and a reservoir of resources for future generations	★	★
C&S Health					
24	*Forest medicines*	Desi uwii	Medicinal products obtained deep in the primary forests	10	9
C&S Enjoyment					

25	*Recreation*	Gaan dang and kule wata	Rapids were children can play	2	0
26	*Tourists opportunities*	Toerist kampu	Lodges were tourists stay, usually situated in areas that are attractive for tourism	2	0
C&S Self-fulfillment					
27	*Religious areas.*	Faka pau	Area for ritual performance inside the village	-	■
28	*Religious areas.*	Wasi moii or tjangaa	Area for ritual performance in the forest	■	■
C&S Social fulfillment					
29	*Washing area*	Lampesi	Special place in the river bank or creek, or large stones in the river where women gather to wash dishes, to bathe and to fish	●	●
30	*Football field*	Bali goön	Place in the village where men gather to play football while other people gather around the field for amusement.	▲	▲
31	*Church*	Keeki	Place in the village to worship according to a Christian religion	★	★
32	*Cemetery*	Geebi	Burial area around the village for community members	■	■
33	*Sacred place*	Taku kamian	Place that preserves ancestral memory	-	■
34	*Place identity*	Fanoudu kamian	Special places in the forests that are essential to preserve Saamaka culture and traditions	-	5
35	*Feeling of attachment.*	Goön doti	Literally translate as “earth” but it describes a feeling of belonging to the land	-	10
36	*Important place*	Neng u Kamian	River islands, river stones, camps, rapids, and other places that are important for various reasons	■	■

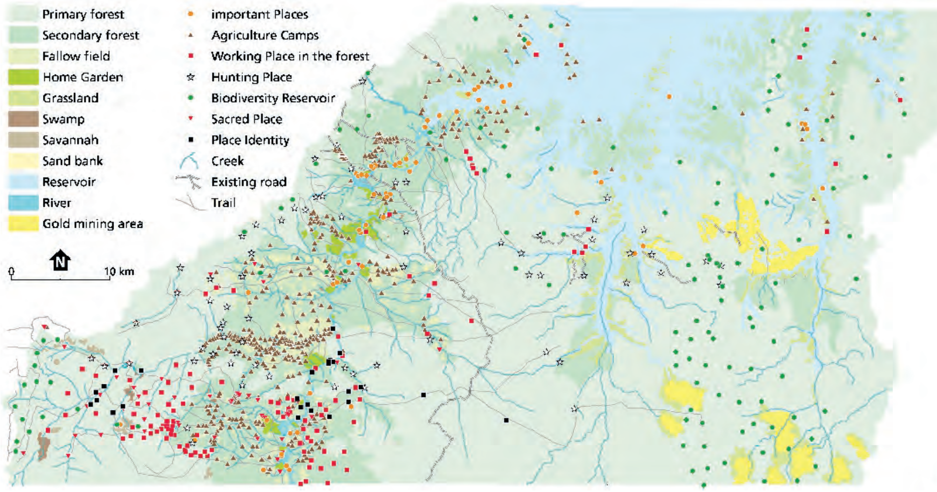

Figure 17 Map georeferenced and digitized from the P3DM in both sub-regions depicting landscape units and mapped ecosystem services.

5.3.3. Prioritization of ecosystem services

The order of importance of ecosystem services varied according to the background and interest of the community participants in each sub-region. For example, in sub-region 1, the highest importance was adhered to few ecosystem services such as timber, crops, medicinal products and wild meat that have income generation value according to the views of participants during focus groups discussions. In sub-region 2, participants assigned relatively high values to feeling of attachment, medicinal products, crops and timber. Table 27 summarizes the relative weights assigned by participants in each sub-region. Noticeable, ecosystem services such as drinking water, forest, biodiversity areas, religious areas, cemeteries, churches, football fields and important places received, deliberately, no weight given the intrinsic value that these features have according the perception of local community participants expressed during the workshops.

5.3.4. Change in the supply and demand of important ecosystem services

Local views related to a change in the demand of ecosystem services show differences among sub-regions. For example, the demand for agriculture and fish has decreased in sub-region 1 while in sub-region 2 these are still highly demanded. Anecdotic evidence suggest that the decrease in the demand of the ecosystem services is related to degradation of the source, out migration, loss of traditional ecological knowledge and changes in life styles, i.e. people are buying more at the local store. Furthermore, local perceptions indicate that there is a severe decline in the supply of fish, wild meat and commercial timber species in sub-region 1 while in sub-region 2 it was for wild meat and fish. Crops and fibers are perceived to have declined moderately in both sub-regions. Forest medicines have declined in sub-region 1 while these have remained unchanged in sub-region 2. Main reasons for these changes relate to over-exploitation of the ecosystem services. Table 28 presents a summary of the underlying reasons explaining change.

Table 28 Main underlying drivers of change in the supply and demand of prioritized ES obtained through local narratives during focus groups workshops. The differences between sub-regions are indicated with S1 (sub-region 1) and S2 (sub-region 2).

Ecosystem service	Trend				Underlying drivers of change	
	Demand		Supply		Demand	Supply
	S1	S2	S1	S2		
Crops	+	++	▼	▼	S1: lack of interest and out migration of young and capable people leaving aged persons who are less and less able to open up new crop areas	Decreasing soil fertility due to shorter fallow periods
Wild meat	+	+	▼▼	▼▼	Smaller mammals and birds that are found easier are commonly the source of protein. Larger animals are hunted with greater effort for ceremonies and occasionally for income	Large mammals have declined due to high hunting pressure, also, noise from tractors, chain saws and other disturbances by human presence
Palm oils	+	+	▲▲	▲▲	S1: Used more and more for ceremonies and rituals only S2: Used on a daily base for cosmetic purposes and for income generation but wide use for cooking is decreasing, people buy in	No change, it is still abundant throughout fields in fallow

					the store due to amount of work	
Fish	+	++	▼▼	▼▼	On a subsistence basis, people are depending more on smaller fish with less nutritional value. Obtaining larger fish currently demands larger distances, more costs, time and effort	Decline of fish with high economic and nutritional value due to unsustainable fishing practices
Timber	++	++	▼▼	▼	No change. It is still widely demanded	S1: Stocks reduced due to high pressure from commercial logging S2: Increased pressure for the construction of boats and houses
Forest medicines	+	+	▼	—	Loss of traditional knowledge about medicinal plants. People are also relying more on western medicines	No change, it is still abundant throughout primary forests

▲▲ Abundant
▼▼ Severe decline
▼ Moderate decline
— No change
++ High demand
+ Moderate to low demand

5.3.5. Usefulness of the approach in the context of the study area

– According to external stakeholders

The opinions of external stakeholders regarding the utility of the P3DM in the context of the Saamaka territory are reflected in table 29. Most opinions coincide that compared to previous methods used, the benefit of the P3DM is related to the ownership of the process and the resulting information by the local communities as well as the opportunity to produce maps with cartographic accuracy in collaboration with community participants. Concerning the usefulness of the P3DM process among distrustful communities, stakeholders indicated multiple opportunities for application where the approach might best fit. For example, stakeholders indicated that it would be applicable for the management of land use conflicts constrained to the Saamaka territory, for supporting land tenure claims and for enabling a legitimate participation of Saamaka communities in REDD+ related projects. However, diverging opinions suggested the need to increase accessibility of physical 3D models for a larger diversity of users of the area as well as access to digital GIS data so that it can be used widely in land use planning. Communication mechanisms in support of the accessibility and usability of the P3DM data also need to be established and maintained.

Table 29 Usefulness of the P3DM according to external stakeholders. Percentage of respondents is relative to N= 32

Questions and responses	%
What is the benefit to of the P3DM when compared to previous methods implemented?	
The co-production of knowledge with cartographic accuracy	27
The ownership of the information and the process by the local communities	25
In the P3DM the information is more complete and more accurate than in the previous ones	19
The 3rd dimension, as it allows a bird-eye view which in turns enables discussions and participation	19
The engagement of the local people in a relative short time	10
In which of the situations described below, would the P3DM be more useful among the Saamaka people?	
To manage land use conflicts bounds to the Saamaka territory, particularly regarding logging, infrastructure and mining	31
For supporting land rights claims of the Saamaka people	21
For an active and transparent participation of the Saamaka people in REDD+ related projects	20
For documenting and safeguarding the knowledge of the Saamaka people	18
For the implementation of Free Prior Informed Consent in the area when planning interventions	10

– According to local communities

We grouped local narratives regarding the utility of the P3DM according to the following three aspects: a tool for advocacy, a tool for learning spatial planning and a tool to transfer traditional ecological and cultural knowledge.

- An advocacy tool

The community participants, including local authorities and local leaders expressed that the P3DM process and the maps generated from it have become an important mean to support multi-stakeholders dialogues on issues that affect the Saamaka people:

> *"Is this map going to be recognized by the government? In that way the areas that are important to us can ultimately be protected from activities wherein we have no voice…"*

Trying to address this, members of the Saamaka communities pursued, during a public event organized with external stakeholders (Fig. 18), the formal recognition of the outputs of the P3DM process on behalf of the Surinamese government thereby respecting the ecosystem services important for livelihoods of the Saamaka communities in land use decision making[6].

- A tool for learning spatial planning

A key point of the P3DM in terms of the utility for the local communities is the learning opportunity in spatial planning issues. The participants indicated that the map is useful for them to understand better the impacts of road infrastructure:

> "*When they were going to extend the road to Pusugrunu there was a consultation meeting with us and we all said yes because since we did not have a good map we did not know exactly what and where would be the consequences of that road. But now we have this map and now* we can take more informed decisions because we can see and show directly the consequence that the road will have on our land".

[6] More details of this event can be found in the blog: Being on a map means to exist: the Saramakaans experience http://www.cta.int/en/article/2016-03-08/saramacca-communities-in-suriname-seek-governme ntrs-recognition-of-their-traditional-knowledge.html.

Furthermore, local authorities mentioned that the map could be used for land zoning negotiation among clans and a support platform in dialogues with outsiders regarding local forest management structures:

> *"The map will be useful for local planning in order to reduce conflicts because in our way of thinking forests lands belong to 'lo's (clans) not to villages. So if a community forest is awarded to a villages where the captain (village chief) is from one 'lo' automatically you can have conflicts with other lo's. So this map will be an important visualization and communication tool among us".*

Figure 18 Saamaka woman (right) handing the map generated during theP3DM process to the district commisionaire (left).

5.3.6. A tool for transfer of traditional ecological and cultural knowledge

A concern among the Saamaka people is that top-down decisions are taken often to the detriment of the communities because of a lack of awareness and knowledge of the things that are important to them. This concerns a lack of knowledge not only by outsiders, but also especially by young community members, which is partly because Saramakaans do not have a written but an oral tradition. A Saamaka chief addressed this issue during a workshop session:

"This is the time to do something on our own, change our minds and do things ourselves. Let us not allow that something like the Brokopondo dam happens to us again, we lost a lot then because our ancestors did not leave anything written about important places. We need to be better prepared when change arrives and the way to be prepared is to have information of the areas that are important to us, so let us use this map as legacy to the future generations so they can know and understand things better".

5.4 Discussion

In applying the P3DM approach for the participatory assessment of ecosystem services to inform a more inclusive and sound land use planning policy in data scarce and marginalized regions of Suriname, we found evidence of the utility of the approach to engage with local communities that spur distrust and opposition towards outsiders. Because of the reservations by local community members in our study area, the beginning of the ecosystem service assessment was time consuming, requiring several meetings with traditional authorities and local leaders. Their concerns helped improving the methodological approach to be used. We felt it needed to render tangible outputs and outcomes that would influence land use decision making. Specifically, outcomes that would help communities to protect their territory from affecting land use activities (i.e. logging, infrastructure developments) and outcomes that would explicitly support them in their land tenure claims. The critical question posed by traditional Saamaka leaders, which made us decide for the P3DM approach was: "how this project is different from those implemented in the past and what is the added value of the new map compared to existing maps?" This kind of question has been posed by other marginalized communities across the tropics who see the uncertainty of the solutions proposed by more exclusionary approaches (Folke et al., 2005). Therefore, in the following sessions we provide an answer by discussing the various indicators of the utility and benefit of the P3DM approach in ecosystem service research among wary communities.

5.4.1. A socially engaging tool

The participation scheme, the time invested in the process, the third dimension and the size of the model suggest that P3DM is explicitly designed to be socially engaging, thereby enhancing participatory production and exchange of ecosystem service knowledge that are pre-requisite for effective integration of ecosystem services into decision making as also suggested in Reyers et al. (2015).

– The scheme of participation

In the P3DM process (legend making and actual mapping), the scheme of participation had a positive effect on discussion time, validation of the information and ownership. Discussions usually lasted 1.5 days, ensuing sufficient time for open deliberations about ecosystem services, values, preferences and drivers of change. Time for meaningful discussions may increase social equity and legitimacy of the outcomes of ecosystem service assessments (Wilson and Howarth, 2002). By contrast, other participatory mapping activities, like those undertaken in other places of Suriname and Colombia (Ramirez-Gomez et al., 2015, 2016), took usually three hours, limiting the amount of information that could be obtained. Furthermore, the scheme of participation permitted an overlap of half a day between outgoing and incoming groups, which provided time for joint discussions, and validation of the information. This represented an efficient way to achieve a robust triangulation of the data. It also added legitimacy to the P3DM by making sure the production of the information and technology was respectful of the diverging values and beliefs of all local community participants as outlined also by Cash et al., (2003). However, there were challenges and drawbacks with respect to the participation of the Saamaka women. In practice, it turned out that a P3DM process, as well as other PGIS tools (McCall and Minang, 2005) is influenced by existing power and gender structures within tribal and indigenous groups, limiting the equal representation of values of all community participants.

– The third dimension

The bird's-eye view of the area and the relief effect enabled a holistic visualization of the entire area that had an effect of stimulating an interactive participation of men and women, children young, adults and elders, who quickly understood the map regardless their literacy level. They spontaneously reflected on conflicting landscape interests and their effects on sources of important ecosystem services without the assistance of the team of researchers. The 3D view also incited discussions on multiple perspectives concerning aspirations, worries and trade-offs of development and its effects on well-being. By contrast, as pointed out by Fagerholm et al., (2012), a particular challenge for PGIS methods is the accurate representation of the spatial dimension of the mapped landscape attributes in relation to the abstract nature of the background maps. This in turn increases the time and demands more skills from the participants and local facilitators to understand the images. Interestingly, using aerial photograph as background map have proven to be successful in other PGIS studies as landscape features can be easily recognized by the PGIS participants (Fagerholm et al., 2012). However, the fact that participants manufacture the 3D models themselves constitutes a boundary activity that enhances the collective learning process, information retrieval, harnesses critical thinking and subsequently leads to a more interactive knowledge co-production. These findings are in line with outcomes in other studies by Castella, (2009) and Bourgoin et al., (2012).

– The size of the models

The large size of models could accommodate a larger amount of participants as usually there should not be more participants than those that can fit around the map or model (Rambaldi and Callosa-Tarr, 2001). Likewise, a large model size resulted in a better inclusion of many important places across a larger territorial extent. Participants indicated that usually maps of the Saamaka territory are restricted to a fringe along the river, excluding many areas of use. By contrast, they mentioned that the extent of the P3DM map represented the area claimed as Saamaka territory.

