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Multi-Scale Analysis of Common-Pool Resources for Ecosystem Conservation in the Orinoco River Watershed

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MULTI-SCALE ANALYSIS OF COMMON-POOL RESOURCES FOR ECOSYSTEM CONSERVATION IN THE ORINOCO RIVER WATERSHED

A Dissertation Presented

By

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DEDICATION

To my parents, Martha and Pedro

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ABSTRACT

MULTI-SCALE ANALYSIS OF COMMON-POOL RESOURCES FOR ECOSYSTEM CONSERVATION IN THE ORINOCO RIVER WATERSHED

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Adaptive management strategies are mechanisms that help governments to overcome problems derived from the sudden change of ecosystems processes and dynamics and to maintain the provision of ecosystem services to the population. These strategies rely on multi-scale networks of governing institutions that work together for the protection of the environment and cooperate for the solution of pressing issues. Sometimes, however, two issues imperil the persistence of local institutions within these networks, (1) their rights to govern their territory and to self-organize are not recognized, and (2) the nested and polycentric systems that operate through the multi-scale network are weak or inexistent. This research studies the case of the Orinoco River Watershed to answer the questions about what are the causes and characteristics that impede the progress towards an ideal multi-scale and polycentric system in developing countries. Three scales are studied: watershed, in the interface between regional and local scales, and local scales. Findings from the analysis of the ecosystem services' spatial distribution at the watershed scale show that the Andean region is essential for the protection of

strategic ecosystems throughout the watershed. Between regional and local scales, the results indicate major disparities between actors about the importance of protecting certain natural resources, also, it was also found that groups of local actors disagree about the main economic factors that drive the socio-ecological dynamics. Through the analysis of Indigenous peoples' Life Plans, at a local scale, it was possible to identify the factors that undermine Indigenous peoples' social resilience. Loss of traditional knowledge is one of the most important aspects, followed by low coverage of basic services. The best-rated indicator was the internal organization, which helps them to maintain their traditions and cohesion among the members within their Indigenous reserve. Even though there is no single solution for addressing the issues derived from a lack of articulation and limited recognition of local institutions, the final chapter summarizes these key findings, to elaborate over what type of strategies could contribute to the improvement of multi-scale and polycentric governance of common-pool resources.

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CHAPTER 1

INTRODUCTION

Communities in developing countries are highly reliant on local ecosystem services (UNDP, 2012; Hailu et al., 2011; Swenson et al., 2011; Randhir & Hawes, 2009) and a rapid degradation of these ecosystems is threatening their livelihoods (Seto et al., 2012; Millennium Ecosystem Assessment, 2005). While governments aim to protect ecosystems that provide these services, they also must find ways for growing their economies; a different role considering that most developing countries base their economies on extractive industries (Ray et al., 2016). Resource management and governance of watershed systems in most of these countries is formally a state responsibility (Randhir, 2016). Indigenous peoples and other non-Indigenous local communities maintain their own sense of responsibility and define governance and management of land and water use. Only a few of them share the authority and responsibility with local actors. Growing awareness of the advantages of having a multi-scale system for the governance of common-pool resources is shifting how these governments interact with local actors.

Effective governance of common-pool resources by local communities has been amply studied throughout the world. It has been suggested that two important external conditions influence the persistence and efficiency of long-lasting local institutions, which are: (1) the existence of multi-scale structures that connect institutions within and across each scale, and (2) governmental authorities that grant local communities some level of authority for crafting and enforcing resource-use rules, and that recognize their right to organize in local institutions (Randhir, 2016; Olsson et al., 2007; Ostrom, 2005, 1990).

In this dissertation, factors that undermine these two conditions are studied at multiple scales using the case of the Orinoco River Watershed (ORW). The ORW is the second largest in South America and covers parts of Colombia and Venezuela. The central argument in this dissertation is that local institutions in developing countries lack two fundamental principles, namely interaction with other multi-scale institutions and public recognition of their rights to organize and govern common-pool resources, and that only it is through the detailed analysis of the factors that undermine these principles, that it is possible to formulate plausible solutions. Thus, this research aims to identify and characterize multi-scale socio-ecological dynamics and governance factors that promote or impede the progress of local governance of common-pool resources within a region undergoing rapid transformations.

1.1 Loss of ecosystem services in watershed systems

Sustaining the growth and development of a society depends upon well-functioning economic and ecological systems; therefore, the success of protecting ecosystems has a bearing on our societal survival. This is especially relevant in developing countries, where dependence on ecosystems by the society is high (Randhir & Hawes, 2009). Degraded environments can result in a breakdown of ecosystem services with detrimental impacts on the quality of life for human and wildlife populations.

Rapid land use changes are transforming ecosystems throughout the world, causing the loss of biodiversity in pan-tropics (Seto et al., 2012), and reducing ecosystem services necessary to sustain human well-being (Millennium Ecosystem Assessment, 2005). Activities that transform the ecosystems include agriculture, urban development, mining, fossil fuel extraction (oil and gas), construction of infrastructure to support the development and economic growth, globalization, and other socioeconomic influences like conflicts. Watershed systems are sensitive to these impacts; for instance deforestation increases flood and erosion risks (Li et al., 2016; Erkal & Yildirim, 2012; Chen et al., 2011), reduces soil capacity to grow food (Dadson et al., 2013), and contributes to climate change (Dadson et al., 2013; Lanckriet et al., 2012).

1.2 Governance of common-pool resources

Environmental regulations aim to protect ecosystems for the well-being of a society. These are necessary for overcoming environmental issues and for preventing further reduction of goods and services (Hasnas, 2009; Ostrom, 2005). There are two common types of policies created by the governments, command-and-control policies, and market-based policies through allowances. Some governments adopt policies that devolve responsibility for governance and management or share power in co-governance arrangements. While command-and-control policies aim at rules and regulations that govern social behavior (Hasnas, 2009), market-based policies use incentives to encourage change in user behavior (Hasnas, 2009; Raymond, 2003).

Factors that challenge the formulation and enforcement of rules in developing countries are corruption, lack of resources to protect the ecosystems, poverty, and internal competition for resources. Under the influence of powerful corporations, developing countries lower their environmental regulations for attracting economic investments.

Therefore global demands for raw materials can lead to unsustainable environmental goals (Gale, 2014; Boyce, 2013).

Also, it is difficult to ensure the provision and protection of services when there is conflict over governance authority, legitimacy, or jurisdictional discrepancies between material law and cultural law. Furthermore, ineffective regulations in these countries can cause the depletion of ecosystem services, which is often correlated with environmental injustice, unequal distribution of wealth and power, and potential cultural extinction (Matthews et al., 2014; Boyce, 2013; UNDP, 2012; Hailu et al., 2011; Swenson et al., 2011).

Common property is often regulated differently as it relies on self-organized and self-governing institutions (Ostrom, 1990). These are complex systems in which people cooperate and create agreements for the use of common-pool resources by resolving conflicts, organizing their institutions, and creating norms, rules, and control mechanisms, all of which are based on their knowledge of the ecosystems (Ostrom, 1990). Local institutions have succeeded in governing fisheries (Berkes, 2009; Moller et al., 2004), community forest and forest reserves (Nagendra et al., 2008), protected areas (Stevens, 2014; Borrini-Feyerabend et al., 2013; Stevens, 1997), and watersheds systems in developing countries (Randhir, 2016; Sharma et al., 2010; Nagendra et al., 2008). They improve socio-ecological adaptability to unexpected changes (von Homeyer, 2010), help with finding successful rules and corrective actions (Premauer & Berkes, 2015), and contribute to human and natural capital at a local scale (Lopez-Gunn, 2012).

In rapidly changing regions of the world, effective adaptive management systems are crucial (Randhir, 2016; Berkes, 2009). Adaptive management involves the participation of local institutions in adapting to stress and environmental changes. However, not all institutions are equally effective in preventing natural resources depletion. Ostrom has suggested eight principles that allow local institutions to govern their common-pool resources effectively (Table 1-1), based on typical characteristics of robust self-governing institutions (Ostrom, 1990). Principles 1 to 6 apply to aspects related to the group of local appropriators (internal principles), and principles 7 and 8 involve higher scales of governance such as regional and national scales (external principles) (Ostrom, 2005).

Principle 7 refers to the minimal recognition of people's right to organize and regulate the use of local resources. For instance, the Colombian national constitution (República de Colombia, Constitución art. 329 1991) recognizes the right of Indigenous peoples to define the use of resources within their territories. Despite this, the advancement of national development projects interferes with Indigenous communities' autonomy to govern their territories (Baena, 2015). Similarly, regional development plans override collective community initiatives for the governance of the resources.

Principle 8 refers to nested enterprises. These are social structures that interact at multiple scales. This is similar to watersheds, which are by nature nested systems where biophysical dynamics are linked by stream networks. Also, within watersheds multiple social actors and institutions interact in the same place and at the same spatial and temporal scales.

Table 1-1. Institutional design principles

Design principle	Description
1. Clearly defined boundaries	The boundaries of the common property, its resources, and users are clearly defined.
2. Proportional equivalence between benefits and costs	The rules that allocate resource products to users. These rules must consider local conditions and costs associated with the extraction and use of the resource.
3. Collective-choice arrangements	An important proportion of the people involved in modifying these rules must represent the group of individuals affected by harvesting and protection rules.
4. Monitoring	The tasks related to monitoring the biophysical conditions and auditing users' behaviors are executed by the users themselves. When monitors are different from the users, they must be accountable to the users.
5. Graduated sanctions	Violators are subject to receive a sanction that is proportional to the seriousness of the offense
6. Conflict-resolution mechanisms	There is access to rapid and low-cost mechanisms for resolving the conflicts at local scale
7. Minimal recognition of rights to organize	The rights of users to devise their institutions are not challenged by external, governmental authorities, and users have long-term tenure rights to the resource
8. Nested enterprises	Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises.

Source: Ostrom, 1990

This works as a polycentric system, in which nested social organizations coordinate efforts at multiple scales to govern common pool resources, they collaborate in the implementation of management practices, and involves the adoption of mechanisms for solving conflicts. Through polycentric systems, state institutions support local governance providing an efficient sanctioning system, and local governing institutions help with mobilizing and coordinating legal actions for the protection of the environment.

At local scales, Indigenous peoples and other local communities have profound links with their territories, and they have a long tradition of governing and conserving their resources (Stevens, 1997). However, their legal tenure right is not always recognized by the national governments (Almeida et al., 2015). The creation of national parks was used in the past as an excuse for the eviction of Indigenous peoples and other local communities from their traditional territories (Stevens, 2014) and only until recent decades collective customary rights are being recognized. These communities and their ways of living are being recognized as important mechanisms for the conservation of the biodiversity (Kothari et al., 2011).

For a long time, states around the world disregarded Indigenous peoples' knowledge and traditions (Berkes, 2009) but during the last few decades, a shift in paradigms of the international regulation of the world's protected areas occurred by recognizing Indigenous rights, and new categories of protected area governance now include the participation of Indigenous peoples and other local communities (Stevens, 2014). Nowadays, protected areas around the world host cases of local institutions that are engaged in the protection of critical ecosystems.

Co-management (also referred as co-governance and shared governance) is a mechanism for collaboratively governing common-pool resources, between the state and local institutions, and some countries have adopted it in the management of protected areas (Premauer & Berkes; 2015; Stevens, 2014; Bown et al., 2013). With co-management, national institutions and regulations incorporate agreements between parties, resulting in some cases in the recognition of Indigenous peoples' traditional institutions and practices as legitimate means for the management of strategic ecosystems. Also, through co-management, Indigenous peoples' traditional ecological knowledge is recognized in environmental sciences (Moller et al., 2009; McGregor, 2004; Moller et al., 2004).

Besides co-governance, in which traditional communities and the state government share power, some countries started to recognize full autonomy over the governance of protected areas and areas that contain important common-pool resources by Indigenous peoples and traditional local communities (Almeida et al., 2015; Stevens, 2014). Some countries have recognized these collective customary tenure systems within the national legislation, but there are cases in which these systems work *de facto* because the governments do not recognize Indigenous peoples' and traditional local communities' conservation values (Almeida et al., 2015).

Overall, environmental issues in developing countries impact their social-ecological systems, imperil their social structures and governmental institutions, and could compromise these institutions under the pressure of international markets that are often preferential to have their investments in countries with less restrictive environmental policies. One dimension of these problems is the need for a better understanding of the multi-scale nature of socio-ecological systems and local governance structures.

The first section below focuses on the current state of strategic ecosystems within watersheds and their main challenges, followed by the state of ecosystem service research; the contribution of this research; the objectives; research questions and hypotheses, and finally the dissertation plan.

1.3 Current state of strategic ecosystems within watersheds and their main challenges

Some of the ecosystem services in watershed systems are hydrologic regulation, maintenance of water quality and quantity, retention of pollutants, filtration of sediments, water storage and percolation into the ground preventing floods, conservation of fish populations for human consumption, timber, erosion prevention, soils for growing food, wildlife, preservation of gene pools and gene flow, medicinal plants, pollination, recreation, and protection of cultural heritage. Changes in watershed biophysical composition affect these services. The most pervasive stressors are deforestation, land-use change, pollution, and water withdrawal (Mekonnen & Hoekstra, 2015; FAO, 2010; Doll et al., 2009; Millennium Ecosystem Assessment, 2005). Explorative industries are less analyzed at a watershed level, but the effects of these industries have detrimental and long-lasting impacts on the systems (Carrasco et al., 2007; Orta-Martinez et al., 2007). All these issues mainly affect developing countries; specifically, local and traditional communities whose livelihoods are intimately linked to their environment.

Watershed systems host multiple biophysical sub-systems, such as streams, wetlands, forests, groundwater, riparian corridors, and marshes, among others, all of which host important wildlife populations. This research is concerned with three main biophysical components in watershed systems: freshwater ecosystems, forests, and biodiversity. Freshwater ecosystems interact within watersheds as part of the complex network of streams, surface, and underground runoff in deep connection with the soils (Brooks, 2003). Hydrological dynamics in watershed systems, such as water flow and water storage, depend upon the interaction between freshwater ecosystems and forest throughout the soils and the atmosphere (Dadson et al., 2013). Biological elements play a crucial role in structuring these ecosystems, and through the trophic cycle, these factors maintain the flow of matter and energy (Iñiguez-Armijos et al., 2014), supporting ecosystem services throughout the watershed. Worldwide, different stressors affect these elements of watersheds, and it is particularly important to understand these stressors and their effect on watershed's ecosystem services to advance towards integral solutions.

Global efforts to protect the environment have led to critical intergovernmental agreements and initiatives. Two agreements are particularly influential in the protection of freshwater ecosystems, forests, and biodiversity. The Ramsar Convention was signed in 1971 to protect wetlands, an important freshwater ecosystem component, around the world. The other agreement is the Convention on Biological Diversity (CBD) signed in 1992 to attain the conservation of biological diversity, sustainable use of biodiversity, and equitable sharing of benefits arising from genetic resources. International agreements have allowed the declaration of protected areas, by the IUCN's World Commission on Protected Areas (Borrini-Feyerabend et al., 2013), and the creation of the world network of biosphere reserves (UNESCO, 1996), for the protection of important ecosystems and the conservation of global biodiversity.

Global efforts in the protection of the environment in developing countries are driven by initiatives to eradicate poverty outlined by the Millennium Development Goals, which define key elements for international cooperation. Under this framework, The United Nations Development Program - UNDP supports sustainable development initiatives around the world. Additionally, REDD (Reducing Emissions from Deforestation and forest Degradation) is used as a mechanism for climate change mitigation through forest management in developing countries.

In addition to those agreements and initiatives, the environmental governance and management take place at all levels, from global/regional to local. It encompasses the rules, practices, policies, and institutions that shape how humans interact with the environment (Ostrom, 2005). Some governance strategies are the promotion of informed decisions based on scientific knowledge, international cooperation (to provide technical assistance, formulate international rules, norms, and standards), and national and regional development planning. For instance, worldwide, protected areas follow four governance regimes: governance by the government (of all levels), shared governance or co-management (multiple stakeholders often including the government), governance by private individuals and organizations, and governance by Indigenous peoples and local communities (Borrini-Feyerabend et al., 2013; Lausche, 2011).

Developing nations face the challenge of governing common-pool resources with limited institutional capacity (Hailu et al., 2011); in the sense of gathering political instruments, knowledge and information, infrastructure, social capital, and facilitating effective communication between and within institutions. Indigenous peoples' territories host an important portion of the world's forests and biodiversity, therefore including these peoples in the future of ecosystems management can play a fundamental role in achieving global conservation goals, a major part of developing countries' challenges.

Developing countries will benefit from improved local environmental governance articulated with multi-scale governance, and a more precise definition of ways to articulate Indigenous peoples to these processes. Some development projects represent significant threats and challenges for these nations and peoples. These nations will have to work to control and manage the detrimental effects of these projects, and they will have to consider Indigenous peoples' rights and cultural values in protecting the watershed's ecosystem services. A detailed overview of the current status of the watersheds' three main components (freshwater ecosystems, forest, and biodiversity), their global status, influencing stressors, impacts on watersheds' ecosystem services, and related governance issues, which together constitute a baseline to analyze watersheds' environmental challenges, is presented in the following section.

1.3.1 Freshwater ecosystem services

About 80% of the world's water resources are impacted by human action (Voorosmarty et al., 2010), making freshwater ecosystems the most endangered ecosystems of the world (Knieper & Pahl-Wostl, 2016). Freshwater ecosystems suffer water stress due to reductions in their ecological streamflow. Agriculture, urban areas, and industries alter water that feeds these ecosystems, not only subtracting an important portion from the ecological stream from inland ecosystems but decreasing 3.5% of the global annual discharge of water into the ocean (Doll et al., 2009). Irrigation systems have been found responsible for increased inter-annual streamflow variability on onequarter of the land area, whereas dams and reservoirs are accountable for the reduction of seasonal flow amplitude in one-sixth of the land area (Doll et al., 2009).

The pollution from agriculture impacts the water quality of freshwater ecosystems (Randhir & Hawes, 2009), which is an essential economic activity in developing countries (FAO, 2012). Recent global estimates of nitrogen load by basins show that 35 million tons of nitrogen are released into freshwaters. Agriculture contributes to 75% of this value, followed by domestic sector and industry, releasing 23% and 2%, respectively (Mekonnen & Hoekstra, 2015). Even though this assessment has a considerable uncertainty range (-33% to 60%), it calls attention to the current pollution crisis in various basins in the world, mostly due to excessive use of nitrogen. For major river basins, freshwater-ecosystems' natural capacity to assimilate and dilute pollutants may be totally consumed by nitrogen load alone (Mekonnen & Hoekstra, 2015).

These variations in the amount and quality of the water threaten the sustainability of aquatic ecosystems and related species, as well as the provision of water for human consumption. Alterations to the amount of water in the streamflow, its annual historical range of variation, and seasonal variability of streamflow can affect freshwater ecosystems and populations. Agricultural activities, irrigation, and loss of soil permeability are issues that affect developing countries. For this reason, it is essential to use an integrated approach in the management of watersheds, ensuring sustainable freshwater ecosystems and efficient use of the water for commercial and human activities.

Another issue that reduces ecosystem services from freshwater ecosystems is the fragmentation of the landscape. Given the complexity of interactions in the stream network within watersheds, the loss of connectivity affects habitat provision for aquatic and terrestrial species (Iñiguez-Armijos et al., 2014; Laurance 2012; Linke et al., 2012; Couceiro et al., 2010). Protection of land-cover in a watershed together with riparian ecosystems helps to maintain the water quality of Andean streams (Iñiguez–Armijos et al., 2014).

The oil industry is another prominent issue in watersheds. Wastewater from oil wells increases freshwater salinity (Moquet et al., 2014; Ma et al., 2012), and oil spills have long-lasting impacts on the ecosystems and human health (Carrasco et al., 2007; Moquet et al., 2014; Adebiyi & Adeyemi, 2015). At a watershed level, it pollutes groundwater and surface water, and increases soil loss (Ma et al., 2012; Couceiro et al., 2010; Uribe-Hernandez et al., 2012). For example, petroleum extraction was found to be responsible for increased salinity in El Tigre river; a small sub-watershed of the Amazon river watershed that on average discharges 2,100 m^3 sec^{-1} $year^{-1}$, less than 1% of the Amazon's total flow. During one hydrological year, between 2006 and 2007, this sub-basin contributed about 20% and 12% of the annual dissolved chlorine (Cl^-) and sodium (Na^+), respectively, in the Amazon (assuming that the yearly deep-water discharge from petroleum activity was 365 m^3 sec^{-1}) (Moquet et al., 2014). This case brings up a great concern about the potential threat that petroleum activities can have at the watershed and regional scales.

Increased concentrations of aromatic hydrocarbons and metals are commonly found in surface and groundwater, as well as in soils near oil wells (Moquet et al., 2014;

Adebiyi & Adeyemi, 2015). Surface and groundwater of the Malian river Basin of China's Longdong Loess Plateau, have been highly degraded by petroleum contamination, agriculture, and domestic wastewater; specifically, by increased salinity and high concentration of chromium, ammonium, and phenols (Ma et al., 2012). The evolution of water degradation in this basin was found to be correlated mainly with petroleum extraction, making the water of this basin unsafe to drink and unsuitable for use in irrigation (Ma et al., 2012). Although it has been proved that the exposure to these conditions could lead to physical malfunction and mental health deterioration (Carrasco et al., 2007), many communities around the world continue to be exposed to these threats.

For developing countries, the petroleum industry's expansion in resource-rich countries is highly controversial as it brings growing opportunities for the economies of these countries but is also linked to deep social, economic, and environmental challenges (UNDP, 2012). Freshwater ecosystems are profoundly impacted by this industry that is the main economic activity of many countries in equatorial latitudes, reducing people's welfare. Indigenous peoples in the upper part of the Amazon (Peru and Ecuador) are directly affected by the pollution from petroleum industries leading several health issues. Blood tests in Indigenous communities in the Amazon show high concentrations of Cadmium and Chromium (Moquet et al., 2014). Oil extraction also correlates with high rates of spontaneous abortion and cancer in these communities (Orta-Martinez et al., 2007).

Indirectly, Indigenous peoples are also affected by the encroachment of petroleum industries in their territories, since high wildlife demand for illegal trafficking and commercialization of bushmeat reduces wildlife populations available to hunt and fish

(Finer et al., 2008). Pollution of drinking water and reduced wildlife lead to malnutrition in Indigenous communities in the Amazon and overall health detriment (Orta-Martinez et al., 2007). Land colonization and oil extraction lead to other challenges for these communities that derive from the economic interests that lead to conflicts between Indigenous communities and governmental and petroleum (Moquet et al., 2014). These dynamics affect the Indigenous social structure and their culture. The challenge for these communities is to overcome their political isolation and empower their knowledge.

Local communities in developing countries are trapped between their needs to produce food for their livelihoods and to become the labor force for the economic projects of agriculture expansion, urban development, and industrial encroachment (Hailu et al., 2011; UNDP, 2006). As discussed above, these processes greatly impact the territories of Indigenous peoples who continue struggling for the defense of their rights, in particular, the right to free, prior and informed consent regarding proposed extractive projects on their lands (Finer et al., 2008).

Governance challenges for the protection of freshwater ecosystems derive from the complex network of elements and interactions involved (Knieper & Pahl-Wostl, 2016). Efficient planning for the conservation of area networks, ensuring freshwater ecosystems health into the future is an ongoing process. Freshwater safeguards require solving social and political issues (e.g., poverty, income inequality, unequal power relationships, and institutional capacity) (UNDP, 2006), but also need to consider the biophysical interactions that take place in a watershed to effectively protect systems that are spatially connected across the landscape. Conserving isolated ecosystems that host endemic or endangered species provide little help in supporting the whole network needed for these species' survival and functioning of these ecosystems (Dudgeon et al., 2006). Therefore, successful protection of freshwater ecosystems and conservation of the biodiversity relies on the integrated management of connected processes that take place in the network of streams, terrestrial, and aquatic ecosystems within a watershed.

Managing the impacts that reduce water availability and ecological streamflow, require a better understanding of the water balance and careful planning of urban and infrastructure development that consider hydrological cycles in the watersheds (Ahmadisharaf et al., 2016; Ficklin et al., 2013; Du et al., 2012; Seto et al., 2012). Best management practices, conservation agriculture, and integrated watershed development have been used as strategies to maintain the services from freshwater ecosystems (Singh et al., 2014; Lanckriet et al. 2012). However, the main impediments are not just related to technical solutions but also governing institutions and rules in their multi-scale interactions.

1.3.2 Forests

Hydrological, sedimentological, and ecological dynamics in watersheds are highly reliant on forested ecosystems. Forests intercept the rain, facilitate percolation of water through the ground, retain sediments, and provide landscape continuity for multiple species. Some of the multiple services found in these ecosystems are wood, hydrological regulation, erosion prevention, habitat provision for wildlife and medicinal plants, recreation, and for many cultures forests also are part of their identities. Nevertheless, forests are highly impacted across the globe. Considering the maximum area that could be covered by forest around the world, only 15% remains intact, 47% is either deforested or degraded, and 38% is fragmented (Hanson et al., 2015; FAO, 2010). From 2000 to

2010, the rates of forest loss were about 13 million hectares per year, and the rates of forest gain were approximately 5.2 million hectares per year (FAO, 2010) resulting in a negative balance with a loss rate of 7.8 million hectares per year.

Land use change is mostly driven by non-subsistence growth factors (i.e. economic growth and population growth), which are related to commercial agriculture that supply the global demands for food, fiber, and biofuels (Eisner et al., 2016). It has also been the cause of forest degradation during the last 50 years (Millennium Ecosystem Assessment, 2005). Other sources of land use change are extractive industry such as oil, gas, minerals, and gold. The impacts are often a result of the construction of access paths for exploratory analysis of hydrocarbon reserves in the underground, pipelines, drilling platforms (Finer et al., 2008), and settlement of people employed in extractive industry (Swenson et al., 2011). Overexploitation of forest goods, human disturbance to the ecological structure inside the forest, and illegal mining of the understories are often sources of forest degradation in regions with extractive industry (Swenson et al., 2011). Deforestation and fragmentation cause loss of ecosystem services, while deforestation alone can double the loss of biodiversity in the tropics (Barlow et al., 2016; Tracewski et al., 2016), and fragmentation affects metapopulations by restricting gene flow and lead to reduced rates of pollination (Kremen et al., 2007).

Protected forest areas are created to conserve biodiversity, maintain water resources, prevent soil degradation, and safeguard cultural heritage. Despite this initiative, only 12% of the world's forest is designated for the conservation of biodiversity (FAO, 2010). Studies demonstrate that human activities around forest reserves are causing the loss of forest's biological diversity (Barlow et al., 2016).

Understory fires, selective cutting of trees, and urban development in the tropics constantly transform protected areas' surrounding environment (Laurence et al., 2012). The regulations that protect strategic ecosystems in the tropics are inefficient in controlling anthropogenic influence in buffer areas limiting the efforts to protect these ecosystems and their biodiversity (Barlow et al., 2016). For instance, Brazilian forest regulations protect 80% of the Amazon rainforest through different protection regimes, but fail to manage the elevated rates of forest degradation and landscape fragmentation around and between protected areas, reducing the efficiency of these policies to 46-61% of their maximum conservation potential (Barlow et al., 2016). Given the strong relationship between forest loss and the fragmentation of the landscape that sustain wildlife populations (Tracewski et al., 2016; Kremen et al., 2007), protecting species with high conservation and functional importance requires not only preventing deforestation, but also the protection of ecosystems in these forests and spatial connectivity through the landscape (Ochoa-Quintero et al., 2015; Barlow et al., 2016).

Even though worldwide deforestation rates are being reduced and afforestation is gaining momentum, the destruction of native forests impacts ecosystems profoundly, and their recovery requires implementation of restoration programs while enhancing regulations to prevent their destruction and adverse transformation. Initiatives that aim to protect forest ecosystems are Reducing Emissions from Deforestation and Degradation (REDD+) (UNFCCC, 2016), which was created in 2005 with the double purpose of protecting forest around the world and for reducing greenhouse gases (GHG) that contribute to climate change. The New York Declaration on Forests, which was adopted in 2014, consists of a voluntary agreement among different interested nations and organizations to commit reducing natural forest loss in half by 2020, and try to end it by 2030.

The REDD+ intends to compensate developing countries for reducing forest-related GHG emissions or sequestering carbon through forest and land-use management strategies (Pistorius, 2012; Gupta et al., 2016). Ideally, REDD+ provides support to local communities willing to change their behavior toward the use of forest resources (Matthews et al., 2014). This program has resulted in the assessment of resources and development of monitoring indicators to measure the equivalent reduction of GHG emissions in each country (Matthews et al., 2014). Obstacles to this program are financial viability, fragmentation in global governance architectures, resistance to the monitoring, reporting, and verification system, and no clear definition of the means to its implementation.

REDD+ does not act on reducing market's demand for forest products or reducing forest conversion for growing food and biofuels, which are main drives of forest degradation, and it had resulted in the displacement of Indigenous peoples. REDD+ formulates rules and agreements that seek for the construction of concepts to be used to communicate or formulate policies and for the regulation of commercial strategies, such as labels that will identify certain forest products as sustainable (Matthews et al., 2014). REDD+ has been criticized for its focus on GHG reduction lacking an ample scope that will provide the instruments to reduce forest destruction (Matthews et al. 2014). Furthermore, REDD+ is expensive, and its implementation heavily relies on the governance capacity of the involved nations; these have been two main hurdles (Matthews et al. 2014).

Multi-scale governance is an effort to integrate global and local governances of forest ecosystem services. It aims to improve interactions among REDD+ stakeholders (public and private) and across various levels of governance (global through local) (Gupta et al., 2016). The nested approach was proposed by Pedroni and collaborators under the REDD+ framework as an alternative for the execution of projects that aim to reduce deforestation and forest degradation at a subnational level (Pedroni et al., 2009).

This suggestion is in response to the frustration in the implementation of REDD+ projects that get stuck due to national governance issues in developing countries, where institutions are slowly improving their technical and institutional capacity (de Janvry & Sadoulet, 2011; Pedroni et al., 2009). However, at subnational levels, NGOs and other organized groups are interested in participating in these projects. Therefore, Pedroni and collaborators formulate a scheme that allows developing countries to advance in the execution of these projects at a subnational level, even before they have fully matured their national governance systems (Pedroni et al., 2009).

Forest management policies in developing countries are still transitioning from restrictive regulations that forbid the use of the forest and imposed fines to violators, excluding local people and often expropriating their land and forest-use rights (Zulu, 2013). More recently in some areas of the world, traditional communities are being allowed to return to their customary territories. Governments are slowly recognizing Indigenous peoples' rights, and more broadly they are engaging in more participatory management strategies such as forest co-management (Zulu, 2013).

Some cases of co-management of forested areas have proved to be difficult due to the low human capital, conflicts between local leaders, and incentives (monetary vs. non-monetary) (Zulu, 2013; Nagendra et al., 2008). There have also been valuable examples of the importance of cooperation that leads to collective benefits, maintained collective participation, and appropriate compensation from the central government to local leaders for the success of locally managed forests (Zulu, 2013). Likewise, these examples demonstrate the benefits of adopting co-management within local communities' territories resulting in more effective conservation of the forest when compared to national parks (i.e., public lands) or open source lands (Nagendra et al., 2008). For instance, Indigenous peoples' traditional practices could explain why the low level of land-use changes in the Amazon occur where these peoples had existed for centuries (Nepstad et al., 2006) and why Brazilian deforestation rates are lower in Indigenous territories (Ricketts et al., 2010). Combined with this, it is important to consider that Indigenous lands and protected areas around the world contain more than 312 billion tons of carbon (Ricketts et al., 2010). All these facts support the importance of improving local governance by implementing co-management strategies and other cooperative actions.

To conclude, forests are ecosystems in which multiple actors with polarized interests interact. Forests' conservation requires an integrated approach that allows maintaining the structure and functions that provide habitat for numerous animal and plant species, as well as the livelihoods of traditional communities such as Indigenous peoples. Landscape connectivity and protection of buffer zones around protected areas are necessary actions that require a participative approach, as they have been proved to be more efficient. This method, is overall constrained by multiple challenges, particularly in developing countries.

1.3.3 Biodiversity

Worldwide, ecosystem health depends on the diversity of biological elements constituting their structure and function (Risser, 1995). Temporary changes in ecosystems disrupt the interactions between biological and physical elements, but it is through the same biophysical attributes that ecosystems recover from those temporary changes (Mori et al., 2013). Global biological diversity can help in solving problems that threaten food production through providing pest-resistant varieties (Evans, 2016; Scarratt et al., 2008), adaptation to extreme climates, and benefits to human health (through medical treatments for current and future diseases). Without adequate and prompt actions to conserve the world's biodiversity, humanity will be losing not just the opportunity to solve these sorts of problems (Evans, 2016; Cardinale et al., 2012), but will be threatening the stability of the ecosystems that support our existence.

Ecological processes in a watershed are highly reliant on its biological composition and vice versa. Unfortunately, the biodiversity of freshwater ecosystems and forests contained in the watersheds are rapidly declining (Barlow et al., 2016; Iñiguez-Armijos et al., 2014; Linke et al., 2012; Bai et al., 2011; Couceiro et al., 2010; Voorosmarty et al., 2010; Dudgeon et al., 2006). Biodiversity erosion decreases crops' resistance to different pests and diseases (Couceiro et al., 2010). For Indigenous peoples, who highly depend on wildlife and forests' plants, loss of biodiversity impacts their traditions and affects cultural diversity (Stevens, 2014). It also affects ecosystems' capacity to recover from disturbances (Evans, 2016; Iñiguez-Armijos et al., 2014; Mori et al., 2013; de Groot et al., 2010), and impair the capacity of the ecosystems to produce goods and services (IPBES, 2016; Maes et al., 2016; Cardinale et al., 2012; Mace et al., 2012, Bai et al., 2011).

Using a meta-analysis, Laurence and collaborators (Laurence et al., 2012) evaluated how specific human activities and habitat disturbance impact different groups of animals within watersheds, and they observed a series of correlations. For instance, freshwater fish are affected by water flow (river and streamflow), stream-dwelling amphibians are affected by soil erosion, terrestrial amphibians by stream sedimentation, non-venomous snakes by water pollution, lizards and larger reptiles by livestock grazing, larger frugivorous birds by exotic plantations, larger game birds by human population density, opportunistic omnivorous mammals by hunting rodents and harvesting of non-timber forest products, bats by mining, understory insectivorous birds by roads, raptorial birds by automobile traffic, apex predators by changes in natural forest cover, and large non-predatory species by selective logging. These impacts can be classified into three main groups of stressors: land-use change, deforestation, and pollution of the environment.

Land-use changes impact freshwater vertebrate populations with particular influence in the tropics. The degradation of wetlands and riparian ecosystems has led to the extinction of 19 mammals, 92 birds, 72 reptiles, and 44 fish species (Dudgeon et al., 2006). Loss of native vegetation reduces stream biodiversity in a watershed. Iñiguez–Armijos and collaborators studied the proportion of native vegetation that needs to be maintained for the conservation of macroinvertebrates diversity in an Andean watershed (Iñiguez-Armijos et al., 2014). They found that 70% of the native vegetation is responsible for the biological composition of macroinvertebrate communities. They suggest that policies for the protection of at least 70% of the native vegetation were necessary to ensure the freshwater health of this watershed, together with management strategies to ensure landscape connectivity (Iñiguez–Armijos et al., 2014). Another important factor for land-use change is urbanization. Urban expansion is growing closer to protected areas, thereby threatening endemic species in 29 of the 182 global biomes. This trend will continue to exacerbate the loss of biodiversity in the future (McDonald et al., 2008).

Deforestation is another risk factor for several species. For instance, between 2000 and 2012, deforestation processes impeded the protection of endangered and threatened species; 484 species of amphibians, birds, and mammals that were previously listed in the IUCN's Red List of species in risk of extinction remain under the same risk category, while 16 new species have entered the list of species with high-risk of extinction (Tracewski et al., 2016). From the three groups, amphibians are the most affected by deforestation, representing 40.5% of the listed endangered species.