Despite the evidence of P3DM as a socially engaging process, our approach was limited in the involvement of policy makers and other external stakeholders. Our P3DM approach was primarily oriented towards the empowerment of Saamaka communities to participate in land use decision making. However, as debated by various scholars (Fischer et al., 2015; Guerry et al., 2015; Knight et al., 2006; Reyers et al., 2015) ecosystem service assessments need to be grounded in a collaborative learning process among all stakeholders involved if the purpose is to have a practical impact and effectively mainstream ecosystem services into land use decision making.

5.4.2. A user-useful process

In terms of user-usefulness, we can distinguish between direct tangible and mid- to long-term outcomes of the P3DM among Saamaka people in Suriname. The physical 3D models, the digitized map and the information produced during the landscape assessment are among the tangible direct benefits that we highlight.

– The physical 3D models

The physical P3DM stayed in the communities, which was fundamental to increase participants' trust in the project. Usually PGIS outputs are taken with the researcher or project team for further geoprocessing, which increases the expectations of the participants regarding what, happens with the information afterwards. In contrast, the physical P3DM model remains in the community and P3DM practitioners take only digital pictures of the model for further analysis. Immediately after the P3DM is created, it becomes an educational tool for the community, especially for children and youngsters. This means that having the model for direct use requires that a space in the village be arranged. This has been challenging in our project due to the large size of the models that were built, hence the P3DMs built have not been yet properly displayed. Nonetheless, community leaders and institutional partners are pursuing conversations with the district commissioner to make a space available in the study area for the physical P3DM so that it becomes accessible for all. We suggest thus that future research projects using the P3DM approach, include in their planning, the allocation of a space where the P3DM can be displayed and permanently available.

– The digitized map

The vetted maps derived from the P3DM process were printed in different formats and distributed among all local traditional authorities, schools and general community members in order to be used for education and communication purposes. Evidence from the field showed that some community members were using the printed version of the P3DM map to communicate with the Forest Service regarding the occurrence of conflicting logging activities inside the territory of a particular village. Thus, the P3DM vetted maps, as well as other visualization means, are necessary in ecosystem service assessments for spatially explicit decision making and monitoring of the consequences of decisions as pointed by Hauck et al., (2013). This means that the digital version of the maps needs to be also available for policy makers so that they can have visual means for understanding how and where the landscape can or cannot be changed in order to enhance the provision of ecosystem services as noted, in a similar fashion by de Groot et al., (2010). In the context of our project, the printed maps were formally presented and distributed to policy makers by local community members as outlined in session 5.3.5; however, policy makers indicated the need to create access to the digital GIS data so that it can be used widely in land use planning. Unfortunately, wide access to the information by local communities and policy makers is still obstructed not only by the lack of capacity to handle GIS data but also due to local bureaucracy regarding who should control access and use of the information.

– Assessment of ecosystem services

The P3DM process proved to be a valuable approach to enable the collective and efficient generation of comprehensive spatial information that describes and prioritizes the characteristics of the landscape and its services for 24 villages in a relative short time and with the involvement of a wide range of participants. Among the benefit of the approach for the characterization of ecosystem services is that it provided a more robust insight into the identification of cultural and regulating services as compared with empirical studies in the Amazon region using 2D mapping (Ramirez-Gomez et al., 2016, 2015). In those studies, the concept of ecosystem services resulted confusing for the participants that limited the amount of information that could be gathered and depicted on the map beyond tangible provisioning services. By contrast, in this study, once the participants were in front of the 3D representation of the whole landscape, it was natural for them to start making associations between landscape units and the services these provided. For example, certain primary forest areas were indicated on the map as important as reservoirs of biodiversity or "mbeti liba". Swampy areas were also indicated as important for regulating the water that flows to creeks. Similarly, a comprehensive list of cultural services provided by primary forest was retrieved by participants during the mapping activities. The participants decided, however, not to include many of these services in the final map to avoid exposure and risk of profanation.

Thus, we argue that the P3DM output reflects the knowledge system of the Saamaka communities and the close representation of the terrain offers opportunities to reconcile the knowledge systems of the public, policy and science as found by van Noordwijk et al., (2013) in landscape studies elsewhere. Finding a common frame of reference and mental models among diverging views of the territory is a key aspect in decision making processes, as was also identified by Sitas et al., (2014). Furthermore, the information generated also reflects the degree of dependency of the Saamaka people on the services provided by the landscape and the value and preferences concerning ecosystem services. In the absence of legally recognized land rights for tribal and indigenous peoples in Suriname, this information can be used to inform policy makers in Suriname in efforts to integrate the protection of livelihoods, culture and traditions into land use plans for the area.

– Assessment of community basic needs

The P3DM also generated information for every village regarding the presence of drinking water wells, health posts, schools, electricity generators and the size of the population (indicated with pushpins of different sizes). This information is absent from official census data (Algemeen Bureau voor de Statistiek in Suriname, 2017) and country reports. Thus, the P3DM becomes a repository of spatially explicit data of community basic needs that can be used in village development plans.

The user-usefulness of the ecosystem service information generated through the P3DM process is fostered when other relevant (external) stakeholders recognize and accept the significance and applicability of the information for spatial planning purposes. In this sense, the presentation event during which the local communities sought government recognition of the maps (Fig. 18) constituted a step towards publicly voicing the concerns of the Saamaka people and, furthermore, towards the acceptance of the map and information by policy makers. Policy makers agreed that the map and the P3DM process present opportunities for managing conflicts related to logging concessions. Arguably, lessons from this work hold significance for the broader application of the P3DM approach for the purpose of free prior informed consent (FPIC) within the study area with respect to the effect of logging, mining, infrastructure and hydropower generation projects on the livelihoods and culture of the Saamaka communities as have been also advocated by Price, (2012b). However, for this to be realized, it is important that in the future, similar projects include a stage in which information is made available to policy makers, through for example, a decision making support platform provided an ethical code for the use of the information is in place.

5.4.3. Is a P3DM enough to improve ecosystem services outcomes for marginalized communities?

The usefulness of the map as referred to by the community members and policy makers presents windows of opportunities. The P3DM has potential to function as a boundary object that can be used to bridge negotiation and fair distribution of ecosystem services benefits through improved communication and visualization between development planners and the local communities in the study area. However, at this stage we cannot yet judge the full user-usefulness of the approach in the study area, as clear applications are still lacking. Several issues need to be addressed, such as the ownership of the products of the P3DM, capacity building of local communities to use the P3DM results in negotiation and decision-making processes, and agreement on ethical principles regarding the use of the information by external stakeholders in Suriname. To further ensure the ownership of the P3DM outputs and outcomes by Saamaka communities, it is important that the GIS data generated during the P3DM process are hold by local communities or by a neutral organization so that community members have permanent access to and control over sensitive information (e.g. spatial locations of certain sacred places which were retrieved in the process) (see also McCall and Dunn, 2012). Additionally, to increase ownership and to guarantee the long-term usefulness of the P3DM outcomes, it is necessary to allocate sufficient time and budget for further training whereby the Saamaka communities build up their skills to manage the information, monitor its use and acquire confidence to become interactive landscape actors.

Moreover, an ethical code for the use of the P3DM information by outsiders as well as by locals needs to be developed and mechanisms in place to implement it in order to avoid overexploitation of the data as has been suggested by Rambaldi et al., (2006a). This is particularly important in Suriname because it happened during the development of this project, that the P3DM derived information was misused by government officials when a villager sought protection of the forest from logging activities occurring inside the village area. The villager brought up the digitized P3DM map to show the government agency how logging operations were threatening areas that were reserved as future sources of timber. Instead, the government office in charge used the map and the information for extending logging operations inside these important areas under the argument that that piece of forest was not in use, since it did not contain any feature indicating that Saramakaans use the area (i.e. any point data indicating current use for agriculture, hunting, culture, income, or future use). A situation like this may exacerbate distrust, opposition and disempowerment of the Saamaka communities.

While formal tenure rights remain unrecognized by the government institutions, it is therefore recommended that ecosystem services assessments using P3DM in similar contexts, include a follow-up stage of participatory spatial planning whereby local communities jointly divide their territory in land use zones representing communal property rights and critical livelihoods systems as suggested by Ostrom, (1990) and documented by Ramirez-Gomez et al., (2016). Although zoning itself does not promote sustainability, it might support the negotiation and implementation of commercial land use restrictions (Lambin et al., 2014) or support land use and conservation policies such as the definition of community conserved areas that can help local people in empowering themselves and getting more control over their territory and its resources (Kothari et al., 2012).

5.5 Conclusions

The P3DM approach presented here offers opportunities for conducting collaborative research on ecosystem services that is socially engaging and user-useful as recommended by Cowling et al., (2008). These elements are needed in order to enhance ecosystem services outcomes for marginalized and disempowered local communities living in remote landscapes under pressure from logging, gold mining and road development projects. We judge the user-usefulness of the P3DM approach to hold significance when local communities without legal tenure rights can use the P3DM outputs as a tangible communication and negotiation tool in full access and control of the local communities involved. For instance, as a means for the thorough implementation of a FPIC designed to achieve social equity in the distribution of the benefits from the use of ecosystem services such as the provision of timber. Operationalizing the user-usefulness of the P3DM for FPIC however, is not only a matter of having one. It requires the strengthening of capacities in local communities to judge, control and monitor the outcomes of the process and the use of the information.

Furthermore, lessons from this work suggest the importance that the use of the P3DM approach in ecosystem services assessment includes a zoning of the areas providing ecosystem services that should be done in collaboration with local communities. This should include spatially explicit representation of the areas of intrinsic ecosystem services value for future generations. Without this evidence, these areas can be interpreted by government or investors, as empty areas that are available for allocation of economic land use activities. Having those areas well defined provides spatial boundaries against which communities can discuss and negotiate ecosystem service trade-offs. Overall, the full potential of P3DM in areas where communities lack full legal rights and capacity is most difficult to achieve and can easily fail if local, regional and national institutions (i.e. CBOs, NGO's, civil society and governmental) do not support and formally recognize the P3DM outcomes.

Finally yet importantly, our P3DM approach for the assessment of ecosystem services was conceived in the diagnostic phase of a larger program on productive landscapes in the hinterland of Suriname. Hence, it was inevitably to raise expectations, among the local communities, regarding follow up implementation stages, which were beyond the project scope. In this sense, it is important that regardless of the underlying motivation to use P3DM in ecosystem service assessments, the expectations generated by local communities participating in the project need to be considered for the P3DM to be a win-win process for both the researchers and the communities. Usually PGIS tools are conceived in the initiation phases of projects (Brown et al., 2014), however, the need to take the P3DM process beyond the engagement, screening and diagnostic phase of a project has been recognized (Brown and Kyttä, 2014). Communities expect that their input will not be merely the provision of information but that this information is rather used to influence decisions. Therefore, it is important to embed the P3DM process into a complete operational model from assessment to implementation as reflected in Cowling et al., (2008) if the purpose is to mainstream ecosystem services, influence local realities and pursue livelihood resilience in remote and marginalized places.

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Chapter 6

Synthesis and discussion

In intact tropical forest regions, one of the main tasks for the coming decades is to strengthen the capacity of indigenous and tribal communities to conserve and sustainably manage these regions. These large, ecologically intact, and relatively undisturbed natural forests in the tropics offer unique opportunities to mitigate two of the greatest environmental problems that the world faces: climate change and the loss of biodiversity. There is ample evidence demonstrating the global importance of management of indigenous and tribal communities for the conservation of intact forest regions (Díaz et al., 2019; Garnett et al., 2018; Watson et al., 2018). However, the rapid expansion of resource extraction, commodity production, mining, and transport and energy infrastructure far into the most remote forest regions of the world, with various consequences for local livelihoods, is challenging the ability of indigenous and tribal communities to effectively conserve these lands.

It is therefore highly relevant and urgent to involve indigenous and tribal communities in land use decision making that affects them, and to consider the entangled social and ecological transformation processes that local communities undergo upon the arrival of external pressures. However, tools and approaches that consistently enable their engagement are not yet sufficiently available (Díaz et al., 2019). Moreover, our scientific understanding of how external pressures affect the spatial and temporal dynamics of ecosystem service use by local communities and how these dynamics affect the conservation of intact forest areas is still limited. The objectives of this doctoral thesis were as follows:

- To assess to what extent external pressures affect the spatial and temporal patterns of ecosystem service provision; and
- To understand how can this knowledge be used to respond to these pressures and support a process of inclusive policy making that recognizes the needs and priorities of indigenous and tribal communities regarding ecosystem service use.

This doctoral thesis is composed of three study cases, one in the Colombian Amazon and two in Suriname.

This chapter provides a summary of the methodological approach and the main findings of each chapter. Then, I provide an answer to the four research questions, including the relevance of the findings for other intact tropical forest regions. Lastly, recommendations for future research, policy makers and practitioners are given.

6.1 Synthesis

Chapter 2 presents a study of changes in space and over time of the provision of locally important ecosystem services to indigenous communities in the region of La Pedrera, in the Colombian Department of Amazonas. In this study, the causes and consequences of such change for the maintenance of traditional livelihoods practices were also investigated. To identify spatial and temporal patterns of change, the methodology integrated 22 focus group discussions, 8 community meetings, and 16 participatory mapping workshops with 158 participants distributed across 10 indigenous communities. Results of the temporal analysis showed that over the past two decades, the demand for food and raw materials has intensified and, as a result, the stock of these services has declined and service-provisioning areas have changed. Further, the results showed that in 20 years' time, the greatest increase in the extent of service provisioning areas has been for timber (60%), bush meat (40%), fish (40%) and thatching materials (60%). By contrast, the analysis reported a decrease in the extent of provisioning areas for medicines (80%), ornaments for traditional dances (50%) and resins (40%), which are ecosystem services linked to traditional livelihood practices. This study demonstrated that the economic needs of indigenous and tribal communities and the proximity to a regional market change the manner in which community members use natural resources and that the decline of important ecosystem services is putting pressure on local communities to adapt their livelihood strategies. This chapter provides evidence that intact forest regions are no longer protected by remoteness and that preventing road infrastructure and commercial land use developments is not enough to avert critical changes in the provision of important ecosystem services across space and over time.

Chapter 3 investigated the size and the spatial distribution of the areas that are essential to maintain the provision of ecosystem services of local importance to indigenous communities. These areas were estimated for a case study in south Suriname. To this purpose, data collection took place through a participatory mapping survey among 191 respondents in five indigenous communities. Participants drew polygons around areas with ecosystem services of cultural, subsistence, future and economic value. The GIS analysis of these polygons resulted in the identification of service provisioning hotspots to which six landscape metrics were applied (Table 16, chapter 3). Further, indigenous communities validated the delineation of these areas as community use zones. The entire area in use by indigenous communities was estimated at a total of 2.7 million hectares. The average size was 532,410 ha per community. The landscape metrics provided an indication of the extent of the area occupied by each ecosystem service value. For example, the hotspots corresponding to ecosystem service value for future generation occupied 60.6% of the total community use zone followed by 44.5% in hotspots with subsistence value, 29.5% in hotspots with cultural value and 19.8% in hotspots with economic value. This case study was used to develop a participatory mapping approach to delineate community use zones that is especially suited for data scarce environments. It has also provided the first baseline information for this intact forest region, which can assist the evaluation of future land-use interventions. Furthermore, the findings of this study have changed the policy dialogue about the conservation of south Suriname and have empowered indigenous communities to declare a conservation pledge regarding their community use zones.

Chapter 4 focuses on the extent to which external pressures influence equity in access to service provisioning hotspots (spatial equity). This was done through an empirical study that compares two sub-regions in the Upper Suriname River Basin: a sub-region where logging and road building occur and a more remote sub-region where these interventions are not yet developed but merely planned. Spatial data was collected for 1995 and 2015 using a participatory GIS survey (n = 493), and aggregated to define provisioning service hotspots for fish, timber and crops (the latter only for the year 2015). Then, different dimensions of spatial equity were explored according to clan membership and authority position, by analyzing variation over time and across regions. The results showed that in the region with roads and logging, spatial equity concerns emerged over time regarding the provision of timber. In the remote region, spatial inequity in access to hotspots of ecosystem services appeared early, ahead of the economic opportunities posed by new roads in nearby forests areas. Our analysis made spatially explicit the places where conflict between users of ecosystem services, associated to asymmetries in access to hotspots of ecosystem services, is most likely. This case study provided an empirical understanding of how local communities with a subsistence economy change their patterns of use of ecosystem services in remote forest regions when economic opportunities present themselves. In outlining these concerns, this chapter suggests that spatial equity analysis unveils an essential social dimension in the use of the space that is integral in spatial planning processes. The main contribution of this study is the development of a spatially explicit approach that constitutes a rapid but robust manner to operationalize the study of spatial equity issues in remote and data-scarce forest regions.

Chapter 5 evaluates to what extent a participatory 3D modelling approach can be effective to harness the co-production of usable ecosystem service knowledge and the inclusion of marginalized local communities - who show distrust and opposition towards outsiders - in land use decision making. To this aim, ecosystem services data were gathered and mapped through four community meetings, 12 focus groups discussions and eight participatory 3D mapping workshops, implemented in 24 tribal villages along the upper Suriname River basin involving 267 local community participants. Similarly, 38 semi-structured interviews were conducted with policy makers. This resulted in the efficient identification and evaluation of 36 ecosystem services over time, representing provisioning, cultural and regulating service categories, with crops, fish, wild meat, timber and forest medicines being identified as most important. The findings show a decrease in the demand and provision of crops, fish and wild meat associated with ecosystem degradation, out-migration and changes in lifestyle, in particular in the northerns part of the basin (sub-region 1). Further, we found that the generation of trust, the production of tangible outputs, the scheme of participation and the third dimension in participatory mapping were important factors to harness the co-production of usable ecosystem service knowledge, while strengthening decision making capacity in marginalized communities. This approach demonstrated how knowledge that is understandable, accessible and usable to a wide range of stakeholders can be co-produced, and how it effectively enhanced the ownership of the knowledge generation process and outcomes.

6.2 Discussion

Based on the findings in the chapters 2 to 5, the answers to the research questions are given and discussed in the following sections.

Recommendations for future research as well as for policy makers and practitioners are presented in the final section.

I. *Can participatory mapping be used to gain insights into the spatial and temporal patterns of ecosystem services provision and use in remote and data scarce intact forest regions?*

The results of this doctoral thesis have demonstrated that participatory mapping can provide a valid means of assessing spatial and temporal patterns of ecosystem service provision that would otherwise be hidden. For example, the participatory mapping approach applied in the study case of La Pedrera (chapter 2) unveiled that service-provisioning hotspots have shifted to more remote places over time because of ecosystem service depletion. This information had been missed in previous forest cover assessments carried out in the study area and which reported lower levels of forest transformation and high intactness (Armenteras et al., 2019; Coca-Castro et al., 2013; Sánchez-Cuervo et al., 2012). However, the findings in this doctoral thesis showed that while the forest in the study area is seemingly undisturbed from above (as observed from remote sensing images), beneath the canopy it is hiding social and ecological issues related to local ecosystem service provision. The participatory mapping approach demonstrates how the gap in knowledge in local and regional land use-cover studies regarding patterns of local ecosystem service provision and use in intact forest regions (Rau et al., 2018) can be filled.

Furthermore, the spatially explicit hotspots approach developed in chapter 2 offered a simple, rapid and robust means to understand the use of ecosystem services by indigenous communities in space and time. This novel approach to capture spatial and temporal patterns of ecosystem service use with limited data and in a spatially explicit manner facilitates their inclusion into local and higher scale land use planning processes. As Strickland-Munro et al. (2016) noted, having social and ecological data in a spatial form is essential to carefully locate and mediate among potentially competing uses in both space and time. Furthermore, from a methodological viewpoint, the benefit of the participatory hotspots assessment approach lies in its ability to assess context-specific data and intangible values that are relevant to local scale planning processes. For example, an overlay of the hotspots map in chapter 2 with existing local customary land use zoning plans within indigenous reserves, showed how access restrictions imposed by those zoning plans have actually contributed towards the overexploitation of provisioning areas where this was permitted (Figure 6). While other participatory mapping studies found a positive correlation between customary land use regulations and forest conservation (e.g. Dalle et al., 2006), the temporal hotspots approach applied in this doctoral thesis unveiled a more complex picture with service provisioning hotspots degradation because of customary land use restrictions. As such, the approach can be used a basis for examining the viability of community-based programs for forest conservation.

The above collection of findings contributes to filling the current deficit of local spatial knowledge in regional and global scenarios of land use planning in intact forest regions, as highlighted in the IPBES Global Assessment Report of ecosystems and biodiversity (Díaz et al., 2019). However, in future research a more in depth analysis of the social processes influencing land-use decisions is necessary to understand better the factors leading to different conservation outcomes in intact forest regions.

Similarly, the spatially explicit delineation of areas that needed to be reserved for future provision of services was an important contribution in this doctoral thesis. For example, in the study case presented in chapter 3, about 60% (~ 1 million hectares) of the area mapped was locally recognized as reserve of essential ecosystem services set aside for the future. As noted by Folke et al. (2005), the role of this type of areas with high social value is crucial, because they are often managed with a rigorous code of conduct, with positive outcomes for forest conservation. While previous approaches have used spatial ecosystem services indicators for the spatial delineation of service provisioning areas (Bagstad et al., 2013b; Serna-Chavez et al., 2014; Syrbe and Walz, 2012), the approach developed in chapter 3, demonstrates how spatial indicators of future service provision can be integrated, in a straightforward way and using limited data. Further, the spatially explicit delineation of service provisioning areas achieved in chapter 3, served as a basis for the development of a spatial zoning approach that maximizes and protects the delivery of important ecosystem services for current and future generations, in line with the recommendation of Willemen et al. (2013). While other studies have used detailed resource mapping approaches to demarcate small provisioning areas in indigenous territories in Amazonia (Albert and Le Tourneau, 2007) and Kenya (Kalibo and Medley, 2007), the study in chapter 3 showed how the provision of local ecosystem services could be mapped across large regions, by applying landscape ecological principles and metrics to indigenous patterns of land use.

Importantly, the spatially explicit delineation of the areas with future, cultural, subsistence and income generation value achieved in chapter 3, empowered indigenous communities to influence conservation policies in a national policy dialogue as to safeguard their community use zones. Taking the co-produced information as a basis, indigenous communities in the study area formulated a conservation pledge of 72,000 square kilometer of 'indigenous conservation corridor' (the so-called South Suriname Conservation Corridor), which was submitted to the National Assembly (Gommers, 2015). Arguably, the empowerment of indigenous communities and co-production of knowledge achieved in chapter 3 constitute a modest step toward providing decision makers with information on local ecosystem services use. When this information is used properly, it can support the inclusion of the needs and priorities of those communities in decision-making. This approach can be replicated in similar regions characterized by weak institutions and a need for capacity building. In line with this, the IPBES Global Assessment Report on biodiversity and ecosystem services (Díaz et al., 2019) emphasized empowerment of indigenous and tribal communities as a determining factor to enhance their quality of life, as well as nature conservation, restoration and sustainable use.

Finally, the participatory mapping methodology applied in chapter 4 was an effective means for assessing potential conflict areas related to asymmetries in access to service provisioning hotspots, in a region characterized by lack of data. In the literature, the spatially explicit identification of areas of (potential) conflict between ecosystem service users has mainly focused on marine environments (e.g. Douvere, 2008; Strickland-Munro et al., 2016). The participatory mapping approach applied in chapter 4, provided a novel method for the inclusion and consideration of a relational understanding of the use of space by different ecosystem services users in remote, data-scarce forest areas. As pointed out by De Vreese et al. (2016), areas subject to conflict between ecosystem service users represent locations with an essential social dimension, which is crucial in spatial planning processes. Although the use of participatory mapping does not provide an immediate solution to land use conflict, the delineation of these locations could be a starting point for understanding the complexity of relationships between ecosystem service users in space, as well as the role that external pressures have in underpinning changes in these relationships.

In synthesis: *In this doctoral thesis, key spatio-temporal patterns in ecosystem service provision and use were unveiled through participatory mapping, which empowered indigenous communities to influence conservation policies in a national policy dialogue as to safeguard their community use zones.*

II. *What factors affect the spatial and temporal patterns of ecosystem services use in remote and intact tropical forest regions under external pressure?*

The findings in this doctoral thesis showed that market penetration was a key factor affecting the spatial and temporal patterns of use of ecosystem services by indigenous communities in La Pedrera (Chapter 2). This study area is roadless and remote, but the expansion of markets in the region has been triggered by the establishment of weekly flights to the district capital and regular visits of commercial boats from Brazil. The penetration of markets has increased the appeal for western goods, while increasing local needs for cash income. Subsequently, it has driven internal migration of families from even more remote forest areas, to places where these goods can be obtained (e.g. the market of the town La Pedrera). The empirical evidence in this doctoral thesis shows that demographic growth around La Pedrera increased consumption pressures on ecosystem services, which gradually led to the overexploitation of service provisioning areas over time. These findings are in line with other studies (e.g. Pérez-Llorente et al., 2013; Vadez et al., 2008; Lu, 2007) that have shown that as soon as markets penetrate remote tropical forest regions, the economic needs of indigenous and tribal communities start to change, altering in turn the manner in which indigenous communities use ecosystem services.

We also found that infrastructure and commercial land use plans were important factors affecting the spatial and temporal patterns of ecosystem service use in the study case in the Upper Suriname River Basin (chapter 4). Empirical evidence in this doctoral thesis shows that in a remote and roadless region, where commercial land use interventions are not yet developed but merely planned, the intensity of the use of timber, fish and crop provisioning services increased over time. This increase was presumably associated with population growth in the area (National Institute for Environment and Development in Suriname et al., 2017). The increase in population is associated with net growth and internal migrations. Local narratives suggested that population from even more remote places in the Upper Suriname River basin has migrated to downstream regions in the basin to be closer to the economic and education opportunities offered by the pavement of the road in nearby forest areas. Similarly, chapter 4 shows that existing asymmetries between local ecosystem service users regarding the access to service provisioning hotspots have become larger over time. It appeared that the expectations created by the foreseeable expansion of economic land use developments in the study area have triggered early claims on service provisioning hotspots.

Some authors pointed at the usefulness of intrinsic conservation attributed to remoteness (e.g. Craigie et al., 2014; Joppa and Pfaff, 2009; Geist and Lambin, 2002). However, the above collection of findings demonstrates that *de facto* forest protection by virtue of remoteness nowadays increasingly requires the aid and intervention of conservation organizations, as also has been suggested by Brooks et al. (2006) and McCauley et al. (2013). Similarly, the belief that local communities are able to commit to sustainable management or conservation of their forests when they have secure tenure rights over these is changing (see examples in Garnett et al. 2007). The findings in the study case presented in chapter 2 provide empirical evidence for this argument and show that tenure security through legal land rights recognition is not necessarily preventing indigenous and tribal communities from using service-provisioning hotspots in a non-sustainable way. For example, in La Pedrera, where communities hold legally recognized tenure, the evidence in chapter 2 shows how service-provisioning hotspots were overexploited by increased use of unsustainable harvesting practices. Thus, as pointed out by Robinson et al. (2014), secured tenure is necessary but not sufficient for successful incentive-based forest conservation policy.

Therefore, this doctoral thesis extends the work of several researchers who have questioned the conventional view of local community as forest stewards (e.g. Agrawal and Gibson, 1999). It also provides evidence for the argument that communities need to be considered as a diversity of actors being strongly influenced by wider social and environmental contexts as also suggested by Ojha et al. (2016). Acknowledging that local communities are becoming increasingly heterogeneous in terms of internal composition, diversity of land use interests, wealth and power, it is recommended that conservation projects in intact forest regions incorporate this social differentiation in community engagement processes.

An important message that emerges from the study cases in chapters 2 and 4 is that the willingness of indigenous and tribal communities to protect tropical forest regions is increasingly linked to the external world. As such, the challenge to protect the Earth’s last intact tropical forest regions is bigger than we thought. Even if remote and intact forest regions would remain roadless, which decreases the likelihood that industrial activities will develop in these areas (Ibisch et al., 2016), the expansion of external pressures nearby is still expected to drive changes in the local spatial and temporal patterns of ecosystem services use inside them.

In synthesis: Even in remote and intact forest regions that stay roadless, the expansion of roads, markets and commercial land uses in their neighborhood is driving changes in the local spatial and temporal patterns of ecosystem services use inside these regions, which may lead to overexploitation and ecosystem degradation.

III. *If external pressures emerge in a remote and intact forest region, how does it affect the spatial and temporal aspects of equity in access to important ecosystem service hotspots?*

The findings in chapter 4 show that when external pressures (e.g. roads and forestry concessions) arrive in remote and intact forest regions, inequity in access to service provisioning hotspots increases. For example, the spatio-temporal analysis in chapter 4 has shown that the most influential and powerful users have maintained or even increased access to important service provisioning hotspots, whereas the access for the large majority of users has remained low or decreased over time (see Figure 13 and Tables 20, 21). The analysis showed that these asymmetries are associated to the expansion of roads and commercial timber activities in the area. Although the asymmetries found are partly due to social disparities associated with ethnic cleavages within communities, in line with Torpey-Saboe et al. (2015), the findings in chapter 4 showed that external pressures are actually exacerbating them. For example, the emergence of inequity as expressed by the Gini coefficient (Gini coefficient $\geq$ 0.4) coincided with the emergence of roads and forestry concessions in the case study in chapter 4 (see Figure 11, Table 22). Furthermore, anecdotic evidence showed that asymmetries in access to service provisioning hotspots were influenced by population pressure triggered by net growth and internal migration. This was particularly the case for the asymmetries found in the access to fish and crop provisioning services. For example, results showed that out of 13 clans, two smaller clans (with small representation in the responses) had nearly 50% of the access to fish provisioning hotspots while a single clan had 33% of access to crop provisioning hotspots. The fact that competition within ethnic groups can increase with the arrival of newcomers was also noted by Torpey-Saboe et al. (2015) for ethnically diverse groups in Nepal.

The findings in chapter 4 also showed that when external pressures arrive in intact forest regions, areas subject to potential conflict between local ecosystem service users emerge. These are areas of co-occurrence of users with differential access capabilities. As pointed out by Strickland-Munro et al. (2016), the spatial identification of potential conflict areas, can foster a proactive land use planning process guided by principles of participation, recognition of local concerns, and equity regarding access to ecosystem services. This makes the methodology suited for data scarce remote forest regions under external pressure. The number and size of the potential conflict areas were larger for timber provisioning hotspots than for fish and crops (Table 23). It was expected that the economically highly profitable provision of timber would be related to the largest spatial inequity in comparison to fish and crops. Other studies across tropical forest found similar conflicts associated to access to timber ecosystem services (e.g.Dasgupta and Beard, 2007; Iversen et al., 2006b; Pacheco et al., 2010). However, without spatial-explicit identifying areas of potential conflict, some incompatibilities between ecosystem service users might remain invisible. For example, in chapter 4, some areas of potential conflict identified for fish and timber provision were remote from settlements (see Figure 12). This means that forests areas should not be assumed be free from conflict in virtue of their remoteness. Mediating potential conflicts is an important aim at both local and higher land use planning scales, and findings of differential access capabilities such as those reported here underscore the need to integrate and account for spatial equity in the planning of commercial logging activities.