The petroleum industry is an important source of environmental pollution in oil-producer watersheds (Ma et al., 2012). Sediments released during petroleum operations augment sediment suspension, reduce dissolved oxygen, and increase nutrients availability in freshwater ecosystems (Adebiyi & Adeyemi, 2015; Moquet et al., 2014; Ma et al., 2012). These effects were found responsible for changes in macroinvertebrate communities' composition, richness, and density of species in the Amazon (Couceiro et al., 2010). Also, a high concentration of aromatic hydrocarbons correlated to lower values of bird richness and evenness in areas polluted by hydrocarbons derived from oil extraction in Mexico (Uribe-Hernandez et al., 2012).

In 1993, the Convention on Biological Diversity (CDB) established goals for the reduction of threats that affect areas with high values of biodiversity. By 2010, biodiversity and ecosystem indicators demonstrate that the goals established through this convention have not been accomplished (Waldron et al., 2013; Pereira et al., 2012; Butchard et al., 2010) and new policies were defined. Even though efforts to conserve the biodiversity had improved during the last decade, several studies demonstrate that it is imperative to improve the performance of environmental regulations at national levels (IPBES, 2016; Maes et al., 2016; Ochoa-Quintero et al., 2015; Ekness & Randhir, 2015; Waldron et al., 2013; Laurance et al., 2012).

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has documented the implementation of biodiversity and ecosystem services modeling in different countries of the world, finding barriers that make it difficult using these models for the formulation of policies that help countries to advance towards biological conservation goals. Common issues across the observed cases include weak social capital, poor articulation between various stakeholders, scientists, and policymakers, and lack of information (IPBES, 2016).

Within nations, there are weak efforts for gathering biodiversity data and a lack of policy approaches for the management of watersheds' landscapes. For instance, the continuing replacement of native vegetation by new cover types hampers the protection of biodiversity in projects that attempt to maintain or recover the continuity along riparian corridors (Iñiguez–Armijos et al., 2014). Projects for the protection of the biodiversity also face financial difficulty for their execution, and there is an unequal distribution of funding among countries, where OECD countries get on average more funding than non-OECD countries which have high biodiversity in important threatened mammal species (Waldron et al., 2013).

It has been estimated that 80% of the world's biodiversity resides within Indigenous territories (Sobrevila, 2008). Local governance of the biodiversity is part of these peoples' lives (Villegas-Arias, 2008) and their identities are shaped by their coexistence with ecosystems (McGregor, 2004). Traditional Ecological Knowledge is a concept used to explain the links between traditional groups and the conservation of biodiversity (Berkes et al., 2000), and is a fundamental aspect of the local governance of the biodiversity (McGregor, 2004; Moller et al., 2004). This knowledge is maintained through generations by cultural transmission and is built through the continuous interaction with the land, and the great diversity of life therein contained (McGregor, 2004).

Four main issues need to be resolved when using Traditional Ecological Knowledge in biodiversity conservation: underestimation of the methods used by Aboriginal communities, loss of this knowledge, power imbalance, and exploitative approaches that seek to extract this knowledge from the communities (McGregor, 2004). Social and economic transformations also put at risk the existence of traditional people in their customary territories within developing countries. Unavoidable changes to the land can cause cultural crashes that force migration or merging of pre-existing communities into new societies, consequently losing their cultural identities, which contain their traditions and their ecological knowledge.

1.3.4 State of ecosystem service research

These social, political and economic issues are some of the most cumbersome obstacles for achieving global environmental goals as they have been found to be highly detrimental for environmental governance at regional, national, and local scales. International agencies that invest in human capital for improving institutional capacity in developing countries, attempt to attend these issues. One of the roles of scientists is to provide information to decision-makers about the effects of human actions on ecosystems services. However, skepticism and criticism about the methods and models used, and the absence of stakeholders' participation, delays the integration of scientific knowledge into policy. This section explains these difficulties.

The protection and conservation of ecosystem services are being promoted worldwide as a strategy to harmonize needs of the market with those of the people and the ecosystems (Martinez-Harms et al., 2015). Because of this, the assessment of ecosystem services has become the primary mechanism used by policy-makers when planning the conservation and protection of strategic ecosystems (Volk, 2013; Potschin & Haines-Young, 2011). Sometimes, the models used for these assessments lack congruence between the definitions of ecosystem services to be studied and the indicators used in their measurement (de Groot et al., 2010). Some studies fail to adequately define the type of ecosystem service to be studied (Braat & de Groot, 2012) leading to errors in the selection of surrogates for these services (Maes et al., 2016).

To address this, environmental scientists must carefully select the indicators and values to assess the capacity of an ecosystem to provide services. When identifying the appropriate indicators, researchers must observe the needs of the community, the benefits obtained through the study of specific ecosystem services, the availability of information, the scale of analysis, and available knowledge of the system (de Groot et al., 2010; Braat & de Groot, 2012). Failures in the definition of the ecosystems services could lead to ambiguous results that cannot be used in the formulation of policies and plans. In the European Union, the current framework for the evaluation of the ecosystem services compiles all the available indicators for specific ecosystems (Maes et al., 2016) thereby providing a good baseline. However, no single mechanism can fully adapt to all types of contexts; therefore, a variety of approaches are needed (IPBES, 2016).

For decision-makers, consistency in the methods and assumptions made in the construction of models is a fundamental aspect. They do not trust results produced by models because they observe that different models work with different approaches (Nahuelhual et al., 2015). Even though this variation is due to the nature of scientific methods, it is important to provide correct and consistent tools accessible to agents and stakeholders involved in the decision-making process. Likewise, it is essential for decision-makers to observe that their realities are correctly represented in these models; careless errors in the definition of the premises, and incorrect association of indicators with specific services can lead to the rejection of the research results by the stakeholders.

Another aspect is the need for improvement in the explanatory power of these models based on the complexity of the biophysical and socioeconomic interactions. There is a potential for oversimplification of these models with a central interest in cause-effect relations, leaving tradeoffs and implications of decisions (e.g., land-use decisions) outside the analysis (Singh et al., 2014; Volk, 2013). It is important for decision-makers to have this information before they can design strategies to prevent the loss of these services without incurring unnecessary costs.

Even though advances in watershed models have allowed for a better interpretation of the effects that biophysical factors have on the provision of ecosystem services, more research is needed (Vigerstol & Aukema, 2011). In this regard, various developments include studying the impacts of human interventions on water availability (i.e., for human consumption and for sustaining ecological flows), improving the communication of uncertainties, and understanding groundwater dynamics (Dadson et al., 2013). Integrated models that combine the several aspects of water governance are being developed, bringing new lights to interdisciplinary research (Knieper & Pahl-Wostl, 2016). This progress involves conceptual and methodological challenges due to the integration of disciplines with different epistemological bases (Pooley et al., 2014).

As demonstrated in the previous section, ecosystem services rely on the specific nature of interdependencies between the structure and diversity of biotic communities and the functioning of ecosystems; however, these interactions remain as unresolved questions in ecology (Braat & de Groot, 2012). New horizons in the research of ecosystem's functions and composition have begun to develop an approach in which metrics that represent multiple processes are embedded in networks of multi-trophic interactions (Reiss et al., 2009); however, this is an on-going approach.

Advancing this area will help with the definition of policies for the protection of integral rather than isolated systems; which is, for instance, one of the conservation issues in protected areas (Premauer & Berkes, 2015). These often have been created to protect highly biodiverse areas, but their surroundings are disturbed continuously, causing total isolation. Another major problem that affects these biologically diverse areas is indirect influence of external ecosystems. In systems like watersheds, network interactions can transform ecosystems in the same catchment through the action of interconnected processes, leading to unexpected modification of the habitat that could impact the survival of multiple species.

The involvement of stakeholders is another challenge in the scientific production of information useful for making decisions (Martinez-Harms et al., 2015). A pillar in watershed management is cohesive work with the multiple stakeholders (Shriver & Randhir, 2006), that enables effective participatory policy, respect for cultural diversity, the inclusion of traditional knowledge, improved communication of important biophysical and socioecological aspects, and that promotes strategical alliances. Allowing representatives of the communities and different organizations to participate in the assessment of ecosystem services brings social perspectives to the valuation (Shriver & Randhir, 2006). Rather than adopting the biophysical approach or the economic approach, having a social approach helps to include other social values (Garcia-Nieto et al., 2015). Contrarily, excluding stakeholders leads to simplification of the valuation of ecosystem services, poor communication between partners, weaknesses of governance over common-pool resources, and stagnation of interdisciplinary methods.

The process of involving stakeholders requires considering multiple contextual variables that might affect decisions and behaviors. For instance, stakeholders with different influence in decisions about environmental management may have a different opinion about the value of ecosystem services than ones with little influence (Garcia-Nieto et al., 2015). Other studies prove that differences in the participants' opinions are explained by their age, place of origin, and gender (Oteros-Rozas et al., 2014), as well as ethnicity, religion, class, and politics. These factors that influence the response of different stakeholders need to be considered by researchers, extending the times of execution of the projects and elevating the costs of the research.

An additional challenge is the development of new and legitimate governance models with an ecosystem services-approach. These governance models cannot be constructed out of the context in which the social dynamics take place. For instance, models created in North America cannot be automatically implemented in South American countries because these two regions have different political and socioeconomic dynamics. Therefore, scientists must study the particular conditions that define the governance systems, their difficulties and conflicts, and they must work together with the central government, Indigenous peoples, and other local communities to improve the governability of the natural resources at all scales of analysis (Verburg et al., 2016).

The effect of the context on individuals' and groups' decisions keeps challenging our understanding of behaviors within the social-ecological system. In this respect, phenomena that should be within the scope of the analysis include the self-organization of the social-ecological elements after a disturbance event (Poteete et al., 2010; Berkes &

Turner, 2006) and the influence of the context on individuals decisions or social norms (Tiwari & Joshi, 2015).

Internal and external dynamics can also affect decisions. For instance, competition for resources and availability of information shape the way individuals within a system behave. Externally some of the factors are market dynamics, extraction of resources, and national and international legislation, Heterogeneity inside the social-ecological system will also have an impact. For instance different Indigenous peoples, ethnic groups, and individuals in different social classes will have different preferences and perceptions about the environment and the values assigned to different goods and services (Schluter et al., 2013; Poteete et al., 2010).

Advancing in our understanding of these context-dependent aspects is part of the improvement of environmental science towards the development of adaptive systems to face future impacts to the environment.

1.4 Contributions of this research

Environmental scientists must advance in the knowledge of complex socio-ecological systems, adopting strategies that bring closer scientific knowledge to national and local decision-makers, and exploring the factors that impede community-based governance, and cooperative mechanisms of governance.

Complex socio-ecological systems in hydrological systems sustain all goods and services in watersheds. Understanding and managing these systems is one of the most challenging environmental issues nowadays. It involves all social and ecological elements present in a watershed, the interactions between and within these groups, and their cross-scale dynamics (from global to local). Another critical issue is the evaluation of conditions that impede horizontal and vertical interactions in watersheds. Some of these factors impede or make difficult the information flow, integration of regional, national, and sub-national initiatives, cooperation between stakeholders, and efficient management of natural resources (Gupta et al., 2016; Randhir, 2016).

Biophysical and socioecological interactions in watersheds need to be explored more in-depth. Currently, hydrological models applied to tropical watersheds must answer the questions about what the systematic biophysical interactions within water networks and linked ecosystems are, and the effects of governance systems and property regimes on these interactions. These are interdisciplinary questions that will help overcome barriers to our understanding of network interactions in tropical watershed systems.

The scientific contribution of this research is to advance our understanding of complex socio-ecological systems' networks in tropical watersheds at multiple scales. The present study analyzes complex social-ecological interactions in developing countries at multiple scales using the case of the Orinoco River Watershed, shared by two developing countries in South America, Colombia and Venezuela. At a large scale, this research assesses cumulative ecosystem services to identify spatial patterns of their distribution and to evaluate possible relations between these patterns and development projects. This research will provide insights into rising issues and conflicts between development processes and the protection of ecosystems at a watershed level.

At the interface between regional and local scales, socio-ecological systems are studied to characterize multi-scale mismatches regarding use behaviors, governance, and management of common-pool resources. This study will be important for better understanding the how mismatches between local and regional institutions work, as well as the underlying causes for Indigenous peoples and non-Indigenous communities.

At a local scale, the comparative analysis of 11 Indigenous peoples' Life Plans, using social resilience indicators, shows spatial variation between communities and key diverging points between these plans and National Development Plans. This study will be important for better understanding multi-scale and complex socio-ecological systems.

Biophysical and socioecological interactions are explored at all scales as well. Initially, the interactions between runoff, soil loss, ecosystems, and infrastructure, are described at a watershed level. Later the analysis at a local scale will solve questions about bidirectional relations in the social-ecological synergy. Further correlation between property regimes, ecosystem services, and governance strategies could bring to light the effect of socio-ecological systems' contexts in the protection of ecosystems in developing countries.

Based on the findings of this research at multiple levels, and accounting for complex social-ecological dynamics, some of the difficulties and opportunities for adopting structural and non-structural strategies for the sustainable management of ecosystems in developing countries are presented. In addition to that, the development of the watershed model will contribute to the tools used by decision-makers in the planning of watershed development. The model that measures the impact of runoff and soil loss on habitat availability will be useful for monitoring land-use changes at sub-watershed levels.

Unique contributions from this research include: (1) advancing knowledge about spatial distribution of ecosystem services in tropical watersheds and their overlap with major development projects in South America; (2) contributing to the body of knowledge about socio-ecological systems in South America, including articulating these locally-explicit governance dynamics involving Indigenous peoples and non-Indigenous communities; (3) comparative analysis of Indigenous peoples within the Orinoco River Watershed using their Life Plans; and (4) articulating structural and non-structural management practices to multi-scale socio-ecological systems networks.

The first unique contribution is based on the following: Four biophysical dynamics have been used to represent the spatial distribution and dimensions of four important ecosystem services, and the integrated analysis of these biophysical elements are then overlapped with socio-economic dynamics to reveal important socio-ecological dynamics at a watershed scale. Although ample literature is found about hydrological dynamics in South America (Laraque et al., 2013), ecological attributes in important South American ecosystems (Hirota et al., 2010), and socio-environmental issues (Finer et al., 2008), only recently have the social and biophysical realms begun to be considered together for the continent (Ochoa-Quintero et al., 2015; Iñiguez-Armijos et al., 2014; Moquet et al., 2014; Swenson et al., 2011). Therefore, more research needs to be done to assess how development projects will impact social-ecological systems in the continent.

This research is unique in articulating the spatial analysis of ecosystem services distribution and development projects at a watershed scale in the second most important watershed in the continent.

The second unique contribution is new insight into socio-ecological systems in South America. Only few cases of socio-ecological systems in South America had been presented in the literature. This research brings to light the analysis of biophysical interactions in socio-ecological systems in the Orinoco River Watershed, the second most important watershed in the continent, and how these interactions result impacted by different socio-economic dynamics. Also, it establishes the connection between the provision of ecosystem services and governing mechanisms for the protection and conservation of strategic regions.

The third unique contribution is based on the following facts. Most of the studies that involve Indigenous communities are conducted in the Amazon, and little is known about the Indigenous peoples in the Orinoco; more specifically their environmental governance is unexplored (Gasson, 2002). This research is unique in studying Indigenous institutions through the qualitative analysis of Life Plans from the environmental sciences perspective, and presents the potential use of the ultimate findings to inform management practices for the protection of priority areas.

The fourth unique contribution is based on the following facts. Management practices are usually presented as a list of objectives that lay outside of the socio-ecological context in which they are to be applied (Ostrom et al., 2007). A significant gap in environmental sciences is to use social-ecological knowledge as a basis for the formulation of management practices and to be able to articulate them to the real needs of complex socio-ecological systems. This research uses a multi-scale framework (Randhir, 2016) to articulate theory and practice aiming for integral management of ecosystem services in an important watershed system in South America.

This research provides useful information to help achieve conservation goals; specifically, for the sustainable development of the Orinoco River Watershed. Main information outputs are: (1) a map of management potentials based on the spatial analysis of runoff, soil loss, carbon storage, and biodiversity; (2) a comparative analysis between Indigenous groups non-Indigenous communities in the Orinoco River Watershed, (3) a characterization of mismatches between local and regional scales; (4) a qualitative analysis of Indigenous peoples' knowledge, social status (equity), and internal organization, based on their Life Plans; and (5) an integrated and multi-scaled analysis with strategies for augmenting connectedness between scales and legitimation of local institutions.

1.5 Objectives, research questions, and hypotheses

The main objective of this research was to identify and characterize multi-scale socio-ecological dynamics and tools which promote or impede the progress of local governance of common-pool resources within a region undergoing rapid transformations. Specific objectives of this research were:

1. To assess the distribution of four ecosystem services using a multifactor analysis
2. To characterize mismatches between and among local and regional actors about use behavior, governance, and management of common-pool resources

3. To analyze attributes that influence the governability of Indigenous peoples over their territories using a qualitative analysis of 11 Indigenous peoples' Life Plans.
4. To define strategies for articulating multi-scale actors and creating governmental initiatives for the recognition of local institutions' rights to govern common-pool resources.

1.5.1 Questions and hypotheses for objective 1

Objective: "To assess the distribution of four ecosystem services using a multifactor analysis"

Research question: How do spatial models contribute to the identification of management opportunities for improving the governance of common-pool resources?

Ho: Spatial models, at the watershed scale, are useful and reliable tools that help decision-makers to build policies and plans for multi-scale governing strategies.

Ha: Watershed-scale spatial models cannot be used for making management decisions.

1.5.2 Questions and hypotheses for objective 2

Objective: "To characterize mismatches between and among local and regional actors about use behavior, governance, and management of common-pool resources"

Research question: What is the topology of mismatches between and among actors?

Ho: There are significant differences in the opinions that actors between and within scales have about use behavior, governance, and management of common-pool resources.

Ha: Significant differences are only present between but not within scales.

Research question: What is needed for improving the links between and among actors?

Ho: Understanding the differences of perceptions, including values, that local and regional actors have about use behavior, governance, and management of common-pool resources, is useful for the creation of bridging mechanisms.

Ha: The knowledge gained about differences of perceptions demonstrates the existence of multi-scale mismatches but is not useful for creating bridging mechanisms.

1.5.3 Questions and hypotheses for objective 3

Objective: "To analyze attributes that influence Indigenous peoples' governance of their territories using a qualitative analysis of 11 Indigenous peoples' Life Plans"

Research question: Are there significant differences in the quality of knowledge, equity, and internal organization between communities of Indigenous peoples in the Orinoco River Watershed?

Ho: Differences in knowledge, equity, and internal organization quality among Indigenous peoples are smaller when compared to national actors. Therefore they can be treated as a single type of group.

Ha: Knowledge, equity, and internal organization quality between communities of Indigenous peoples throughout the Orinoco River Watershed vary significantly.

Research question: How do Indigenous peoples' Life Plans compare to National Development Plans?

Ho: Indigenous peoples' Life Plans have similar characteristics (e.g., principles, goals, and methods) when compared to National Development Plans.

Ha: Indigenous peoples' Life Plans are radically different when compared to National Development Plans.

Research question: How could Indigenous peoples' Life Plans be used for articulating local governance with the national government?

Ho: Indigenous peoples' Life Plans are useful tools for articulation local governance with the national government.

Ha: Indigenous peoples' Life Plans offer insights about various ethnic groups in the watershed, but they cannot be used for improving future collaborations with the national government.

1.5.4 Questions and hypotheses for objective 4

Objective: "To define strategies for articulating multi-scale actors and creating governmental initiatives for the recognition of local institutions' rights to govern common-pool resources"

Research question: How key findings from this research can help define solutions for the multi-scale articulation in the Orinoco River Watershed?

Ho: Evidence from this research can be used for making decisions about strategies for articulating actors across and within scales, and for the construction of practical national initiatives for recognizing locals' authority over common-pool resources.

Ha: The findings from this research are informative, but they cannot be used for making decisions.

1.6 Dissertation plan

The dissertation will be presented in five chapters. The introduction presents the main problem and its background, along with the objectives. The following chapter, titled "Spatial assessment of ecosystem services in a large tropical watershed: the case of the Orinoco River Watershed" shows how ecosystem service assessment can be useful for exploring management opportunities at the watershed scale. It describes the hydrological and sedimentological models built for the assessment.

The third chapter is the "Assessment of mismatch in governance scales for managing of common pool resources in the Orinoco River Watershed." There, local social actors are fully characterized, and the survey designed for this study is presented. The complex net of interactions among actors are revealed in this chapter, and the differentiation of groups by topic allows to see the converging and diverging points.

The fourth chapter is titled "Integrating Indigenous Peoples' traditional knowledge for the sustainable development of the Orinoco River Watershed." In this chapter are introduced the concepts related to Life Plans and social resilience, from which indicators for the qualitative analysis of the Life Plans are obtained. Three important categories of analysis are used in this analysis: knowledge and learning, social equity, and social structure and organization. With this, differences between Indigenous peoples are discussed, as well as the different visions that they have about the future development of the watershed as compared to the National Development Plans. Lastly, by comparing different cases, this chapter exemplifies how Life Plans could be used for articulating Indigenous peoples' Life Plans in the Orinoco River Watershed with National Development Plans.

The last chapter presents the "Strategies for the protection of ecosystem services in the Orinoco River Watershed." It reviews the main findings of this research, and build a case to explain how bridging organizations, social learning, and conflict management could be implemented. Additionally, it discusses existing opportunities for co-management and initiatives that the national governments could adopt to improve vital information systems and technology tools. In the last part, the main challenges and future research are discussed.

The main focus of this research is the multi-scale analysis of common-pool resources in socio-ecological systems within the Orinoco River Watershed for the protection and conservation of fundamental attributes that sustain the provision of ecosystem services. This is accomplished through the development of the five above mentioned objectives that together provide an approach to understanding complex interactions of socio-ecological systems within watersheds, emphasize the biophysical aspects to be considered to protect essential hydrological processes, and advance our understanding of non-traditional and traditional forms of governance. The information and conclusions achieved through this research will contribute to future research and will enable further actions for the sustainable development of the watershed.

CHAPTER 2

A SPATIAL ASSESSMENT OF ECOSYSTEM SERVICES IN A REGIONAL TROPICAL WATERSHED: THE CASE OF THE ORINOCO RIVER WATERSHED

2.1 Introduction

Healthy watershed ecosystems produce safe water for human consumption (Iñiguez–Armijos et al., 2014; FAO, 2012; Randhir & Hawes, 2009), healthy soils to produce food (Leh et al., 2013), sustain medicinal plants, fish, and other wildlife species (Laurence et al., 2012; Uribe-Hernandez et al., 2012; Bai et al., 2011; Dudgeon et al., 2006; du Toit et al., 2004), support regional hydrological (Doll et al., 2009; Conway, 1990) and sedimentological dynamics (Erkal & Yildirim, 2012; Chen et al., 2011), and regulate local climate (Dadson et al., 2013; Aufdenkampe et al., 2011). Unplanned development and watershed management that does not consider complex socio-ecological interactions had resulted devastating for local communities, causing the reduction of ecosystem services and making unsustainable population growth (Millennium Ecosystem Assessment, 2005).

Multiple ecosystem services provided by watersheds worldwide are losing their ecological and biophysical structures, thereby compromising the livelihood of human communities. Pervasive stressors in watershed systems are deforestation (Hanson et al., 2015; FAO, 2010), land-use change (Eisner et al., 2016; Swenson et al., 2011), pollution (Moquet et al., 2014; Uribe-Hernandez et al., 2012; Couceiro et al., 2010; Randhir & Hawes, 2009), and water withdrawal (Doll et al., 2009). Deforestation and agriculture operations deplete the soils, increase erosion, release CO_2, and reduces the capacity to store carbon. Water pollution from fertilizers, industrial use of water, agriculture, urban areas, and industries reduces the minimum stream required to sustain freshwater ecosystems or its ecological stream.

2.1.1 Issues related to the conservation and effective management of strategic ecosystem

While there is a need for maintaining healthy ecosystems to sustain essential services to local communities in Latin American (Hailu et al., 2011; UNDP, 2006), at national and regional scales the economies of these countries use natural resources exploitation for economic growth (Ray et al., 2016). The environmental consequences of coal mining include water pollution and loss of unique ecosystems that sustain biodiversity. Coal mining in the north of Colombia has caused health issues among Indigenous peoples, African-descent communities, and other minorities (Cardoso, 2015). Whereas this business generates close to 1% of the GDP of the country, local communities do not benefit from it, furthermore environmental agencies have made limited responses to resources management and restoration needs (Cardoso, 2015).

Environmental regulations exist to deal with these issues, however, Latin American countries face two main challenges. First, market demands for raw material create incentives to relax environmental regulations and consequently, countries with less restrictive regulations can attract more investments (Gale, 2014; Boyce, 2013). Second, they have limited institutional and economic capacity to manage natural resources.

2.1.2 Management and governance using a socio-ecological systems approach

Multi-scale governance aims for the articulation of decisions made by different governing institutions that have decision power at various levels of a social-ecological system (i.e., national, regional, local) (Ostrom, 2005). Maintaining the interactions between local, regional, and national entities improve adaptive management and resilience capacity (Premauer & Berkes, 2015; Barnes & Van Laerhoven, 2015; Gruby & Basurto, 2014). Co-governance, shared governance, or co-management is a specific form of multi-scale governance, in which state and local institutions collaborate for making decisions and managing common-pool resources (Stevens, 2014; Berkes, 2009). Under co-management arrangements, governments share specific responsibilities with local institutions, who not only maintain autonomy but have the support of the state to enforce their rules, and gain access to useful information. Conversely, the national government has direct access to local information (e.g., results from experiments and monitoring) and assistance with the implementation of rules. (Ostrom, 2005)

The use of a socio-ecological approach for environmental management and planning can also help achieve multiple objectives (e.g., poverty alleviation, solution of conflicts for the use of resources, and mitigation of impacts from extractive industries). This approach helps to formulate solutions that incorporate the context and its limitations for better governance and management of strategic ecosystems. In developing countries, a social-ecological approach can be appropriate to assess environmental challenges from land-use transformation (Ochoa-Quintero et al., 2015; Iñiguez-Armijos et al., 2014; Moquet et al., 2014; Swenson et al., 2011). Based on the assessment of ecosystem services, this research identifies ecosystem management potential in a watershed undergoing rapid land-use transformations. It approaches the question on how spatial models contribute to the identification of management opportunities for improving the governance of common-pool resources?

For this, the main objective is to assess the distribution of four ecosystem services using a multifactor analysis. Two models that represent spatial physical processes are created. The results are combined with existing spatial data to test the hypothesis about whether or not information at a watershed scale contributes to the ongoing efforts for the conservation and multi-scale governance of common-pool resources.

A unique contribution from this research is advancing knowledge about the spatial distribution of ecosystem services in tropical watersheds and their overlap with major development projects in South America. Furthermore, this research defines areas with different management potential for the protection of strategic ecosystems, using a spatial model that combines four ecosystem services in the ORW. This research will contribute to the social-ecological analysis by recognizing how ecosystem services are distributed in the ORW and by correlating this distribution with the execution of practices that could augment ecosystem services, prevent future damage of the ecosystems, and improve adaptive management.

The following section provides a background for the discussion of the ecosystem services that are going to be analyzed in this research. Later, the study area will be presented followed by methods, results and discussion, an analysis about the management implications of this research, and conclusions.

2.2 Types of ecosystem services in watersheds and their indicators

There are four types of ecosystem services: provisioning, regulating, supporting, and cultural services (Maes et al., 2016). Ecosystem services' indicators used in biophysical models and methods for the assessment of ecosystem services can involve direct measurement of biophysical attributes. Although this is useful at small scales, models are better suited for assessing ecosystem services at large scales. Models for the assessment of ecosystem services help with defining conservation priorities (Naidoo et al., 2008), wildlife protection (Krishnaswamy et al, 2009), and for the management of natural resources (Du et al., 2012; Souchere et al., 2010). These models use the biophysical information to build indicators for the presence of an ecological service (Table 2-1 and Table 2-2). In this section these indicators are presented for the relevant services studied in this research.

2.2.1 Water

Some of the provisioning services in watersheds are surface and ground water for drinking and non-drinking purposes (FAO, 2012; Doll et al., 2009). These services sustain food production, industrial activities, and domestic needs. Some of the indicators used to measure these services are river discharge, surface water availability, use of water per sector, the volume of water bodies, reservoir water, or collected precipitation (Cardinale et al., 2012) (Table 2-1).

Maintenance of good chemical conditions in freshwater is a regulating service (Mekonnen & Hoekstra, 2015; Moquet et al., 2014; Leh et al., 2013; Ma et al., 2012; Merem, 2011; Lal, 2004) that prevents water pollution and eutrophication. It is also a supporting service (Randhir & Ekness, 2013) that sustains freshwater niches for fish populations and wildlife. Two common indicators used for measuring this service are nutrient retention, using runoff together with Nitrogen and Phosphorus yield-values (Leh et al., 2013), and through water quality parameters, such as the concentration of nitrate, nitrite, ammonia, and phosphorus (Mekonnen & Hoekstra, 2015; Moquet et al., 2014; Ma et al., 2012).

Water chemical conditions are linked to the amount of sediment in freshwater systems (Leh et al., 2013; Randhir & Ekness, 2013; Merem, 2011; Lal, 2004), therefore the amount of suspended solids is also used for the assessment of good water quality. Another approach consists in analyzing the terrain's rain erosivity, soil erodibility, slope, and conservation and management practices through RUSLE method (Renard et al., 1997; Wischmeier & Smith, 1978) (Table 2-1); thanks to the evolution Geographic Information Systems, during the last two decades this method has been implemented at large scales (Desmet & Govers, 1996).

Biological indicators are also used for the assessment of water quality. When comparing chemical conditions between different freshwater ecosystems, it was found that benefits obtained from communities with high richness values are not significantly higher than the low richness communities, however, these studies show that slight differences can have a very positive impact at larger scales (Handa et al., 2014). For instance, the regulation of the Nitrogen cycle was slightly better in biological communities with multiple functional species compared to those with fewer functional species (Handa et al., 2014).

Table 2-1. Water and sediment attributes for the assessment of ecosystem services. Regulatory (R) and Provisioning (P) services.

Ecosystem service	**Water**	**Sediments**
Surface water for drinking and non-drinking purposes (P)	River discharge Surface water availability Use of water per sector The volume of water bodies Reservoir water Collected precipitation	
Ground water for drinking and non-drinking purposes (P)	Ground water bodies Ground water abstraction	
Maintenance of good chemical conditions in freshwater (R)	Nutrients and other chemical components that reduce water quality The microbiological composition of water Groundwater quality	Suspended sediments
Hydrological cycle and water flow maintenance (R)	Number of floods Snow cover Capacity for maintaining baseline flow Water supply and discharge (hydrological modeling) Drought and water scarcity	Infiltration capacity of the soils Water storage/delivery capacity of the soil
Soil formation through decomposition and fixing processes (R)		Soil organic matter
Mediation of waste (R)	Biochemical detoxification/decomposition/mineralization in land/soil and sediments contained in freshwater and marine systems	
Micro and regional climate regulation (R)	Ground water level	
Buffering attenuation of liquid flows (R)		Water holding capacity of soils
Buffering and attenuation of mass flows (R)	Sediment retention of waterbodies Ground water level evolution	Sediment retention (RUSLE-USLE) Soil erosion risk

Source: Compiled from Maes et al., 2016

Other studies have demonstrated that biodiversity and good chemical conditions in freshwater are linked (Iñiguez-Armijos, et al. 2014; Cardinale, 2011; Couceiro et al., 2010), in those cases, macroinvertebrates richness and evenness are often used as proxies for this service.

Hydrological cycle and water flow maintenance is another regulatory service important for regional climate and for local ecosystems (Dadson et al., 2013; Aufdenkampe et al., 2011; Doll et al., 2009; Conway, 1990). It is measured using counts of number of floods, snow cover, by measuring the regularity of the baseline flow, droughts and water scarcity assessments, water supply and discharge through hydrological modeling, soil's infiltration capacity, and soil's water storage/delivery capacity (Maes et al., 2016) (Table 2-1). Micro and regional climate regulation (Dadson et al., 2013; Aufdenkampe et al., 2011), it helps to maintain hydrological dynamics that sustain ecosystems and crops (Harris et al., 2012; Eigenbrod et al., 2010; Naidoo et al., 2008; Lal, 2004), and it is assessed by measuring groundwater levels (Maes et al., 2016) (Table 2-1).

Buffering attenuation of liquid flows is a regulatory service (Iñiguez-Armijos, et al. 2014) that prevents floods and it is estimated measuring the water holding capacity of soils (Maes et al., 2016). The mediation of waste by ecosystems is another regulatory service (Maes et al., 2016; Handa et al., 2014), that is useful for mitigating small amounts of pollution reducing the costs of water treatment (Conway, 1990), and it is measured using species diversity of plants and algae (Cardinale et al., 2012) (Table 2-2).

2.2.2 Soil

Buffering and attenuation of mass flows is a regulatory service (Lin et al., 2016; Erkal & Yildirim, 2012; Chen et al., 2011) that prevents erosion and reduces the soil-erosion risk over local communities (Chen et al., 2011; Teh, 2011). Some of the indicators used for its assessment are sediment retention of waterbodies, ground water level evolution, sediment retention through RUSLE model (Renard et al., 1997), and soil erosion risk (Maes et al., 2016; Erkal & Yildirim, 2012; Chen et al., 2011).

Healthy soils for growing food is a supporting service (Handa et al., 2014; Leh et al., 2013; Erkal & Yildirim, 2012; Chen et al., 2011). This is one of the crucial services in developing countries, it supports the economic growth (Huber-Sannwald et al., 2012) and helps to alleviate hunger and poverty (FAO, 2012). Plant diversity is often used as an indicator for this ecosystem service (Cardinal et al., 2012) (Table 2-2), this is because more diverse crop systems (e.g., agroecological systems) have higher primary production levels that monocultures (Cardinale et al., 2007) and they contribute to maintain healthy soils.

2.2.3 Carbon

Carbon is present in every ecosystem and living organism, and it is correlated with the mediation of waste by ecosystems, a regulatory service. One surrogate for the assessment of this service is the concentration of Carbon, Nitrogen, Phosphorus, Potassium, Calcium, Magnesium, and Sulfur in the soil (Maes et al., 2016) (Table 2-1 and Table 2-2). Another regulatory service is soil formation through decomposition and fixing processes (Handa et al., 2014; Leh et al., 2013). It is important for crops and to mitigate greenhouse gases (Harris et al., 2012; Eigenbrod et al., 2010). It is assessed using measurements of carbon content in the soil (Maes et al., 2016) and soil biodiversity (Cardinale et al., 2012).

Global climate regulation by reduction of greenhouse gas concentrations is another regulatory service that can be assessed calculating carbon stock (tons of C) through different techniques. One of them is measuring above and below ground biomass (Harris et al., 2012), another is measuring the organic soil combined with above ground vegetation (Eigenbrod et al., 2010), and also using biome-based carbon estimations (Naidoo et al., 2008).

Indirect methods for the assessment of global climate regulation consist in measuring ecosystems composition and biomass. For instance, heterogeneous ecosystems are correlated with higher accumulation of biomass (Cardinale, 2011), an indicator of higher carbon storage in plants and therefore an indicator of global climate regulation. Methods for measuring biomass are plant biodiversity (Bai et al., 2011; Cardinale et al., 2007; Lal, 2004) and ecosystem stabilization (Evans, 2016), which is calculated by measuring the reduction in the number of plant species over time (Evans, 2016). Overall, communities composed of various species tend to maintain the same average biomass values through time than those with less number of species.

Carbon sequestration (Tons C $year^{-1}$) is also used for measuring this service, however, this indicator varies significantly between biomes and plant species (Lal, 2004) and depends on net primary production and net ecosystem production (Maes et al., 2016).

2.2.4 Biodiversity

It is not possible to know all the services that derive from biodiversity attributes; this is so, because of the complex interactions between multiple organisms and their environment and their relationships to specific ecosystem services (Mace et al., 2012). However, it is important to connect biodiversity and management of watersheds ecosystems for several reasons. Given that it is not yet possible to predict how environmental transformations will impact the complex interactions within ecosystems in the future, increasing ecosystem resiliency is becoming an important practice in environmental management. Under uncertain climate scenarios, ensuring diverse genetic diversity will confer higher resiliency attributes to the ecosystems (Mace et al., 2012) and help stabilize ecosystems over time (Evans, 2016). Organisms at all trophic levels can improve the food production (Mace et al., 2012) and can increase resistance against different pests (Mace et al., 2012).

Some common services obtained from highly diverse ecosystems are presented in Table 2-2. Wild animals and their outputs (Cardinale et al., 2012) and biomass production with nutritional value (Davalos et al., 2011) are two provisioning services. Healthy ecosystems that sustain medicinal plants, fish, and other wildlife species is a supporting service (Laurence et al., 2012; Uribe-Hernandez et al., 2012; Bai et al., 2011; Dudgeon et al., 2006).

All of these services are important for sustaining local communities' livelihoods in remote regions, for instance, bushmeat is used as a source of protein by many local communities in South America (Matallana et al., 2012) and multiple rural communities depend on medicinal plants found in the forest (Mertz et al., 2007). For these services, biodiversity assessments of plants and animals are used as indicators (Cardinale et al., 2011) together with a social assessment of the use that locals give to the different species (Lasso et al., 2011).

Table 2-2. Biodiversity attributes that have been found to be linked to specific ecosystem services in ecosystem functioning and services studies.
Supporting (S), Regulatory (R), and Provisioning (P) services.

Ecosystem service	**Linked biodiversity attributes**
Maintaining nursery populations and habitats (S)	Tree species distribution Biodiversity value (Species diversity or abundance, endemics or red list species and spawning location)
Wild animals and their outputs (P)	Species composition of fish populations
Maintenance of good chemical conditions in freshwater* (R)	Macroinvertebrates diversity (richness and evenness)
Mediation of nutrient pollutants in soil and water (R)	Species diversity of plants and algae
Biomass production with nutritional value (P)	Plant, algae, and mushroom diversity (richness) Animal diversity Genetic diversity
Biomass production for materials (P)	Plant diversity Animal diversity
Pest and disease control (R)	Plant diversity Herbivores natural enemies
Global climate regulation by reduction of greenhouse gas concentrations (R)	Plant diversity
Soil formation and composition (R)	Plant diversity
Pollination and seed dispersal (R)	Insect diversity

Source: Adapted from Cardinale et al., 2012
* There are many studies that concluded that waterborne pathogens are not correlated to increased biodiversity (Cardinale et al., 2012).

The correlation between biodiversity and ecosystem function has been proved in different experiments (Handa et al., 2014; Cardinale, 2011). High richness values have been linked to higher rates of litter decomposition by trees and shrubs, and N fixation in five biomes around the world (Handa et al., 2014); all of which are regulatory services. In experimental environments, it has also been proved that higher biodiversity levels increase the probability of populating all available niches and therefore increasing the biomass production in aquatic ecosystems (Cardinale, 2011).

Species that can only survive in highly specific and unique niches will have larger opportunities in heterogeneous ecosystems; therefore, high richness values will result in better use of the available niches (Cardinale, 2011). Based on this, some ecologists have stated that high biodiversity values indicate the high provision of habitat (Cardinale, 2011), a supporting service. This type of service is related to maintenance of habitat for animal and plant species, including those which some communities rely on for food, material, medicine, and other livelihood and wellbeing contributions. Also, maintaining nursery populations and habitats (Dudgeon et al., 2006; du Toit et al., 2004) is one of the supporting services found in watersheds. It is important to maintain migratory species (Malmqvist & Rundle, 2002), for sustaining metapopulations (Akcakaya et al., 2007), and for achieving the goals of conservation (Ochoa-Quintero et al., 2015). Some of the indicators used for measuring this service are tree species distribution, species diversity, species abundance, endemics or red list species, and spawning locations (Cardinal et al., 2012).

2.3 Methodology

2.3.1 Study area

The Orinoco River Watershed (ORW) is in the northeast corner of South America between 2.5° to 7°N and -74° to -67.5°E and it is about 1 million Km^2. This is a bi-national watershed. Colombia encompasses 37% of the total area, and Venezuela the remaining 63% (Figure 2-1).

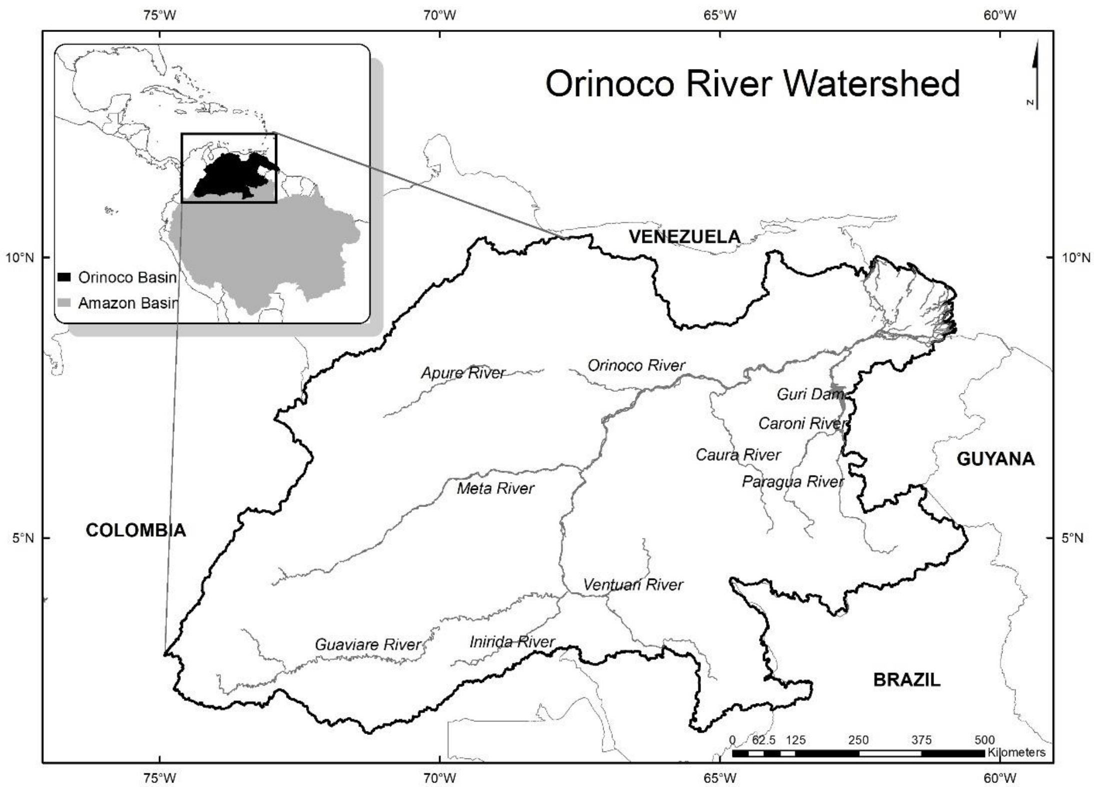


Figure 2-1. Location of the Orinoco River Watershed

The Orinoco is one of the most important hydrologic systems in South America (Silva, 2005). Its mainstream is the third in the world (Laraque et al., 2013), and ranks fifth in terms of sediment movement (150 million Ton $year^{-1}$) (Silva, 2005). The hydrological characteristics of the Orinoco are essential for the structure and function of 18 ecosystems that provide habitat to a great diversity of life (Lasso et al., 2010). This mega-diverse region is among the world's highest priorities for conservation (Lasso et al., 2010, WWF, 2016). Alterations in the hydrology will reduce the ecosystems' productivity and their biomass, therefore, biogeochemical cycles also will be impacted.

2.3.1.1 Biophysical characteristics

The weather in this watershed is driven by the intertropical convergence zone, and orographic and convergent mechanisms (Silva, 2005). The precipitation regime in the watershed is unimodal with high precipitations occurring between April and September (289 mm – 2949 mm), peaking in May and June. From October through March (142 mm - 1475 mm) the precipitation is lower with the drier conditions taking place from mid-December through January Overall the south portion of the watershed has larger precipitation values than the north (Figure 2-2).

High elevations within the watershed are found along the Andes mountain range (5,193 m) and north-west, and the Guyana region (2,820), to the south-east. The rest of the watershed is mostly gradual in inclination (Figure 2-3).

The combination of the water forces and the weather regimes is responsible for the pedogenesis of this watershed. Precipitation and surface runoff detach sediments from the Andean region that are then transported by the stream and deposited in the floodplains during overflow events.

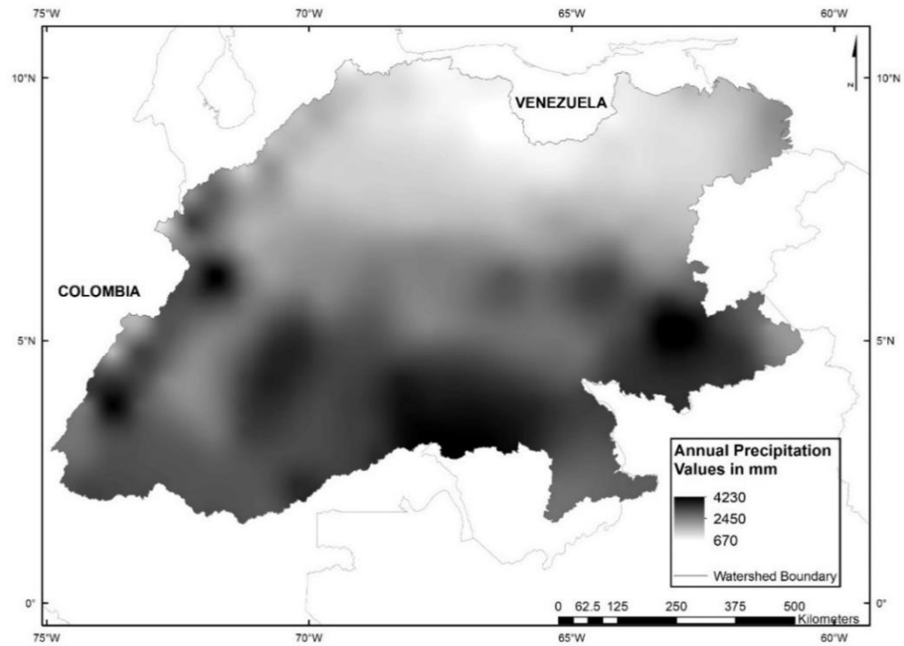


Figure 2-2. Annual precipitation distribution.
(Source: Schneider et al., 2011)

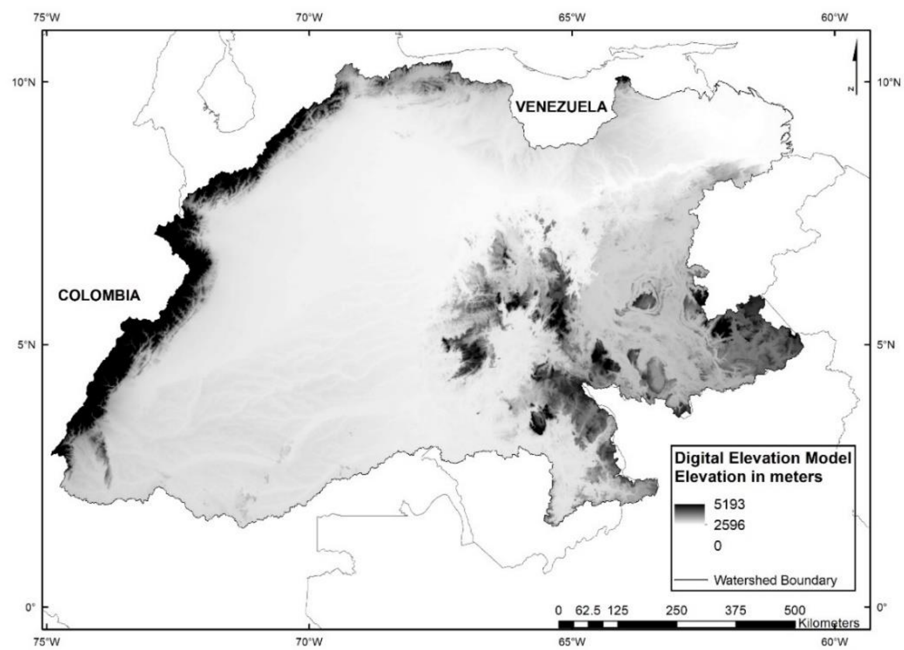


Figure 2-3. Elevation values from the digital elevation model. White color shows the highest places in the watershed; particularly in the Andean region
(Source: CGIAR-CSI SRTM, 2008)

Sediment movement through the watershed is complex and it has its origins in quaternary processes when the sediments were carried from the Andean mountains to the depressions along the savanna. Current active fluvial activity is shaping the landscape and transporting new sediments. Characteristic flatlands in this watershed transport water slowly and a slight variation in the level of the terrain is significant for the accumulation of sediments. Likewise, depending upon the permeability of the soil, there can be a larger accumulation of sediments in poorly drained soils.

Two main land cover types are found in the ORW: forests and savannas; however, within each of them exist important ecological differences. Forests refers to the rainforest in the south, the Andean forest in the east, and the Guyana’s forests in the southwest. Savanna is the second most important land cover type. It includes grasslands, shrubs, isolated trees and palms, and is intermingled with crop areas (Figure 2-4).

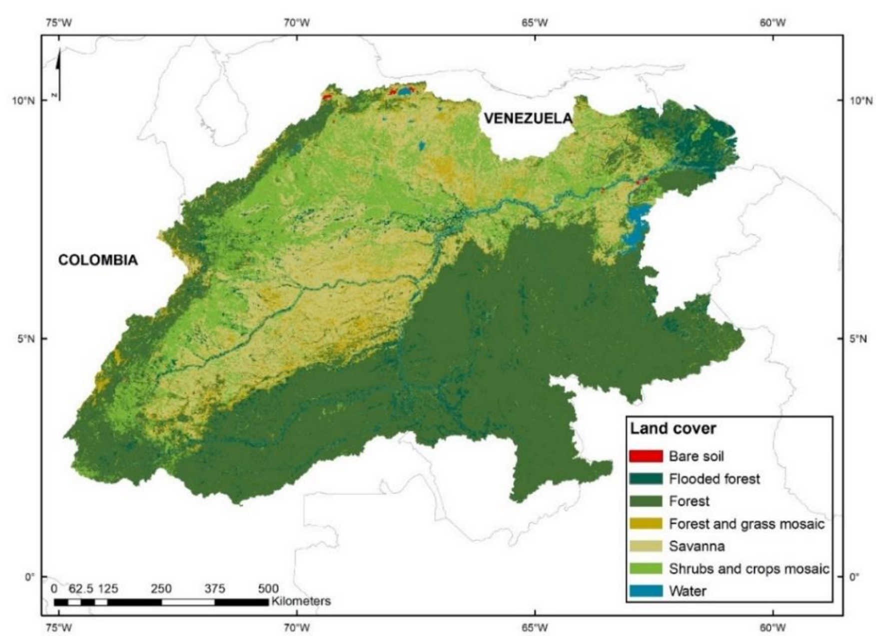


Figure 2-4. Land cover types
(Source: ESA, 2014)

Overall, forests have different physiological and ecological characteristics when compared with savannas. Thanks to trees' root-system, forests retain sediments in the soil, preventing erosion (Tracewski et al., 2016; Iñiguez-Armijos et al., 2014; Chen et al., 2011) and they store larger quantities of carbon. Hydrologically they are responsible for high transpiration, whereas savannas have higher losses of water through evaporation. Provision of habitat is different in each region, and eco-hydrologically they influence the types of water. This will be presented in the description of different regions of the ORW.

Soils in the ORW vary depending on the type of vegetation, slope, and composition. Along the Andes mountain range, where the slope and elevation are high, the soils are well drained and are composed of coarse and fine particles. Along the piedmont the slopes are steep with soils that range from coarse to fine with muddy to sandy arrangements that are prone to erosion (IGAC, 1999). Soils along the plains are composed of medium to coarse particles. There, the slope is lower with a mosaic of flatlands at high, medium, and low altitudes.

This diversity of terrains is linked to different types of soil drainage (Figure 2-5) that can be high, medium-high, and medium-low drainage. Soils composition in the plains can be clays in the flooded areas and poor soils with high ferric content (Lasso et al., 2011). Towards the Guyana Shield the terrain has diverse geomorphologies. In the steepest areas there is high erosion and the soils are composed of middle to large sediments.

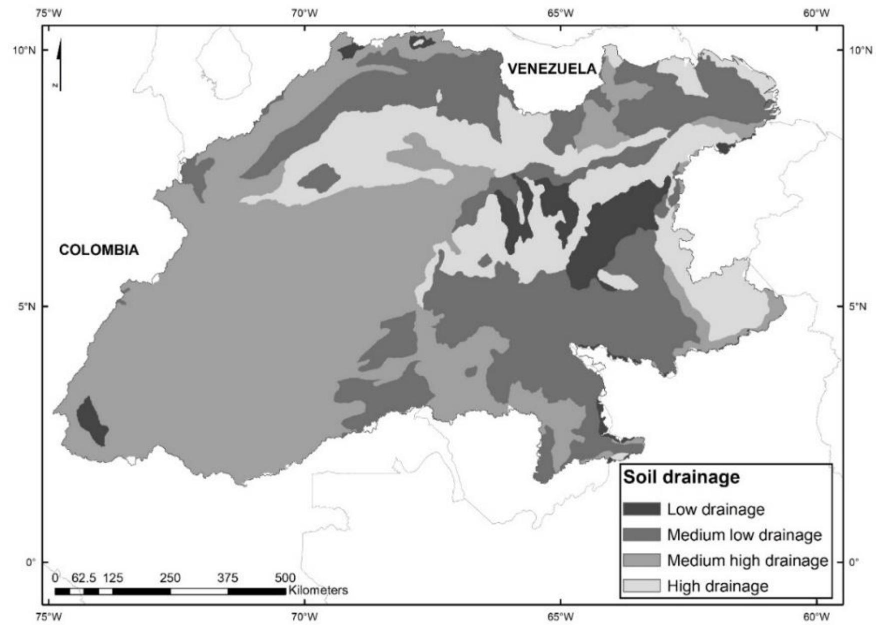


Figure 2-5. Soil drainage
(Source: FAO, 2012)

2.3.1.2 Eco-regions

Based on the study developed by Lasso and collaborators, 10 eco-regions (Figure 2-6) are considered in the present research (Lasso et al., 2010). These are: Altillanura or highlands, Andes and Piedmont, Orinoco Corridor, Guyana, Llanos, Macarena, Orinoco-Amazonas transition or Transitional, Orinoco Delta, White Sands, and Flooded Llanos.

Diverse types of forests mostly cover the Andes and Piedmont, but due to anthropogenic transformations, some of the tree species in this region are highly endangered. The soils in this region are well drained. Steep hills facilitate sheet erosion, and also rill erosion. This is worsened by poor management practices. The streams in these rivers move with great energy due to the slope of the terrain, and consequently, they have great sediment carrying capacity. The water of rivers that start in the Andes is loaded with nutrients and electrolytes, and hence are very rich and productive rivers. The erosive processes occur mostly in the piedmont (Lasso et al., 2010).

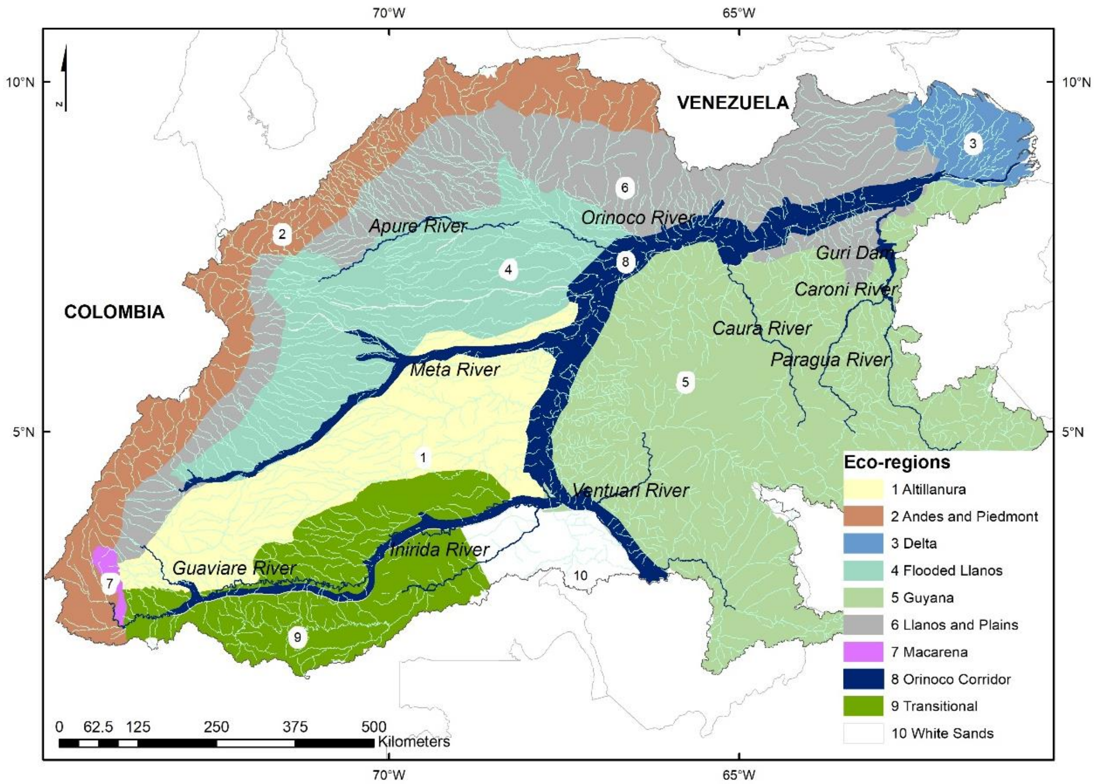


Figure 2-6. Eco-regions in the study watershed
(Source: Lasso et al., 2011)

North of the watershed, are found *Los Llanos* (the flatlands). There, the landscape is constituted by extensive areas of plains and flatlands crossed by rivers. In *Los Llanos*, both well-drained or poorly drained areas (with periodical floods) are present. The first correspond to the Llanos and Plains region and the second to the Flooded Llanos region. The sediments transported by rivers across *Los Llanos* are retained in the Flooded Llanos (Lasso et al., 2010).

Macarena is a region with high annual precipitation (on average 5,000 mm) with a predominance of humid forests and with some floristic elements from savannas and the tepuis (protuberant granitic formations in the highlands of the Guyana region). The Altillanura or highland is a region without inundation and with moderate to high drainage and poor soils with low carbon content. The rivers in this region are translucent to green, and during the wet season tend to be whiter and full of sediments. The Guyana region produces rivers of humic-rich black-water rivers and is covered by flooded forests that produce organic matter, which, due to decomposition, create nutrients that taint the water and make it acidic. The water is oligotrophic and with low sediments. This is the oldest region in the watershed and is composed of highly eroded granitic rocks.

In the Orinoco-Amazonas transition or the Transitional region, savanna converges with rainforest. Geomorphological characteristics of this region are the transition from high-lands into low-lands with sporadic emergent hills. Consequently, a vegetation gradient is observed from rainforest in the south to savannas in the north, crossing grasslands, sandy savannas, and flooded forest (Lasso et al., 2010). The water that flows through this region is translucent, black, white or a combination of these three. A small region here identified as the White Sands has been reported to be of immense importance for unique plant species in the south of the watershed (Berry & Wiedenhoeft, 2004). These are seasonal flooded riverine forests.

Riparian corridors are present along the rivers in the entire watershed. However, the literature often mentions that there is a unique corridor that starts in the south-east of the watershed and runs south-north and east-west. Given that riparian corridors have common attributes, here the Orinoco Corridor region has been defined as a single encompassing riparian corridor of the main rivers in the watershed. This corridor is mostly covered by forests and shrubs adapted to flooding conditions. Therefore it has been recognized as a region of wetlands with great ecological value. It hosts 75 endangered plant species, and the lower corridor, near the delta, has unique and diverse ecosystems (Lasso et al., 2010).

Overbank deposition is important for the formation of floodplains during flood season when the river carries and deposits sediments that accumulate and reinvigorate the soils in the valleys. Historically, the accumulation of sediments has formed layers of sediments that total to 3 and 5 meters in height. Populated corridors with plants that are adapted to these conditions will have a higher sediment potential than non-populated corridors (Rosales et al., 1999). This corridor connects to the Orinoco delta, which is composed of mangrove swamps, palms, and rainforest with predominant humid to very humid conditions.

2.3.1.3 Socioeconomic characteristics

About 6.5 million people inhabit the ORW, mostly localized in the Andes and Piedmont region (Figure 2-6). Until the middle of the 20th century, there was low urban development and rural occupation was predominant. Since then, petroleum extraction has been a prominent activity, and this has promoted urban development in the watershed during the last 30 years (Andrade et al., 2009). Urban development in the ORW is growing along the rivers and roads. The largest expansion of these urban centers is taking place around those places where the petroleum business is present (Sanchez-Silva, 2003) (Figure 2-7).

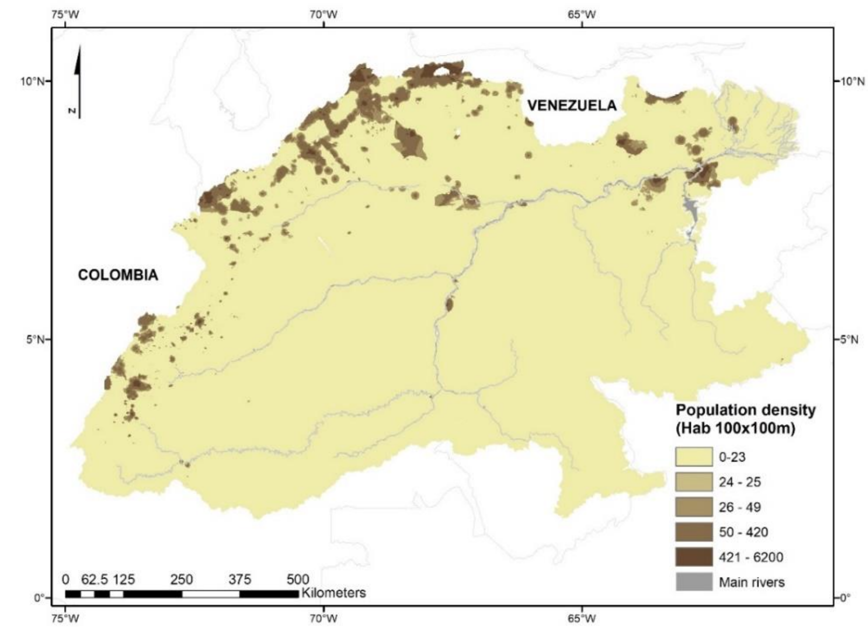


Figure 2-7. Population density and distribution. Number of habitat in 100 m^2
(Source: WorldPop, 2013)

Amerindian settlement in the Orinoco has more than ten thousand years of history and nowadays it is represented by 23 ethnolinguistic groups (Gasson, 2002); 15 of them are in the Colombian portion of the watershed (Ministerio de Cultura, 2014) (Figure 2-8). Although these groups were nomads, they are becoming more sedentary, which is changing their behavior, cultural and social relations, and their ecological knowledge (Villegas-Arias, 2008; Sanchez-Silva, 2003). Some of the challenges that these peoples face today are ecological degradation, colonization of their territories by non-Indigenous people, lack of lands to sustain the Indigenous population, and cultural clashes caused by the incursion of industries and foreigners into their territories (Finer et al., 2008; Villegas-Arias, 2008; Sanchez, 2007).

Despite these transformations, these Indigenous peoples generally conserve their cultural traditions and they continue the generational transmission of their knowledge.

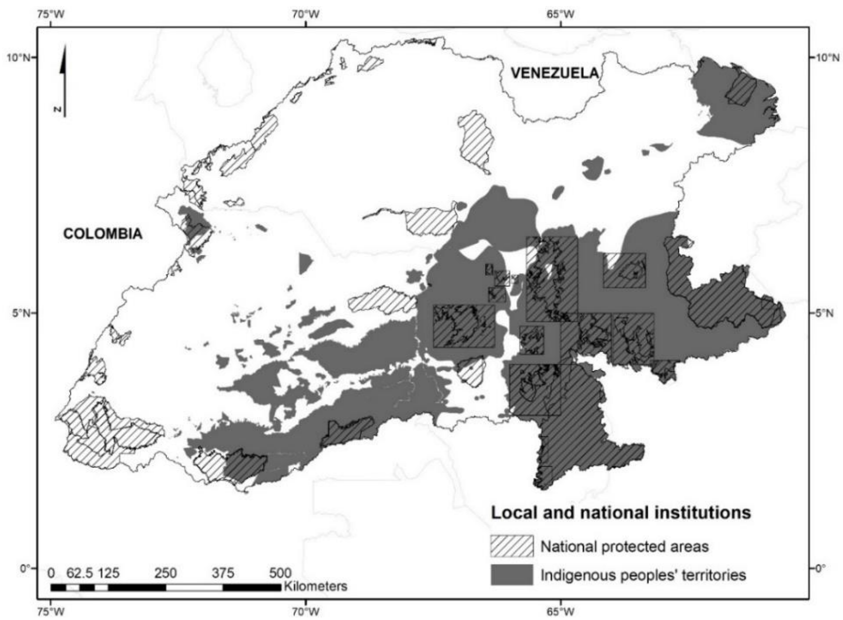


Figure 2-8. Map of protected areas and Indigenous peoples' territories
(Source: Houghton, 2008)

Currently, agribusinesses such as palm oil (Figure 2-9) and expansion of rice monocultures are promoting a new wave of migrations to the Orinoco. The main economic activities in this region are extensive ranching, commercial fishing, farming of a wide variety of food products, and mining. Illegal activities, such as illegal mining, illegal commercial timber extraction, and coca plantations, are also important economic activities in this region. Unauthorized mining is localized in the south-central region, whereas coca plantations are restricted to Colombian territory (Jimenez, 2012). All these economic activities represent the main challenge for the sustainability of the region (Lasso et al., 2010).

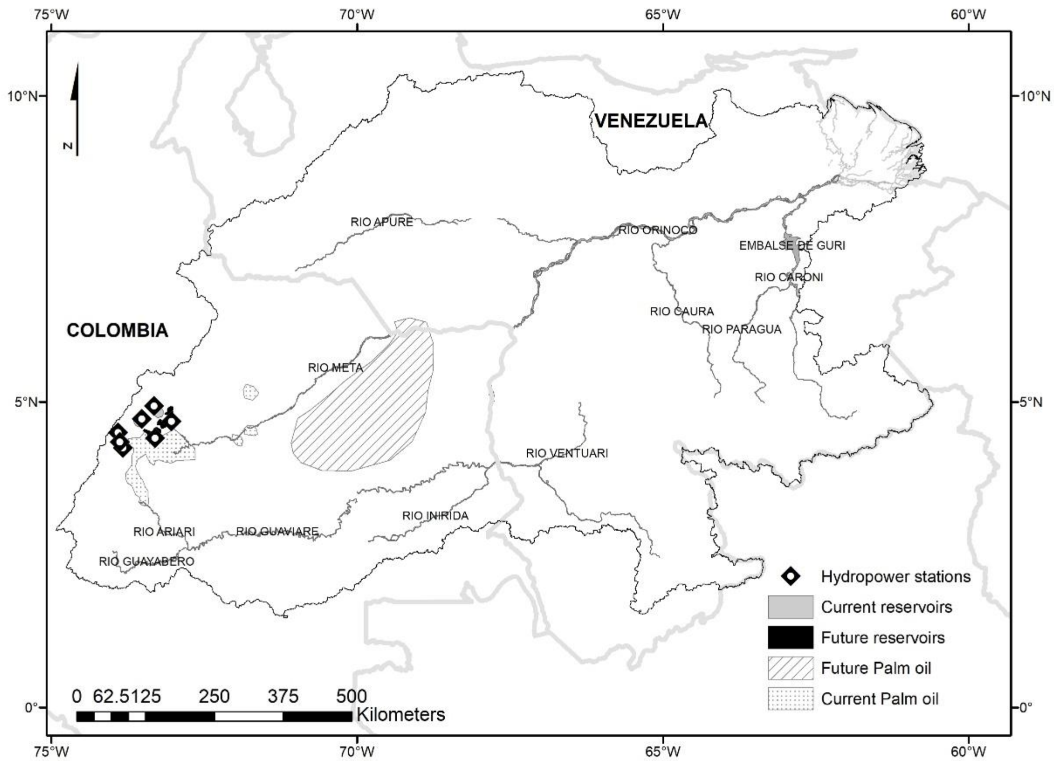


Figure 2-9. Hydropower, reservoirs, and palm oil plantations
(Source: Houghton, 2008)

Future economic development of this watershed will be determined by international ventures and government policies in Venezuela and Colombia. Venezuela is focused on the exploitation of mineral resources in the Mineral Arch (Figure 2-10) such as tantalite (coltan), uranium, thorium, gold, diamond, silver, nickel, quartz, kaolinite, feldspars, and Iron (Sanz, 2016), while continuing with the petroleum extraction in the Orinoco Petroleum Belt (Figure 2-11). Colombia will intensify the production of beef, rice, and palm oil, and will continue with oil exploration and exploitation (Andrade et al., 2009).

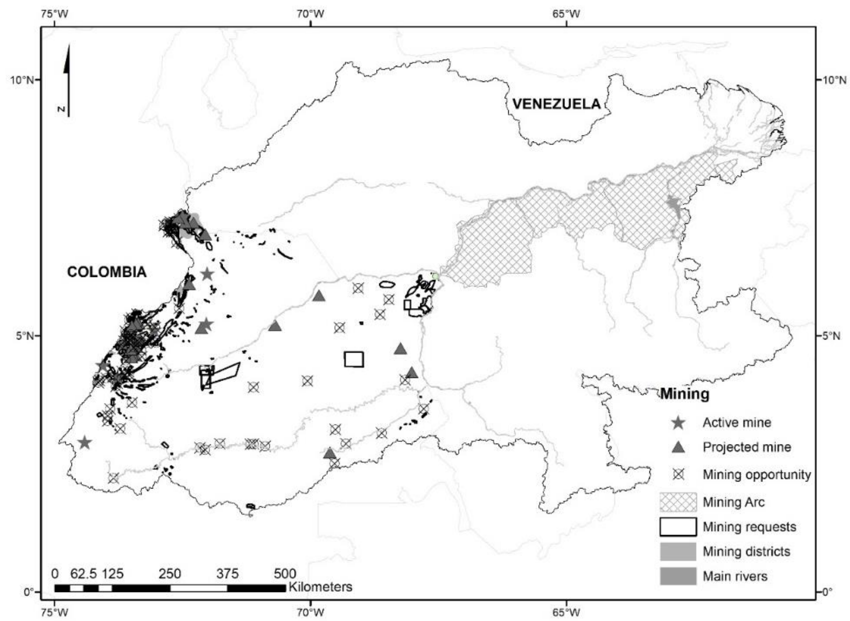


Figure 2-10. Mining activities
(Source: Houghton, 2008)

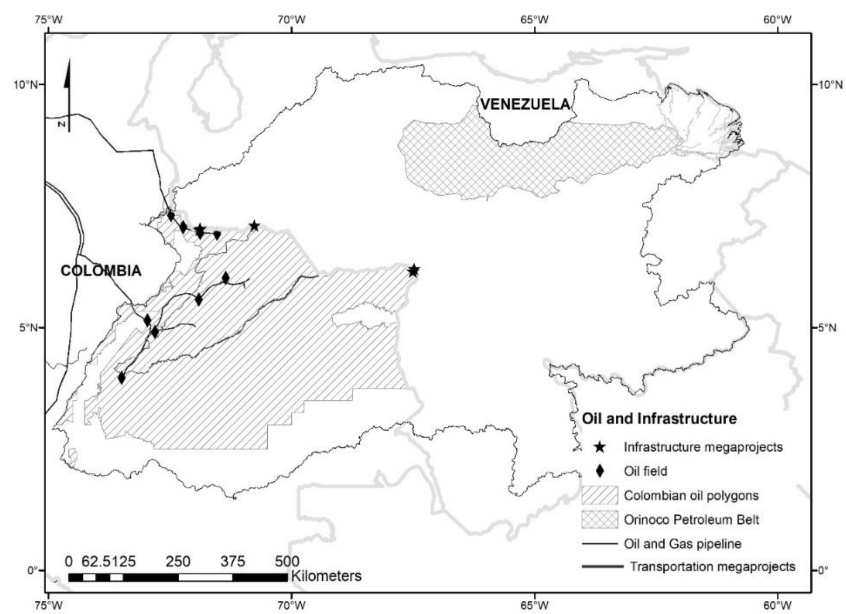


Figure 2-11. Oil exploration and extraction, and infrastructure
(Source: Houghton, 2008)

Illegal activities, such as unauthorized mining, wood extraction, and coca plantations, are also important economic activities in this region; unauthorized mining is localized in the south-central region, whereas coca plantations are restricted to Colombian territory (Jimenez, 2012). All these economic activities represent the main challenge for the sustainability of the region (Lasso et al., 2010).