<u>In synthesis:</u> *When external pressures emerge in intact forest regions, pre-existing asymmetries in access to service provisioning hotspots increase, and these patterns of spatial inequity are also reflected by emerging areas of potential conflict between user groups with differential access.*

IV. *Can a combination of analytical methods and participatory mapping be used to co-produce usable knowledge on ecosystem services in support of inclusive decision-making and policies?*

Through the implementation of diverse participatory mapping approaches, the findings in this doctoral thesis provided useful elements and tools to facilitate the co-production of usable knowledge on ecosystem services in support of inclusive decision-making dialogues. These include the overall participatory approach, co-production of knowledge between local communities and researchers, the usefulness of a 3D effect in participatory mapping, as well as the role of an internal champion and knowledge broker. These elements and tools are anchored in a knowledge co-production process with indigenous and tribal communities.

– Participatory approaches increase ownership of the knowledge generation process

Evidence in this doctoral thesis showed that the scheme of participation was a determining factor to develop a sense of ownership of the process and outputs among local communities. For example, in the participatory 3D approach, chapter 5, participation in all stages of the process was structured by allowing an overlap of half a day between outgoing and incoming groups of participants, providing time for joint discussions, discernment and validation of the information being conveyed. This scheme of participation ultimately improved the local acceptability of final representations of the diverging values and beliefs of all local community participants. As noted by (McCall, 2003), the inclusion of different views and perspectives is essential to enhance legitimacy and ownership of the knowledge generation process.

Nonetheless, ownership should cover all stages of knowledge production, and it implies the holding of data sources and the final information product itself (McCall and Dunn, 2012a). However, in all study cases limited capacity was created for local community participants to handle the raw and processed data. The data are still trapped in the bureaucracies of local community organizations, and the question who should control access and use of the information has not been resolved. Hence, to increase ownership and to guarantee the long-term usefulness of the knowledge products, it is necessary to allocate sufficient time and budget for further training, whereby the local communities can build up their skills to manage the information, monitor its use and acquire confidence to become interactive users of their own information.

Finally, a key question is whether ownership of knowledge includes the right to prevent others from using it (McCall and Dunn, 2012a). It happened during the development of the case study in chapter 5 that information on the maps produced in the process was misused by government officials when a villager sought protection of the forest from logging activities occurring inside the village area. The villager brought up the map to show the government agency how logging operations were threatening areas that were reserved as future sources of timber for the community. Instead, the government office in charge used the information on the map to extend logging operations inside these important areas under the argument that this forest area was not in use, since it did not contain any feature indicating a community use of the forest (i.e. any point data indicating current use for agriculture, hunting, culture, or income). Hence, the development and enforcement of an ethical code to protect the use of the knowledge produced is key in order to avoid overexploitation of the data, as has been suggested by Rambaldi et al. (2006).

– Co-production of knowledge between local communities and researchers increases trust and respect between knowledge systems

Despite setting the environment for collaboration, some tensions can emerge during the knowledge co-production process. Tensions may emerge in relation to the expectations of indigenous and tribal communities regarding the spatial knowledge to be generated. For example, in all study cases adjustment of the ecosystem service classification had to be made to accommodate the expectations of local participants. Originally, the Millennium Ecosystem Assessment classification system was taken as a starting point, however, in practice this was not in line with what the participants wanted to represent on the map. As McCall and Minang, (2005) noted, in participatory research, the choice of the map legend is a crucial first step for marginalized communities to acknowledge their priorities. In south Suriname for instance (chapter 3), communities were highly concerned about a plan of the government to build a dam, which would have an impact on many rapids, waterfalls and other places of high cultural, subsistence and economic value. Thus for them, a typology of place values, according to the classification in Brown and Reed (2000) was more appropriate than the initial ecosystem services classification.

By contrast, in the study case of the Upper Suriname River (chapter 5), a landscape services typology according to Haines-Young and Potschin (2011) was more relevant. For the communities in that region, it was essential that the map would show that they were more than small villages along the river (as this is how outsiders tend to see them). Therefore, through the chosen typology, participants could depict the services that are important for them, including the social services of nature (e.g. places in the landscape, different from home and work, which provide opportunities for social interactions), the provision of residential space and the provision of communication paths between villages. As Tengö et al. (2017) argued mobilizing indigenous and tribal communities´ knowledge for action requires adaptation of knowledge products or outcomes into forms that facilitate trust, respect and mutual comprehension in the face of differences between actors; all other objectives must be acquiescent to this basic requirement. We take this a step further by concluding that not only adaptation of knowledge products is necessary, but also that co-production of knowledge between local communities and researchers at equal levels is essential to increase trust and respect between representatives of both types of knowledge systems.

– The 3D effect in participatory mapping was a robust way to connect knowledge systems

One of the major challenges in knowledge co-production is a lack of in depth understanding of key concepts (e.g. ecosystem services), which often results in superficial interactions between indigenous and scientific knowledge holders (Fazey et al., 2013). In this sense, the participatory mapping approach applied in chapter 5 proved very useful. The third dimension of the map provided a bird's-eye view of the area and the relief aspect enabled a holistic visualization of the entire area. Once the participants were in front of the 3D representation of the whole landscape, it was natural for them to start making associations between ecosystems and the services these provided, thus the 3D effect was useful to address epistemological differences (Brugnach and Ingram, 2012). For example, without any intervention of the scientists, participants pointed out swamps that were clearly visible by the relief effect, and indicated the hydrological regulating function that these have. Moreover, the participatory 3D approach showed to be effective for engaging men, women, children, young, adults and elders who quickly understood the map regardless their literacy level. They spontaneously reflected and interactively discussed on important land use issues and their effects on sources of important ecosystem services without the assistance of the team of researchers. Hence, the participatory 3D mapping approach in chapter 5 was an effective mechanism for creating synergies across knowledge systems in a transparent, respectful and equal manner as suggested in (Tengö et al., 2014).

– An inspired internal champion and a broker organization are needed to increase the usability of participatory maps in decision making

Findings from this doctoral thesis show that a key determinant of usability of spatial knowledge is the presence of an inspired and enthusiastic local champion (i.e. a person or group of persons from the local community), who can bring the co-produced knowledge forward in relevant decision-making processes. The findings of this doctoral thesis showed that without an inspired and enthusiastic champion, the likelihood of use of participatory maps in decision-making is low. For example, the knowledge products developed in chapter 5, such as the 3D models and the vetted maps derived from them have been widely presented and officially distributed in different policy and civil society settings by the research host institution. Despite the receptivity, popularity and inspiration that the process, outputs and outcomes of the approach in chapter 5 attained among the public (Rambaldi, 2016), the maps have remained unused in decision making after three years since their creation. A retrospection of the research in chapter 5 suggests that the lack of empowerment of an internal champion and the absence of a broker organization to promote the use of the maps, are considered two of the most salient reasons.

By contrast, the participatory maps produced in chapter 3 have been taken forward to inform a conservation dialogue among policy makers and indigenous communities. Indigenous communities who participated in the research process used the co-produced maps during a multi-stakeholder dialogue held in Paramaribo on 23 February 2015. During that event, members of the indigenous communities advocated the use of those maps among policy makers, as a basis for decision-making regarding the protection of their territories against encroaching activities (see Figure 10). This led to the signing of a proposal for an indigenous conservation corridor spanning 72,000 square kilometers of pristine tropical forest. This proposal for the 'South Suriname Conservation

Corridor' was presented to the National Assembly of Suriname on March 5, 2015 (Gommers, 2015).

The enthusiasm of a group of champions and the support of a knowledge broker organization were key factors in using the maps co-produced in south Suriname in policymaking. The internal champions were two influential traditional authorities who were, from the beginning, enthusiastic on the research. They not only played an important role in engaging other (wary) community members in the mapping process, but they also were the main advocates of the need to use the spatial knowledge generated at both the local and national level (see more detail in Ramirez-Gomez et al., 2013). This is in line with findings of Crona (2006) who demonstrated how groups of fishermen in East Africa were able to champion collective action towards sustainable use of coastal and marine ecosystems, through knowledge exchange among relevant stakeholders. The key role of local champions in ecosystem management was also stressed by Olsson et al. (2007). Furthermore, the champion role of the community members in the study case in chapter 3 was cultivated by an international NGO that played an important role in bringing together government and indigenous representatives, as well as in bridging their respective values and views. This points out at the importance of leadership and bridging institutions as key factors in enhancing the likelihood of knowledge application in policy making, as was also suggested by Berkes (2009).

<u>In synthesis:</u> *The overall participatory approach, the co-production of knowledge between local communities and researchers, the usefulness of a 3D effect in participatory mapping and the engagement of an inspired local champion and broker were identified as crucial factors to foster the application of knowledge co-produced through participatory mapping in decision making.*

6.2.1. General limitations

A number of limitations are acknowledged in this doctoral thesis. First, a note of methodological caution is added regarding the temporal analysis in chapters 2 and 4. Since the historical datasets was based on perception, it relied on the memory of the respondents, which could affect the spatial accuracy of the findings. The effect of bias in the historical data was partly redressed by using a threshold to define consistent spatial aggregations of service provisioning locations as has been done in other studies (Brown and Pullar 2012). Second, the mapping of ecosystem services constitutes an isolated factual data-collection exercise embedded in the social practices, worldviews and power relations that shape a given community. This can make data-collection methods used in all study cases in this doctoral thesis susceptible to biases like gender, education, wealth and geographical location. Third, the mixed ecosystem services classification systems employed in this doctoral thesis might have limitations to compare and generalize the results to other regions. A minimum set of well-defined terms that effectively encompass the ecosystem services in study would be needed to facilitate comparisons and generalizations across regions. Yet, it is crucial that any classification used must be in concrete terms that are clear and relevant to the daily lives of people with whom knowledge is being co-produced. Lastly, there is a tendency for spatial analysis to oversimplify the complexity of real-world application. For example, in the case study in chapter 3, one of the resulting community use zone was the largest in area, but had the smallest population. This complexity exists in other indigenous territories across the Amazon where indigenous people, especially the young, are migrating to cities or frontier zones where they can better access education, health care, and commodities (Alexiades, 2013; Pérez-Llorente et al., 2013). Therefore, when determining the size, management, and characteristics of proposed community use zones, data on population size, growth, and out-migration should be incorporated, although this could prove difficult in resource and data-scarce regions.

6.2.2. Relevance of the findings for other intact tropical forest regions

While considering the caveats mentioned above, the approaches and findings in this doctoral thesis are relevant to other local communities and can be applied in tropical forest regions elsewhere in the world. For example, the participatory mapping approach to delineate areas of ecosystem service use developed in the south Suriname case (chapter 3) can be particularly relevant to countries where the collective rights of indigenous and tribal peoples have not been recognized. Besides Suriname, these include countries in the Congo Basin such as the Central African Republic, the Democratic Republic of Congo and Gabon (Rights and Resources Initiative, 2015). Forest communities in these countries have little tools to claim land titles to areas they have, in some cases, inhabited for hundreds of years (Eisen et al., 2014). Furthermore, the need to demarcate areas of community use is urgent in these countries because in the absence of a defensible documentation of the areas they use, State or business entities can continue large projects, such as dams, highways, mining, logging, and industrial agriculture, which often provoke land grabbing issues and trigger changes in land ownership (Zoomers 2010). Few examples of participatory mapping of community use zones exist across the developing world (see Gellert, 2015 for cases in Indonesia, Brandt et al., 2014 for cases in the Congo Basin and Borras et al., 2012 for cases in Latin America). Therefore, the participatory mapping approach to delineate community use zones developed in this doctoral thesis may also be used elsewhere to empower indigenous and tribal communities to protect their territories against the effect of these external pressures.

For some other countries where land rights of indigenous and tribal communities are legally recognized and where territories have been clearly demarcated, the approach to delineate areas of use is less relevant. For example, countries such as Brazil, Bolivia, Peru, Mexico and Colombia, which have the highest shares of national land area owned or controlled by indigenous communities in the world (Rights and Resources Initiative, 2015). Notwithstanding, despite legal security of tenure in these countries, recent political developments in Brazil and Colombia for example, are placing *de facto* rights in indigenous lands in peril. Unfavorable changes in legislative protection of indigenous communities' reserves is expected to increase the expansion of agri-business, infrastructure development, and timber and mineral extraction into and around indigenous land[7]. In this sense, participatory mapping approaches developed in this doctoral thesis can become relevant for these countries as well. For example, the expected changes in spatial and temporal patterns of locally important ecosystem services as a result of increasing pressures will require assessment approaches at reduced investment of time and money, like the ones developed in chapter 2 (delineation of service provisioning hotspots and community use zones) and 5 (participatory 3D mapping). In a wide range of intact forest regions, these approaches can be used to empower local communities, map access to ecosystem services, and recognize customary rights, for example as part of processes of free, prior and informed consent vis-à-vis external pressures.

6.3 Recommendation for future research

The findings in this doctoral thesis are an important contribution to solve the challenges of data scarcity in intact tropical forest regions. Nevertheless, a few important research gaps remain. An important future consideration regards the integration of demographic factors such as in- and out-migration patterns. For example, spatial analysis made in the south Suriname case, chapter 3, resulted in the identification of the largest community use zone for indigenous territories with the smallest population size. Similarly, in chapter 4, it seemed likely that out-migration patterns had an important influence on spatial equity

[7] https://www1.folha.uol.com.br/internacional/en/brazil/2019/01/majority-of-brazilians-against-reducing-indigenous-reservations.shtml

outcomes, but there was not sufficient demographic data to demonstrate this. To this regard, future research should overcome the challenge of demographic data scarcity in remote and intact forest regions to take the effect of migration patterns into account in spatial analysis.

Furthermore, this doctoral thesis has demonstrated how different analytical and participatory mapping approaches can be combined to enable the inclusion in policy making of indigenous and tribal communities, inhabiting intact forest regions. However, the analysis made in this doctoral thesis constitutes an aggregate perspective of local communities while policy making often affects social groups and individuals in a community in an uneven manner. In particular, the effect of external pressures on the provision of ecosystem services may be felt differently by women and men (Agrawal 2010). The scant attention to gender issues in this doctoral thesis relates, on the one hand, to local hierarchies of participation (women tended to have a limited voice during workshops while men were assumed as the decision makers and the knowledge holders). On the other hand, it was associated to time limitations as the women were usually at home taking care of the children or in the agriculture fields. Thus, future research would greatly benefit from examining how a more balanced inclusion of gender perspectives can be implemented in participatory mapping and in eventual decision-making and policies regarding intact forest regions. This is also vital in the context of the SDGs, as these are to be achieved while no one is left behind (UN, 2015), including in the most remote, and often socially marginalized, forest regions of the world.

A final consideration for future research would be to explore, empirically, how different land-use zoning strategies can systematically incorporate ecosystem services provisioning areas identified by local communities, for example by integrating them into existing environmental assessment methods, such as Strategic Environmental Assessment (SEA). This is important because often community use areas do not show active use by local communities and hence, land use policy makers tend to interpret them as ‘empty’ zones that are available for allocation of economic land use activities, as happened in the study case of the Upper Suriname River (chapter 5). This could further contribute to transdisciplinary research processes aimed at developing action-orientated outcomes in support of sustainable management of tropical forest regions (Kerkhoff and Lebel 2015).