For this and other emergent productive industries, the Colombian government is in the process to adopt new legislations such as the adoption of Zidres zones (República de Colombia, ley 1776 2016). Through this law, the government is planning to identify the best locations for implementing business. It is unclear how these zones will be defined, but the legal measures that are under evaluation suggest that some people will be evicted from their lands (Oxfam et al., 2017). People who live in rural areas and depend on their lands and territories consider this law a threat to their rights, and public reports and media have called this a violation of the nation's patrimony (Oxfam et al, 2017; Redacción Judicial, 2017).

2.3.2 Conceptual model

Policies focused on the protection and management of ecosystem services are an integral part of development strategies (Ranganathan et al, 2008), because they help advance towards effective management of natural resources while incorporating the interests of the population (Ahmadisharaf et al., 2016; Souchere et al., 2010; Chung & Lee, 2009).

Watershed management and governance of common-pool resources in watershed systems rely on knowledge of the biotic and abiotic factors that influence the availability of ecosystem services (Randhir & Tsvetkova, 2011; Randhir & Hawes, 2009) and on the interdisciplinary knowledge of socio-ecological dynamics (Randhir & Raposa, 2014). Research on social-ecological systems has pointed out that understanding socio-economic dynamics and governance at higher levels (e.g., at a watershed scale) is necessary for the effective governance of common-pool resources (Choe, 2004).

The conceptual model used in this research (Figure 2-12) builds on these concepts. Here, management opportunities can be identified by studying biophysical factors that impact ecosystem services and the linked socio-economic factors that affect the protection of strategic ecosystems at a watershed level.

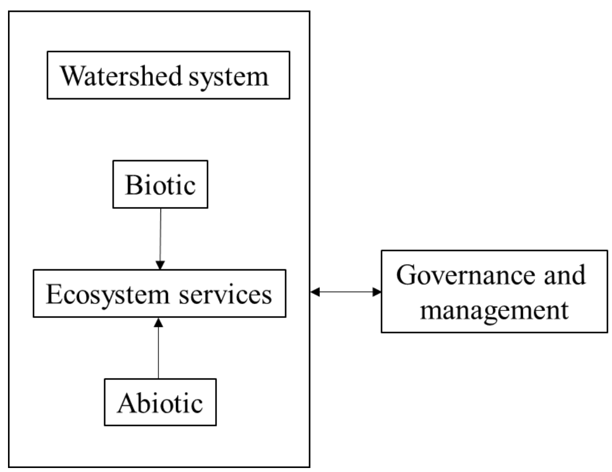


Figure 2-12. Conceptual model

Four ecosystem services are studied in this research: Provision of water for drinking and non-drinking purposes (W), regulation of good chemical conditions (WQ), global climate regulation (C), and supporting nursery populations and habitats (H). The proxies for each of the services were runoff (m^3 sec^{-1}), soil loss (KTon $year^{-1}$), carbon storage (MgC ha^{-1}), and species richness respectively. Runoff and soil loss values were obtained through the construction, calibration, and validation of spatial models, carbon storage was obtained from NASA's forest carbon stocks (Saatchi et al., 2011), and species richness from an exhaustive synthesis developed by Colombian and Venezuelan scientists in 2010 (IAVH et al., 2010).

2.3.3 Empirical model

The empirical model for the spatial assessment of ecosystem services and environmental management is presented in Figure 2-13. Each of four ecosystem services correlates to eco-hydrological dynamics. Water availability for drinking and not-drinking purposes correlates to the measurements of runoff or surface water. Sediment retention that mitigates and attenuates mass flows and helps to maintain good chemical conditions in freshwater, correlates to the measurements of tons of transported sediments or sediment movement. Carbon storage that helps in regulating global climate, correlates to above and below ground biomass measurements. Habitat provision, important for maintaining populations, correlates to species richness, which is a biodiversity attribute.

The ecosystem services are unified in the Ecosystem Service Index (ESI). This index represents the overall distribution of aggregated services throughout the watershed. ESI values are used to identify zones within the watershed and to analyze levels of overlapped ecosystem services. Management likelihood is analyzed using the socio-ecological approach. Based on this, potential management and political strategies for the protection of the watershed are discussed.

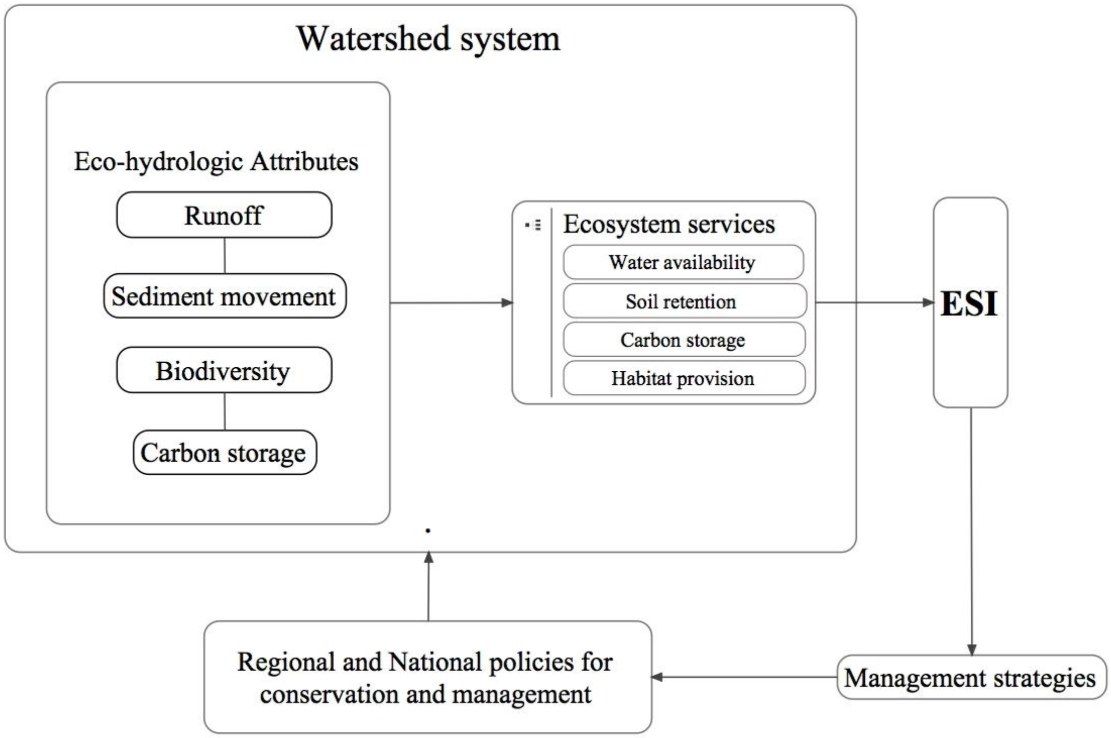


Figure 2-13. Empirical model of the Ecosystem Services Index (ESI)

2.3.4 Methods

Surface water available (provision ecosystem service) is analyzed measuring runoff values. It is important for solving issues such as water shortage for agricultural, industrial, and domestic use. Buffering of mass flow, that refers to the capacity of a system to store soil particles that are being transported through the water by surface runoff and along the streams, is measured estimating values of soil loss for the watershed.

2.3.4.1 <u>Runoff model</u>

The Soil Conservation Service Curve Number (SCS-CN) method (USDA, 2004) is used to model surface flow in the watershed. The SCS-CN employs precipitation in mm (P) and maximum potential retention (S). When P is larger than the initial abstraction (I_a), runoff in m^3 sec^{-1} (Q) can be estimated using Equation 1.

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \qquad S = \frac{25400}{CN} - 254 \tag{1}$$

I_a is the proportion of precipitation that leaves the system before it can be accumulated and added to the soil's water storage. Although I_a is affected by external factors, such as interception (leaves and stems) and wind speed, SCS-CN has defined a general approximation to its calculation (Equation 2) using λ=0.2.

$$I_a = \lambda S \tag{2}$$

Q in this research is calculated in mm. CN is the curve number for the land use and soils combination that is empirically derived (USDA, 2004). The CN vary depending upon the land cover, soil drainage and the Antecedent Moisture Condition (AMC); the AMC accounts for rainfall intensity and duration, total rainfall, ground moisture conditions, vegetation density, stage of growth, and temperature. There are three AMC classes: CN-II or average condition, CN-I or dry condition and CN-III or the wet condition. Given the climatic conditions of the ORW, the runoff model is evaluated for the average and dry scenarios.

GlobCover land cover map (ESA, 2014) describes 17 different cover types that were reclassified into seven as shown in Table 2-3. For this it was first considered the mainland covers and their cover area, then sub-types were assigned to these main classes based on physiological, ecological, and hydrological similarities.

Table 2-3. Reclassified values for land cover map.

GlobCover label	New label	Area (Km^2)
Rainfed croplands	Shrubs and crops mosaic	1,171
Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)	Shrubs and crops mosaic	45,106
Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)	Shrubs and crops mosaic	**143,933**
Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)	Forest	**489,490**
Closed (>40%) broadleaved deciduous forest (>5m)	Forest	1,176
Mosaic forest or shrubland (50-70%) / grassland (20-50%)	Forest and Grass mosaic	**48,530**
Mosaic grassland (50-70%) / forest or shrubland (20-50%)	Forest and Grass mosaic	13,851
Closed to open (>15%) (broadleaved or needle-leaved, evergreen or deciduous) shrubland (<5m)	Forest	11,618
Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)	Savanna	**202,994**
Sparse (<15%) vegetation	Forest and Grass mosaic	601
Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water	Flooded forest	**39,862**
Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water	Flooded forest	120
Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water	Flooded forest	8,554
Artificial surfaces and associated areas (Urban areas >50%)	Urban	**801**
Bare areas	Urban	50
Water bodies	Water body	**13,775**
Permanent snow and ice	Urban	72

Soil drainage classes presented in the Harmonized World Soil Database (FAO et al., 2012) correspond to the Hydrologic Soil Groups used to define CN values. Low drainage implies high runoff attributes. Therefore HSG = 1 will have the largest CN values within each land cover type and HSG = 4 the lowest CNs. From the final runoff, evapotranspiration is subtracted. The CNs used are presented in Table 2-4.

Table 2-4. Curve numbers assigned to the different types of land cover and Hydrological Soil Groups (HSG) for dry (CN-I) and average conditions (CN-II).

Land Cover Types	**HSG**	**CN-I**	**CN-II**
Forest	1	59	77
	2	51	70
	3	35	55
	4	15	30
Savanna	1	59	77
	2	51	70
	3	36	56
	4	18	35
Shrubs and crops mosaic	1	72	82
	2	58	76
	3	45	65
	4	25	43
Forest and Grass mosaic	1	62	79
	2	53	72
	3	38	58
	4	16	32
Flooded forest	1	72	86
	2	72	82
	3	54	73
	4	37	57
Water bodies	1	94	98
	2	94	98
	3	94	98
	4	94	98
Bare soil	1	85	94
	2	80	91
	3	72	86
	4	59	77

2.3.4.2 Soil loss model

The Revised Universal Soil Loss Equation – RUSLE (Equation 3) was used in the construction of the soil loss model.

$$A = RK(LS)(CP) \tag{3}$$

Where A is the amount of sediments and is typically measured in tons of sediments produced in that area per year (typically KTon ha^{-1} $year^{-1}$). R corresponds to the erosivity factor, K is the erodibility factor. L is the length of the slope and S in the steepness of the slope. C is the factor that establishes the soil loss ratio, and it involves five subfactors: prior land-use, canopy cover, surface cover, surface roughness, and soil moisture. P is the factor that accounts for protection practices. R was obtained using the Equation 4 proposed by Silva (2004), and it is expressed in KJ mm h^{-1} ha^{-1} y^{-1}.

$$R = 3.76 * \frac{{M_x}^2}{P} + 42.77 \tag{4}$$

M_x is monthly precipitation in mm and P is the annual precipitation in mm. K was obtained through empiric values (Renard et al., 2000). These values vary according to the soil's organic matter content and texture; which was extracted from the Harmonized Data Base. A correction factor of 1.292 was used to convert imperial to the metric system. The final units for K are t h KJ^{-1} mm^{-1}.

LS factor is usually estimated through empirical methods that apply to small and uniform watersheds. In complex watersheds, like the ORW, it is advised to account for the complexity of the terrain. Remote sensing approaches use depressionless DEM to estimate L and two ranges in the slope for S (Equation 5).

$$LS = \left(\frac{F_{ac} * Cell\ Size}{22.1}\right)^m * S * 1.4 \tag{5}$$

If $\theta < 9\%$ $\quad S = (\sin(\theta * 0.01745) * 10.8) + 0.03$

If $\theta > 9\%$ $\quad S = (\sin(\theta * 0.01745) * 16.8) - 0.5$

θ is the slope of the terrain in degrees. F_{ac} is the flow accumulation estimated using DEM the cell size is 90 m, and *m* is the susceptibility of the soil to be eroded according to the slope of the terrain (Table 2-5).

Table 2-5. m values used in LS

***m* values**	**Slope**
0.2	< 1%
0.3	1% - 3%
0.4	3% - 5%
0.5	5% - 10%
0.6	> 10%

C factor accounts for the influence of land cover characteristics, such as prior land-use, land cover, and roughness. Nine cover types for defining C factor values are presented in Table 2-6. C values for each of these classes were assigned based on literature review. The land-cover classification was performed in ENVI using MODIS images and ground truth data from previous high-resolution (200 m) classification maps (IAVH & IGAC, 2004) and available Google Earth images; all of which were processed using ArcGIS 10.5 (ESRI, 2017).

P factor values were assigned to different ecological regions based on their physiographic characteristics (Table 2-7). Sedimentological dynamics of these regions are reviewed later in the section dedicated to the study area.

Table 2-6. C factor values based on land cover

Land Cover	C values	References
Forest	0.004	CORTOLIMA, 2013; Teh, 2011
Savanna	0.03	CORTOLIMA, 2013; Teh, 2011
Shrubs and crops mosaic	0.07	CORTOLIMA, 2013; Kamaludin et al., 2013
Forest and Grass mosaic	0.0224	CORTOLIMA, 2013; Franzmeier et al., 2009
Flooded forest	0.001	Teh, 2011
Waterbody	0	Teh, 2011
Rice	0.15	CORTOLIMA 2013; Panagos et al., 2015; Kuok et al., 2013
Palm Oil	0.2	Kamaludin et al., 2013; Kuok et al., 2013
Urban (Bare soil)	0	Franzmeier et al., 2009

Table 2-7. P factor for different ecological regions in the Orinoco River Watershed.

Region	P values
Altillanura	1
Andes and Piedmont	0.5
Orinoco Corridor	
- Main corridor	0.9
- Riparian floodplains	0.4
- Riparian Corridors	0.4
Guyana	1
Macarena	1
Transitional	0.9
Orinoco Delta	0.4
White Sands	0.4
Llanos and Plains	0.5
Flooded Llanos	0.4

2.3.4.3 Carbon storage

For global climate regulation by reduction of CO_2 in the atmosphere this study uses the global measures for carbon storage from NASA's forest carbon stocks (Saatchi et al., 2011). Pre-existing carbon storage values are available for Above-Ground Biomass

(AGB), Below-Ground Biomass (BGB), and forest carbon storage. Carbon storage is the amount of total biomass carbon or 50% of the sum of Above-Ground Biomass (AGB) and Below-Ground Biomass (BGB) (Saatchi et al., 2011).

2.3.4.4 Species richness - H

Scientists from Colombia and Venezuela worked together to produce a synthesis of the current state of the biodiversity in the ORW (Lasso et al., 2011, 2010). Part of the outcomes was the creation of the cartography of species richness by groups in the Orinoco. Resulting maps are available through the Alexander von Humboldt Institute (IAVH et al., 2010), and in the present research, the species richness values were calculated using three biological groups: birds, fish, and mammals.

2.3.4.5 Ecosystem Service Index – ESI

The four ecosystem services analyzed in this research are then used to create the Ecosystem Service Index – ESI (Equations 6 and 7), to observe the spatial distribution of these services.

$$ESI = \sum_{i} \alpha X_i \tag{6}$$

$$ESI = aW + bWQ + cC + dH \tag{7}$$

Surrogates in the ESI represent each ecosystem service in diverse ways. Runoff (m^3 sec^{-1}) is used as a surrogate for “Surface water for drinking and non-drinking purposes” a provisioning service recognized by the letter W. Surface water is important for communities in this watershed for transportation, fishing, human consumption, and for sustaining ecological flow. Runoff can be an effective indicator of water provision when representing the total supply of water.

Soil loss (KTon $year^{-1}$) is a surrogate for “Buffering and attenuation of mass flows,” a regulatory service, and is represented by the letter S. This measurement helps to identify what areas need to be protected or managed to retain sediments and thus prove mass stabilization and control of erosion rates. Sediment retention also helps to maintain normal sediment inputs to streams influencing aquatic habitat for different freshwater species. In agricultural watersheds sediments carry nutrients causing water pollution; therefore, soil loss is occasionally used to assess water quality at large scales. Soil loss units are ton ha^{-1} $year^{-1}$; however, in the present research, seasonal estimations are also considered.

Carbon storage or total carbon is measured in megatons of carbon per area (MgC ha^{-1}) is a surrogate for “Global climate regulation by reduction of greenhouse gas concentrations”, another regulatory service represented by the letter C. Carbon is a greenhouse gas that when retained in terrestrial ecosystems contributes to global climate regulation by reducing its concentration in the atmosphere.

Species richness can be correlated to several services (Table 2-2), however, in this research, it will be analyzed as a surrogate for habitat availability (H). Since natural populations depend on good ecosystem conditions, accounting for the number of species will indicate the level of importance of a specific region. Highly perturbed ecosystems reduce their capacity to provide good quality habitats to sustain large populations, resulting in loss of biodiversity. Furthermore, biodiversity is important to maintain resilience capacity, in agroecosystems insect biodiversity sustain pollination, and in freshwater systems, diverse aquatic and riparian communities are correlated with good water quality.

Spatial models were built using ArcGIS 10.4 with GCS WGS 1984 spatial reference and D WGS 1984 datum. Data description and sources are presented in Table 2-8. The land cover map corresponds to information available for the decade of 2000 to 2010, consequently, precipitation and actual runoff data for 2000 was used for the construction of the models.

Table 2-8. Data used in this research

Data	Source Database	Details
Actual runoff data	- The Global Runoff Data Center (GRDC, 2017) - Colombian Hydrologic Information System (SIRH) (IDEAM, 2016)	Daily discharge measurements (mm^3 sec^{-1})
Actual sediment transportation	SIRH (IDEAM, 2016)	Daily sediment transportation (KTon)
Land cover	GlobCover (ESA, 2014)	Average land cover 2000-2010 300 m resolution
Hydrologic Soil Groups	Harmonized World Soil Database (FAO et al., 2012)	500 m resolution
Precipitation	Global Precipitation Climatology Centre (GPCC) (Schneider et al., 2011)	Monthly precipitation for 2000 in mm
DEM	CGIAR-CSI SRTM, 2008	500 m and 90 m resolution
Total carbon storage	Jet Propulsion Laboratory, California Institute of Technology, 2011	1 Km resolution
Species richness	Instituto de Investigación de Recursos Biológicos Alexander von Humboldt (IAVH, 2010)	Project: Biodiversidad de la cuenca binacional del Orinoco

2.3.4.6 Calibration and validation

Runoff and soil loss models were evaluated using error variance, efficiency, and consistency, through the coefficient of determination (R^2) (Moriasi et al., 2007), Nash-Sutcliffe Efficiency (NSE) (Moriasi et al., 2007, White & Chaubey, 2005), and percentage of bias (pBias) (Moriasi et al., 2007) respectively. R^2 describes the proportion of the variance in measured data explained by the model, it ranges from 0 to 1 with higher values indicating less error variance, and typically values greater than 0.5 are considered acceptable. NSE determines the residual variance compared to the measured data, it ranges between - ∞ to 1 with its optimal at 1, and values between 0 and 1 are considered acceptable. Finally, pBias measures the tendency of the simulated data to be larger or smaller compared to the observed data, it could be positive or negative, and has its optimal values at 0.

One soil loss model was analyzed for three-time sets: overall year, during the dry season, and the wet season. Three runoff models were created, two for each different humidity conditions (dry CNI and average humidity CNII) (Soil drainage classes presented in the Harmonized World Soil Database (FAO et al., 2012) correspond to the Hydrologic Soil Groups used to define CN values. Low drainage implies high runoff attributes. Therefore HSG = 1 will have the largest CN values within each land cover type and HSG = 4 the lowest CNs. From the final runoff, evapotranspiration is subtracted. The CNs used are presented in Table 2-4.

Table 2-4) and one that accounts for physical features that were not included in the model due to lack of information (e.g., interbasin transfer of water, water storage in reservoirs (Figure 2-14), and underground water movement and storage). The runoff and soil loss models were calibrated and validated using daily measurements of discharge data ($m^3 s^{-1}$) and sediment movement (Kton day^{-1}) respectively (Figure 2-14). The surface runoff values were obtained after baseflow separation using the program BFLOW (Arnold & Allen, 1999), by subtracting baseflow from the direct flow.

2.4 Results and discussion

The results from the elaboration of the runoff and soil loss models are presented first, followed by the results for the carbon and species richness, and finally it is presented the consolidated ESI and management potentials.

2.4.1 Runoff and soil loss models

Actual observed data were obtained for the year 2000 from the meteorological stations presented in Figure 2-14. Notice that all stations located close to the Meta river will relate to savanna vegetation (hereafter called savanna region) and the ones close to the Guaviare river will represent rainforest vegetation (hereafter called rainforest region). This is an important distinction because the results are analyzed separately.

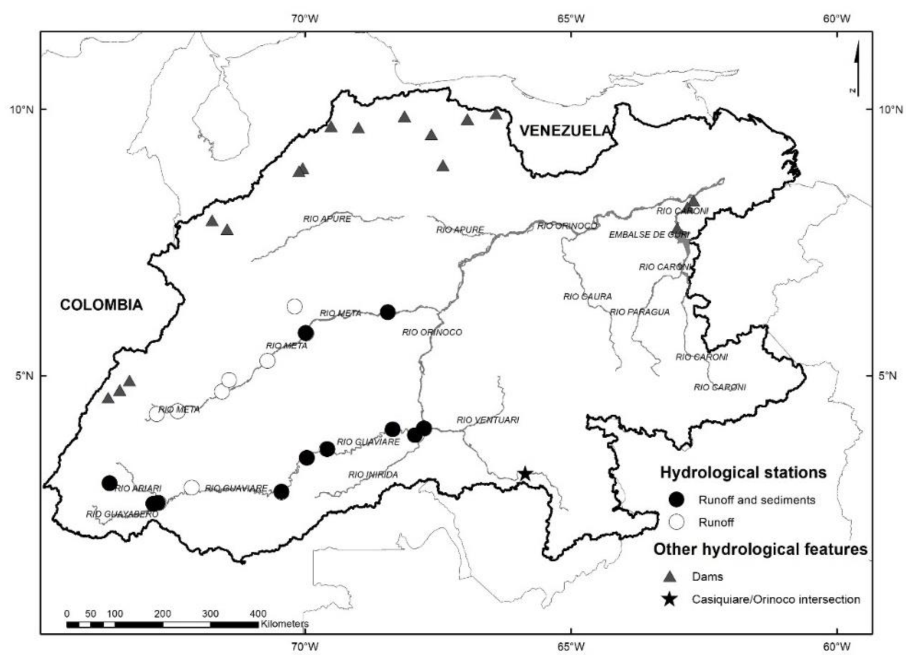


Figure 2-14. Location of the stations used for the calibration and validation of the runoff and soil loss models, along with additional hydrological features not included in the runoff model

Missing values were treated differently depending on the number of consecutive days without measurements. Up to three consecutive days were filled with the average values form the six days around those missing data. Up to twelve were filled with the average from the twelve days around them. Months with more than twelve missing data were discarded. Outliers were identified and removed. Errors and efficiencies for these models are summarized in Table 2-9 and Table 2-12.

2.4.1.1 Runoff model

Total discharge values obtained from the observed data were used to describe general characteristics of the flow patterns in different regions and times of the year (Figure 2-15). This exploratory analysis shows that peak discharges for the rainforest happen throughout the year but in the savanna, it takes place during the dry season.

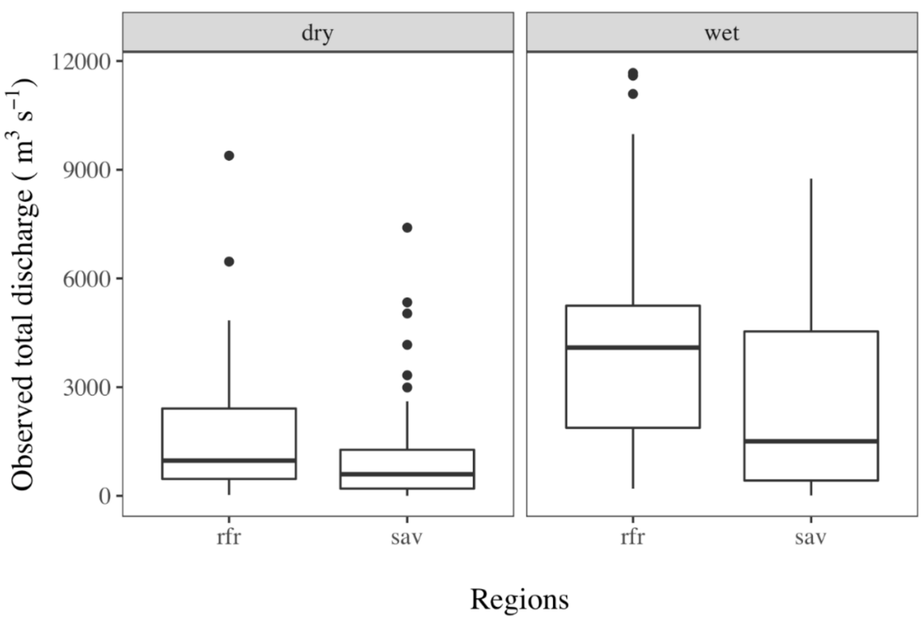


Figure 2-15. Observed total discharge distribution by season of the year and regions rfr: rainforest, sav: savanna.

Rainforest discharges are lower during the dry season and towards higher values during the wet season, whereas in the savanna the distribution does not change between seasons, and it is slightly lower values. For both regions, flow variability is higher during the rainy months.

When comparing runoff models using dry humidity conditions (CNI) and average humidity conditions (CNII), it was found that CNI underestimates runoff but CNII overestimates them, except for the dry season (Table 2-9). The histograms for both models show a higher density of simulated data for the first bar (0-500 m^3 sec^{-1}) than for observed data (Figure 2-16 and Figure 2-17); most of which correspond to underestimations for the driest months of the year. Likewise, CNII's range of values is higher than CNI's, that compensates for the lower estimations. The correlations between observed and simulated data are similar for both models (Figure 2-16 and Figure 2-17).

Table 2-9. Errors and efficiencies for the runoff models under the dry and average humidity assumptions

Dry (CNI)			
	NSE	**R^2**	**pBias**
CNI year	-0.17	0.34	-51.8
CNI_dry	-0.63	0.27	-93.1
CNI_wet	-0.38	0.25	-48.0

Average humidity (CNII)			
	NSE	**R^2**	**pBias**
CNII year	-4.39	0.39	55.7
CNII_dry	-0.51	0.33	-56.2
CNII_wet	-4.98	0.26	65.8
CNII_20	-2.16	0.39	24.6

During the dry season (months 10-12 and 1-3 in Figure 2-18) observed surface runoff differs little from simulated data compared to the differences during the wet season (months 4-9 in Figure 2-18). When these models were analyzed by region it was found higher efficiency in savanna than rainforest. CNI underestimate the values in both cases (Figure 2-19). Conversely, CNII overestimates the values (Figure 2-20). However, it is less biased in the rainforest.

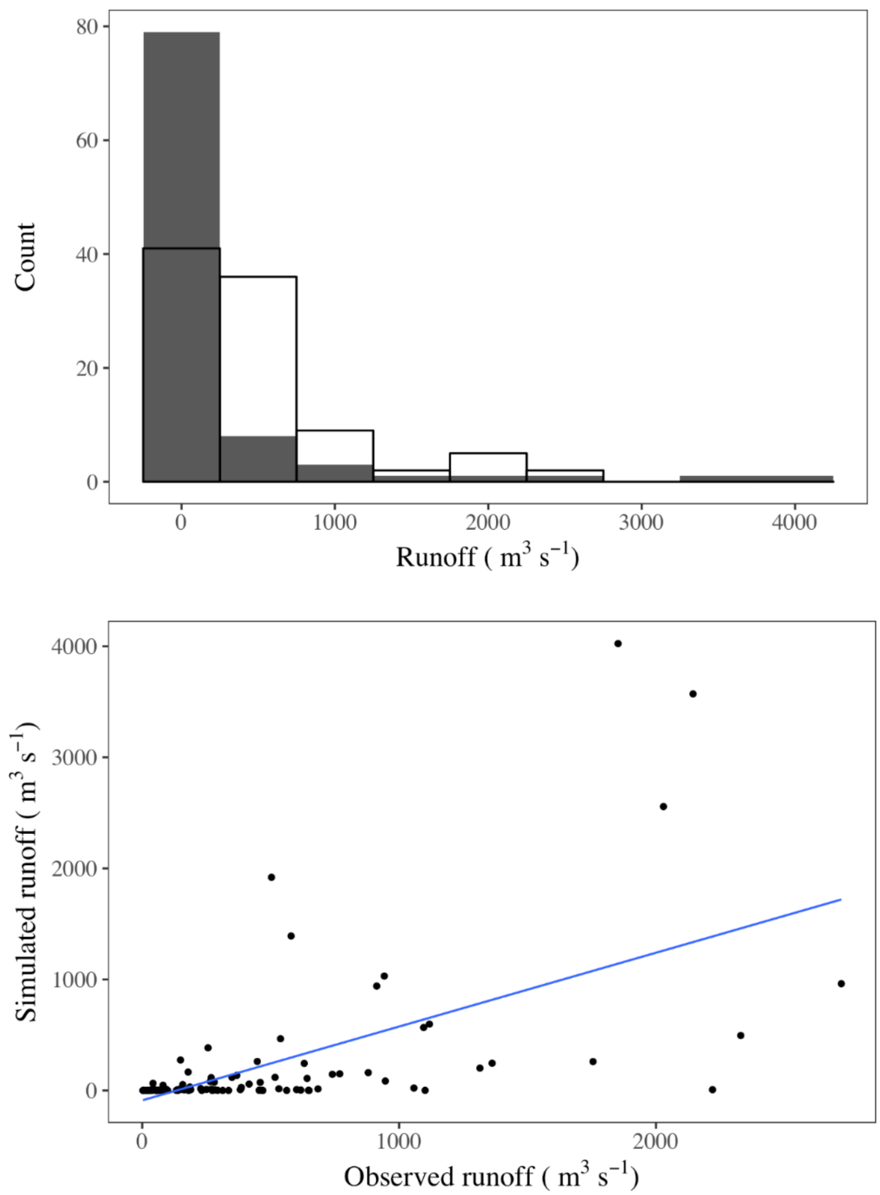


Figure 2-16. Histogram and regression showing the relationships between observed runoff data and the results from the simulations using CNI (dry conditions)

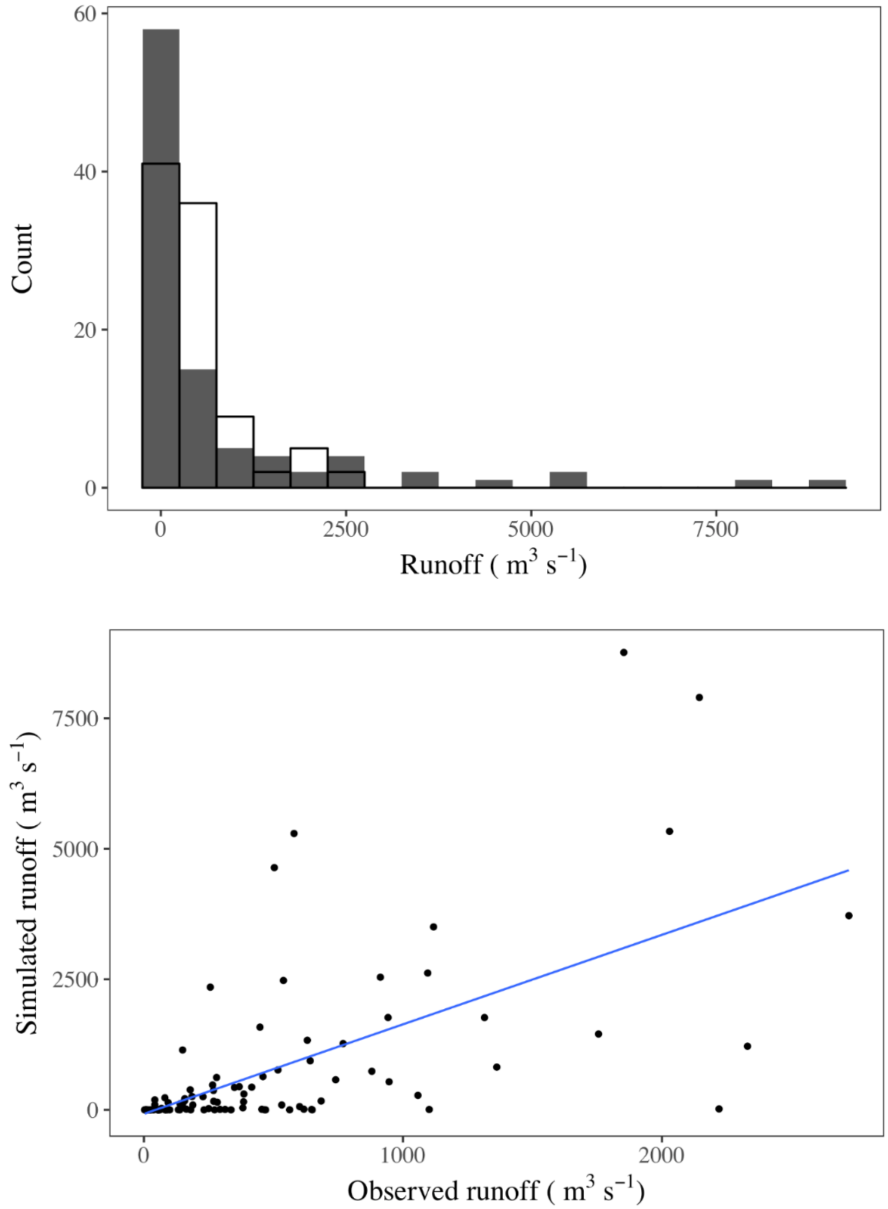


Figure 2-17. Histogram and regression showing the relationships between observed runoff data and the results from the simulations using CNII (average humidity conditions)

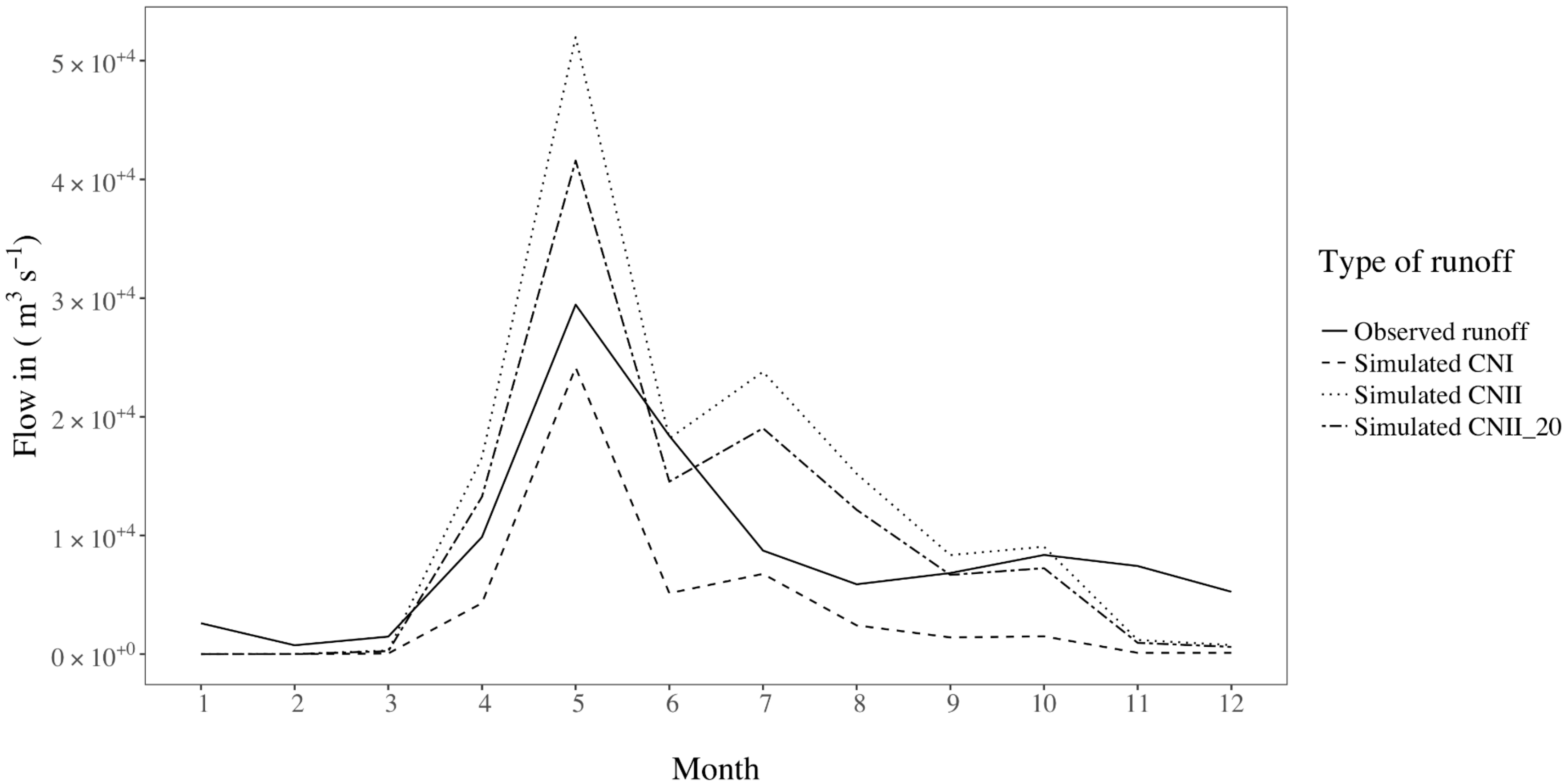


Figure 2-18. Runoff profile for the observed data compared with model results for three scenarios: dry conditions (CNI), average humidity conditions (CNII) and average humidity with a 20% reduction.

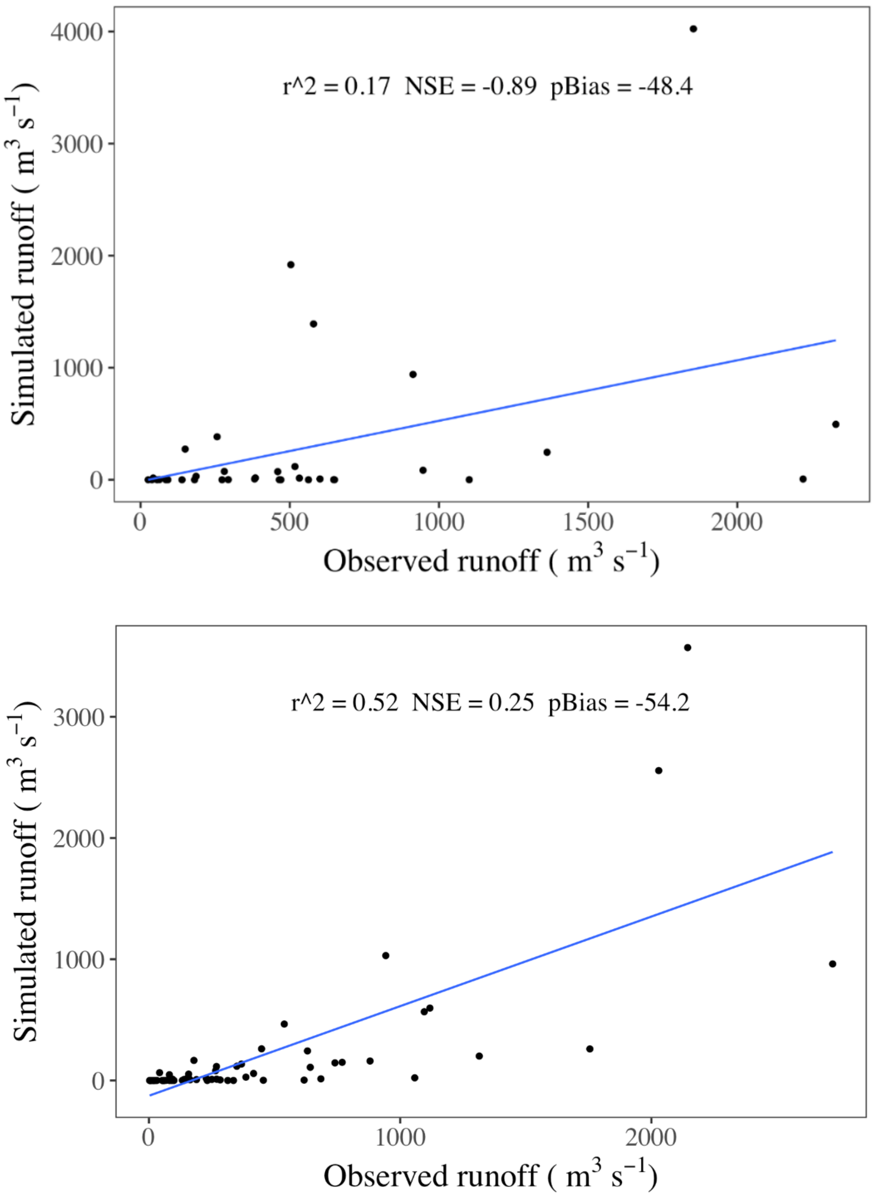
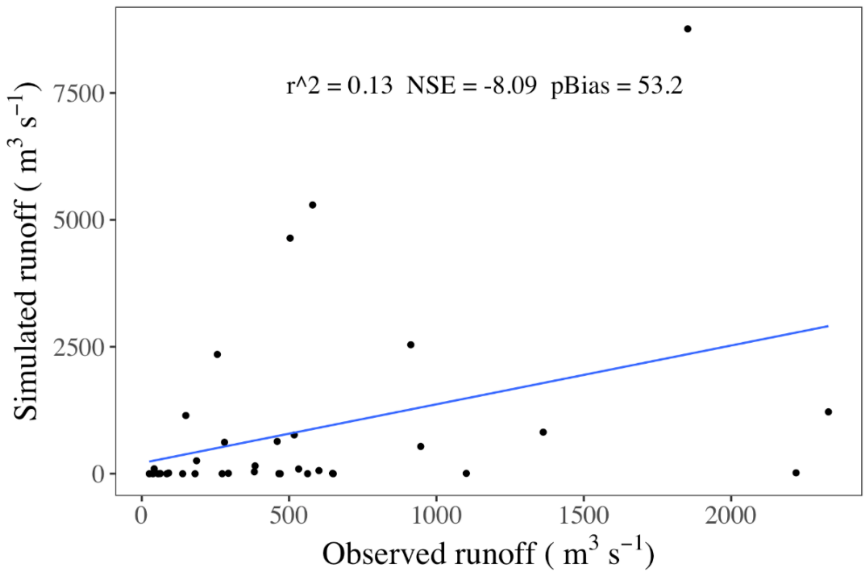


Figure 2-19. Regression by region for the CNI model (dry humidity conditions).
Top: Rainforest - Bottom: Savanna



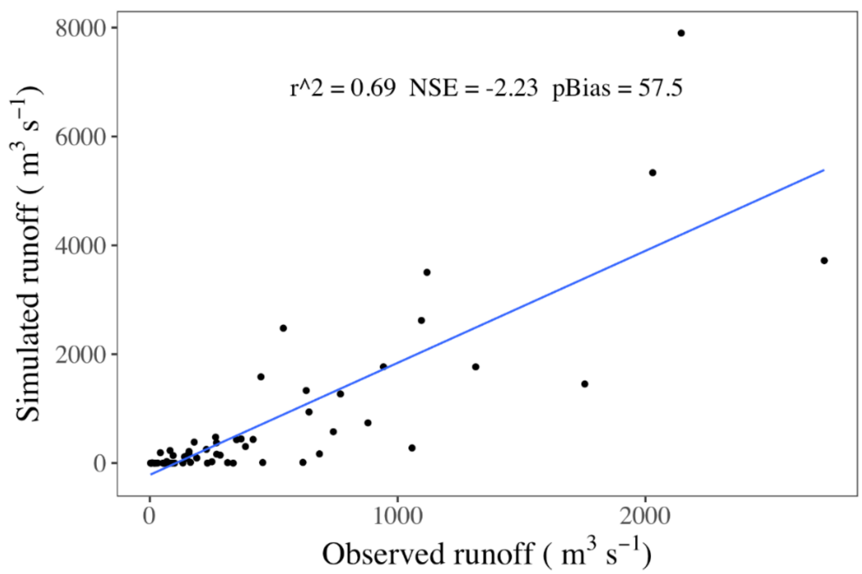


Figure 2-20. Regression by region for the CNII model (average humidity conditions). Top: Rainforest - Bottom: Savanna

Previous studies in the Cerrado Brazil, indicate that portions of this region can be better evaluated using low humidity conditions, whereas others resulted in more efficient models when average humidity is assumed (Soulis & Valiantzas, 2012). The results obtained by the present study show that the assumption of average humidity conditions

(CNII) for the watershed result in better estimations of the runoff in both savanna and rainforest. When CNII was adjusted for a 20% (CNII_20) reduction in its final results, the efficiency of the model improved from NSE: -3.53, r^2 0.34, pBias 33.7 to NSE: -1.74, r^2 0.34, pBias 7. Therefore CNII_20 was used for the surface runoff simulation in the ORW. The results from the validation are presented in Table 2-10.

Table 2-10. Validation results using the selected model (CNII_20)

	NSE	**R^2**	**pBias**
CNII_20	-0.27	0.72	24.6

During the calibration, model CNII_20 showed that for both seasonal and regional variations, the model consistently (represented by pBias) underestimates runoff in the dry season and overestimates it in the wet season (Figure 2-21 and Figure 2-22), and savannas show better correlation and efficiency. The consistency of the model was the lowest in the rainforest during the dry season but was the highest during the wet season.

Overall, the consistency of the models improved with both the assumption of more humid conditions and with 20% reduction of runoff values, which might correspond to the water withdrawals from the Casiquiare (Figure 2-14). Other aspects control the efficiency such as seasonal and regional variation.

Maps in Figure 2-23 show the runoff spatial distribution, the results are shown in the first map. Then, runoff is reclassified for dry and wet seasons. Higher runoff values take place in the south with lower values in the north of the watershed. During the dry season, runoff reduction extends towards the south. White Sands region is permanently flooded throughout the year.

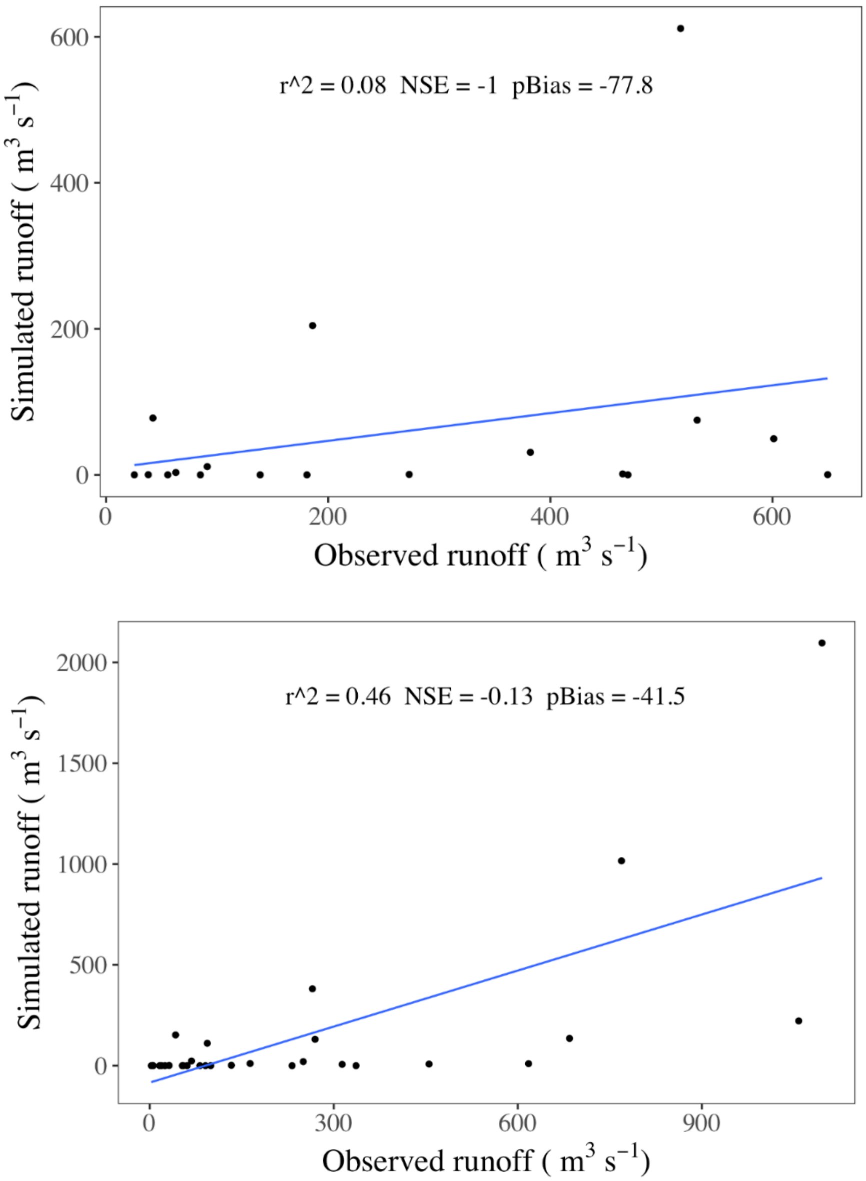


Figure 2-21. Regressions during the dry season by region under the average humidity scenario with 20% reduction. Top: Rainforest - Bottom: Savanna

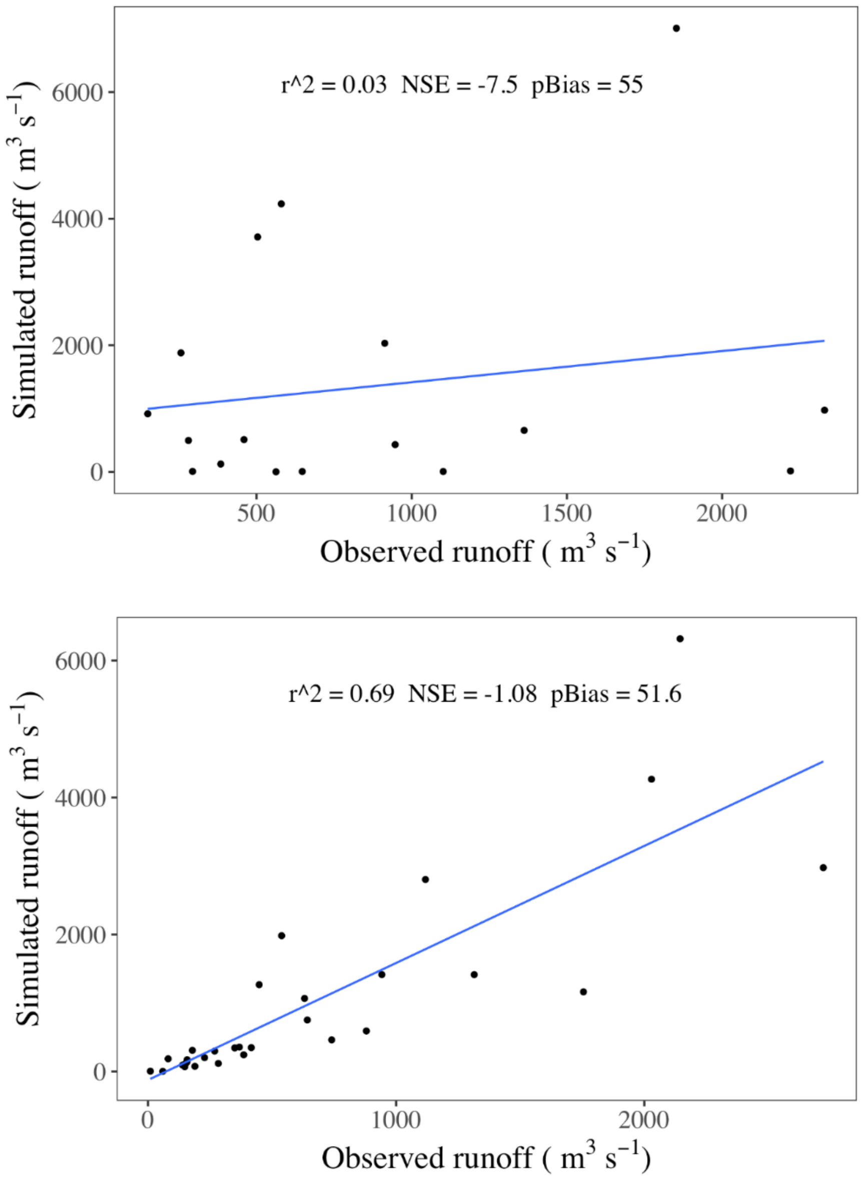


Figure 2-22. Regressions during the wet season by region under the average humidity scenario with 20% reduction. Top: Rainforest - Bottom: Savanna

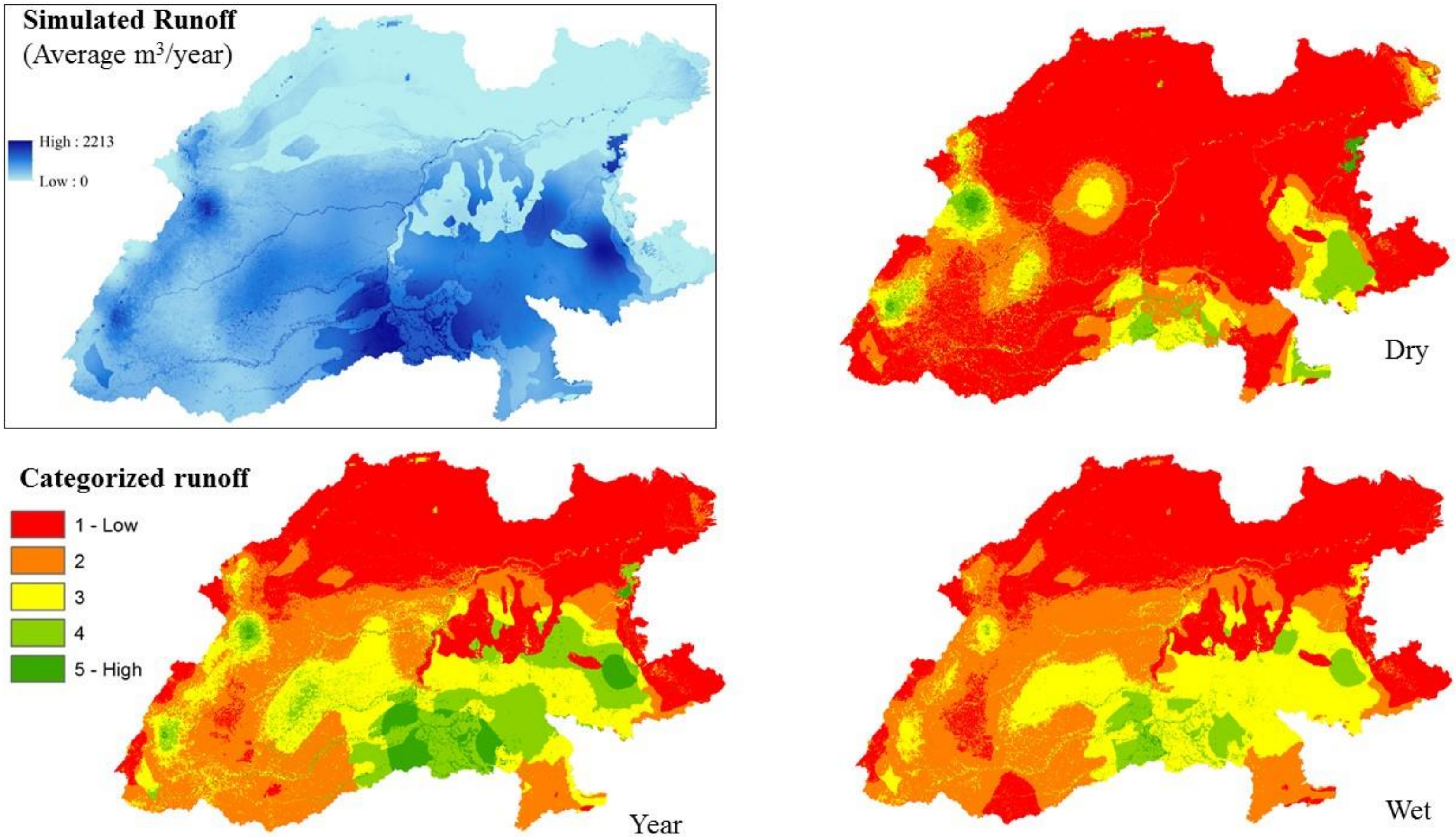


Figure 2-23. Spatial distribution of simulated runoff values.
Up-left map shows the result from the runoff model using CNIII with 50% increment of the overall runoff. Three remaining maps show the results when categorized into five ranks.

After the White Sands, the Altillanura and Guyana regions have the largest runoff values, followed by the Transitional, Orinoco Corridor, and Macarena regions (Table 2-11). At a medium-low level are found the Flooded Llanos and the Andes and Piedmont regions. At the lowest level of average annual surface runoff are the Llanos and Plains and the Delta regions.

Even though, the Andes and Plains experience low retention of surface runoff, certain locations towards the south and up in the Andes have high surface runoff throughout the year. Likewise, Llanos and Plains have a higher surface runoff in the south branch during the wet season. During the dry season, the Flooded Llanos region suffers an extreme reduction of surface runoff.

Table 2-11. Statistic values of average surface runoff (m^3 sec^{-1} $year^{-1}$) by region based on CNII - 20%.

Region	Min	Max	Mean	SD
White Sands	172	2,213	1,182	263
Altillanura	147	2,028	565	241
Guyana	0	2,113	547	396
Transitional	147	2,024	474	242
Orinoco Corridor	0	2,174	435	409
Macarena	201	1,338	387	148
Flooded Llanos	0	1,979	236	193
Andes and Piedmont	0	2,035	214	250
Llanos and Plains	0	2,008	128	255
Delta	0	1,294	70	89

2.4.1.2 Soil loss

Simulated values from the soil loss model were compared with the actual observed data (Table 2-12). The efficiency was better than the one obtained through the runoff model with a coefficient of determination closer to 0.5 and underestimation of the values. When comparing the results of soil loss from dry season versus wet season, the first had better efficiency than the latter. Also, during the dry season the model overestimates the transport of sediments, and during the wet season they are underestimated.

Table 2-12. Error and effectiveness for the soil loss models

Model	**NSE**	**R^2**	**pBias**
RUSLE year	0.47	0.52	-13.7
RUSLE_dry	0.59	0.68	32.9
RUSLE_wet	0.12	0.43	-26.9

Slight variation between seasons can be expected. Sediment transportation is affected by the precipitation; therefore, with increased variation in the intensity and periodicity of the rains, it is expected to have larger yields of sediments. Conversely, during the dry season, the production of sediments gets reduced, and models tend to overestimate yields.

According to the soil loss model, most of the sediments transported throughout the watershed come from the Andes and Piedmont region (Figure 2-26). This is consistent with previous findings that indicate that the Andes produces between 1,000 and 1,500 Tons of sediments by Km^2 $year^{-1}$ (Zinck, 1977). The south-west also shows some sediment production around the Macarena region, as well as the Guyana region. The Altillanura region has a lower yield than the previous regions. For the remaining regions, there is no sediment yield.

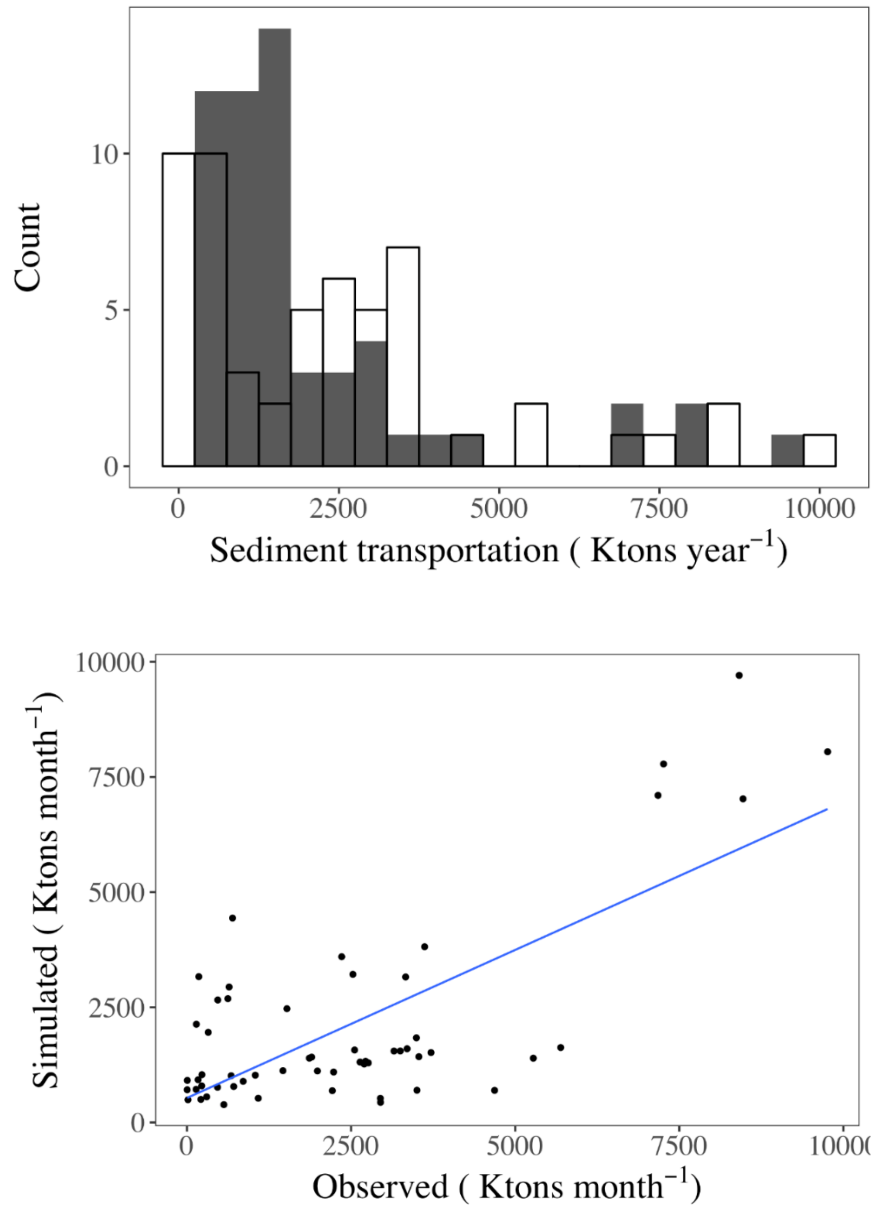
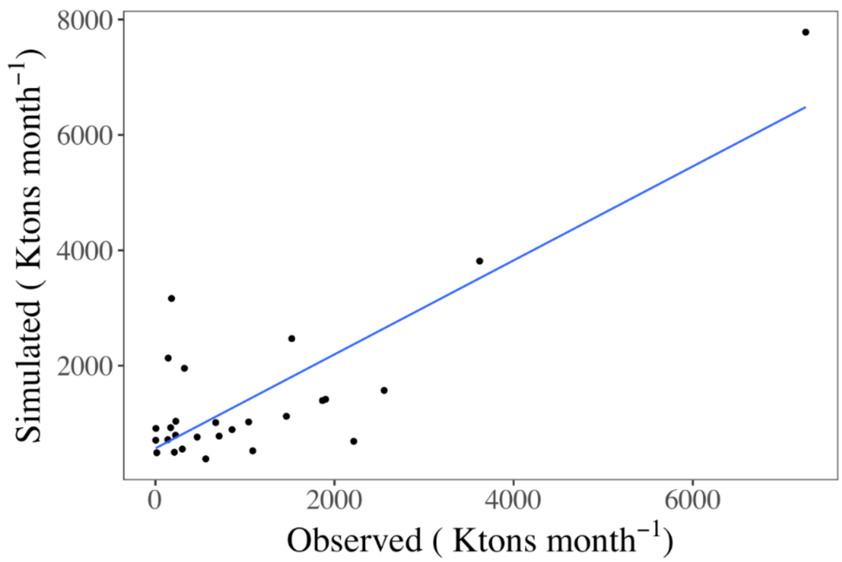


Figure 2-24. Histogram and regression for soil loss model for the entire year.



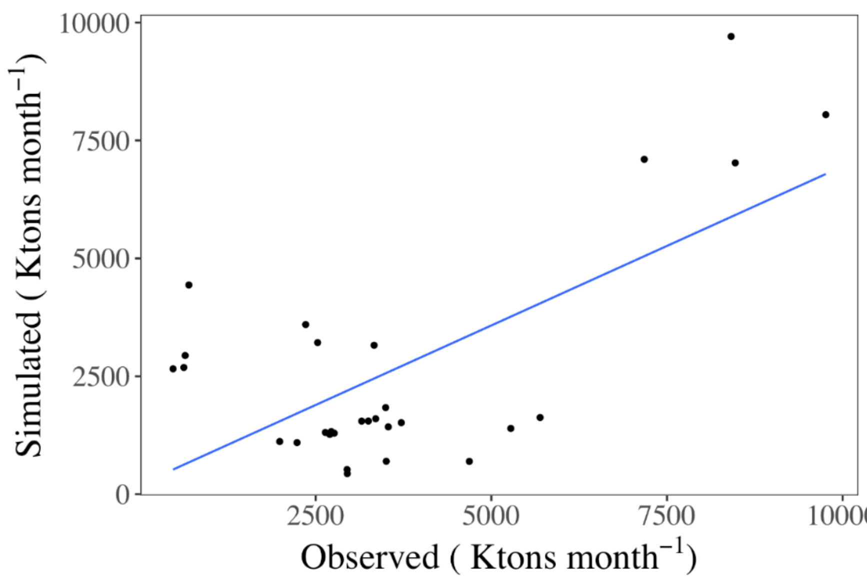


Figure 2-25. Regression with observed and simulated soil loss model for dry (Top) and wet (bottom) seasons.

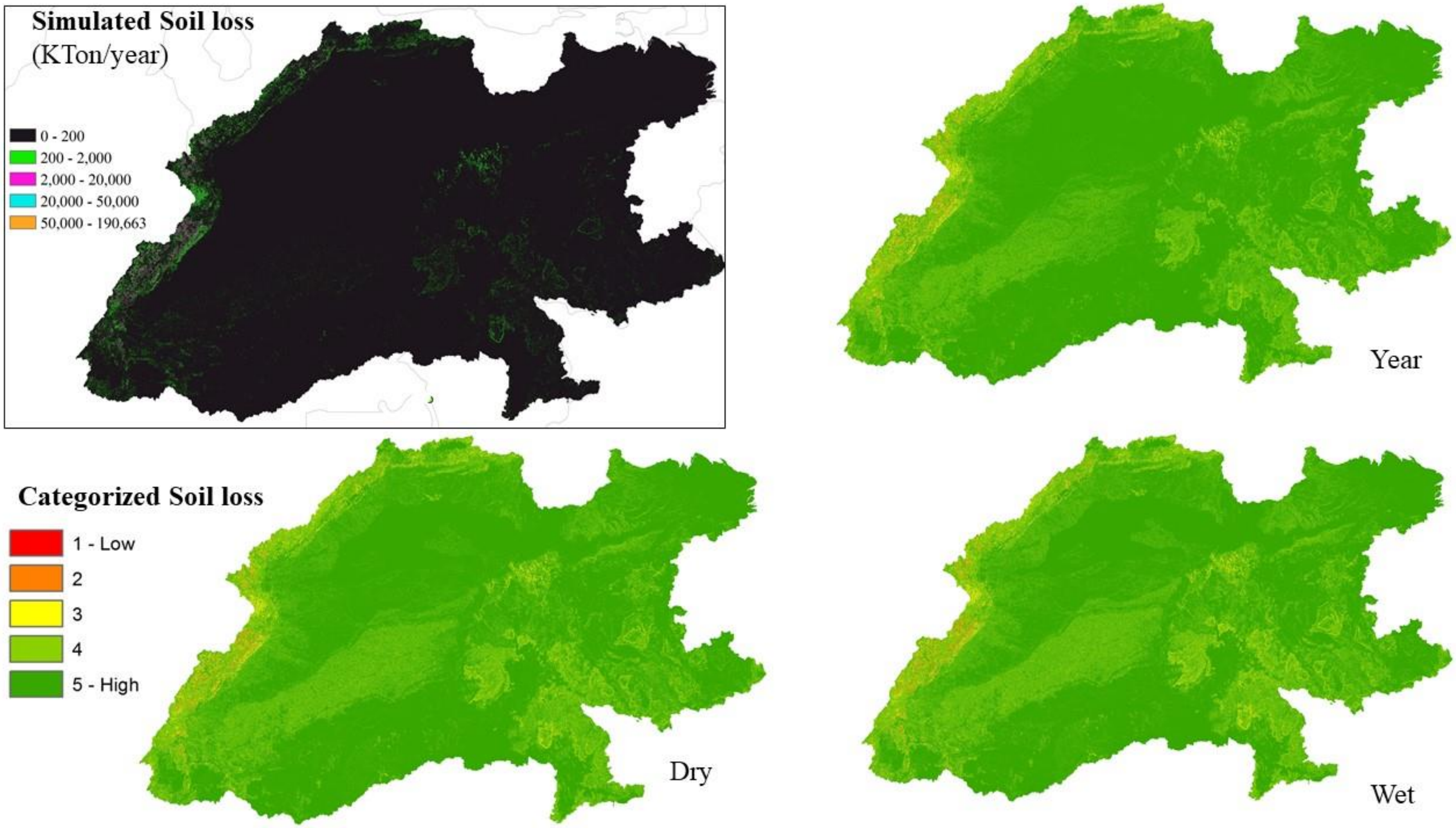


Figure 2-26. Spatial distribution of simulated Soil Loss.
Up-left map shows the result from the model using a logarithmic scale. The other three maps show the results when categorized into five ranks

2.4.2 Carbon and Species richness

Carbon results are separated into biomass (above and below ground) and total carbon storage (Figure 2-27). Above Ground Biomass (AGB) larger than 250 Mg ha^{-1} contains 35% of the biomass in the watershed, and it is distributed along Guyana, Macarena, Delta, Andes and Piedmont, Transitional, and White Sands. These forests show good conservation conditions. Previous studies have found that above this threshold local hydrological dynamics are improved. Areas with AGB values between 150-200 Mg ha^{-1} represent 11% of the total biomass, and are associated with deforestation, as will be explained below. The remaining 54% of the biomass (AGB 0-200 Mg ha^{-1}) is mostly found in the Flooded Llanos, Altillanura, Orinoco Corridor, and Llanos and Plains regions. However, the Andes and Piedmont also have large portions that fall into this category.