6.4 Recommendation for policy makers

Three main recommendations for policy makers are derived from the findings in this doctoral thesis. First, I recommend using this knowledge to understand the patterns of ecosystem service use by indigenous and tribal communities in intact forest regions and, to respond to complex and multiple realities in the field based on this local knowledge. This means the replacement of top-down decision-making processes, where the land use and conservation-oriented agendas of governments and donors tend to be imposed on the real expectations of communities regarding the use of their ecosystem services. This is an urgent message in particular for policy makers in Suriname who seem to have a poor understanding of customary land use systems. For example, customary land tenure systems in the Upper Suriname River are typically clan-based, where rights-holders are associated with specific forest areas and whose boundaries may be demarcated by streams, rivers or other natural features. Such systems are generally very well defined and accepted by local forest communities but are poorly understood by policy makers and hardly recognized in formal national law. As a result, the allocation of economic land use activities often conflicts with internal land use arrangements. Thus, a better understanding of local realities will lead to more compatible, and hence effective, land use decisions.

Second, I suggest integrating the participatory maps generated in this doctoral thesis into other spatial data layers used in local consultation (or concertation) processes. The integration of the indigenous and tribal communities' spatial knowledge and priorities into existing land use decision support systems could enable a peer-to-peer dialogue between local communities and policy makers. This is important because despite the rhetoric of community empowerment and participation characterizing government consultation processes, economic land use allocation is often promoted in a top-down manner. The use of a bottom-up approach can lead to better-designed decision support systems that effectively account for the needs, wishes and current realities of communities.

Third, I recommend creating policy mandates that require the use of the participatory mapping approaches such as those presented in this doctoral thesis, into Strategic Environmental Assessments (SEAs) and Environmental Impact Assessments (EIA) concerning land use interventions in or around intact forest regions. Although in some countries in Southeast Asia like Indonesia and Laos, legislation has created the space for participatory mapping practice to become operational (Sulistyawan et al., 2018), a formidable challenge persists in realizing the potential offered by participatory mapping processes. Effective administrative mechanisms and regulatory instruments to support the integration of participatory mapping knowledge in land use decision making could overcome this challenge. While achieving this, it could reciprocally increase the effectiveness of SEAs and EIAs as instruments of good governance of forest regions.

6.5 Recommendations for practitioners

Besides recommendations for future research and policy, a few practical lessons can be drawn from this doctoral thesis. This section provides specific recommendations for practitioners to enhance the relevance of participatory mapping research projects for local communities.

– Communication and trust building come before advocacy

Language and cultural differences represent formidable barriers to engage with indigenous and tribal communities effectively. In this sense, lessons from this doctoral thesis (chapter 5) showed that participatory mapping projects with indigenous and tribal communities must first establish trust through communication; all other participatory mapping objectives must be compliant to this basic requirement.

– Identifying and cultivating the internal champion

As evidence showed in this doctoral thesis, participatory mapping projects with indigenous and tribal communities are unlikely to be successful without a strong internal "champion" who advocates the aims of the project and enjoys the trust and respect of the community. Thus, researchers and practitioners should identify, in the early stages of the project, a sympathetic participant who can receive the training and technical assistance to be able to advocate the use of the co-produced knowledge among policy makers.

– Perceived threats can overcome participatory inertia

The presence of perceived external threats can help overcome indigenous and tribal communities' reluctance to participate in mapping (similar to the study cases in chapter 3 and 5). The timing of the participatory mapping project is therefore important. A participatory mapping process should be proactive and anticipate threats to help indigenous and tribal communities plan and secure continued access to the lands that sustain them. Yet, some actual negative impacts from development can help motivate local community participation by showing that development threats are real. Optimal timing should therefore be early enough to influence major land use decisions, and not too late to create a sense of collective urgency to engage.

– Early success builds momentum

Outputs derived from the implementation of participatory mapping activities in one community may provide tangible results and maps that can be used to overcome hesitance to participate in other communities. This was evidenced during the fieldwork in the context of this doctoral thesis (chapter 3), as seeing mapped output helped other villagers to overcome their distrust and fear regarding the project. The lesson here is to select initial study sites or groups with the highest probability of successful participation and to use these favorable outcomes to build momentum for the more challenging sites or groups.

– Manage community expectations

A key challenge in applied research is to manage community expectations about the project regarding follow up implementation stages, which are usually beyond the scope of research studies. There is a natural tendency to look at the potential of participatory mapping methods to address a myriad of social and environmental problems. However, the path from the generation of participatory spatial information to effective social action based on that information is one that few have travelled. Therefore, it is important to embed the research process into a complete operational model from assessment to implementation, as mentioned by Cowling et al. (2008), if the purpose is to influence local realities and pursue livelihood resilience of local communities in remote and intact forest regions under external pressure.

7 Appendices

Table A1. Service provision hotspots distribution index for level of authority in Sub-region 1 in the period 1995 and 2015.

User category	Ecosystem service	N	Total SPH (ha)		SPH distribution index	
			1995	2015	1995	2015
	Fish		233	251	58.3	62.3
Capitein	Timber	4	215	285	53.3	71.3
	Crops		·	129	·	25.8
	Fish		208	230	16.0	17.7
Assistant capitein	Timber	13	188	226	14.5	17.4
	Crops		·	119	·	9.2
	Fish		199	227	0.9	1.0
No authority function	Timber	221	136	181	0.6	0.8
	Crops		·	111	·	0.5

Table A2. Service provision hotspots distribution index for level of authority in Sub-region 2 in the period 1995 and 2015.

User category	Ecosystem service	N	Total SPH (ha)		SPH distribution index	
			1995	2015	1995	2015
	Fish		392	473	130.6	157.6
Capitein	Timber	3	224	450	74.6	150.0
	Crops		·	396	·	132.0
	Fish		204	459	20.4	45.9
Assistant capitein	Timber	10	429	599	42.9	59.9
	Crops		·	311	·	31.1
	Fish		240	518	60	129.5
Dresimen	Timber	4	154	194	38.5	48.5
	Crops		·	426	·	106.5
	Fish		359	536	1.5	2.26
No authority function	Timber	237	334	379	1.4	1.6
	Crops		·	388	·	1.6

Table A3. Calculation of Gini Coefficient among clans for fish provision in 1995, sub-region 1.

Clan	*SPH Distribution index*	j=	i= 1	2	3	4	5	6	7	8	9	10	11	Sum	Gini
1	*1*	1	0	0	5,5	8,5	0,8	9	3,1	14,2	3,8	10	10		
2	*1*	2	0	0	5,5	8,5	0,8	9	3,1	14,2	3,8	10	10		
3	*6,5*	3	5,5	5,5	0	3	4,7	3,5	2,4	8,7	1,7	4,5	4,5		
4	*9,5*	4	8,5	8,5	3	0	7,7	0,5	5,4	5,7	4,7	1,5	1,5		
5	*1,8*	5	0,8	0,8	4,7	7,7	0	8,2	2,3	13,4	3	9,2	9,2		
6	*10*	6	9	9	3,5	0,5	8,2	0	5,9	5,2	5,2	1	1		
7	*4,1*	7	3,1	3,1	2,4	5,4	2,3	5,9	0	11,1	0,7	6,9	6,9		
8	*15,2*	8	14,2	14,2	8,7	5,7	13,4	5,2	11,1	0	10,4	4,2	4,2		
9	*4,8*	9	3,8	3,8	1,7	4,7	3	5,2	0,7	10,4	0	6,2	6,2		
10	*11*	10	10	10	4,5	1,5	9,2	1	6,9	4,2	6,2	0	0		
11	*11*	11	10	10	4,5	1,5	9,2	1	6,9	4,2	6,2	0	0		
Mean	***6,9***	**Vertical Sum**	**64,9**	**64,9**	**44**	**47**	**59,3**	**48,5**	**47,8**	**91,3**	**45,7**	**53,5**	**53,5**	620,4	0.37

Table A4. Calculation of Gini Coefficient among clans for fish provision in 2015, sub-region 1.

Clan	SPH Distribution index	j=	i= 1	2	3	4	5	6	7	8	9	10	11		
1	*2*	1	0	1	7	9	0	27	2.1	18.5	3.3	16.6	15.5		
2	*1*	2	1	0	8	10	1	28	3.1	19.5	4.3	17.6	16.5		
3	*9*	3	7	8	0	2	7	20	4.9	11.5	3.7	9.6	8.5		
4	*11*	4	9	10	2	0	9	18	6.9	9.5	5.7	7.6	6.5		
5	*2*	5	0	1	7	9	0	27	2.1	18.5	3.3	16.6	15.5		
6	*29*	6	27	28	20	18	27	0	24.9	8.5	23.7	10.4	11.5		
7	*4.1*	7	2.1	3.1	4.9	6.9	2.1	24.9	0	16.4	1.2	14.5	13.4		
8	*20.5*	8	18.5	19.5	11.5	9.5	18.5	8.5	16.4	0	15.2	1.9	3		
9	*5.3*	9	3.3	4.3	3.7	5.7	3.3	23.7	1.2	15.2	0	13.3	12.2		
10	*18.6*	10	16.6	17.6	9.6	7.6	16.6	10.4	14.5	1.9	13.3	0	1.1		
11	*17.5*	11	15.5	16.5	8.5	6.5	15.5	11.5	13.4	3	12.2	1.1	0	Sum	Gini
Mean	***10.91***	**Vertical Sum**	**100**	**109**	**82.2**	**84.2**	**100**	**199**	**89.5**	**122.5**	**85.9**	**109.2**	**103.7**	1185.2	0.45

Table A5. Calculation of Gini Coefficient among clans for timber provision in 1995, sub-region 1.

	SPH		i=												
Clan	*Distribution index*	j=	1	2	3	4	5	6	7	8	9	10	11		
1	*3*	1	0	0	1.4	0	0.8	3	6.7	6.8	7.3	9.9	11.8		
2	*3*	2	0	0	1.4	0	0.8	3	6.7	6.8	7.3	9.9	11.8		
5	*1.6*	5	1.4	1.4	0	1.4	2.2	4.4	8.1	8.2	8.7	11.3	13.2		
11	*3*	11	0	0	1.4	0	0.8	3	6.7	6.8	7.3	9.9	11.8		
4	*3.8*	4	0.8	0.8	2.2	0.8	0	2.2	5.9	6	6.5	9.1	11		
10	*6*	10	3	3	4.4	3	2.2	0	3.7	3.8	4.3	6.9	8.8		
8	*9.7*	8	6.7	6.7	8.1	6.7	5.9	3.7	0	0.1	0.6	3.2	5.1		
7	*9.8*	7	6.8	6.8	8.2	6.8	6	3.8	0.1	0	0.5	3.1	5		
6	*10.3*	6	7.3	7.3	8.7	7.3	6.5	4.3	0.6	0.5	0	2.6	4.5		
9	*12.9*	9	9.9	9.9	11.3	9.9	9.1	6.9	3.2	3.1	2.6	0	1.9		
3	*14.8*	3	11.8	11.8	13.2	11.8	11	8.8	5.1	5	4.5	1.9	0	Sum	Gini
Mean	***7.08***	**Vertical Sum**	**47.7**	**47.7**	**60.3**	**47.7**	**45.3**	**43.1**	**46.8**	**47.1**	**49.6**	**67.8**	**84.9**	588	0.34

Table A6. Calculation of Gini Coefficient among clans for timber provision in 2015, sub-region 1.

Clan	SPH Distribution index	j=	i= 1	2	3	4	5	6	7	8	9	10	11		
2	*1*	2	0	2.6	4	6	11.1	12	5	24	27.1	27.5	35.8		
5	*3.6*	5	2.6	0	1.4	3.4	8.5	9.4	2.4	21.4	24.5	24.9	33.2		
10	*5*	10	4	1.4	0	2	7.1	8	1	20	23.1	23.5	31.8		
1	*7*	1	6	3.4	2	0	5.1	6	1	18	21.1	21.5	29.8		
4	*12.1*	4	11.1	8.5	7.1	5.1	0	0.9	6.1	12.9	16	16.4	24.7		
9	*13*	9	12	9.4	8	6	0.9	0	7	12	15.1	15.5	23.8		
11	*6*	11	5	2.4	1	1	6.1	7	0	19	22.1	22.5	30.8		
6	*25*	6	24	21.4	20	18	12.9	12	19	0	3.1	3.5	11.8		
3	*28.1*	3	27.1	24.5	23.1	21.1	16	15.1	22.1	3.1	0	0.4	8.7		
8	*28.5*	8	27.5	24.9	23.5	21.5	16.4	15.5	22.5	3.5	0.4	0	8.3		
7	*36.8*	7	35.8	33.2	31.8	29.8	24.7	23.8	30.8	11.8	8.7	8.3	0	Sum	Gini
Mean	***15.10***	**Vertical Sum**	**155.1**	**131.7**	**121.9**	**113.9**	**108.8**	**109.7**	**116.9**	**145.7**	**161.2**	**164**	**238.7**	1567.6	0.43

Table A7. Calculation of Gini Coefficient among clans for crops provision in 2015, sub-region 1.

Clan	*SPH Distribution index*	j= \ i=	1	2	3	4	5	6	7	8	9	10	11		
1	*8*	1	0	0.2	2.3	3.2	6.2	1.7	2.3	14.1	3.7	5.7	8.2		
2	*7.8*	2	0.2	0	2.5	3.4	6	1.5	2.1	14.3	3.5	5.5	8.4		
3	*10.3*	3	2.3	2.5	0	0.9	8.5	4	4.6	11.8	6	8	5.9		
4	*11.2*	4	3.2	3.4	0.9	0	9.4	4.9	5.5	10.9	6.9	8.9	5		
5	*1.8*	5	6.2	6	8.5	9.4	0	4.5	3.9	20.3	2.5	0.5	14.4		
6	*6.3*	6	1.7	1.5	4	4.9	4.5	0	0.6	15.8	2	4	9.9		
7	*5.7*	7	2.3	2.1	4.6	5.5	3.9	0.6	0	16.4	1.4	3.4	10.5		
8	*22.1*	8	14.1	14.3	11.8	10.9	20.3	15.8	16.4	0	17.8	19.8	5.9		
9	*4.3*	9	3.7	3.5	6	6.9	2.5	2	1.4	17.8	0	2	11.9		
10	*2.3*	10	5.7	5.5	8	8.9	0.5	4	3.4	19.8	2	0	13.9		
11	*16.2*	11	8.2	8.4	5.9	5	14.4	9.9	10.5	5.9	11.9	13.9	0	Sum	Gini
Mean	***8.73***	**Vertical Sum**	**47.6**	**47.4**	**54.5**	**59**	**76.2**	**48.9**	**50.7**	**147.1**	**57.7**	**71.7**	**94**	754.8	0.36

Table A8. Calculation of Gini Coefficient among clans for fish provision in 1995, sub-region 2.

Clan	*SPH Distribution index*	j=	i= 1	2	3	4	5	6	7	8	9	10		
1	*4.3*	1	0	19.2	20.7	31.6	60.1	19.2	0.7	14.4	13	54		
2	*23.5*	2	19.2	0	1.5	12.4	40.9	0	18.5	4.8	6.2	34.8		
3	*25*	3	20.7	1.5	0	10.9	39.4	1.5	20	6.3	7.7	33.3		
4	*35.9*	4	31.6	12.4	10.9	0	28.5	12.4	30.9	17.2	18.6	22.4		
5	*64.4*	5	60.1	40.9	39.4	28.5	0	40.9	59.4	45.7	47.1	6.1		
6	*23.5*	6	19.2	0	1.5	12.4	40.9	0	18.5	4.8	6.2	34.8		
7	*5*	7	0.7	18.5	20	30.9	59.4	18.5	0	13.7	12.3	53.3		
8	*18.7*	8	14.4	4.8	6.3	17.2	45.7	4.8	13.7	0	1.4	39.6		
9	*17.3*	9	13	6.2	7.7	18.6	47.1	6.2	12.3	1.4	0	41		
10	*58.3*	10	54	34.8	33.3	22.4	6.1	34.8	53.3	39.6	41	0	Sum	Gini
Mean	***27.59***	**Vertical Sum**	**232.9**	**138.3**	**141.3**	**184.9**	**368.1**	**138.3**	**227.3**	**147.9**	**153.5**	**319.3**	2051.8	0.37

Table A9. Calculation of Gini Coefficient among clans for fish provision in 2015, sub-region 2.