Lower biomass values in the White Sands (183 Mg ha^{-1} on average) could be explained by high runoff values that indicate frequent floods. Although this area is covered by trees adapted to the permanently flooded ground (Berry & Wiedenhoeft, 2004), the density and size of this vegetation could not be as high as in the Transitional region or the neighbor section of the Guyana region, both of which have lower runoff values. Permanently flooded areas are usually less covered by tall vegetation. The same situation is presented in the Delta region where the AGB is 152 Mg ha^{-1} on average.

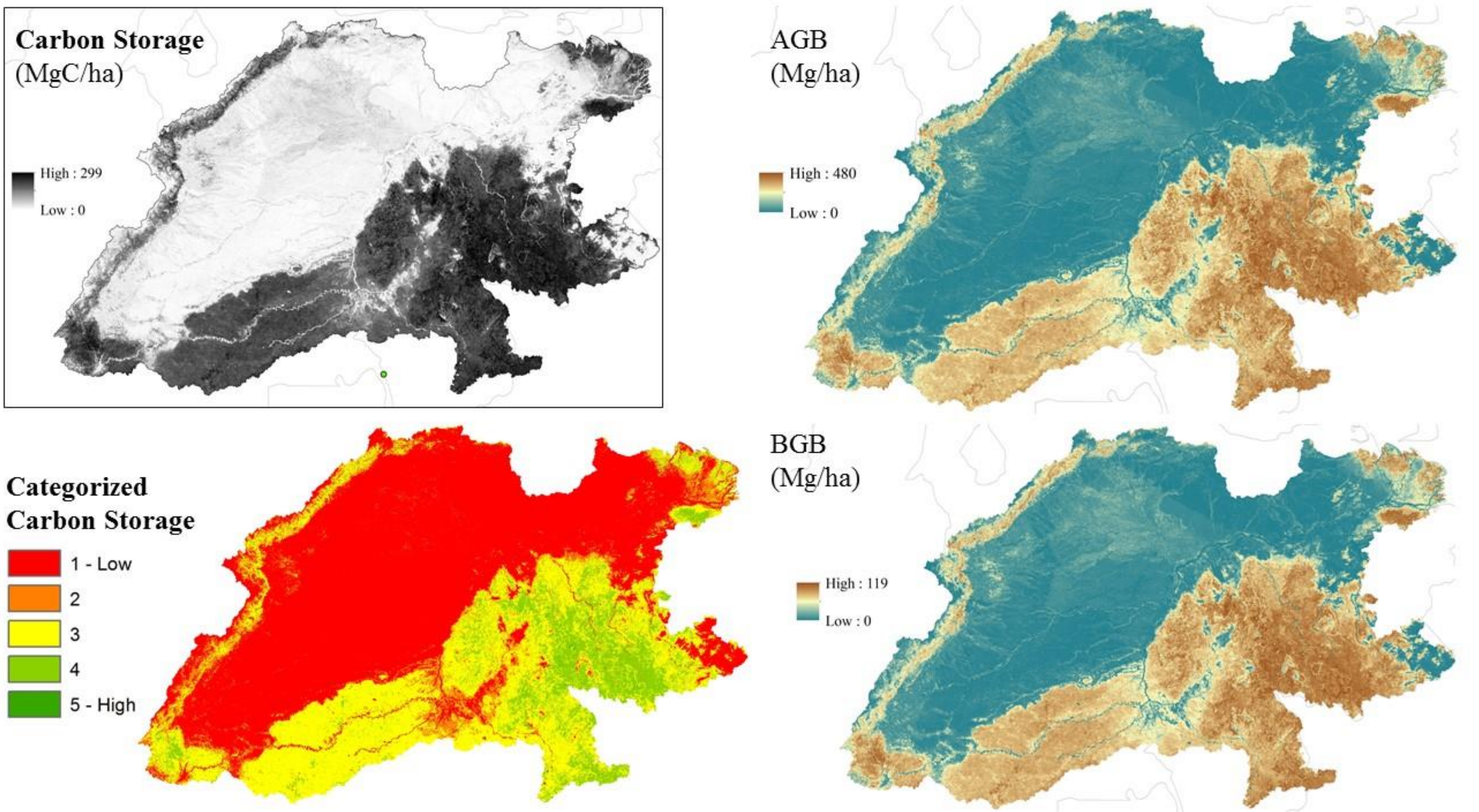


Figure 2-27. Spatial distribution of carbon storage.

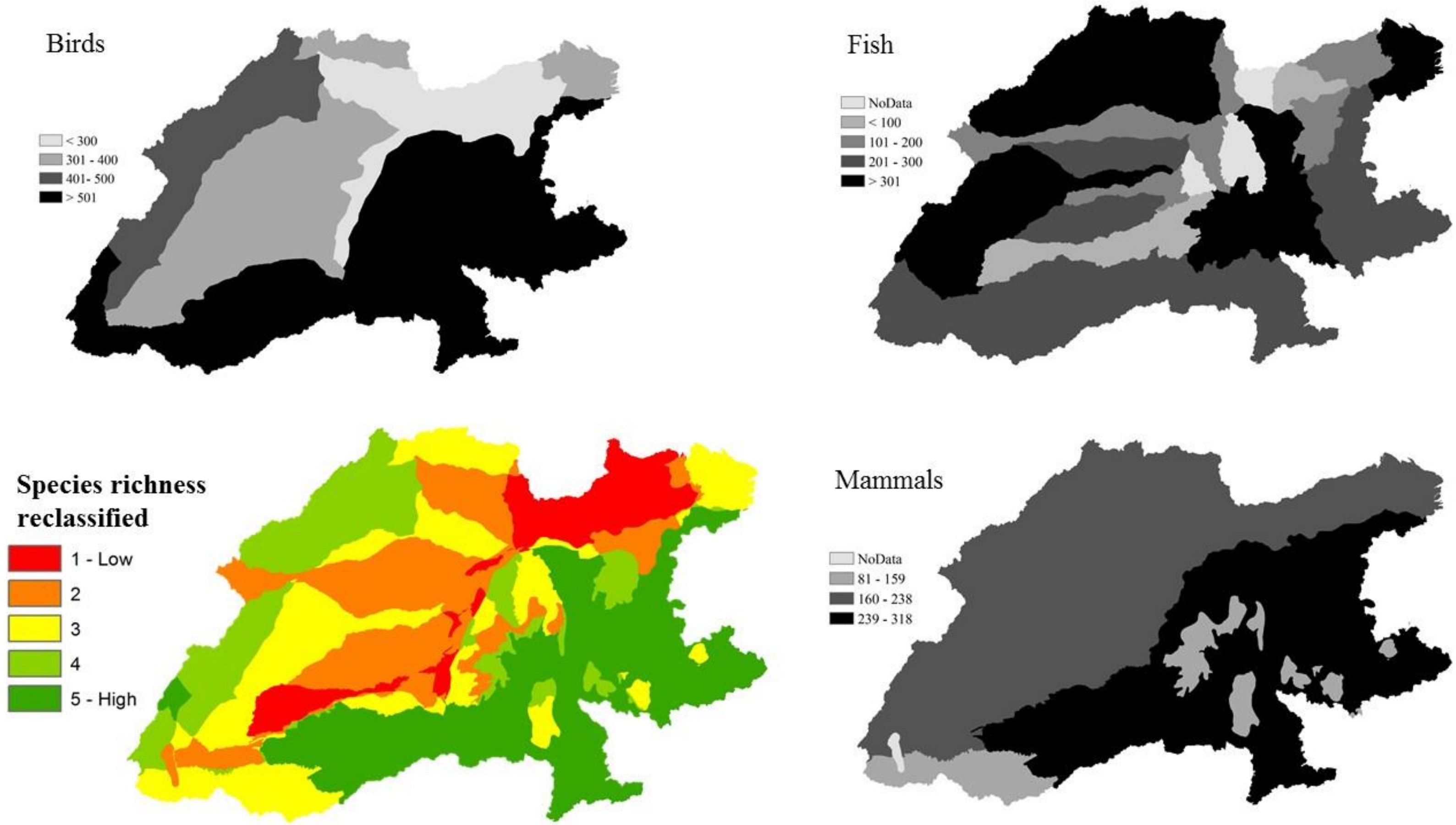


Figure 2-28. Spatial distribution of species richness

Lower AGB values, 150-200 Mg ha^{-1} are found in the area of the basin with historical processes of transformation. For instance, the Andes and Piedmont contain close to half of the population in the watershed, and previous studies have highlighted intensive deforestation processes during the last 50 years. Similarly, the Transitional region (biomass is on average 226 Mg ha^{-1}), has suffered recent processes of colonization by ranchers and farmers. The connective forest between the Transitional and Macarena regions disappeared during the last 50 years, and currently only low biomass values are found. Satellite images show a landscape dominated by patches of forest with low biomass. This same process has been taking place north of the Guyana region.

Carbon storage in the ORW is particularly difficult because of ongoing transformation processes in the Transitional and Andes and Piedmont regions, and because of the nature of savanna ecosystems, which have reduced biomass and therefore lower carbon storage. Although carbon storage has been considered one of the main services provided by the forests in the Andes and Piedmont, Transitional, Guyana, and Macarena regions (Lasso et al., 2010), factors such as intense deforestation and concentration of industrial activities are impacting this service. Also, as a consequence of climate variation there are sporadic fires the reduce biomass in these regions' forests, and intense droughts affect plant growth.

Highest carbon storage is found towards the south and middle of the Guyana region, and towards the end of Guyana, south of the Delta. The Macarena also has high carbon storage values. Small pockets of high carbon storage are located along the Andes.

Species richness is observed for birds, fish, and mammals. Figure 2-28 indicates that south Guyana, White Sands, and the south portion of the Transitional region have high richness values. The Andes and Piedmont region also has high values of species richness, but it is also one of the regions with higher threatened categories (Lasso et al., 2010).

The Orinoco Corridor region has very low richness but it is home to important endemic plants (Lasso et al., 2010) and some portions are found to have high values of threatened species for fish around the Guaviare river (Lasso et al., 2010). Fish are highly threatened in the Colombian portion except for the south portion of the Transitional, the Altillanura, and a small portion of the Flooded Llanos regions. Mammals are the most pervasive endangered group in the ORW, especially in the Andes and Piedmont, Guyana, Transitional, and White Sands regions.

The map with reclassified species richness show the lowest values along the Orinoco Corridor, the Venezuelan Llanos and Plains, and the west portion of the Altillanura region. Species richness is high in the middle and southern-most portions of Guyana, the White Sands, and the middle portion of the Transitional region. The Andes and Piedmont have medium-high species richness values except for a small portion in the central region.

2.4.3 Ecosystem Service Index – ESI

ESI values range between 4 and 17, where 4 are the places with the lowest cumulative ecosystem services and 17 represents the areas with maximum cumulative ecosystem services (Figure 2-29).

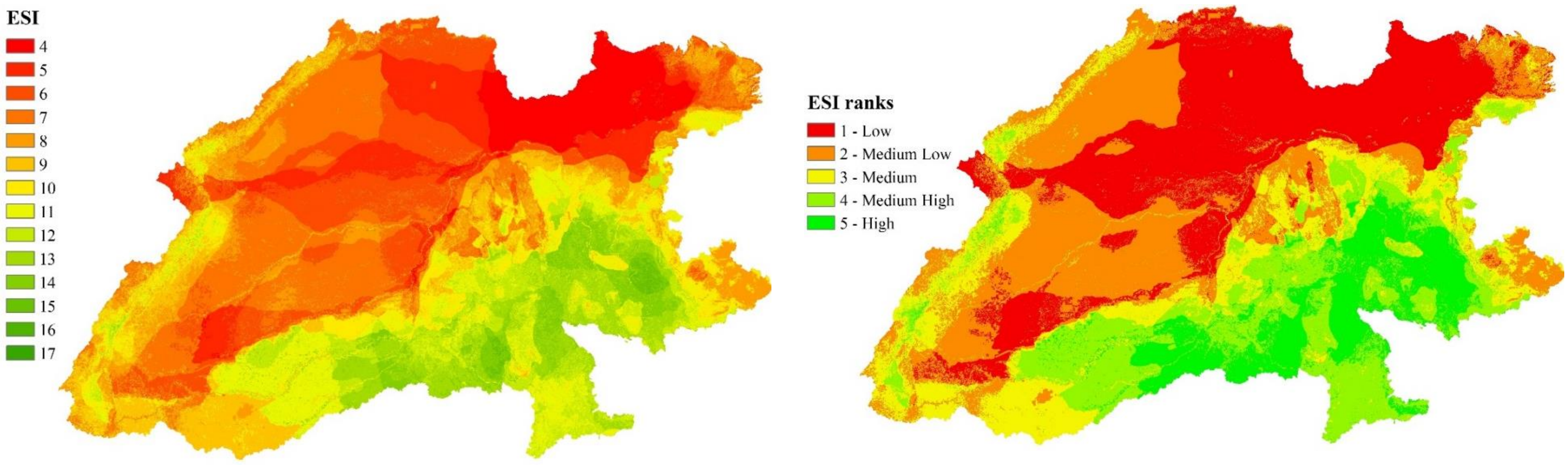


Figure 2-29. Spatial distribution of the Ecosystem Service Index.

Areas where ESI was low (4-5) represent 19% of the total area, with annual surface water availability of on average 59 m^3 sec^{-1} and zero soil loss. Regarding the services associated with the retention and reduction of CO_2 in the atmosphere, the vegetation contained in the Low ESI category does not store considerable amounts of carbon as compared with the highest ESI categories.

Only isolated areas towards the east of the Llanos and Plains region have carbon storage larger than 200 Mg ha^{-1}. Habitat availability is low overall; however, the northern portion of the Andes and Piedmont have medium levels of habitat provision, particularly for fish.

Portions of the watershed with Low ESI are not suitable for implementing water harvesting practices, habitat provision is only significant in the northern portion of the Andes and Piedmont region, otherwise, the habitat provision is deficient. Based on these results, management practices should focus on reducing the impacts within the Flooded Llanos region and on implementing management practices, such as ecosystem restoration within the Orinoco Belt where most of the petroleum industry is concentrated (Figure 2-11).

Towards the north of the Andes and Piedmont region, there is another patch which ranked as Low ESI. However, it is an area that ranks 3 in species richness and is in a portion of the watershed with very low surface water availability. Essential attributes of this patch are the presence of forest islands, relatively low anthropogenic presence despite its proximity to urban areas, and high provision of habitat for bird species.

Areas with medium-low ESI (6-8) cover 36% of the total area (Table 2-13) and have low soil loss and carbon storage values, as well as medium surface run-off and richness. Areas with medium-low ESI (9-11) cover 18% of the watershed and medium-low surface runoff and carbon storage, species richness that is higher than the previous two categories, and soil loss in the low spectrum. Areas with medium-high ESI (12-14) cover 20% of the watershed, they are found in places with relatively high surface runoff, carbon storage at medium range, low soil loss, and very high species richness attributes. Finally, areas with High ESI (15-17) cover 8% of the watershed and are found in areas with very high surface runoff and species richness, medium-high carbon storage, and with the highest ranks of soil loss.

Table 2-13. ESI values and corresponding average categories for each variable.

ESI Categories	ESI	Area (Km^2)	Runoff	Soil Loss	Carbon	Richness
	4	62,973	1.02	1.00	1.00	1.00
Low	5	46,667	1.06	1.00	1.02	1.89
	6	82,261	1.41	1.00	1.03	2.17
	7	129,331	1.80	1.01	1.07	2.53
Medium low	8	154,525	2.00	1.01	1.14	3.05
	9	77,587	2.13	1.05	1.58	3.39
Medium	10	73,717	2.10	1.05	2.15	3.66
	11	108,028	2.38	1.05	2.69	3.71
Medium-high	12	75,578	2.78	1.08	2.88	4.50
	13	125,302	2.90	1.03	3.09	4.94
	14	68,048	3.48	1.04	3.50	4.99
High	15	10,912	3.91	1.08	3.99	5.00
	16	140	3.75	2.14	4.01	4.98
	17	2	3.60	3.82	3.55	4.91

Regions were ESI is high coincide with most Indigenous peoples’ territories (Figure 2-30). This result was expected since it is often found that within Indigenous peoples’ customary territories ecosystems remain better preserved (Sobrevila, 2008;

Stevens, 1997). The delineation of Indigenous peoples' territories not always recognizes the ancestral right over the land (Del Cairo, 2012; Gasson, 2002), because of this, many important regions within the ORW with the high provision of ecosystem services laid outside of what is now defined as their territories. This is especially noticeable in the southern portion of the watershed (Figure 2-30), but it is also true for the Andes and Piedmont region where ancestral groups used to live (Del Cairo, 2012).

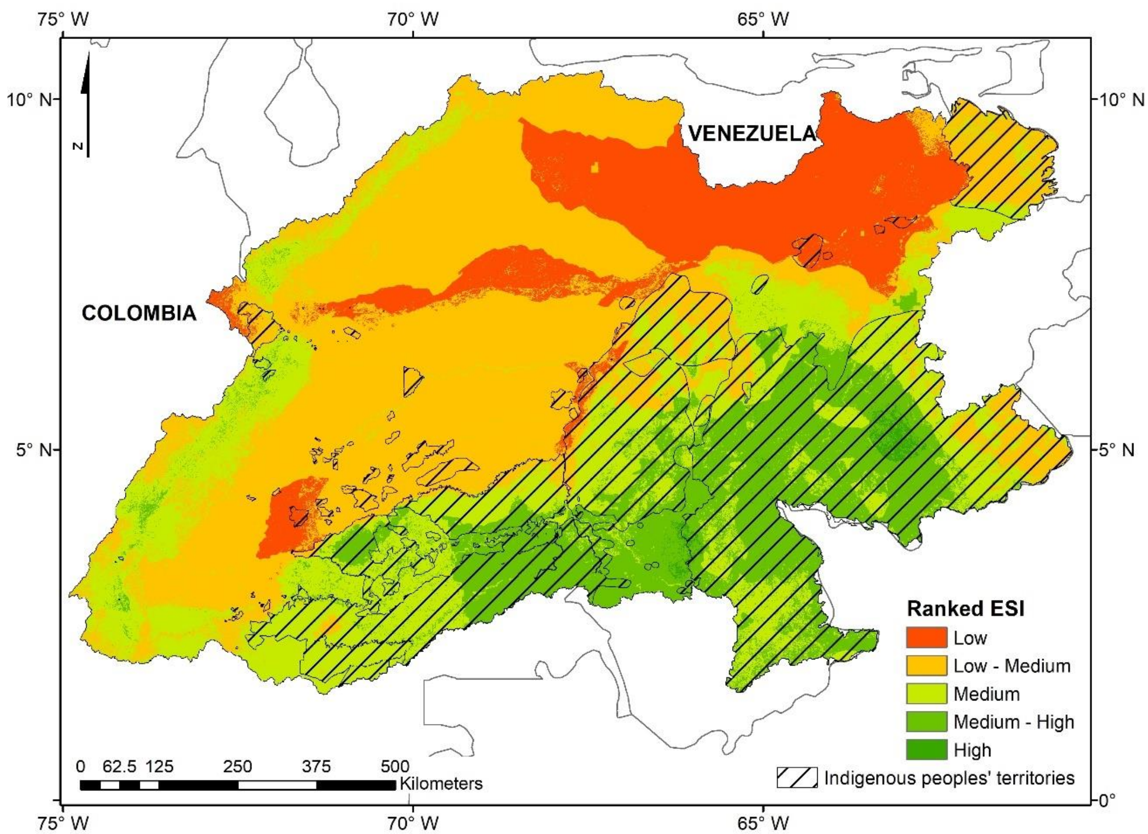


Figure 2-30. Overlap of Indigenous peoples' territories and the ESI

Also, ecosystems within Indigenous peoples territories in the ORW have been deeply transformed by conquerors that have used the land for pasture and farmlands (Del Cairo, 2012; Gasson, 2002), because of this, some portions of the ORW with low ESI also overlap with Indigenous territories (Figure 2-30). Overall, the areas covered by current Indigenous peoples' territories cover significative portions of the watershed where the ESI has high values. Figure 2-31 indicates that about 75% of the areas with high ESI and 82% with medium-high ESI are Indigenous territories. These results indicate that areas with high conservation potential for the protection of ecosystem services, are currently governed by communities with a long tradition of sustainable ecosystem-management practices.

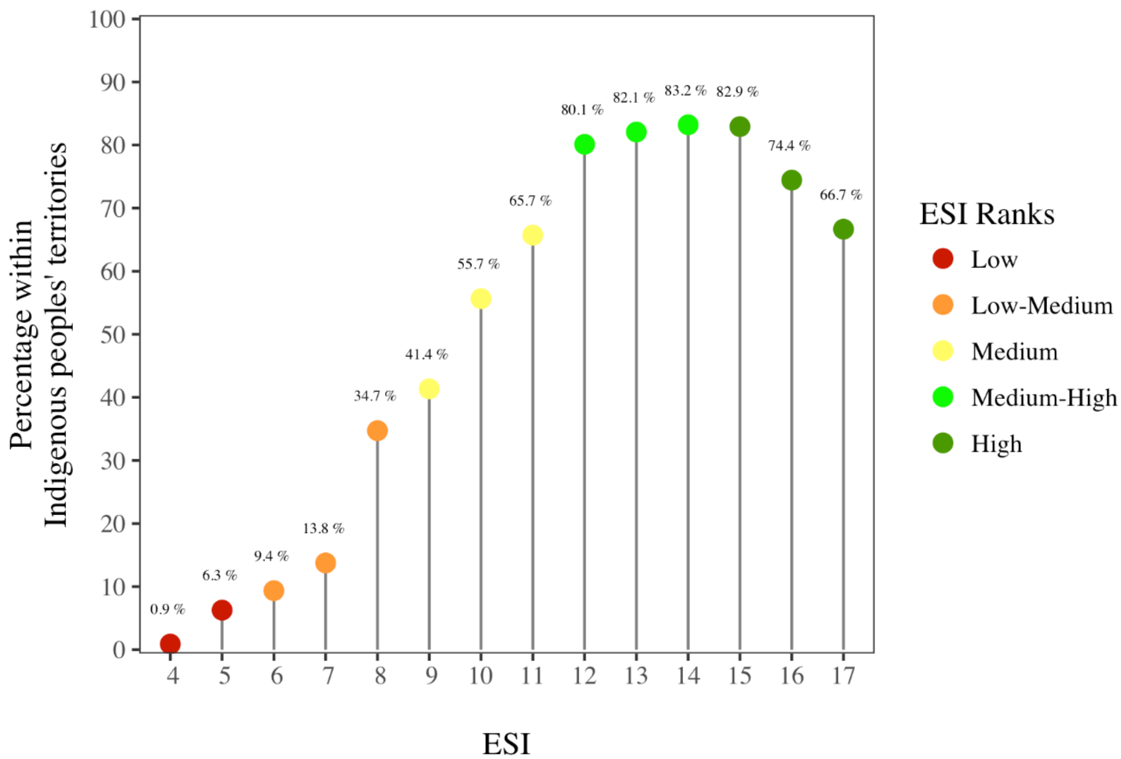


Figure 2-31. Percentage of area covered by Indigenous peoples' territories by ESI

2.5 Management implications

Management practices such as water harvesting are important for augmenting crop yields (Sekar & Randhir, 2007) and for recovering the organic soil (Lal., 2004), and in semiarid regions are an alternative source of water for domestic use (Li & Gong, 2002). Water harvesting is used for irrigating crops in places where local runoff water accumulates, by using runoff diversion systems and storing water in ponds and micro-dams for supplemental irrigation (Sekar & Randhir, 2007; Hatibu et al., 2006). Besides understanding hydrological dynamics and the construction of infrastructure, water harvesting also requires the interest of local and government institutions and that funding is available for the execution of projects.

Another practice consists of installing barriers for the retention of sediments in areas with great soil loss. Regions with high soil loss values are prone to erode, creating unstable soils that can be risky for communities. However, regions where soil particles are retained or transported through the water by surface runoff and along the streams, are important for mitigating erosion and support soil formation and hydro-sedimentological dynamics. Large sediment accumulation can be found in floodplains (Rosales et al., 1999), wetlands, lakes, and flatlands (Warne et al., 2002). Trees in the forest also retain sediments and prevent the loss of soil. Therefore, the protection of the soil also involves the management of those areas within a watershed where sediments are accumulated and retained.

Reforestation, or the establishment of trees in pre-existing forests, is another management practice that has positive impacts on the regulation of local hydrologic dynamics (Hession et al., 2000). It promotes soil formation, constitutes an important habitat for multiple species, facilitates spatial connectivity through the landscape, and enhances CO_2 sequestration from the atmosphere among other benefits. Areas with both good availability of water and proper infiltration of the water are essential for adopting this practice.

The integration of these practices creates a synergy that considers biophysical variables and their connections in the social-ecological system. This way, ecosystem services are used as both the mean and the goal in the protection and management of natural resources. For instance, available surface water is an ecosystem service that is widely protected, and by doing so related ecosystem services, such as water available for irrigating trees used in reforestation projects or regulation of the ecological flow, also get protected.

Considering the results from the ESI, it is possible to identify areas with different management potential, particularly for restoration projects, water harvesting for agriculture and local consumption, and the establishment of new protected areas.

2.5.1 Socio-ecological potentials

Different management potentials result from overlapping Indigenous peoples' territories with the results from the spatial model. The accumulation of ecosystem services was medium-high within Indigenous territories (in the Transitional, White Sands, and Guyana regions), and medium and medium-high in nearby areas with rapid human population growth (in the Andes and Piedmont and Transitional regions). High runoff was between medium-high and high in the Andes and Piedmont region (from the south to the middle portion of this region) and in the Llanos and Plains region (parallel to the same portion along the Andes and Piedmont). High soil loss processes take place in the Andes and Piedmont region.

2.5.2 Low potentials

Conflicts with economic projects, such as oil, mining, and palm oil, reduce the potentials for managing important ecosystems. For instance, eco-hydrological and regional climatic dynamics are controlled by unique Andean ecosystems, such as paramos and cloud forest in the headwaters, and they influence three regions: Andes and Piedmont, Llanos and Plains, and Flooded Llanos. Despite this, intense oil exploration and extraction is impacting the socio-ecological systems.

2.5.3 The potential for ecosystem restoration

Ecosystem restoration projects augment land cover, reduce streams' suspended solids, improve wildlife habitats, and increase carbon sequestration. These projects are often limited by the availability of water needed for growing plant species. Therefore, areas with higher surface water are preferable. Also, areas with high biodiversity of species involved with the dispersion of seeds (e.g., birds and terrestrial mammals) have been found to be positively correlated with successful restoration projects.

Restoration projects for the ORW can help with critical issues such as the transformation of natural hydro-sedimentological dynamics due to human occupation of the Andes. Even though, previous studies have found that 90% to 95% of the total sediment yield in the ORW comes from the Andean mountain range (Rosales et al., 1999; Zinck, 1977), the settlement of human populations have transformed terrestrial ecosystems, and therefore sedimentation and reduction of the water quality. Because of this, restoring the land cover in the Andes and Piedmont region could benefit the water quality for human consumption and could help retain the sediment yield from the Andes.

Changes in the hydro-sedimentological dynamics of the watershed alter the influx of sediments that shape aquatic habitats. This issue can also be addressed through the ecological restoration of rivers headwaters. Land changes in the Andes are affecting aquatic habitats of the Meta's riparian corridor (Lasso et al., 2010), which has been declared by federal agencies of Colombia and Venezuela as a priority area for the conservation of the Orinoco biodiversity, along with other areas such as the headwaters of the Meta river and the Guaviare river.

2.5.4 Potential for water harvesting

Water harvesting is practiced through technologies that intercept rainfall and surface water. High runoff values in the ORW indicate areas where this water-management strategy can be more effective. Harvested water is often used in agriculture and for other human activities. It could also be a valuable resource for communities in small villages and towns with growing population. Urban development in this watershed is taking place in the Andes and Piedmont region. Smaller settlements have increased their population sizes in other regions during the last decades. Higher harvesting potential is found in the middle portion of the Andes and Piedmont region, followed by the Altillanura region and sections of the Guyana region.

2.6 Conclusions

Through the spatial assessment of the four variables considered in this study, it is possible to conclude that the areas better suited for executing restoration projects in the Andes and Piedmont are in the south portion of this region, where runoff values and species richness are categorized as high.

Spatial distribution of the ESI show higher concentration of ecosystem services in five main regions of the watershed: Guyana, White Sands, Transitional, Macarena, and Andes and Piedmont regions. These results are important for adopting policies and practices towards the protection of areas where ESI values are high. For instance, areas around cities like San José del Guaviare and Guyana City show high ESI values, however, urban expansion in these areas is causing accelerated deforestation. Focusing management on these boundary areas, where ecosystems provide important services to the growing population and at the same time are being pressured by the conversion of forest into agricultural and grasslands, could be important for the future development of the watershed.

The results indicate a high potential for the protection of areas with medium-high levels of ecosystem services, due to the overlapping of these areas with Indigenous territories. Threats to areas with medium and medium-high levels of ecosystem services are located in areas with high population densities in the Andes and Piedmont and Transitional regions, these could also represent opportunities for future cooperation with local organizations. The results also show high potential for ecological restoration and soil retention in the Andes and Piedmont region, and water harvesting in the middle portion of the Altillanura region, in the Transitional region, and in the south-east portion of the Guyana region.

The spatial analysis of ecosystem services showed that the Andes and Piedmont region is one of the most important regions in the watershed. This region hosts more than 40% of the total population living in the ORW (WorldPop, 2013), produces 90% to 95% of the total sediments that travel through the stream network (Rosales et al., 1999; Zinck, 1977), and has a medium potential of restoration. It also has one of the highest concentration of mining and oil extraction, and upcoming projects will intensify the pressure over the remaining ecosystems, threatening the provision of services to local communities.

Runoff dynamics in the ORW are better represented by a model that considers 20% more than the average humidity. The soil loss model confirms previous findings regarding the high production of sediments in the Andes. Guyana region also shows soil loss processes, but at a much lower range, and the rest of the watershed has extremely low sediment yields. These results indicate that the major factor involved in the soil loss process is the elevation of the terrain.

The ESI gathers the results from the four ecosystem services surrogates and allows us to see that the regions with the largest accumulation of ecosystem services are the Guyana and White Sands located in remote areas, which are dominated by rainforest ecosystems. Following these, are the Transitional, Andes and Piedmont, and Macarena regions. These regions are highly pressured by deforestation processes and urban development. Using the ESI for planning resource management and conservation in these areas will help prioritize actions for the protection of ecosystem services.

Regarding restoration projects and water harvesting, the results of this research show that the areas with higher potentials for these activities are the southern and mid-portions of the Andes and Piedmont region. There, restoration projects could have important benefits for aquatic ecosystems in the Meta river riparian corridor and on the Meta and Guaviare rivers' headwaters.

This study also showed the importance of acknowledging the effect that global dynamics have on the future development of the watershed not only at a watershed level, but also at a national, subnational, and local scales. The influence of the global economy, mainly through the demand of natural resources, is impacting all layers of the watershed. Therefore, the success in protecting basic ecosystem services highly depends on the capacity of the governing institutions to articulate at multiple scales.

CHAPTER 3

MISMATCHES AMONG GOVERNANCE SCALES IN THE ORINOCO RIVER WATERSHED

3.1 Introduction

Multi-scale approaches that help articulate multi-actor dynamics are necessary for the governance of common pool resources (Randhir, 2016; Ostrom, 2005, 1990). Upscaling and downscaling of strategies for the protection of local commons requires strong connection and integrated management between stakeholders, therefore, problematic relationships between actors and deficient communication, can cause mismatch and disconnections within and across scales, and thereby interrupt the flow across the system (Wilson, 2006; Ostrom, 2005), reducing local capacity to govern common-pool resources. Effective multi-scale interaction is pivotal for effective collective management of common-pool resources (Ostrom, 1990) and for avoiding resource overexploitation and loss of biodiversity (Cinner et al., 2012; Berkes, 2009).

Within multi-scale systems, vertical discontinuity interrupts the flow of information and understanding of the dynamics and mechanisms of complex socio-ecological systems, whereas horizontally this affects cooperation among the actors at a given scale. Both types of disruptions reduce the capacity of the socio-ecological system to respond to sudden changes and to formulate adaptive co-management strategies (Berkes, 2009; Olsson et al., 2007). Finding solutions to improve the interactions in multi-scale systems, requires better understanding of the conditions under which the disconnections are taking place (Olsson et al., 2007), this will allow for better solutions to the disconnection problem, will reduce the costs of common-pool resources management, and could increase efficacy in the protection of the resources.

In this research, factors affecting interactions between actors within the Orinoco River Watershed (ORW), a binational South American basin, will be identified. The case uses two scales and four actors: Indigenous peoples and non-Indigenous communities at local scales, and researchers and federal employees at the regional scale.

Many Indigenous peoples in this watershed are settled in Indigenous reserves, but there are still nomadic and semi-nomadic groups that travel through the watershed within their customary territories (Villegas-Arias, 2008). Indigenous peoples' economies are based on fishing, hunting, gathering and on growing cassava. Some communities raise domestic animals (cows and pigs), and the ones on the piedmont grow diverse types of crops. Due to the loss of much of their ancestral territories (other than their reserves), Indigenous peoples face daunting challenges for their survival and maintenance of their traditional knowledge.

Non-Indigenous communities represent most of the population. The main activities of these communities are farming, fishing, and ranching. There are three distinct groups within non-Indigenous communities: Llaneros, 1950's settlers, and the new settlers. The differences between these groups are presented later in this chapter. Overall, non-Indigenous communities struggle for access to the land and to maintain their economy, which is reliant on resources within their properties and on common-pool resources.

Researchers are composed of scientists who work at universities, public research institutes, and non-government agencies. Half of them live within the watershed and the other half live outside of it. Federal employees are professionals who work for environmental agencies at regional scales. These agencies oversee managing natural resources and verifying the correct functioning of industries. Most of these federal employees are from the Orinoco region.

Differences between these actors regarding conservation objectives and unequal perceptions about needs of the population can impair mutual understanding and cooperation (Crona & Parker, 2012). Finding common interests and major differences among stakeholders, will contribute to solve conflicts that impair the protection and rational use of these resources. This will also help develop proper incentives for local participation (Rica et al., 2012; Gutierrez et al., 2011; Berkes, 2009) and to adopt efficient natural resources management (Berkes et al., 2006).

The objective of this research is to characterize mismatches between and among local and regional actors about natural resources use behavior, governance, and management of common-pool resources. This will help answer two main questions: what is the topology of mismatches between and among actors? and what is needed to improve the links between and among actors? In this research, the topology of mismatches is understood as the nertwork formed by the agreements or disagreements (links) between stakeholders (nodes). The method used for the identification of these topologies and their interpretation is explained in the methods section.

Two hypotheses were formulated: first, vertical differences or differences between local and regional actors, would be higher than horizontal differences, and second, that by identifying the topology of these differences it would be possible to understand what are the critical factors that impede or facilitate the interaction between groups of stakeholders.

The unique contribution of this research is to augment the body of knowledge about socio-ecological systems in South America and provide a new insight about the issue of how to articulate locally-explicit governance dynamics involving Indigenous peoples and non-Indigenous communities. This research brings light to the analysis of biophysical interactions in socio-ecological systems in the Orinoco River Watershed, the second most important watershed in the continent, and show how different socio-economic dynamics impact these systems. Also, it establishes the connection between the provision of ecosystem services and governing mechanisms for the protection and conservation of strategic regions.

The following section presents the area of study, a description of the survey's structure, and the methods used for analyzing the data. Then, the results of the survey are presented in three sections: first, the characteristics of each local group, second, the conditions of common-pool resources in the visited regions; highlighting use behavior, governance, and management of natural resources; and third, presenting and discussing differences between groups of actors that resulted statistically different in the statistical analysis. The closing section presents suggestions for reducing gaps between actors, and the main conclusions.

3.2 Methodology

3.2.1 Study area

This research was conducted in the Colombian portion of the Orinoco River Watershed (ORW). It comprises an area of 363,135 Km^2, which is the 37% of the total area of the watershed. The ecoregions in this portion of the watershed are dominated by savannas from the central portion towards the north, and rainforests to the south and east. Eight ecoregions are found in the study area (Figure 3-1). The Andes and piedmont region is the most densely populated area in the watershed, with intensive land use and the ecosystems have been largely transformed. Despite of this, the spatial analysis of ecosystem services in this region showed that the Andes and piedmont has high potential for the restoration and management of strategic ecosystems, with potential positive impacts in the middle and lower portion of the watershed.

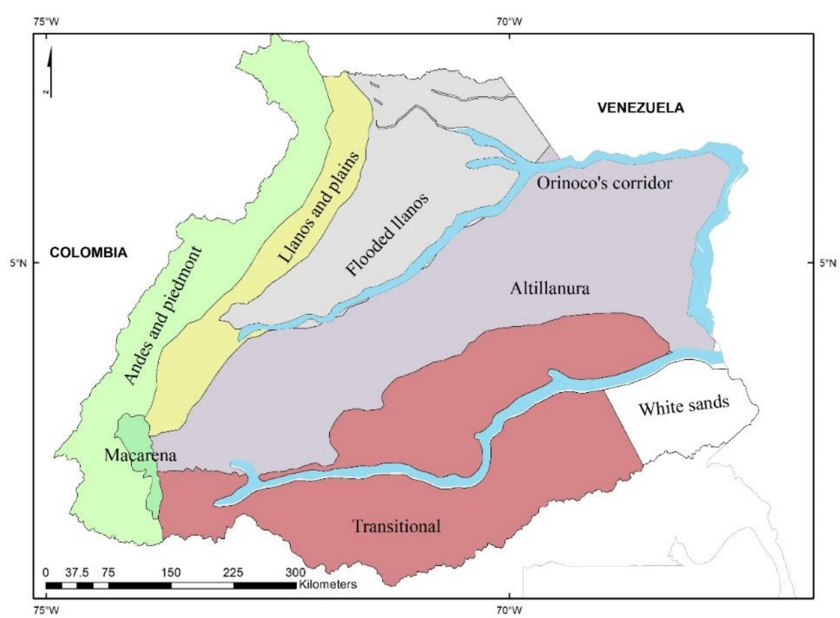


Figure 3-1. Regions within the study area.

The Llanos and Plains, together with Flooded Llanos are the second most populated area. It has been reported that in this regions groundwater is a primary source for the local population (Lasso et al., 2011). The Altillanura and White Sands have low population density and human groups mostly belong to ethnic groups. The Transitional region is where the savanna and the rainforest intersect. During the last decades the ecosystems in this region have been highly transformed due to encroachment of unplanned settlements. These are groups of people that have arrived seeking for business opportunities linked to illegal activities such as wood extraction, gold mining, and coca plantations.

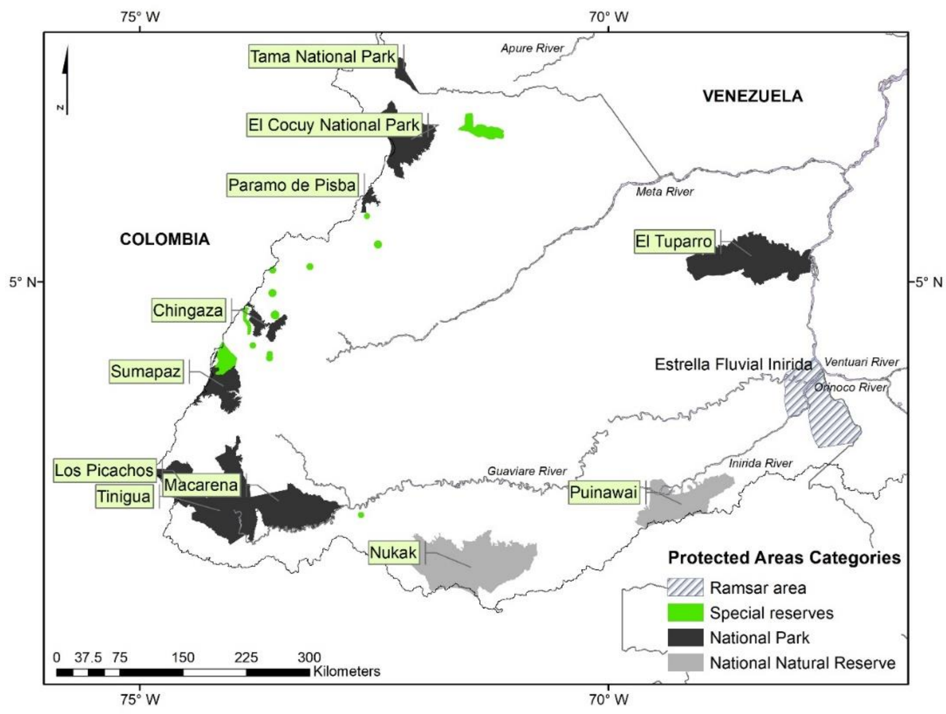


Figure 3-2. Protected Areas Categories in the Colombian portion of the Orinoco River Watershed

Four types of protected areas are found within the study area (Figure 3-2). Special reserves that constitute small forested patches for the protection of local resources, they cover an area of 2,017 Km^2. One Ramsar area designed for the protection of wetlands in the intersection of the Orinoco, Atabapo, Guaviare, and Inirida rivers that covers an area of 2,530 Km^2. Nine national parks designed for exclusive conservation of biodiversity hotspots with an area of 32,336 Km^2 (RAISG, 2018), and two national natural reserves designated for restricting the use of natural resources in sensitive areas, with an area of 22,309 Km^2.

Overlaps of Indigenous peoples' territories with National Parks in the ORW account for a total area of 81,738 Km^2, 1,41 Km^2 in Colombia and 80,317 Km^2 in Venezuela. The total indigenous territory in Colombia is 97,134 Km^2 and in Venezuela is 277,551 Km^2, meaning that only 4.4% of the Indigenous peoples' territories in Colombia are protected by National Parks, but in Venezuela is close to 43% (based on the information found in RAISG).

In the Colombian portion, the ORW is undergoing rapid urban development. This is a consequence of the industrial projects for expanding palm oil plantations, oil exploration and exploitation, and mineral extraction. Ecosystem services produced in the ORW sustain the livelihoods of local communities and support the water provision for Bogota, Colombia's capital.

3.2.2 Survey's structure

Main data was collected through surveys administered to four groups of actors, Indigenous peoples (IP), non-Indigenous communities (NI), researchers (R) and federal employees (F), at the locations presented in Figure 3-3. A sample of the survey is included in Appendix A.

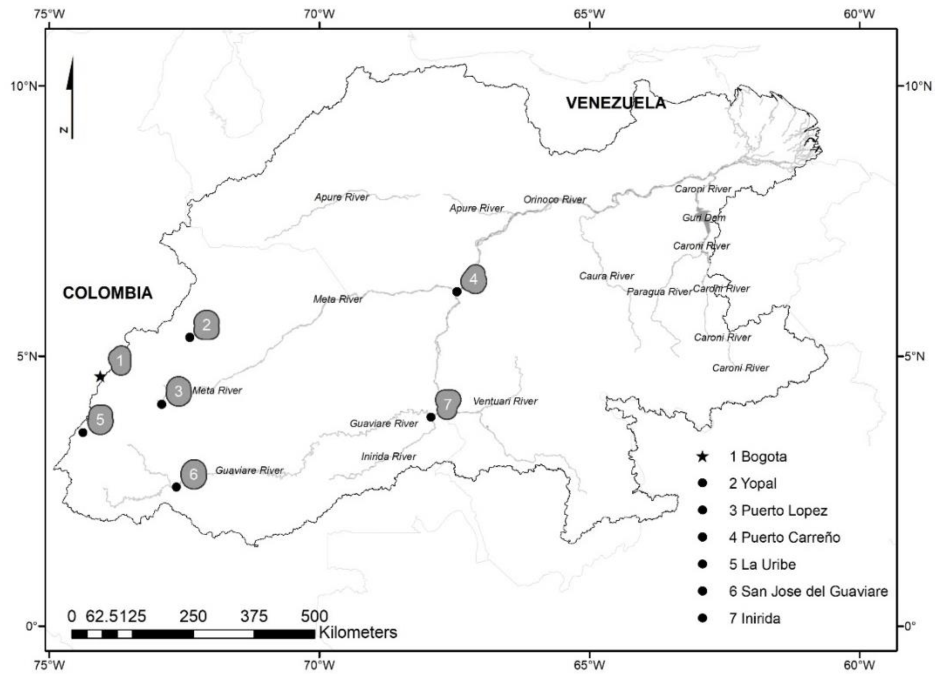


Figure 3-3. Surveyed locations

To evaluate the nature of socio-ecological interactions within this watershed and their impacts on natural resources, the survey was administered to actors that directly or indirectly affect the use and management of natural resources in the watershed at a regional scale, and to users at a local scale. A list of possible participants was created by looking at the websites of organizations linked to the environmental work in the Orinoco. Also, during a preliminary phase, key local actors were identified and contacted. Before providing the information, the participants were informed about the objectives of this research and they agreed to complete the survey after having read the survey consent form (Protocol ID: 2015-2506 UMass IRB). The description of the objectives and content of the survey was explained verbally when the participant was not literate.

Essential information provided by the participants in this research are quoted and cited with the identification number used for coding the interviews and surveys. The codes were GSJ, MLU, MPL, CY, VPC, GI, BOG, for participants from San José del Guaviare, La Uribe, Puerto López, Yopal, Puerto Carreño, Inírida, and Bogotá respectively. Indigenous peoples participants were coded with IP.

The survey was administered to 88 respondents: 13 Indigenous participants, 44 non-Indigenous participants, 14 federal employees, and 17 researchers (7 from academic institutions and 10 from NGOs). Surveys and interviews from non-Indigenous participants, federal employees, and researchers were collected in all six locations (Figure 3-3), but for Indigenous peoples, it was only possible for San José del Guaviare, Yopal, and La Uribe. For these peoples, additional observations were made in remote areas within the municipalities of Puerto Carreño and Inírida (Figure 3-3).

This survey had three sections, use-behavior, governance strategies, and management practices (Figure 3-4), and it was administered in the locations presented in Figure 3-3 during two seasons: June 2015 and February 2016. Additional data came from interviews and personal observations.

The first section of the survey involved the perception of local use behavior about eight natural resources. Three sets of questions collected participants' perceptions about (1) levels of dependence on each of these resources, (2) level of resource demand through economic activities, and (3) level of concern about the current state of these resources.

The second section focused on governance aspects that include: (1) conservation incentives, where participants graded how many cultural values, economic values, ecologic values, and landscape values can be an incentive for conservation, (2) conservation likelihood under different property regimes, that explores participants' perception about conservation in areas with different types of tenure (private, public, national parks, Indigenous reserve, and lands with open access), and (3) governance strategies, where participants grade the effectiveness of formal and informal strategies.

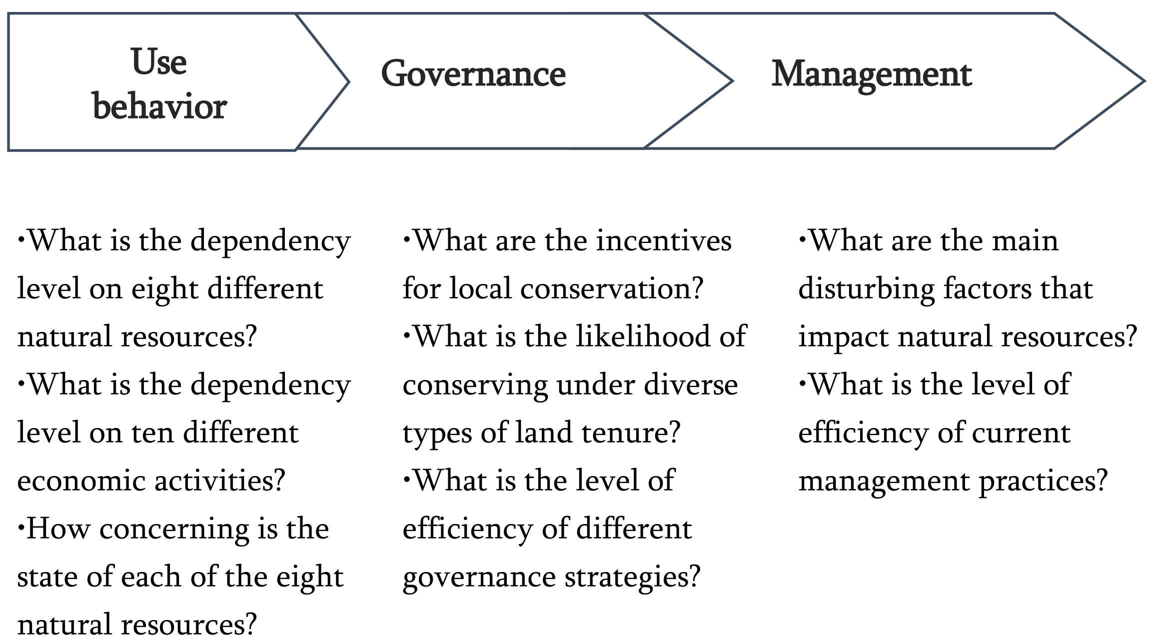


Figure 3-4. Core questions used for each of the survey sections.

A total of 15 strategies were classified into four categories (Table 3-1) (1) Policies, such as regulation for conservation of areas with high ecological value, regional planning and urban development planning, (2) Regulations, including implementation of the rules, fines, agents of control and bans on fishing seasons, and imposing hunting controls, (3) Internal rules, composed through agreements among the members of a community (written or verbal agreements) and through solutions to conflicts, and (4) Cooperation, which assesses cooperation within a single community, cooperation between communities, cooperation between communities and the central government, and cooperation between communities and universities. The first two categories correspond to formal strategies and the other two are informal strategies.

The third section had two set of questions: (1) factors that impact natural resources, (2) needs for management and efficiency of ongoing management practices.

Table 3-1. Governance strategies

Type	Categories	Strategies
Formal	Policies	Areas for conservation Regional planning Urban development planning
	Regulations	Rules and fines Agents of control Fish banning Control over hunting practices
Informal	Internal rules	Verbal agreements Written agreements Conflict resolution
	Cooperation	Cooperation within the community Cooperation between communities Cooperation with the central government Cooperation with universities

In implementing the survey, each participant was assisted individually by verifying that each question was understood correctly. This procedure not only reduced inconsistencies from differences in the interpretation of the questions but also allowed participants to explain their answers and provide examples. These conversations were documented and used in the interpretation of the results.

3.2.3 Analysis

For the analysis of the results obtained through the surveys were used different approaches: rank-order of the results to observe trends about use-behavior, governance and management of common-pool resources, box-plot analysis to observe variation in the responses obtained by each group, Pearson chi-squared (χ^2) test (Bolker, 2008) to identify significant differences between pairs of groups for the different variables, and the construction of networks to represent the topology of mismatches (Figure 3-5).

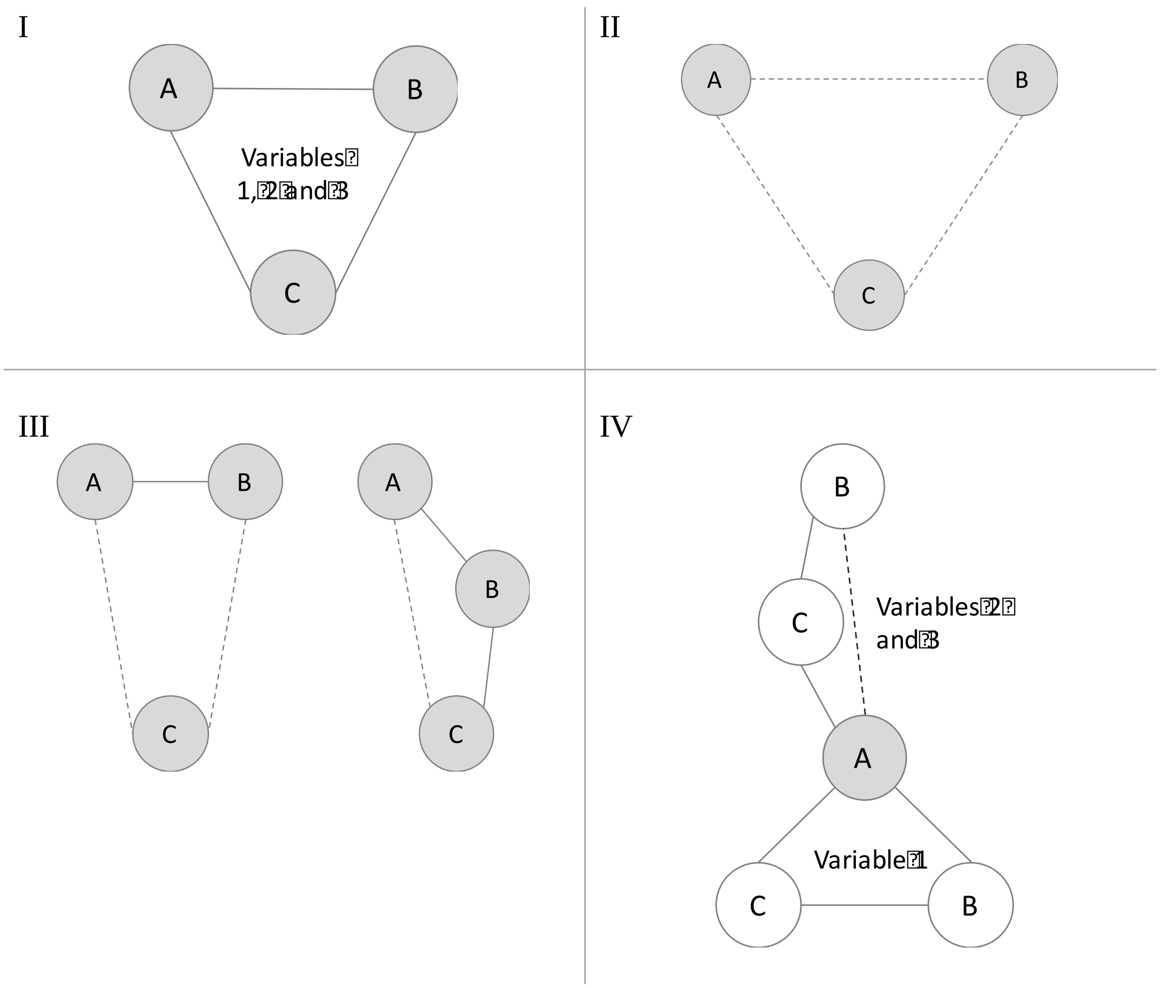


Figure 3-5. Ways in which elements A, B, and C can interact.

The nodes in Figure 3-5 represent groups of actors, solid links represent agreements, and dashed links disagreements about different variables. When no differences between groups were found, the topology was a positive symmetric interaction (first quadrant). When all actors disagreed, the topology was a negative symmetric interaction (second quadrant). When there was a partial agreement between actors, the topology was asymmetric involving agreements and disagreements between groups (third quadrant).

Finally, these topologies were grouped around a central actor to represent the results for all variables within a question; this is multiple agreements and disagreements about multiple variables within each of the survey question between all four groups (fourth quadrant). For instance, in Figure 3-5, the central element A has no differences with elements B and C for Variable 1, but for Variables 2 and 3, there are differences for the pair A-B, but not between the pairs A-C and B-C.

Notice that the length of the lines is representing differences between elements, the longer the lines the more dissimilar the elements are. Also, when differences between actors are low, the number of nodes and links in the network is lower (Figure 3-5– I) but when actors have larger disagreements the network will have multiple branches (Figure 3-5 – IV).

3.3 Results

First, results from the survey describe the regional variation of local actors in the study area; second, widespread characteristics of the social-ecological systems; and third, disparities between groups of actors.

3.3.1 Regional variation of local actors

The analysis of the variation found in this research and its underlying causes must consider the characteristics of the various groups of local communities that coexist in the ORW. Therefore, in this section are presented prominent features of Indigenous peoples and non-Indigenous communities, their history, and essential regional variation.

3.3.1.1 Indigenous peoples

Since the 15th century, IP in the ORW have been colonized (del Cairo & Rozo, 2006) and most of these ethnic groups have interacted intensively with western civilizations and have learned and adjusted to new socio-political and economic situations. On the other hand, some semi and fully isolated ethnic groups are still undergoing some forms of colonization and are still adapting. This research focuses on Indigenous communities that live near areas of development and maintain constant interaction with non-Indigenous communities.

For the areas visited during this research (Figure 3-3), it was observed that interactions between Indigenous groups and non-Indigenous communities vary between localities and that this relationship is hierarchical (non-Indigenous communities have more power than Indigenous groups). In those locations, non-Indigenous communities have greater regional power and Indigenous peoples' territories are embedded in this regional matrix. Indigenous peoples are highly dependent on forest products, particularly wood, seeds, and medicinal plants, and are less so on wildlife. Indigenous peoples do not consume the same amount of animal proteins that their ancestors used to eat, and this is explained by the reduction of wildlife and fish populations. Indigenous peoples experience unfair competition for resources, they are outnumbered by non-Indigenous people, and their ancient mechanisms for hunting, fishing, and cutting trees are not as efficient as non-Indigenous communities tools (e.g., fishing nets and chainsaw).

In all locations, Indigenous peoples are highly dependent on traditional medicine, but with the transformation of the ecosystems, medicinal plants which can only be found in the forest are disappearing. This resource is often unnoticed by all other actors, but it is essential for Indigenous peoples' survival. Nowadays, Indigenous peoples are mostly reliant on the production of food within their reserves and they mostly grow cassava. Many Indigenous peoples in the Orinoco live close to areas of urban development, where the ecosystems have been heavily impacted and deteriorated. During their occasional incursions into the forest, Indigenous peoples collect seeds for medicinal purposes and for growing foods which are known to have important nutritional attributes.

Water for human consumption is extracted from wells in most Indigenous peoples and non-Indigenous communities. Thanks to the State projects, some Indigenous reserves have filtration and distribution systems, but still, chronic diarrheal diseases in infants and adults were reported by the participants (GSJ16). People in the visited communities comment that water is becoming less available with time, particularly groundwater, and that the water quality in the streams is not as good as it used to be.

Locations where Indigenous peoples participated in the survey were San Jose del Guaviare, Yopal and La Uribe. In each of these, Indigenous peoples live in different socio-economic and politic conditions and these are important for understanding these communities.

3.3.1.1.1 San Jose del Guaviare

San Jose del Guaviare is the capital of Guaviare Department. It is in the Transitional region between the Orinoco and the Amazon, at the boundary of agricultural expansion, and it is a region undergoing rapid transformation. Indigenous reserves are small and densely populated due to a constant influx of Indigenous peoples migrating from the southern jungle. Immigrants escape from violence and constant confrontation between illegal armed actors (guerrillas, paramilitaries, and gangs) that are invading their territories. These groups are engaging in various illegal actions such as deforestation, wood commercialization, and drug businesses; it has been reported that production and processing of drugs is the main cause of deforestation in this region (Dávalos et al., 2011).

Historically, the territory where San Jose del Guaviare now exists belonged to the Jiw people. Jiw people are semi-nomads, but their behavior in this region has changed to sedentary. Here, one of their reserves is Barrancón. According to one of the Indigenous leaders, this reserve was initially organized by the previous generation in the 1950's (GSJ19), but eventually, new settlers took control of the town and the Indigenous peoples were expulsed. In the 1990's, they fought to regain territory and obtained legal recognition of their reserve.

At that time, they were 250 Indigenous people; currently, 30 families (around 800 Indigenous people) live there. The rapid growth of the population is explained by the immigration process. Families that have been living in the reserve the longest have more power in the decisions, and different families have different interests as well. Despite this, they are all interested in protecting the ecosystems within their reserve. However, their governance strategies are adapted to large territories where they can alternate the use of resources. The reserves' ecosystems cannot sustain the population anymore, and they are undergoing shortages in the production of food.

According to one of the Indigenous leaders in the Barrancón Indigenous reserve, new settlers are progressively entering Indigenous territories, they are transmitting their ways of thinking from within, not just from the outside, and they are earning power within the reserve by marrying Indigenous women (GSJ15). Young generations of Indigenous peoples are not as interested in their natural environment as they are in learning new cultural patterns, but it is the cultural law that children and young learn their cultural traditions, so elders continue cultivating and transmitting their ancestral knowledge (GSJ19). Unfortunately, because of the confinement imposed by the reserves and the reduced space they have for growing food, Indigenous people have been adopting new ways of survival, and consequently, they are losing their ancestral traditions (GSJ15).

La Maria, another reserve in San Jose del Guaviare, is composed of 75 people. This reserve is smaller than Barrancón and they behave as a single family (GSJ16). Unlike Barrancón, La Maria was assigned to the Indigenous people 25 years ago. Pieces of land or "left overs" from the big farmlands is what constitutes this reserve. Until recently, they used to build their own houses, but with the massive transformation of the forest into agriculture land, they could not access the construction materials they need. Currently, wood is still used for cooking and building fishing canoes.

Soils in La Maria are extremely poor and compacted. Occasionally, with the help of the town's authorities, Indigenous people here access to machines to work the soil, but this only improves the crop's yields slightly. A local project from FAO has been trying to help with this issue (FAO, 2018), but it requires that the Indigenous people learn how to produce and consume new types of food. One of them commented: "We receive some help from FAO, they bring materials. But we do not need that, what we need are healthy ecosystems like savannas, forests, and wetlands, not chickens or food, we need more lands with good soils to grow food". Malnutrition is a huge problem in this reserve.

Non-Indigenous communities know well that soils in San Jose del Guaviare are not good for growing food. Historical documents often mention that the settlement of this region was difficult, and many settlers had to leave because they could not survive on the products obtained from the agriculture (del Cairo, 2012). Remaining groups of these peasants are mostly dedicated to raising cattle (GSJ17). Indigenous peoples also know that the nutrients in the soil cannot support permanent crops and they developed a shifting agricultural system that rotates plots of land in the jungle. When they had access to the land they used to grow food in the same plot for no more than a couple of growing cycles, then, they would move to other plots while the previous recovers and they would not use the first plot until after three or four years of recovery (del Cairo, 2012). However, despite this knowledge, Indigenous peoples cannot implement this system in their reserves.

3.3.1.1.2 Yopal

Yopal is the capital of Casanare Department and is located to the east of the watershed. Settlements of people coming from various of the country have been sharing territories with traditional groups of Indigenous peoples. The most recent history of colonization of this region took place during the 19th century, when, commissions of ranchers established cattle as their main form of colonization (Molano, 1989). Here, more than anywhere else in the Orinoco, Indigenous peoples have experienced extended periods of colonization and interaction with western culture. They have been living at the crossroads where their Life Plans intersect others' plans for economic growth. Because of this interaction, some Indigenous groups have learned how to interact with the government and they have organized their peoples into associations that demand protection of their Indigenous rights; however, there are many other Indigenous people with no political representation (CY10).

Models of development in this region have been imposed without considering the existing communities; these are mostly projects that seek industrialize the land for monocrops and extraction of oil. Yopal became the development hub around which several oil businesses were established between the 1950's and 2015 in Casanare. With the international collapse of oil prices, the economy of this region has been heavily affected. Non-Indigenous participants during this research talked about how this crisis has led them back to the land to grow food and raise cattle and finding new ways of survival.

For Indigenous peoples, the oil industry has been a problem that has affected their culture and the environment. During the interviews, one Indigenous leader and a researcher who works for the government narrated how Indigenous peoples have been affected by the oil industry; the Indigenous leader talked about the Indigenous reserves located to the south-central portion of Casanare and the researcher about those to the north-east. Both described the incursion of petroleum companies in Casanare as a constant violation of Indigenous rights. According to them, there has been a violation of free, prior, and informed consent. Several Indigenous peoples have reported invasion of their territories by these companies.

Environmental degradation from oil exploration and extraction is impacting Indigenous communities in this region, mostly due to water pollution, river sedimentation, and reduction in the water table. Indigenous peoples suffer periodical water scarcity and they notice reductions in fish populations due to water stress. Inside of their reserves Indigenous peoples have observed that water dynamics have changed since petroleum companies arrived.

Eight Indigenous reserves to the south-center of the state are the home of 1,789 people. The Indigenous leader of the region spoke about the current situation of these reserves. According to him, similar to what was observed in San Jose del Guaviare, these reserves are too small for sustaining all the members of the Indigenous community. They mostly depend on cattle and agricultural products, but the soil is poor, and the water is scarce during the dry season. For them, internal cooperation is very important for solving problems, and rules are created and discussed among Indigenous governors. They have rules for the use of resources, they restrict fishing and protect important ecosystems. Fishing used to be one of the most important activities. Their ecological calendar is changing, and they are adjusting to new regimes for growing food.

According to the researcher interviewed in Yopal, Indigenous peoples in the north-east have suffered more than any other from the impact of the oil business. Their communities face issues like prostitution, drugs and alcoholism, and robbery. They were dispossessed of their lands and sanctuaries, and they continue experiencing cultural decay, “they are the icon of the conquest and eviction suffered by Indigenous peoples in the Orinoco” (CY10). These Indigenous peoples do not speak their ancestral language and they have lost their traditions. Fish is a crucial resource for them, and they have constant conflicts with non-Indigenous fishermen. They learned how to raise cattle and they rely on it for their survival.

As part of the process of the occupation of the Orinoco in the north, new settlers have taken possession of sacred places where Indigenous peoples used to honor their gods and ancestors. Areas with important biodiversity, such as lakes, wetlands, and *morichales* (ecosystems where the *moriche* palm dominates), are inaccessible to these peoples, they belong to the Nation or to non-Indigenous owners. One of the interviewed researchers said, “this is part of the genocide” (CY10).

3.3.1.1.3 La Uribe

La Uribe is a municipality at the west of Meta Department. Official reports classify La Uribe as one of the towns used by the FARC guerrillas as a base (DANE et al., 2010). Indigenous peoples have been exposed to the armed conflict, a situation that has increased their vulnerability. Humanitarian crimes against Indigenous leaders have been committed by different illegal armed groups. They have been accused of being FARC members by the public force and of being informants by the guerrillas. Until the ceasefire, the Indigenous reserves were occasionally war fields and consequently, there has been irreparable damages to these communities. Despite this, the Indigenous organizations in this region are strong and cohesive; they work together for their own survival amidst these conflicts. Some of them, however, are not legally recognized as Indigenous reserves by the government of Colombia, they do not receive financial help, and their territories are referred as Indigenous settlements.

Even though Indigenous peoples are not part of any armed group, some young Indigenous people have joined the guerrillas. This has affected the Indigenous peoples in this area because they are constantly working for their independence and freedom (DANE et al., 2010). During the last 15 years, Indigenous peoples in La Uribe has been stigmatized for living in the territory where the FARC operates, and no attention or support has been provided by the central government. Their claims have been dismissed by every governmental agency (DANE et al., 2010).

Indigenous peoples in these communities migrated from the west side of the Andes, outside of the ORW, and they started to arrive in the second half of the 20th century. One of their leaders explained that their knowledge is quickly disappearing because of these migrations and disconnection from their ancestral territories. In these “new lands” they have been settlers as well and have little knowledge about the use of many wild plants and animals. Indigenous institutions are clearly defined with publicly elected officers and specific roles. They are cooperative and share the goods produced on their land. Decisions about the use of natural resources in their territories are made by the officers, who analyze and discuss their needs.

Soils in Indigenous peoples’ lands used to be more productive, but in recent years the food production has been declining; this is very worrisome because agriculture is their main activity. All resources within their properties are used for their own benefit and they treasure their forests and they want to conserve more. However, with the depletion of nutrients and organic matter in the soil, they have been clear-cutting for new parcels of crops; the wood is used for building houses. They now raise and consume chicken and pork. They hunt when needed, however, bushmeat is not an important part of their diet anymore. They do not use medicinal plants, at least not from this region, but they are interested in recovering their traditional ways for healing illnesses.

3.3.1.2 Non-Indigenous communities (NI)

Three types of local communities can be defined in the ORW. These are the Llaneros, who arrived at the savannas two centuries ago and develop a whole cultural identity around the practice of ranching; the farmers and fishermen, who spread along the rivers and settled in the Andean piedmont in the 1950's, and the new settlers, who started to arrive to the watershed in the late 1990's.

3.3.1.2.1 Llaneros

Ranching has always been the most emblematic feature for the Llaneros. It is through cattle that they settled in the Orinoco savannas and all their traditions are shaped by it. Not long ago, raising cattle was a prominent business. Now that the prices for a head of cattle are declining, owners of substantial portions of lands are selling their properties, and new businesses are emerging in the region, such as industrial crops of rice and palm oil, and oil extraction (CY11). This is affecting the Llaneros and their ecosystems in many ways: it is fragmenting the landscape, polluting the water bodies, destroying the ecosystems, and changing cultural traditions. According to one of the interviewed researchers, "With the encroachment of palm oil plantations, to the Llaneros it is happening the same that happened to the Indigenous peoples with the loss of their territories and traditions with the arrival of cattle to the Orinoco." (CY10)

Those Llaneros with low income are highly reliant on their cattle and use their lands for growing food as well. Many Llaneros commented that they have been losing their cultural traditions due to the economical transitions (from farming and ranching into the extractive industry) and consequently they stopped producing food. Now that oil companies are withdrawing from the region, they have a whole generation that does not know how to work the land.

3.3.1.2.2 Peasant colonization in the 1950's

Between the 1930's and the middle 1950's, groups of poor peasants started to organize and demand lands and benefits from the government. They founded small groups based on liberal inspired ideologies that later became the guerrillas. Other poor peasants migrated to the Orinoco searching for lands where they could sustain their families (Molano, 1989). These two processes; the consolidation of armed groups and the migration of individual families of poor peasants, converged on the eastern side of the Andes and their destinies grew intertwined. Along with this process, in 1932 the government proclaimed a law to promote new settlements in regions with no apparent owners; those were mostly Indigenous territories. The objective was to stimulate the land production through the expansion of the agricultural frontier. Between 1932 and the 1950's, people from all regions in the country arrived at "no-body's land" often called "*tierras baldías*".

The *tierras baldías* were lands populated by Indigenous peoples, but neither the government nor the peasants who started colonizing these territories recognized Indigenous peoples' rights over the land. Peasants arrived from places from all around the country, and those who adapted to the conditions of these new territories settled and eventually obtained legal documents for their lands. There are, however, extensive portions of the ORW that are not being used for productive purposes, lands that now belong to the Nation and are on the target for future development projects. Later, as part of the description of the ORW's social-ecological systems, the status of the *tierras baldías* and new expansion projects will be presented in the second section of results.

This second type of conquerors established in fertile lands along the Andes and Piedmont and differ from the Llaneros in many ways. Peasants arrived in the 20^{th} century, their main activity is their agriculture; although they also raise cattle, grazing them in hills and mountains. Peasants do not embrace the Llanero's culture, which is characterized by specific music, dances, songs, and poetry that describe their work and their relationship with horses and cattle amidst ecosystems unique to the savanna region. Peasants' culture is tainted by the violence caused by the internal conflict that started in the 1950's. They have their own music and dances according to the region they come from and they live in the mountains amidst forested ecosystems.

At their arrival, peasants had to "fight" nature, open their path through the jungle, and learn how to work the land and produce. In one of the research locations, they described how over time their economic activities have changed. They started extracting rubber, then they commercialized fur, later they grew illegal crops, and most recently their economy is devoted to agriculture. All these activities have caused profound transformations in the landscape, and this had influenced their perception about biodiversity. One member of a local community commented that "In the 1960's and 1970's we used to hunt wildlife and trade the skin. We used to consume bushmeat in massive quantities. But now, the populations of deer, tapir and wild pig are very small, and if we hunt we do not do it with an economic interest anymore." (MLU08).