Clan	*SPH Distribution index*	j=	i= 1	2	3	4	5	6	7	8	9	10		
1	*2.9*	1	0	5.7	11.1	77.5	47.9	24.6	94.1	27	11.4	114.7		
2	*8.6*	2	5.7	0	5.4	71.8	42.2	18.9	88.4	21.3	5.7	109		
3	*14*	3	11.1	5.4	0	66.4	36.8	13.5	83	15.9	0.3	103.6		
4	*80.4*	4	77.5	71.8	66.4	0	29.6	52.9	16.6	50.5	66.1	37.2		
5	*50.8*	5	47.9	42.2	36.8	29.6	0	23.3	46.2	20.9	36.5	66.8		
6	*27.5*	6	24.6	18.9	13.5	52.9	23.3	0	69.5	2.4	13.2	90.1		
7	*97*	7	94.1	88.4	83	16.6	46.2	69.5	0	67.1	82.7	20.6		
8	*29.9*	8	27	21.3	15.9	50.5	20.9	2.4	67.1	0	15.6	87.7		
9	*14.3*	9	11.4	5.7	0.3	66.1	36.5	13.2	82.7	15.6	0	103.3		
10	*117.6*	10	114.7	109	103.6	37.2	66.8	90.1	20.6	87.7	103.3	0	Sum	Gini
Mean	***44.3***	**Vertical Sum**	**414**	**368.4**	**336**	**468.6**	**350.2**	**308.4**	**568.2**	**308.4**	**334.8**	**733**	4190	0.47

Table A10. Calculation of Gini Coefficient among clans for timber provision in 1995, sub-region 2.

Clan	*SPH Distribution index*	j=	i= 1	2	3	4	5	6	7	8	9	10		
1	*3.2*	1	0	1.8	4.6	5.05	15.4	22.1	24.8	26.6	60.05	77.1		
7	*5*	2	1.8	0	2.8	3.25	13.6	20.3	23	24.8	58.25	75.3		
2	*7.8*	3	4.6	2.8	0	0.45	10.8	17.5	20.2	22	55.45	72.5		
6	*8.25*	4	5.05	3.25	0.45	0	10.35	17.05	19.75	21.55	55	72.05		
3	*18.6*	5	15.4	13.6	10.8	10.35	0	6.7	9.4	11.2	44.65	61.7		
9	*25.3*	6	22.1	20.3	17.5	17.05	6.7	0	2.7	4.5	37.95	55		
5	*28*	7	24.8	23	20.2	19.75	9.4	2.7	0	1.8	35.25	52.3		
8	*29.8*	8	26.6	24.8	22	21.55	11.2	4.5	1.8	0	33.45	50.5		
4	*63.25*	9	60.05	58.25	55.45	55	44.65	37.95	35.25	33.45	0	17.05		
10	*80.3*	10	77.1	75.3	72.5	72.05	61.7	55	52.3	50.5	17.05	0	Sum	Gini
Mean	***26.95***	**Vertical Sum**	**237.5**	**223.1**	**206.3**	**204.5**	**183.8**	**183.8**	**189.2**	**196.4**	**397.1**	**533.5**	2555.2	0.47

Table A11. Calculation of Gini Coefficient among clans for timber provision in 2015, sub-region 2.

Clan	*SPH Distribution index*	j=	i= 1	2	3	4	5	6	7	8	9	10		
1	*4.3*	1	0	13.5	10.9	79.7	36.7	58.5	1.7	24.2	26.3	53.7		
2	*17.8*	2	13.5	0	2.6	66.2	23.2	45	11.8	10.7	12.8	40.2		
3	*15.2*	3	10.9	2.6	0	68.8	25.8	47.6	9.2	13.3	15.4	42.8		
4	*84*	4	79.7	66.2	68.8	0	43	21.2	78	55.5	53.4	26		
5	*41*	5	36.7	23.2	25.8	43	0	21.8	35	12.5	10.4	17		
6	*62.8*	6	58.5	45	47.6	21.2	21.8	0	56.8	34.3	32.2	4.8		
7	*6*	7	1.7	11.8	9.2	78	35	56.8	0	22.5	24.6	52		
8	*28.5*	8	24.2	10.7	13.3	55.5	12.5	34.3	22.5	0	2.1	29.5		
9	*30.6*	9	26.3	12.8	15.4	53.4	10.4	32.2	24.6	2.1	0	27.4		
10	*58*	10	53.7	40.2	42.8	26	17	4.8	52	29.5	27.4	0	Sum	Gini
Mean	***34.82***	**Vertical Sum**	**305.2**	**226**	**236.4**	**491.8**	**225.4**	**322.2**	**291.6**	**204.6**	**204.6**	**293.4**	2801.2	0.40

Table A12. Calculation of Gini Coefficient among clans for crops provision in 2015, sub-region 2.

Clan	*SPH Distribution index*	j=	i= 1	2	3	4	5	6	7	8	9	10		
1	*1.6*	1	0	30.5	8.1	7.3	23.4	8.65	0.1	22.3	25.7	69		
2	*32.1*	2	30.5	0	22.4	23.2	7.1	21.85	30.6	8.2	4.8	38.5		
3	*9.7*	3	8.1	22.4	0	0.8	15.3	0.55	8.2	14.2	17.6	60.9		
4	*8.9*	4	7.3	23.2	0.8	0	16.1	1.35	7.4	15	18.4	61.7		
5	*25*	5	23.4	7.1	15.3	16.1	0	14.75	23.5	1.1	2.3	45.6		
6	*10.25*	6	8.65	21.85	0.55	1.35	14.75	0	8.75	13.65	17.05	60.35		
7	*1.5*	7	0.1	30.6	8.2	7.4	23.5	8.75	0	22.4	25.8	69.1		
8	*23.9*	8	22.3	8.2	14.2	15	1.1	13.65	22.4	0	3.4	46.7		
9	*27.3*	9	25.7	4.8	17.6	18.4	2.3	17.05	25.8	3.4	0	43.3		
10	*70.6*	10	69	38.5	60.9	61.7	45.6	60.35	69.1	46.7	43.3	0	Sum	Gini
Mean	***21.085***	**Vertical Sum**	**195.05**	**187.15**	**148.05**	**151.25**	**149.15**	**146.95**	**195.85**	**146.95**	**158.35**	**495.15**	1973.9	0.47

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Summary

One of the main challenges for the coming decades is to strengthen the capacity of indigenous and tribal communities to conserve and sustainably manage intact tropical forest regions. These large and relatively undisturbed natural forests in the tropics offer unique opportunities to mitigate two of the greatest environmental problems that the world faces: climate change and the loss of biodiversity. There is ample evidence demonstrating the global importance of management of indigenous and tribal communities for the conservation of these regions. In spite of that, the rapid expansion of resource extraction, commodity production, mining, and transport and energy infrastructure far into the most remote forest regions of the world, with various consequences for local livelihoods, is challenging the ability of indigenous and tribal communities to effectively conserve these lands. It is therefore highly relevant and urgent to involve these communities in the land use decision making that affects them, as well as to consider the entangled social and ecological transformation processes that they undergo upon the arrival of external pressures. However, tools and approaches that consistently enable their engagement are not yet sufficiently available. Moreover, our scientific understanding of how external pressures affect the spatial and temporal dynamics of ecosystem service use by local communities and how these dynamics affect the conservation of intact forest areas is still limited.

This doctoral thesis has been designed to address this pressing gap in knowledge. First, it aims to assess to what extent external pressures affect the spatial and temporal patterns of ecosystem service provision in remote and data scarce forest regions; and second, it seeks to understand how this knowledge can be used to respond to these pressures and support a process of inclusive policy making that recognizes the needs and priorities of indigenous and tribal communities regarding ecosystem service use. It is composed of three study cases,

one in the Colombian Amazon (chapter 2) and two in Suriname (chapters 3, 4 and 5).

Chapter 2 analyses changes in space and over time of the provision of locally important ecosystem services to indigenous communities in the region of La Pedrera, in the Colombian Department of Amazonas. In this study, the causes and consequences of such change for the maintenance of traditional livelihoods practices were also investigated. To this aim, the methodology integrated 22 focus group discussions, 8 community meetings, and 16 participatory mapping workshops with 158 participants distributed across 10 indigenous communities. Results of the temporal analysis showed that over the past two decades, the demand for food and raw materials has intensified and, as a result, the stock of these services has declined and service-provisioning areas have shifted. Further, the results showed that in 20 years' time, the greatest increase in the extent of service provisioning areas has been for timber (61%), bush meat (42%), fish (43%) and thatching materials (62%). By contrast, the analysis reported a decrease in the extent of provisioning areas for medicines (81%), ornaments for traditional dances (53%) and resins (40%), which are ecosystem services linked to traditional livelihood practices. This study demonstrated that the economic needs of indigenous and tribal communities and the proximity to a regional market change the manner in which community members use natural resources and that the decline of important ecosystem services is putting pressure on local communities to adapt their livelihood strategies. The spatially explicit hotspots approach developed in this chapter, offered a simple, rapid and robust means to understand the variation in use of ecosystem services by indigenous communities across space and time in data scarce regions.

Chapter 3 investigated the size and the spatial distribution of the areas that are essential to maintain the provision of ecosystem services of local importance to indigenous communities. These areas were estimated for a case study in south Suriname. Communities in this study region do not hold legal land rights. To this purpose, data collection took place through a participatory mapping survey among 191 respondents in five indigenous communities. Participants drew polygons around areas with ecosystem services of cultural, subsistence, future and economic value. The GIS analysis of these polygons resulted in the identification of service provisioning hotspots (where high amounts of ecosystem services are present) to which six landscape metrics were applied. Further, indigenous communities validated the delineation of these areas as community use zones. The entire area in use by indigenous communities was estimated at a total of 2.7 million hectares. The average size was 532,410 ha per community. The landscape metrics provided an indication of the extent of the area of each ecosystem service valued as important. The hotspots corresponding to ecosystem services value for future generations occupied 60.6% of the total community use zone followed by hotspots with subsistence value (44.5%), cultural value (29.5%), and economic value (19.8%). The spatially explicit delineation of areas that needed to be reserved for future provision of services was an important contribution of this doctoral thesis. This case study was used to develop a participatory mapping approach to delineate community use zones that is especially suited for data scarce environments. It has also provided the first baseline information on ecosystem services for this intact forest region, which can assist the evaluation of future land-use interventions. Furthermore, the findings of this study have empowered indigenous communities to influence national conservation policies as to safeguard their community use zones.

Chapter 4 focuses on the extent to which external pressures influence equity in access to service provisioning hotspots, which is referred to as 'spatial equity'. This was done through an empirical study that compares two sub-regions in the Upper Suriname River Basin: a sub-region where logging and road building occur and a more remote sub-region where these interventions are not yet developed but merely planned. Spatial data was collected for 1995 and 2015 using a participatory GIS survey (n = 493), and aggregated to define provisioning service hotspots for fish, timber and crops (the latter only for the year 2015). Then, different dimensions of spatial equity were explored according to clan membership and authority position, by analyzing variation in access to ecosystem services over time and across regions. The results showed that in the region with roads and logging, spatial equity concerns emerged over time regarding the provision of timber. In the remote sub-region, spatial inequity in access to hotspots of ecosystem services appeared early, ahead of the economic opportunities posed by new roads in nearby forests areas. Our analysis made spatially explicit the places where conflict between users of ecosystem services, associated to asymmetries in access to hotspots of ecosystem services, is most likely. This case study provided an empirical understanding of how local communities with a subsistence economy change their patterns of use of ecosystem services in remote forest regions when economic opportunities present themselves. In outlining these concerns, this chapter suggests that spatial equity analysis unveils an essential social dimension in the use of the space that should be integrated in spatial planning processes. The main contribution of this study is the development of a spatially explicit approach that constitutes a rapid but robust manner to operationalize the study of spatial equity issues in remote and data-scarce forest regions.

Chapter 5 evaluates to what extent a participatory 3D modelling approach (P3DM) can be effective to promote the co-production of usable ecosystem service knowledge and the inclusion of marginalized local communities - who show distrust and opposition towards outsiders - in land use decision making. To this aim, ecosystem services data were gathered and mapped through four community meetings, 12 focus groups discussions and eight participatory 3D mapping workshops, implemented in 24 tribal villages along the upper Suriname River basin involving 267 local community participants. Similarly, 38 semi-structured interviews were conducted with policy makers. This resulted in the efficient identification and evaluation of 36 ecosystem services and its representation in a 3D model of the landscape. These ecosystem services belonged to provisioning, cultural and regulating service categories, with crops, fish, wild meat, timber and forest medicines being identified as most important. The findings show a decrease in the demand and provision of crops, fish and wild meat associated with ecosystem degradation, out-migration and changes in lifestyles. This approach demonstrated how knowledge that is understandable, accessible and usable to a wide range of stakeholders can be co-produced, and how the use of a third dimension in participatory mapping effectively enhanced the ownership of the knowledge generation process and outcomes.

The main conclusions that stem from this doctoral thesis are the following:

First, it has demonstrated how participatory mapping can be used to gain insights into the spatial and temporal patterns of ecosystem services provision and use in remote and data scarce forest regions. While the forest in the study areas may seem undisturbed from above (as observed from remote sensing images), beneath the canopy it is hiding social and ecological issues related to local ecosystem service provision. The participatory mapping approaches applied in these study cases demonstrated how gaps in knowledge regarding patterns of local ecosystem service provision and use in intact forest regions can be filled in local and regional studies.

Second, this thesis provided evidence of the factors affecting the spatial and temporal patterns of ecosystem services use in remote and intact tropical forest regions under external pressure. The findings showed that the willingness of indigenous and tribal communities to protect tropical forest regions is increasingly linked to the external world and as such, the challenge to protect the Earth's last intact tropical forest regions is bigger than we thought. Thus, even if remote and intact forest regions stay roadless, the expansion of roads, markets and commercial land uses in their neighborhood is driving changes in the local spatial and temporal patterns of ecosystem services use inside these regions, which is in turn leading to overexploitation and ecosystem degradation.

Third, when external pressures emerge in intact forest regions, pre-existing asymmetries in access to service provisioning hotspots increase, and these patterns of spatial inequity are also reflected by emerging areas of potential conflict between user groups with differential access. The analysis showed that although the asymmetries found are partly due to social disparities associated with ethnic cleavages within communities, external pressures, such the expansion of roads and commercial timber activities, are actually exacerbating them. This means that forest areas should not be assumed to remain free from conflict in virtue of their remoteness. Mediating potential conflicts is an important aim at both local and higher land use planning scales, and findings of differential access capabilities such as those reported here underscore the need to integrate and account for spatial equity in the planning of any commercial land use activities.

Lastly, the results in this doctoral thesis suggest that the overall participatory approach, the co-production of knowledge between local communities and researchers, the usefulness of incorporating a third dimension in participatory mapping and the engagement of an inspired local champion and broker were identified as crucial factors to foster the usability of knowledge produced through participatory mapping in land use decision-making.

In future research, a more in-depth analysis of the social processes influencing land-use decisions would be needed to better understand the factors leading to different conservation outcomes in intact forest regions. Yet, the findings in this doctoral thesis are an important contribution to solve some of the challenges of data scarcity in intact tropical forest regions. In particular, it contributes to filling the current deficit of local spatial knowledge in regional and global scenarios of land use planning in intact forest regions, as highlighted in the latest IPBES Global Assessment Report of ecosystems and biodiversity. Finally, I have also shown how the generated information and the mapping process itself have strengthened the capacities of local communities to participate more effectively in national dialogues on land use and conservation.

Samenvatting

Een van de belangrijkste uitdagingen voor de komende decennia is het versterken van de capaciteit van inheemse en tribale gemeenschappen om intacte tropische bosgebieden te behouden en duurzaam te beheren. Deze grote en relatief ongerepte natuurlijke bossen in de tropen bieden unieke kansen om twee van de grootste milieuproblemen waarmee de wereld wordt geconfronteerd tegen te gaan: klimaatverandering en het verlies van biodiversiteit. Er is veel bewijs dat het wereldwijde belang van het beheer van inheemse en tribale gemeenschappen van deze gebieden voor het behoud ervan aantoont. Echter, de snelle uitbreiding van grondstofwinning, de productie van goederen, mijnbouw en transport- en energie-infrastructuur tot in de meest afgelegen bosgebieden van de wereld, met uiteenlopende gevolgen voor de lokale bestaansmiddelen, vormt een uitdaging voor het vermogen van inheemse en tribale gemeenschappen om deze gebieden effectief te beschermen. Het is daarom zeer relevant en urgent om de gemeenschappen te betrekken bij besluitvorming over landgebruik die hen beïnvloedt, en aandacht te besteden aan de sociale en ecologische transformatieprocessen die ze ondergaan bij de intrede van externe drukfactoren. Instrumenten en benaderingen die hun betrokkenheid op een consequente manier faciliteren, zijn echter nog niet voldoende beschikbaar. Bovendien hebben we nog steeds een beperkt wetenschappelijk begrip van de manier waarop externe druk de ruimtelijke en temporele dynamiek van het gebruik van ecosysteemdiensten door lokale gemeenschappen beïnvloedt en hoe deze dynamiek de instandhouding van intacte bosgebieden beïnvloedt.

Dit proefschrift is ontworpen om deze prangende lacune in kennis te adresseren. Het onderzoek beoogt ten eerste om te beoordelen in hoeverre externe druk de ruimtelijke en temporele patronen in ecosysteemdiensten beïnvloedt, en ten tweede om te begrijpen hoe deze kennis kan worden gebruikt om op deze druk te reageren en

ondersteuning te bieden bij een proces van inclusief beleid, dat de behoeften en prioriteiten van inheemse en tribale gemeenschappen met betrekking tot het gebruik van ecosysteemdiensten erkent. Het proefschrift bestaat uit drie studie casussen: één in het Colombiaanse Amazone gebied (hoofdstuk 2) en twee in Suriname (hoofdstukken 3, 4 en 5).

Hoofdstuk 2 analyseert veranderingen in de ruimte en in tijd van het aanbod van lokaal belangrijke ecosysteemdiensten voor inheemse gemeenschappen in de regio La Pedrera, in het Colombiaanse departement Amazonas. In deze studie werden ook de oorzaken en van dergelijke veranderingen en de gevolgen voor het behoud van traditionele bestaansmiddelen onderzocht. Hiertoe omvatte de methodologie 22 focusgroepsdiscussies, 8 gemeenschapsvergaderingen en 16 workshops voor participatieve kartering, met 158 deelnemers behorend tot 10 inheemse gemeenschappen. Resultaten van de temporele analyse toonden aan dat in de afgelopen twee decennia de vraag naar voedsel en grondstoffen is toegenomen, wat leidde tot een afname van de voorraad van deze diensten en verschuivingen van de extractiegebieden. Verder lieten de resultaten zien dat in 20 jaar tijd de groei van de extractiegebieden het sterkst was voor hout (61%), wild vlees (42%), vis (43%) en materialen voor dakbedekking (62%). De analyse toonde daarentegen een afname van de gebieden die medicijnen leveren (81%), ornamenten voor traditionele dansen (53%) en harsen (42%), wat ecosysteemdiensten zijn die horen bij traditionele manieren van leven. Deze studie heeft aangetoond dat de economische behoeften van inheemse en tribale gemeenschappen en de nabijheid van een regionale markt de manier waarop leden van de gemeenschap natuurlijke hulpbronnen gebruiken verandert en dat de achteruitgang van belangrijke ecosysteemdiensten lokale gemeenschappen onder druk zet om hun bestaansstrategieën aan te passen. De in dit hoofdstuk ontwikkelde ruimtelijk expliciete hotspots-aanpak biedt een eenvoudige, snelle en robuuste manier voor data-schaarse regio’s om variatie in het gebruik van ecosysteemdiensten door inheemse gemeenschappen in ruimte en tijd te begrijpen.

Hoofdstuk 3 onderzocht de omvang en de ruimtelijke verdeling van de gebieden die essentieel zijn voor het behoud van ecosysteemdiensten die lokaal belangrijk zijn voor inheemse gemeenschappen. Deze gebieden zijn bepaald voor een studie casus in zuid Suriname. Hiervoor vond gegevensverzameling plaats via een participatief karteringsonderzoek onder 191 respondenten in vijf inheemse gemeenschappen. Deelnemers trokken polygonen rond gebieden met ecosysteemdiensten van culturele, bestaansmiddelen gerelateerde, toekomstige en economische waarde. De GIS analyse van deze polygonen resulteerde in de identificatie van 'hotspots' (concentraties) van ecosysteemdiensten waarop zes landschapsstatistieken werden toegepast. Verder valideerden inheemse gemeenschappen de afbakening van deze gebieden als zones voor gemeenschapsgebruik. Het totale gebied dat door inheemse gemeenschappen wordt gebruikt, wordt geschat op een totaal van 2,7 miljoen hectare. De gemiddelde afmeting is 532.410 hectare per gemeenschap. De landschapsstatistieken geven een indicatie van de omvang van het gebied dat gebruikt wordt voor elke ecosysteemdienst. De hotspots die horen bij de ecosysteemdiensten voor de toekomstige generaties namen 60,6% van de totale zone voor gemeenschapsgebruik in beslag, gevolgd door die voor levensonderhoud (44,5%, *subsistence*), culturele waarden (29,5%) en economische waarde (19,8%). De ruimtelijk expliciete afbakening van gebieden die gereserveerd moeten worden voor toekomstige levering van ecosysteemdiensten is een belangrijke bijdrage van dit proefschrift. Deze studie casus werd gebruikt voor de ontwikkeling van een participatieve karteringsmethode om zones van gemeenschapsgebruik te karteren, die vooral geschikt is voor data-schaarse gebieden. Het heeft ook de eerste baseline informatie verschaft voor dit intacte bosgebied, wat kan helpen bij de evaluatie van toekomstige interventies op het gebied van landgebruik. Bovendien hebben de bevindingen van deze studie inheemse gemeenschappen in staat gesteld het nationale natuurbeschermingsbeleid te beïnvloeden om zo hun zones voor gemeenschapsgebruik te beschermen.

Hoofdstuk 4 richt zich op de mate waarin externe druk een rechtvaardige verdeling in de toegang tot hotspots van ecosysteemdiensten beïnvloedt ("ruimtelijke (on)gelijkheid" of *spatial equity*). Dit werd gedaan in een empirisch onderzoek dat twee sub-regio's in het Boven-Suriname rivier stroomgebied vergelijkt: een sub-regio waar houtkap en wegenbouw plaatsvinden en een meer afgelegen sub-regio waar deze interventies nog niet zijn ontwikkeld maar alleen gepland. Ruimtelijke gegevens werden verzameld voor 1995 en 2015 met behulp van participatief GIS onderzoek (n = 493), en geaggregeerd om hotspots van ecosysteemdiensten te definiëren voor vis, hout en gewassen (de laatste alleen voor 2015). Vervolgens werden verschillende dimensies van ruimtelijke gelijkheid onderzocht per etnische clan en autoriteitspositie, door variatie in toegang tot ecosysteemdiensten in de tijd en tussen sub-regio's te analyseren. De resultaten toonden aan dat in de sub-regio met wegen en houtkap na verloop van tijd zorgen over ruimtelijke gelijkheid ontstonden met betrekking tot de beschikbaarheid van hout. In de afgelegen regio ontstond de ruimtelijk ongelijke verdeling in de toegang tot hotspots van ecosysteemdiensten al vroeg, vooruitlopend op de economische kansen van nieuwe wegen in nabijgelegen bosgebieden. Onze analyse gaf ruimtelijk expliciet aan op welke plaatsen conflicten tussen gebruikers van ecosysteemdiensten het meest waarschijnlijk zijn, geassocieerd met asymmetriën in toegang tot hotspots van ecosysteemdiensten. Deze studie casus gaf een empirisch inzicht in de manier waarop lokale gemeenschappen met een zelfvoorzienende economie hun gebruikspatronen van ecosysteemdiensten in afgelegen bosgebieden veranderen, wanneer zich economische kansen voordoen. Door deze punten van zorg te schetsen, suggereert dit hoofdstuk dat de analyse van ruimtelijke gelijkheid een essentiële sociale dimensie van ruimtegebruik onthult, die geïntegreerd zou moeten worden in ruimtelijke planningsprocessen. De belangrijkste bijdrage van deze studie is de ontwikkeling van een ruimtelijk expliciete benadering die een snelle maar robuuste manier biedt om de studie van ruimtelijke gelijkheidsvraagstukken in afgelegen en gegevensarme bosgebieden te operationaliseren.

Hoofdstuk 5 evalueert in hoeverre een participatieve 3D-model benadering (P3DM) effectief kan zijn om de coproductie van bruikbare kennis van ecosysteemdiensten te bevorderen en gemarginaliseerde lokale gemeenschappen - met wantrouwen en oppositie tegenover buitenstaanders - te betrekken bij de besluitvorming over landgebruik. Voor dit doel werden gegevens over ecosysteemdiensten verzameld en in kaart gebracht via vier gemeenschapsvergaderingen, 12 focusgroep discussies en acht workshops met gebruik van participatieve 3D-kartering. Dit werd geïmplementeerd in 24 tribale dorpen langs het Boven-Suriname rivier stroomgebied, met deelname van 267 lokale gemeenschapsleden. Ook werden er 38 semigestructureerde interviews gehouden met beleidsmakers. Dit resulteerde in de efficiënte identificatie en evaluatie van 36 ecosysteemdiensten in een 3D-model van het landschap. Deze ecosysteemdiensten behoorden tot de categorieën voedselvoorziening, culturele en regulerende diensten, waarbij gewassen, vis, wild vlees, hout en bosmedicijnen als de belangrijkste werden geïdentificeerd. De bevindingen tonen een afname van de vraag naar en het aanbod van gewassen, vis en wild vlees geassocieerd met de achteruitgang van ecosystemen, emigratie en veranderingen in levensstijl, met name in het noordelijke deel van het stroomgebied dat minder afgelegen is. Deze aanpak laat zien hoe kennis die begrijpelijk, toegankelijk en bruikbaar is voor een breed scala van belanghebbenden, samen kan worden geproduceerd en hoe het gebruik van een derde dimensie in participatieve kartering het eigendom van het proces van kennisontwikkeling en de resultaten effectief heeft verbeterd.

De belangrijkste conclusies die uit dit proefschrift voortkomen zijn als volgt:

Ten eerste heeft het aangetoond hoe participatieve kartering kan worden gebruikt om inzicht te krijgen in de ruimtelijke en temporele patronen van het aanbod en gebruik van ecosysteemdiensten in afgelegen en data schaarse bosgebieden. Hoewel het bos in de studiegebieden van bovenaf schijnbaar ongestoord is (zoals waargenomen via remote sensing beelden), verbergt het kronendak sociale en ecologische problemen die verband houden met de levering van lokale ecosysteemdiensten. De participatieve karterings-benaderingen die in deze studie casussen werden toegepast, toonden aan hoe hiaten in kennis over patronen in het aanbod en gebruik van lokale ecosysteemdiensten in intacte bosgebieden kunnen worden opgevuld in lokale en regionale studies.

Ten tweede maakte dit proefschrift inzichtelijk welke factoren de ruimtelijke en temporele patronen van het gebruik van ecosysteemdiensten beïnvloeden in afgelegen en intacte tropische bosgebieden die onder externe druk staan. De bevindingen toonden aan dat de bereidheid van inheemse en tribale gemeenschappen om tropische bosgebieden te beschermen in toenemende mate verbonden is met de buitenwereld. Als zodanig is de uitdaging om de laatste intacte tropische bosgebieden van de aarde te beschermen groter dan we dachten. Dus zelfs als afgelegen en intacte bosgebieden vrij van wegen blijven, zorgt de uitbreiding van wegen, markten en commercieel landgebruik in de wijdere omgeving voor veranderingen in de lokale ruimtelijke en temporele patronen van het gebruik van ecosysteemdiensten in deze regio's, wat vervolgens leidt tot overexploitatie en ecosysteemdegradatie.

Ten derde, wanneer externe druk ontstaat in intacte bosgebieden, nemen de bestaande asymmetriën in de toegang tot hotspots toe en worden deze patronen van ruimtelijke ongelijkheid ook weerspiegeld in gebieden met een opkomend potentieel voor conflicten tussen gebruikersgroepen met differentiële toegang. Hoewel de gevonden asymmetriën deels te wijten zijn aan sociale ongelijkheden die verband houden met etnische scheidslijnen binnen gemeenschappen, toonde de analyse aan dat externe druk, zoals de uitbreiding van wegen en commerciële houtkapactiviteiten, deze juist verergert. Dit betekent dat bosgebieden niet als vrij van conflicten mogen worden beschouwd vanwege hun afgelegen ligging. Bemiddeling in potentiële conflicten is een belangrijk doel op zowel lokale als hogere niveaus van landgebruiksplanning, en bevindingen ten aanzien van verschillen in toegangsmogelijkheden zoals hier worden gerapporteerd, onderstrepen de noodzaak om criteria van ruimtelijke gelijkheid te integreren en te verantwoorden in de planning van mogelijke commerciële landgebruiksactiviteiten.

Ten slotte laten de resultaten in dit proefschrift zien dat de algehele participatieve aanpak, de coproductie van kennis door lokale gemeenschappen en onderzoekers, het nut van het incorporeren van een derde dimensie in participatieve kartering en de betrokkenheid van een geïnspireerde lokale voorvechter en intermediaire organisatie cruciale factoren zijn om te bevorderen dat kennis die gezamenlijk is geproduceerd via participatieve kartering ook daadwerkelijk gebruikt kan worden in besluitvorming over landgebruik.

In toekomstig onderzoek is een diepgaandere analyse van de sociale processen die beslissingen over landgebruik beïnvloeden noodzakelijk, om een beter begrip te krijgen van de factoren die leiden tot effectieve natuurbescherming in intacte bosgebieden. De bevindingen in dit proefschrift leveren al wel een belangrijke bijdrage aan het oplossen van enkele uitdagingen van de schaarste aan gegevens over intacte tropische bosgebieden. Het draagt vooral bij aan het opvullen van het huidige tekort aan lokale ruimtelijke kennis over intacte bosgebieden in regionale en wereldwijde scenario's van landgebruiksplanning, zoals wordt benadrukt in het nieuwste IPBES Global Assessment Report over ecosystemen en biodiversiteit. Tot slot heb ik ook laten zien hoe de gegenereerde informatie en het karteringsproces zelf hebben bijgedragen aan de versterking van de capaciteit van lokale gemeenschappen om effectiever te participeren in nationale dialogen over landgebruik en natuurbescherming.

Resumen

Uno de los mayores retos en las próximas décadas es el de fortalecer la capacidad de las comunidades indígenas para que continúen manejando de manera integral y sostenible los bosques intactos que habitan. Estos bosques naturales de gran extensión en los trópicos ofrecen oportunidades únicas para mitigar dos de los mayores problemas ambientales que enfrenta el mundo: el cambio climático y la pérdida de biodiversidad. Existe amplia evidencia que demuestra como el manejo local que las comunidades indígenas realizan en estos bosques beneficia la conservación de estas áreas a escala global. Sin embargo, la creciente expansión de usos comerciales de la tierra dentro y alrededor de los bosques intactos, incluyendo la extracción de recursos madereros, la producción a gran escala de productos básicos, la minería, la ganadería y la infraestructura de transporte y energía, han generado diversas consecuencias para los medios de vida locales, debilitando así la capacidad de las comunidades locales para manejar y conservar efectivamente estas áreas.

Por este motivo, se hace urgente la necesidad de dar voz a las comunidades indígenas en la toma de decisiones territoriales que las afectan, así como considerar los intrincados procesos de transformación social y ecológica a los que están expuestas al llegar las presiones externas. No obstante, las herramientas y enfoques que consistentemente permiten su participación en la toma de decisiones sobre usos del suelo, aún no están suficientemente disponibles. Además, nuestro entendimiento científico sobre cómo las presiones externas afectan las dinámicas espaciales y temporales de los servicios ecosistémicos de los cuales las comunidades indígenas dependen y cómo esto a su vez influencia la conservación de los bosques intactos, es todavía precario. Esta tesis de doctorado busca abordar estos vacíos de conocimiento fundamentales a través de dos objetivos. Primero, generar un entendimiento sobre cómo las presiones externas afecta la dinámica

espacial y temporal de servicios ecosistémicos de uso local y segundo, busca entender cómo este conocimiento puede ser usado para responder a estas presiones y promover así procesos de tomas de decisiones sobre uso de la tierra más inclusivos, que reconozcan las necesidades y prioridades de las comunidades indígenas en relación al uso de los servicios ecosistémicos de los que dependen.

La tesis está compuesta de tres casos de estudio, uno en la Amazonía Colombiana (capítulo 2) y dos en Surinam (capítulos 3, 4 y 5).

El **capítulo 2** analiza cambios en espacio y tiempo de los servicios ecosistémicos de provisión más importantes para las comunidades indígenas en el corregimiento de La Pedrera, Departamento del Amazonas, Colombia. En este estudio, algunas de las causas y consecuencias de dichos cambios, en relación a las prácticas de manejo local, fueron también investigadas. Para este propósito, la metodología integró 22 discusiones en grupos focales, 8 reuniones comunitarias y 16 actividades de mapeo participativo con un total de 158 personas distribuidas en 10 comunidades indígenas. Los resultados del análisis temporal mostraron que en las últimas dos décadas, la demanda por alimentos y materia prima se intensificó y, como consecuencia, la cantidad de estos servicios disminuyo y las áreas donde éstos se encontraban, cambiaron. Asimismo, los resultados mostraron que en 20 años, la mayor expansión de áreas de provisión fue para madera (61%), carne de monte (42%), pesca (43%) y palma para la fabricación de techos (62%). Por el contrario, el análisis reportó una reducción en el tamaño de áreas de provisión de medicinas (81%), ornamentos para bailes tradicionales (53%) y resinas (40%), los cuales están relacionados con modos de vida tradicional. Del mismo modo, este estudio demostró cómo las crecientes necesidades económicas de las comunidades indígenas, así como la proximidad a centros de comercio, cambia la manera cómo las comunidades indígenas usan y manejan los servicios ecosistémicos de provisión y cómo el detrimento de estas áreas afecta el manejo adaptativo que ha caracterizado las comunidades indígenas de la Amazonía. La aproximación espacial desarrollada en este capítulo ofrece una simple, rápida y robusta manera para entender los factores que influyen en el uso local de servicios ecosistémicos, a través del tiempo y el espacio, en regiones caracterizadas por la escasez de información.

El **capítulo 3** investigó el tamaño y la ubicación espacial de las áreas de uso que son esenciales para mantener la provisión de servicios ecosistémicos de importancia local para comunidades indígenas en el sur de Surinam. Dichas comunidades carecen de titulación colectiva de la tierra. Para este propósito los datos fueron colectados a través de una actividad de mapeo participativo individual con 191 personas en cinco comunidades indígenas. Utilizando como base una cartografía impresa de la zona, los participantes dibujaron polígonos alrededor de las áreas de provisión de servicios de subsistencia, culturales así como áreas importantes para la provisión de ingresos económicos y áreas de reserva para la provisión de servicios ecosistémicos en el futuro. El análisis espacial de ésta información resultó en la identificación de áreas importantes (*hotspots*) para la provisión de dichos servicios a los cuales se aplicaron seis métricas de paisaje que asistieron la delimitación de áreas de uso. El análisis arrojó cinco áreas en uso que en total sumaron 2.7 millón hectáreas. El tamaño promedio de dichas áreas fue 532,410 hectáreas por comunidad indígena. Las métricas de paisaje proporcionaron una indicación de cuales servicios son principalmente valorados. Por ejemplo, los *hotspots* correspondientes a áreas de provisión futura ocuparon 60.6% del total del área de uso, seguido por *hotspots* de servicios ecosistémicos relacionados con subsistencia (44.5%), valor cultural (29.5%) y económico (19.8%). La delineación espacial de las áreas con valor para el uso futuro es una contribución importante de esta tesis de doctorado. La metodología aplicada en este caso de estudio fue especialmente diseñada para llenar vacíos de información en zonas pobremente estudiadas. Asimismo, los resultados obtenidos constituyen una línea base de información que puede ser usada para la evaluación de impactos de usos de la tierra. Esto es especialmente importante en zonas donde las comunidades indígenas carecen de derechos colectivos sobre el uso de la tierra. Relacionado con esto, los resultados obtenidos en este caso han sido usados por las comunidades indígenas para influenciar políticas nacionales de conservación encaminándolas a la preservación de sus áreas en uso.

El **capítulo 4** estudia cómo las presiones externas afectan la equidad en el acceso a áreas de provisión de importantes servicios ecosistémicos, lo que ha sido denominado en este capítulo como equidad espacial. La metodología empleada incluyó una comparación entre dos regiones, en la Cuenca alta del río Surinam: una región afectada por la extracción comercial de madera y por la expansión de infraestructura de carreteras y otra región, más remota, donde estas intervenciones están planeadas pero aún no ejecutadas. Datos espaciales fueron colectados para los años 1995 y 2015 a través de una actividad de mapeo histórico participativo con 493 residentes de la Cuenca. Los datos colectados fueron agregados para definir áreas de importancia (hotspots) para la provisión de pesca, madera y cultivos (este último solo cuenta con datos para el 2015). Después, diferentes dimensiones de equidad fueron estudiadas de acuerdo a pertenencia a clanes y a la posición de autoridad, analizando esto a través del tiempo y del espacio y comparando entre regiones. Los resultados mostraron que en la región con intervenciones existen preocupaciones antes la emergencia de inequidad espacial en relación a la provisión de madera. Asimismo los resultados mostraron que aspectos de inequidad espacial se anticiparon en la región más remota con las expectativas económicas generadas en relación a nuevas carreteras en zonas de bosque cercanas. El análisis también mostró las áreas que son más susceptibles a conflictos entre usuarios relacionados con asimetrías de acceso a *hotspots*. Este estudio proporcionó un entendimiento empírico sobre cómo las comunidades con una economía de subsistencia cambian sus patrones de uso de servicios ecosistémicos en bosques remotos a medida que las presiones externas se van presentando. Este capítulo sugiere que un análisis sobre equidad espacial puede resaltar una dimensión social esencial en el uso del espacio la cual debe ser integrada en proceso de ordenamiento territorial. La principal contribución de este estudio es el desarrollo de una metodología que constituye una manera rápida pero robusta de operacionalizar aspectos de equidad espacial en regiones remotas de bosque, que han sido poco estudiadas y las cuales se encuentran bajo presión.

El **capítulo 5** evaluó en qué medida el mapeo 3D participativo (P3DM) es efectivo para promover la generación de conocimiento usable en la práctica de toma de decisiones así como su efectividad para promover la inclusión de las prioridades y necesidades de las comunidades indígenas marginadas, en procesos de planeación de usos de la tierra. Para este propósito se realizaron cuatro reuniones comunitarias, 12 grupos de discusión focal y ocho talleres de mapeo participación en 24 comunidades en la Cuenca alta del río Surinam. En total se contó con la participación de 267 personas. Igualmente, se realizaron 38 entrevistas semi-estructuradas con tomadores de decisiones de política de uso del suelo. La aplicación de estas metodologías resultaron en la eficiente identificación y evaluación de 36 servicios ecosistémicos y su representación espacial en un modelo 3D del paisaje. Estos servicios ecosistémicos se agruparon en tres categorías, incluyendo servicios de provisión, servicios culturales y servicios de regulación. Del primer grupo, cultivos, pesca, carne de monte, madera y medicinas silvestres fueron priorizados. Sin embargo, los resultados mostraron una reducción en la demanda de cultivos, carne de monte y pesca atribuida, de acuerdo a la percepción de las comunidades locales, a la degradación de las fuentes donde éstos son obtenidos, a factores demográficos y a cambios en los modos de vida tradicionales, en particular en la región norte de la zona de estudio la cual es afectada por intervenciones externas (ej. carreteras y extracción comercial de madera). La metodología P3DM demostró su efectividad para producir conocimiento sobre servicios ecosistémicos, de manera simple pero robusta, útil y asequible para diferentes actores, especialmente para actores locales. La metodología P3DM también demostró cómo el uso de la tercera dimensión en el mapeo participativo, favorece la apropiación del proceso y del conocimiento por parte de las comunidades locales que lo proveen.

Las principales conclusiones que se derivan de ésta tesis doctoral son las siguientes:

Primero, ha demostrado cómo el mapeo participativo puede ser usado para generar entendimiento sobre procesos espaciales y temporales asociados a la provisión de servicios ecosistémicos en regiones boscosas remotas y para las cuales existe muy poco conocimiento. Aunque los bosques, observados desde arriba, parecen intactos, esconden, debajo del dosel, diferentes problemas sociales y ecológicos relacionados a la provisión de servicios ecosistémicos locales que amenazan su conservación. Por eso, el mapeo participativo en estas áreas es una herramienta importante para llenar vacíos de conocimiento sobre patrones de provisión y uso de los servicios ecosistémicos en bosques intactos.

Segundo, ésta tesis doctoral puso en evidencia los factores que afectan dichos procesos espaciales y temporales en el uso local de servicios ecosistémicos en bosques remotos y que se encuentran bajo presión externa. Los resultados han mostrado que el interés de las comunidades locales para proteger los bosques donde viven, está estrechamente asociado con factores externos y por eso, el reto de conservar bosques intactos es más grande de lo que se piensa. Aunque se mantuvieran estas áreas libre de intervenciones como carreteras, centros económicos, mercados, entre otros, usos comerciales de la tierra en regiones boscosas aledañas provocan cambios adversos dentro de estas regiones libre de desarrollo.

Tercero, cuando las presiones externas emergen en regiones intactas, las asimetrías preexistentes en cuanto a la equidad en el acceso a áreas importantes de provisión (hotspots), incrementa. Estos patrones de equidad espacial son también reflejados con la emergencia de áreas de conflicto potencial entre usuarios con diferentes posibilidades de acceso. El análisis mostró que a pesar de que algunas de las asimetrías encontradas se relacionan con asuntos étnicos, las presiones externas, como la producción comercial de madera y la expansión de carreteras, están exacerbándolas. Esto quiere decir que los bosques intactos no están conservados intrínsecamente en virtud de su condición remota. Del mismo modo, mediar los conflictos que puedan emerger debe ser un objetivo importante en procesos de toma de decisiones sobre el territorio. Así, los resultados sobre acceso asimétrico, como las que se informan aquí, subrayan la necesidad de integrar aspectos de equidad espacial en la planificación territorial.

Por último, los resultados de esta tesis sugieren que el esquema de participación, la colaboración entre investigadores y comunidades locales, la integración de la tercera dimensión en el mapeo participativo, así como la presencia de un líder empoderado y una organización facilitadora, son aspectos cruciales para promover el uso del conocimiento generado a través de mapeo participativo, en procesos de toma de decisiones sobre el territorio.

En investigaciones futuras, análisis más profundos serían requeridos sobre los procesos sociales influenciando los procesos de toma de decisión para poder entender mejor los factores que afectan la conservación efectiva de los bosques intactos. Sin embargo, los resultados de esta tesis doctoral son una contribución importante para resolver retos relacionados con vacíos de conocimiento en regiones con bosques intactos. En particular, la tesis contribuye a llenar el déficit de conocimiento local espacial que aún caracterizan evaluaciones globales del estado de la biodiversidad, como fue realzado en el último Informe de Evaluación Global sobre Biodiversidad y Servicios Ecosistémicos (IPBES) de mayo del 2019. Por último, he mostrado cómo la información generada así como el proceso de mapeo han fortalecido la capacidad de las comunidades locales para participar más efectivamente en diálogos nacionales sobre el uso de la tierra y conservación.

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About the author

Sara Olga Inés Ramírez Gómez was born on July 15th 1978 in Pereira, Colombia where she also attended school. After graduating from high school and before starting her bachelor in Environmental Sciences at the Universidad Tecnológica de Pereira, Colombia (2005), Sara designed and implemented a one-year project on her own, titled *Alianza con la niñez y el medio ambiente.* During her entire bachelor, Sara was actively involved in the birdwatching group of the university, through which she got involved in different conservation projects with local and regional environmental institutions. In 2002, Sara did a research internship with Fundación Pro-Sierra Nevada de Santa Marta, including the inventory of birds during six months of fieldwork. For her bachelor thesis, Sara stayed six months in Central Kalimantan, Indonesia, to conduct fieldwork related to the design of a conservation corridor involving agroforestry systems. This bachelor thesis received a mention of honor in 2005. In 2006, Sara started a research master in Tropical Ecology at the University of Amsterdam, The Netherlands. In this period (2006-2008), Sara did a first research internship with Tropenbos International Suriname related to the biophysical characterization of a savanna landscape in Suriname and a second one with the Center for Latin American Studies CEDLA focused on spatial analysis of deforestation along the Corredor Norte in the Bolivian Amazon.

In the past seven years, she has worked with international NGOs including Conservation International Suriname and Colombia, WWF Guianas and Tropenbos International Suriname, on topics that involve participatory GIS to inform land use and marine spatial planning. Empowering local communities as to enable their participation in decision-making, is a theme that has played a central role in her work over those years. Sara was responsible for the acquisition of project funds (>140 kEuro) and assisted in obtaining finance for other projects

(350 kEuro), which she successfully implemented and managed in the last five years, including financial management and reporting. All this work experience has been relevant for and culminated into the PhD research project at Utrecht University.

Scientific publications

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Other publications

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