Communitarian organizations, called JAC (Junta de Acción Comunal in Spanish), are commonly found in these communities. These are social organizations created for solving problems within a community (Barragan & Malagón, 2007). Neighbors get together to discuss and prioritize key issues, they adopt rules and coordinate *mingas*, or gatherings for working on community projects, such as road construction and water management, or individual projects to help members of the community (for instance the construction of houses). JACs formulate rules and mechanisms for the protection and management of natural resources.

La Uribe is one of those cases where the JACs used to have the support of the guerrillas; this was the main authority for territorial control and surveillance of rules. Now that the FARC is not present in this region, the JAC does not have the same support for governing the forest, and emerging environmental groups, mostly farmers, are promoting better agricultural practices to reduce erosion, water pollution, and protection of forested areas.

3.3.1.2.3 New settlers

In the 1930's, a new group of settlers was attracted by large-scale projects of massive and intense extraction of natural resources. These new settlers started to populate the Altillanura or portions of the savanna between the Meta and the Guaviare rivers (Figure 3-3). Their only purpose was wealth accumulation and they had no concern for local communities (Molano, 1989). This settlement continues to the present with the development of new extractive industries, such as palm oil and petroleum, and this is part of the structure that supplies raw materials to the international market.

Around the 1970's, a complementary process took place in the Altillanura. This was a scenario where paramilitary groups and drug traffickers, conducted illegal business and perpetuated humanitarian crimes (Somo & Indepaz, 2015). The national government and paramilitary groups started conversations for their surrender and delivery of weapons in 2003, and after this started the project for the "Reconquest of the Altillanura", through which multiple international companies started to acquire big portions of land for monocrops of palm oil.

Some non-Indigenous communities have the idea that some Indigenous peoples are uncivilized and that they have a poor interaction with the environment. One participant from a local community commented "In our community, we protect the riparian corridor and because of that, we have monkeys and *guacamayas* (macaws) that live in it. We take care of our environment, but since a small group of Nukak has been hanging-out this neighborhood we do not see the same wildlife. They climb the trees and hunt the animals that we treasure." (GSJ20)

The relationship with the federal employees is conflictive for most of these actors. Among Llaneros, federal environmental entities are inefficient, but they do not have good mechanisms to replace the federal enforcement of rules. Among peasants, federal environmental entities are institutions that do not have a real presence in their territories, and they only show up to support projects that will affect their livelihoods. Among the third group of new settlers, they know little about these entities. They think of them as another element of the government, but they do not have a strong opinion.

3.3.2 Widespread characteristics of social-ecological systems in the study area

3.3.2.1 Use behavior and key issues

Results indicating the level of dependence on natural resources by each of the groups (Indigenous peoples – IP, Non-Indigenous communities – NI, Researchers – R, and Federal employees – F), levels of concern, and disturbing factors are presented in Table 3-2.

Water was the most important resource for all the groups, it is used in all economic activities and it is considered the resource of most concern. Point-source pollution was chosen by the majority as the most impacting factor on water bodies. All the towns surveyed are currently disposing their wastewaters directly into the streams, and even though some actors have the opinion that it is not affecting the water quality, there is a general concern about the lack of treatment plants.

Participants from the F and R groups report non-point pollution as another cause of water degradation. Ranchers and farmers are worried about the reduction of the water table and the extinction of water springs. Water scarcity is not a widespread issue yet, but there have been cases where intense droughts impacted wildlife populations. A smaller proportion of the participants showed concern about droughts and variability in the local weather.

Table 3-2. The rank order of natural resources and disturbing factors. IP: Indigenous peoples; NI: Non-Indigenous communities; R: Researchers; F: Federal employees

A. Ranking of natural resources according to the level of importance

Resources	IP	NI	R	F	Overall rank	Scale
Water	1	1	1	1	1	Most important
Soil	1	2	2	2	2	
Wood	2	3	5	3	3	
Fish	5	4	3	4	4	
Wildlife	6	7	4	5	5	
Wild fruits and vegetables	4	5	7	6	5	
Medicinal plants	3	6	8	8	6	
Minerals	7	8	6	7	7	Least important

B. Ranking of natural resources according to the level of concern

Resources	IP	NI	R	F	Overall rank	Scale
Wildlife	1	3	1	2	1	Most concerning
Water	1	1	2	3	1	
Wood	3	2	2	1	2	
Fish	3	3	3	3	3	
Soil	1	4	4	4	4	
Wild fruits and vegetables	2	5	5	5	5	
Medicinal plants	4	6	6	6	6	
Minerals	5	7	6	7	7	Least concerning

C. Ranking of disturbing factors

Factors	IP	NI	R	F	Overall rank	
Deforestation	1	1	1	2	1	Most disturbing
Fires	1	4	6	1	2	
Point-source pollution	3	3	2	4	2	
Droughts	2	2	5	4	3	
Non-point pollution	6	5	3	2	4	
Erosion	5	7	5	3	5	
Floods	4	6	7	7	6	
Urban development	7	8	4	6	7	
Road construction	7	10	5	5	8	
House construction	8	9	9	8	9	
Invasive species	9	11	8	9	10	
Channelization	9	12	10	10	11	
Dams	9	12	11	11	12	Least disturbing

Soil was ranked as the second most important resource because it sustains some of the most important economic activities in the watershed; however, it is also of great importance because it is linked to land ownership. As it was mentioned before, inequities around land tenure and lack of legal recognition of Indigenous peoples' ancestral territories have been pressing issues for local communities.

Soils in the watershed are used for ranching and food production. In this research, two types of cropping systems were considered, commercial and subsistence crops. Commercial crops are monocultures of rice and palm oil, with the palm industry expanding in certain portions of the watershed. Subsistence crops refer to the production of food for home consumption. Even though commercial and subsistence crops are both transported to big cities outside of the watershed, the commercial crops are mostly produced to supply big markets, whereas the latter is partly consumed within the watershed. For local communities, the reduction of the soils' nutrients for growing food is very concerning.

Subsistence crops include fruits and vegetables as different resources. Fruits and vegetables are those foods grown by locals on their private properties for household consumption. Except for Indigenous peoples, fruits, and vegetables, as well as medicinal plants, are ranked among the least important resources by all respondents (Table 3-2).

Wood is the third most important resource in the watershed. Wood is used in the construction of houses and for building fences and delineate property boundaries. Despite ample regulations for the protection of the forest, illegal trade of wood is a major issue in the watershed. During the interviews and conversations with the people of the region, many mentioned that at night they see copious amounts of wood floating downstream in the river, and trucks loaded with wood are frequently confiscated.

Deforestation is considered the highest impacting factor on natural resources by all the participants. This, together with fires and ranching, is causing the massive and rapid destruction of forested ecosystems in the watershed (Dávalos et al., 2011). The situation of native forests is of great concern for the participants, who recognize the important of these ecosystems for the conservation of water bodies and wildlife. Management practices, such as reforestation, are most needed and ongoing reforestation efforts are generally considered ineffective. According to the participants, areas designated for protection of forested ecosystems are generally effective, but surveillance and control still need to be improved inside of these reserves.

Fish is ranked fourth in the list of important resources. This basin's stream network supports diverse fish populations, making the Orinoco river a major destination for sport fishing. Fish are also consumed by inhabitants, and some species are commercialized and exported. Along the rivers are found populations that during certain portions of the year rely on fish extraction, thus positioning fishing as the third most important economic activity (these results are presented in the next results' section in Table 3-4).

The reduction of fish stocks is of great concern to all participants. This reduction is mostly attributed to fish overexploitation (Lasso et al. 2011). The fish is mostly consumed locally, but regions where fish populations are abundant export fish to the main cities. Another source of fish exploitation is through the trade of ornamental fish (for tanks and aquariums). This is poorly managed due to the lack of scientific knowledge about how many fish can be sustainably commercially harvested, and techniques used for the catching, storing, and distributing fish are causing the deterioration of fish populations (Ajiaco-Martínez et al., 2012).

Wildlife is the fifth in the list of important natural resources, yet, it ranks first in the list of resources of concern. Wildlife has been heavily affected by the colonization of the watershed (Molano, 1989), and some of the species still consumed by diverse communities in the watershed have been severely affected by the transformation of the ecosystems (Lasso et al., 2011). Some local restaurants offer bushmeat. The consumption of wildlife is illegal; however, Indigenous peoples can legally hunt within their territories.

Minerals were the last in the list of important resources, however, it is well known that mining is responsible for deforestation and water pollution in the ORW, mostly in the Department of Guainía in Colombia, and in the States of Amazon and Bolivar in Venezuela (Lasso et al., 2011).

3.3.2.2 Governance of common-pool resources

The governance of common-pool resources in the ORW follows a centralized scheme where the central government imparts policies and legislation executed through federal agencies at regional and local scales. Indigenous institutions, private owners, and local communities also govern within their territories in concordance with the national legislation. Within this hierarchical structure, the participation of local communities has specific objectives. They are involved in the process as sources of information about the local situation, they are called to public meetings where projects are presented to the community, and under certain circumstances, they are represented by leaders within the community to contribute to the formulation of plans.

This watershed has few cases of local institutions actively governing the common-pool resources and these are mostly within Indigenous reserves. The case of farmers in La Uribe governing common-pool resources through the JAC (previously introduced in the description of other local actors), is another case of local governance. Numerous local leaders and community-based organizations are present throughout the watershed, however, in this research, no other local institutions (like JAC) were recognized.

Through the survey, four types of values that could represent incentives were presented to the participants (i.e., cultural, economic, landscape, and ecologic) to assess what type has the best chance to motivate the sustainable use of common-pool resources among local communities. Among all participants, cultural incentives were found to have the largest likelihood of stimulating conservation, followed by economic, landscape, and ecological values (Table 3-3).

Table 3-3. The rank order of incentives for conservation

Incentives	**IP**	**NI**	**R**	**F**	**Overall rank**	**Scale**
Cultural	2	2	1	2	1	Most incentivizing
Economic	3	3	3	1	2	
Landscape	4	1	2	3	2	
Ecologic	1	4	3	4	3	Least incentivizing

Participants were also asked about five types of property (i.e., public, private, national park, Indigenous reserves, and communal areas) with the objective of having them assess which category of land tenure would likely lead to conservation. Indigenous reserves had the highest likelihood (Table 3-4), followed by private property, and national parks, with public lands and communal areas as types of properties where conservation is less likely to occur.

Table 3-4. The rank order of tenure types as areas where resources are more likely to be protected

Land tenure	**IP**	**NI**	**R**	**F**	**Overall rank**	**Scale**
Indigenous reserves	1	1	3	1	1	More likely
Private	2	3	1	2	2	
National parks	4	2	2	3	3	
Commons or open-source areas	2	5	4	5	4	
Public	3	4	5	4	4	Less likely

Regarding communal areas, IP showed the largest likelihood among all groups, but significant differences were only found between IP and F. Another interesting finding was that while answers from IP and NI, for both public and communal areas, were skewed towards the middle-higher likelihood, F and R were skewed towards middle-low likelihood for the same types of land tenure. Non-Indigenous participants are less optimistic about conservation in private lands than other groups. The same happened with the R group, whose expectations are lower for national parks when compared to other groups.

Regarding governance strategies, this study found that, even though formal strategies are the most commonly used strategies, they are considered to be the least efficient by participants. Informal strategies, on the other hand, were considered to have medium to low levels of efficiency. The strategies considered to be least efficient by this study’s participants were those related to planning (regional and urban), hunting control and fishing bans, and cooperation with the state and universities (Table 3-5).

Fines and control over the use of natural resources are considered to be generally inefficient, and rules are only slightly better. Internal regulations are perceived to be more effective by the participants, who believe that agreements have a low to medium level of effectiveness and that conflict resolution processes vary from low to medium. Cooperation between and within communities are considered to be the most effective ways of resource management.

Non-Indigenous communities perceived that conservation strategies have low effectiveness; some even think that conservation actions are not taken in their towns. Participants within the R group, unanimously think that conservation practices have low efficacy, whereas for F answers vary from medium to low.

Views regarding the effectiveness of verbal agreements are significantly different between NI and F, with the NI group grading to vary from low and high (large variation), and the F group between medium to low (lower variation). This can be interpreted as non-Indigenous communities having divided opinions about verbal agreements. While some members of the NI group think of it as a good, medium, or low-efficiency strategy, an important portion believes that verbal agreements are not used (These trends are later discussed and presented in Figure 3-15). On the other hand, participants from the F group are more inclined to believe that this strategy has a medium level of efficiency.

IP opinions about the efficiency of these governing strategies differed greatly from all other groups. Eleven strategies, out of 15, were perceived to be significantly different. In the following section, these differences are discussed in detail.

Table 3-5. The rank order of governance strategies by strategy category

Ranking of policy strategies

Policies	**IP**	**NI**	**R**	**F**	**Overall rank**	**Scale**
Regulations for conservation	1	3	1	1	1	Most efficient
Regional planning	3	2	1	2	2	
Urban development	2	1	2	3	2	Least efficient

Ranking of regulation strategies

Regulations	**IP**	**NI**	**R**	**F**	**Overall rank**	**Scale**
Rules	1	1	3	1	1	Most efficient
Fines	3	3	1	2	2	
Agents of control	2	2	3	3	3	
Bans on fishing	5	4	2	4	4	
Hunting control	4	5	4	5	5	Least efficient

Ranking of strategies related to internal rules

Internal rules	**IP**	**NI**	**R**	**F**	**Overall rank**	**Scale**
Written	3	1	2	1	1	Most efficient
Verbal	1	2	3	2	2	
Solution of conflicts	2	3	1	3	3	Least efficient

Ranking of cooperation strategies

Cooperation	**IP**	**NI**	**R**	**F**	**Overall rank**	**Scale**
Within the community	1	1	1	1	1	Most efficient
Between communities	2	2	2	2	2	
With the state	3	3	4	2	3	
With universities	4	4	3	3	4	Least efficient

3.3.3 Mismatches between actors

Maintaining ecosystem services in the watershed is important for local communities' livelihoods, and for the sustainable development of the region. Consensus on different perceptions about indispensable resources in the watershed sets the baseline for more inclusive management plans. Therefore, the analysis of significantly different pairwise comparisons is fundamental for identifying conditions that lead to disconnections between groups. Based on the six pairwise comparisons between the four groups (IP – NI; IP – R; IP – F; NI – R; NI – F; R – F) a total of 420 comparisons were made, finding 108 statistically significant differences between these pairs (26%). Table 3-6 summarizes these differences, and detailed results are shown in Figure 3-6 to Figure 3-14.

The largest differences were found between Indigenous peoples and all other groups: IP – R (31 variables), IP – F (29 variables), and IP – NI (20 variables). Non-Indigenous communities were the next group: NI – R (14 variables), and NI – F (11 variables). The least difference was between researchers and federal employees (5 variables). It was found that NI, F and R have different views about the importance of minerals and wildlife (i.e., NI-F, NI-R, F-R), and that Indigenous peoples' view is particularly divergent regarding medicinal plants.

Significant differences identified through the statistical analysis are used in this section to discuss the principal differences and mismatches across scales. When there were found to be several disparities between groups, these were analyzed according to the level of disagreement, where strong disagreements have 3 to 6 pairs of actors that disagree about a specific topic, middle level of disagreement have two, and low level of disagreement has only one pair.

Table 3-6. Summary of the most significant differences between groups.
IP: Indigenous People; NI: Non-Indigenous communities; F: Federal employees; R: Researchers

	IP - NI	IP - R	IP - F	NI - R	NI - F	R - F
			Natural Resources Use Behavior			
Q1.	Minerals, Wildlife, Wild Fruits & Vegetables, Medicinal plants, Wood	Minerals, Wild Fruits & Vegetables, Medicinal plants, Wood	Medicinal plants	Fish, Minerals, Soil, Wildlife	Wildlife, Minerals	Wildlife
Q2.		Minerals, Wild Fruits & Vegetables	Minerals		Minerals	
Q3.	Cattle, Construction, Fish farming, Hunting, Subsistence crops	Cattle, Construction, Fish farming, Mining, Oil industry	Cattle, Tourism, Construction, Fish farming, Mining, Subsistence crops	Mining		

Topic by question:

Q1 Level of dependency on eight natural resources
Q2 Level of concern about the state of eight natural resources
Q3 Level of dependency on ten different economic activities

	IP - NI	IP - R	IP - F	NI - R	NI - F	R - F
			Governance of common-pool resources			
Q.4	Landscape		Communal areas	Ecologic, Landscape	Ecologic, Landscape	
Q.5	Formal: Control, Fines Informal: Conflict resolution, Verbal agreements, Cooperation within the communities	Formal: Conservation, Control, Fines, Fish bans, Planning, Rules Informal: Conflict resolution, Verbal agreements, Written agreements, Cooperation with universities, Cooperation within the communities	Formal: Conservation, Control, Fines, Fish bans, Planning Informal: Verbal agreements, Written agreements, Conflict resolution	Formal: Conservation Informal: Cooperation with universities	Formal: Conservation Informal: Verbal agreement	Formal: Conservation

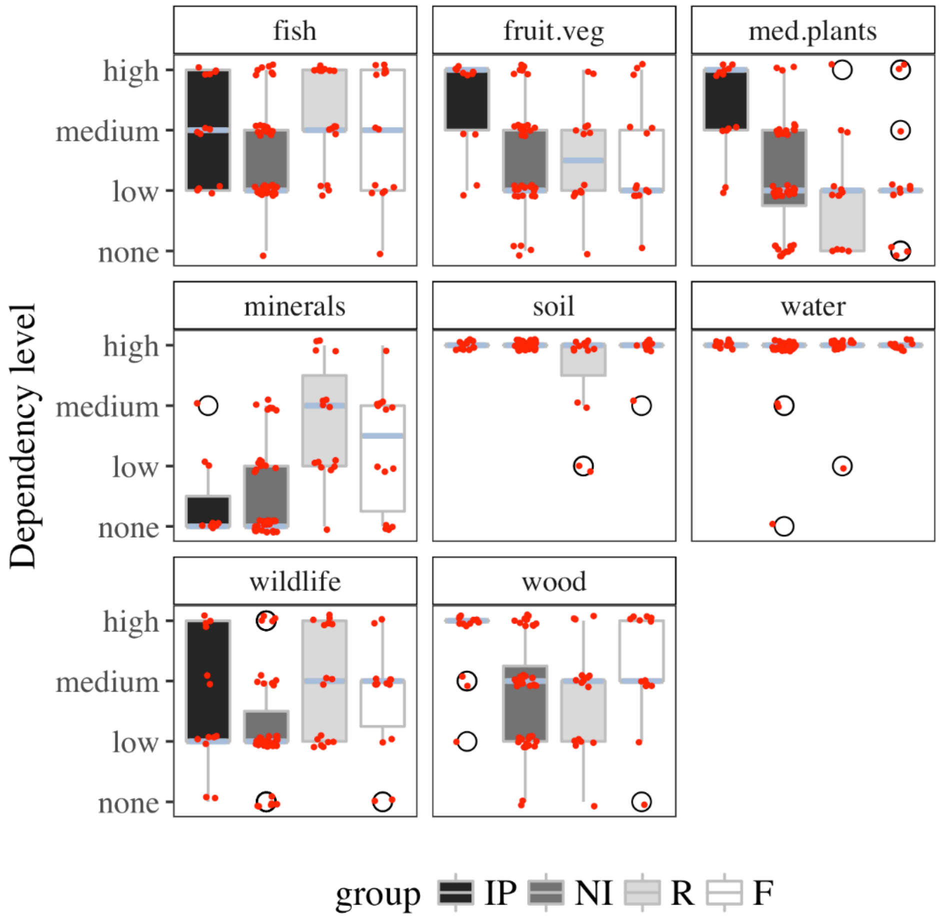
Topic by question:

Q4 Conditions and values that work as incentives for local conservation
Q5 Level of effectivity of formal and informal governance strategies

	IP - NI	IP - R	IP - F	NI - R	NI - F	R - F
			Management practices			
Q.6	Point source pollution	Non-point pollution, Invasive species, Urban development	Channelization, Non-point pollution, Erosion, Fires, Construction of roads, Urban development	Invasive species, Construction of roads, Urban development	Channelization, Fires, Invasive species, Construction of roads, Urban development	Channelization Fires
			Management practices			
Q.7	Control of invasive species, Selective cut, Water treatment, Water flow control	Reduction in the use of agrochemicals, Protection areas, Reforestation, Selective cut, Water treatment, Water flow control	Protection areas, Reforestation, Selective cut, Water treatment, Water flow control			Selective cut

Topic by question:

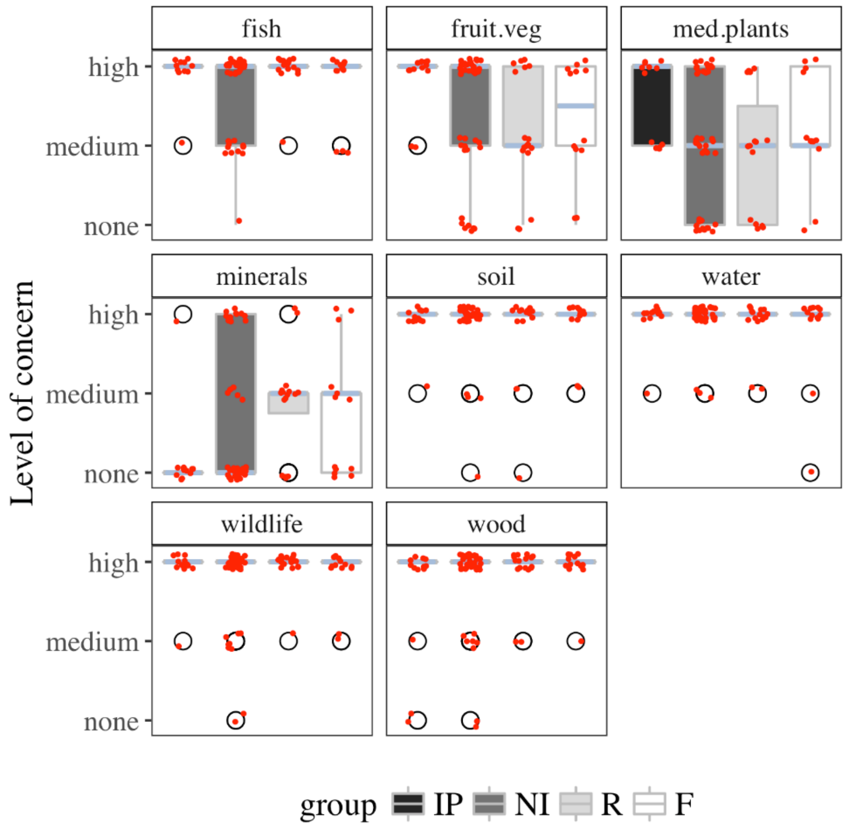
Q6 Most impactful factor on the environment
Q7 Efficiency level of current management practices (or the urgency level to develop new ones) for ensuring a healthy environment and securing the provision of ecosystem services



Pair		Variable	χ^2
F	NI	Minerals	9.7
F	NI	Wildlife	11.27
F	R	Wildlife	8.96
IP	NI	Fruits and vegetables	11.23
IP	R	Fruits and vegetables	7.78
IP	F	Medicinal plants	10.36
IP	NI	Medicinal plants	17.53
IP	R	Medicinal plants	11.17
IP	R	Minerals	12.94
IP	NI	Wood	11.78
IP	R	Wood	10.01
NI	R	Fish	8.17
NI	R	Minerals	21.96
NI	R	Soil	11.23
NI	R	Wildlife	8.56

Chi square (χ^2) values for pairwise comparisons with statistical differences

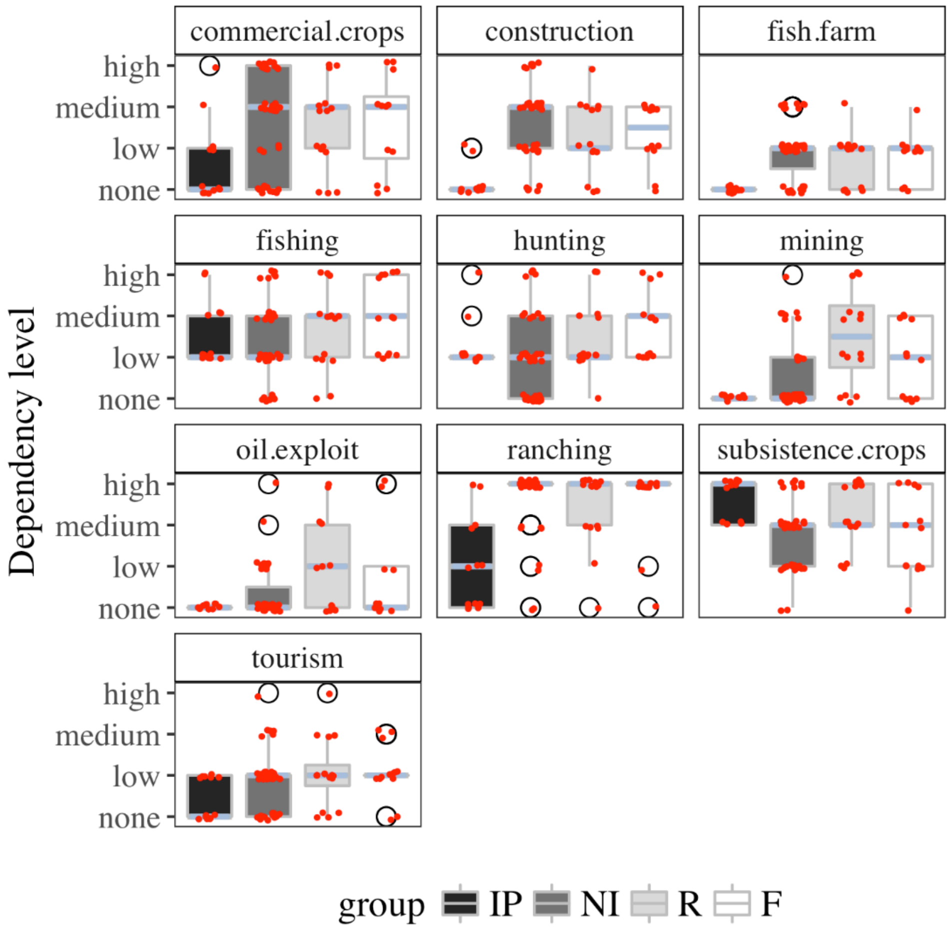
Figure 3-6. Distribution of answers to question 1 by group
"What is the dependency level on eight natural resources through direct consumption?"
IP: Indigenous People; NI: Non-Indigenous communities; F: Federal employees; R: Researchers



Pair		Variable	χ^2
IP	R	Fruits and vegetables	7.67
IP	F	Minerals	6.44
IP	R	Minerals	13.3
NI	R	Minerals	15.03

Chi square (χ^2) values for pairwise comparisons with statistical differences

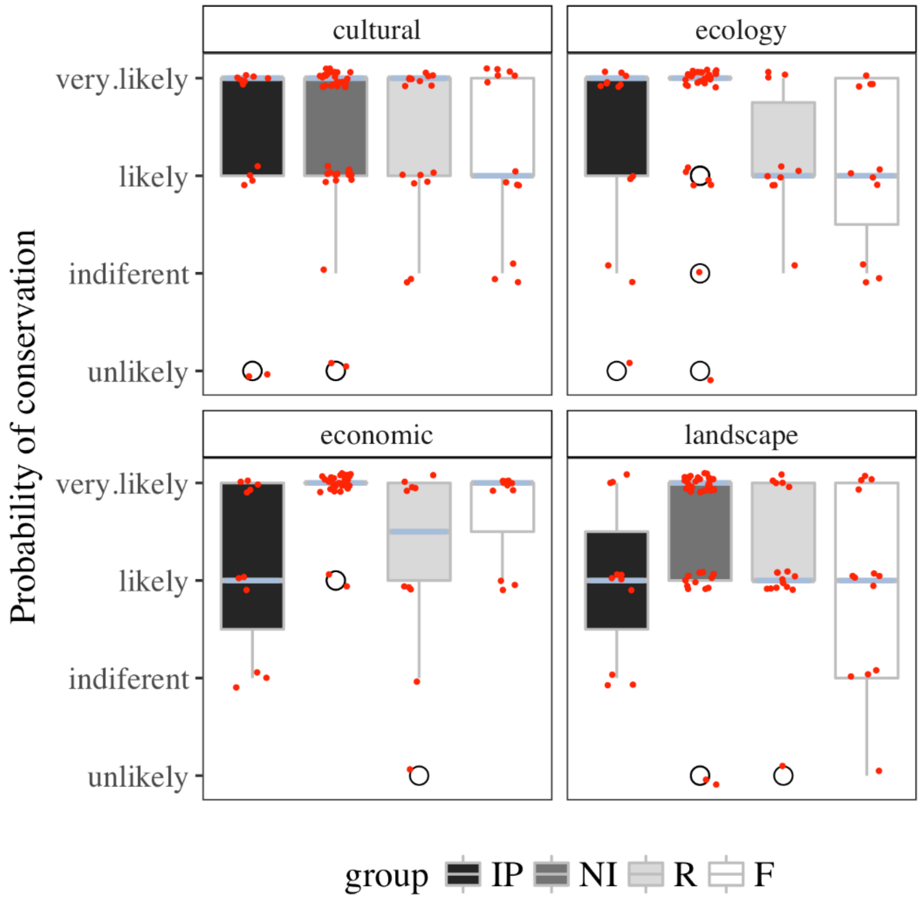
Figure 3-7. Distribution of answers to question 2 by group
"What is the level of concern about the state of eight natural resources"
IP: Indigenous People; NI: Non-Indigenous communities; F: Federal employees; R: Researchers



Pair		Variable	χ^2
IP	F	Cattle	12.8
IP	NI	Cattle	20.47
IP	R	Cattle	10.37
IP	F	Construction	11.1
IP	NI	Construction	20.22
IP	R	Construction	10.07
IP	F	Fish farming	12.18
IP	NI	Fish farming	19.47
IP	R	Fish farming	12.76
IP	NI	Hunting	8.74
IP	F	Mining	7.88
IP	R	Mining	12.98
IP	R	Oil industry	8.56
IP	F	Subsistence crops	8.07
IP	NI	Subsistence crops	13.93
IP	F	Tourism	6.06
NI	R	Mining	10.91

Chi square (χ^2) values for pairwise comparisons with statistical differences

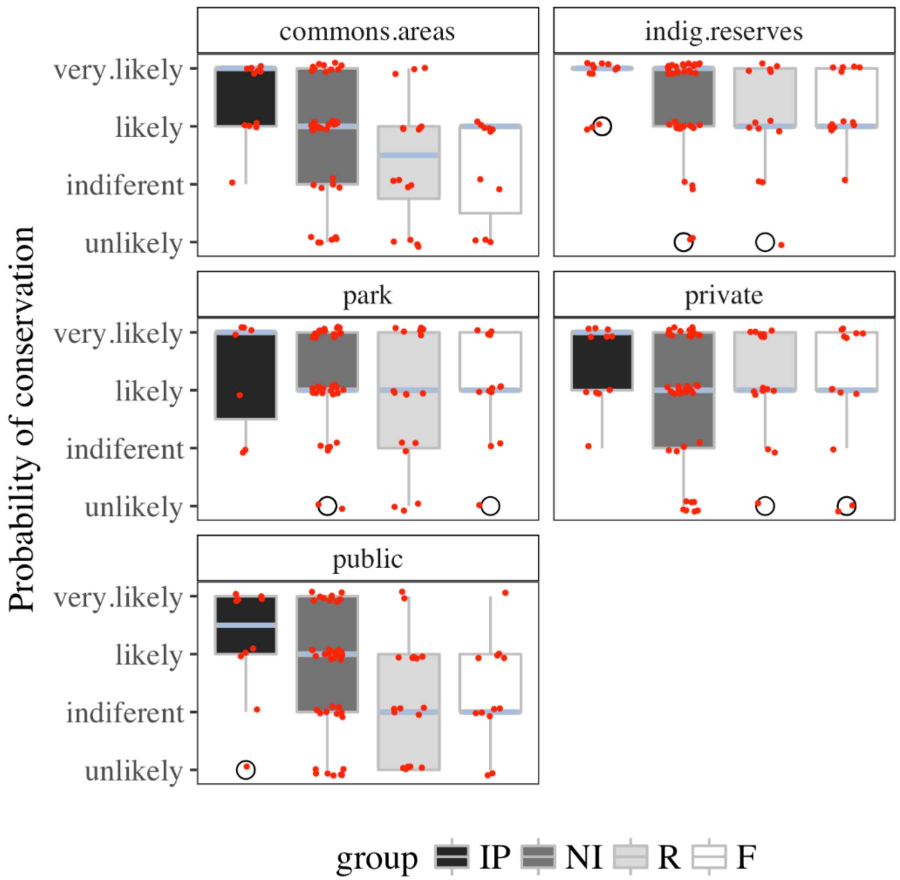
Figure 3-8. Distribution of answers to question 3 by group
"What is the dependency level on ten different economic activities?"
IP: Indigenous People; NI: Non-Indigenous communities; F: Federal employees; R: Researchers



Pairs		Variable	χ^2
F	NI	Ecology	8.89
F	NI	Landscape	11.62
IP	F	Common areas	9.73
IP	NI	Landscape	14.29
NI	R	Ecology	9.04
NI	R	Landscape	7

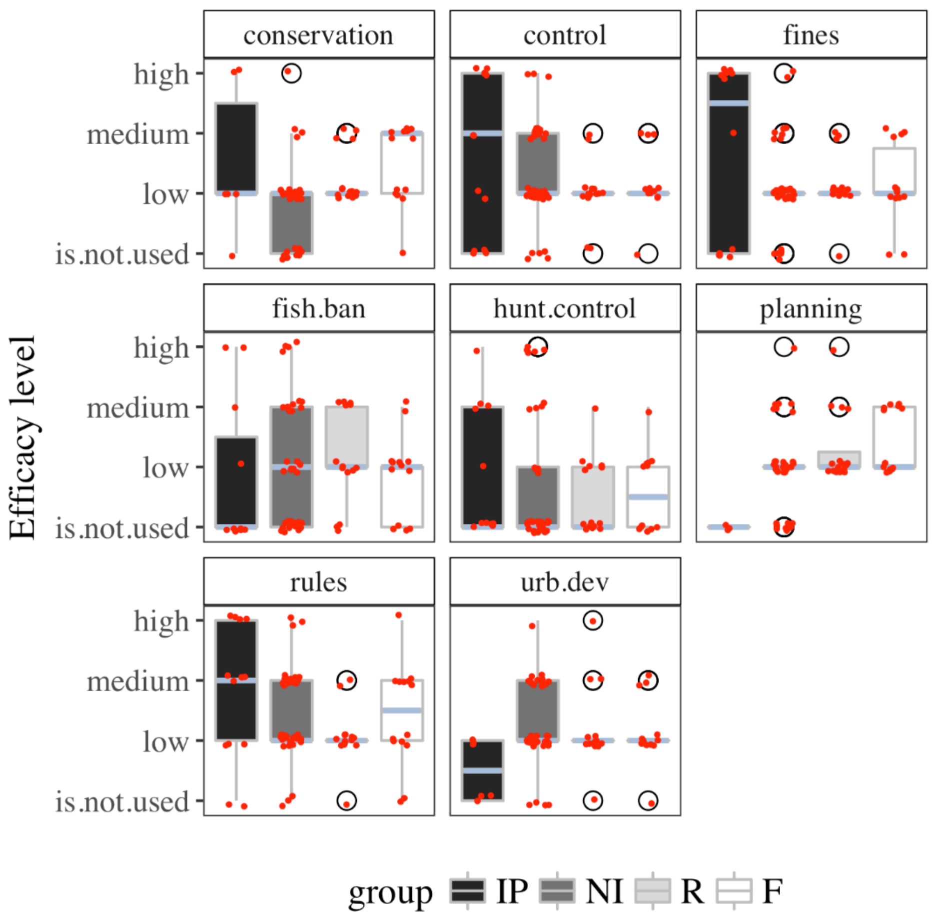
Chi square (χ^2) values for pairwise comparisons with statistical differences

Figure 3-9. Distribution of answers to question 4A by group.
"What are the chances of conserving an ecosystem if it has a cultural, ecological, economic or a landscape value?"
IP: Indigenous People; NI: Non-Indigenous communities; F: Federal employees; R: Researchers



No statistical differences were found

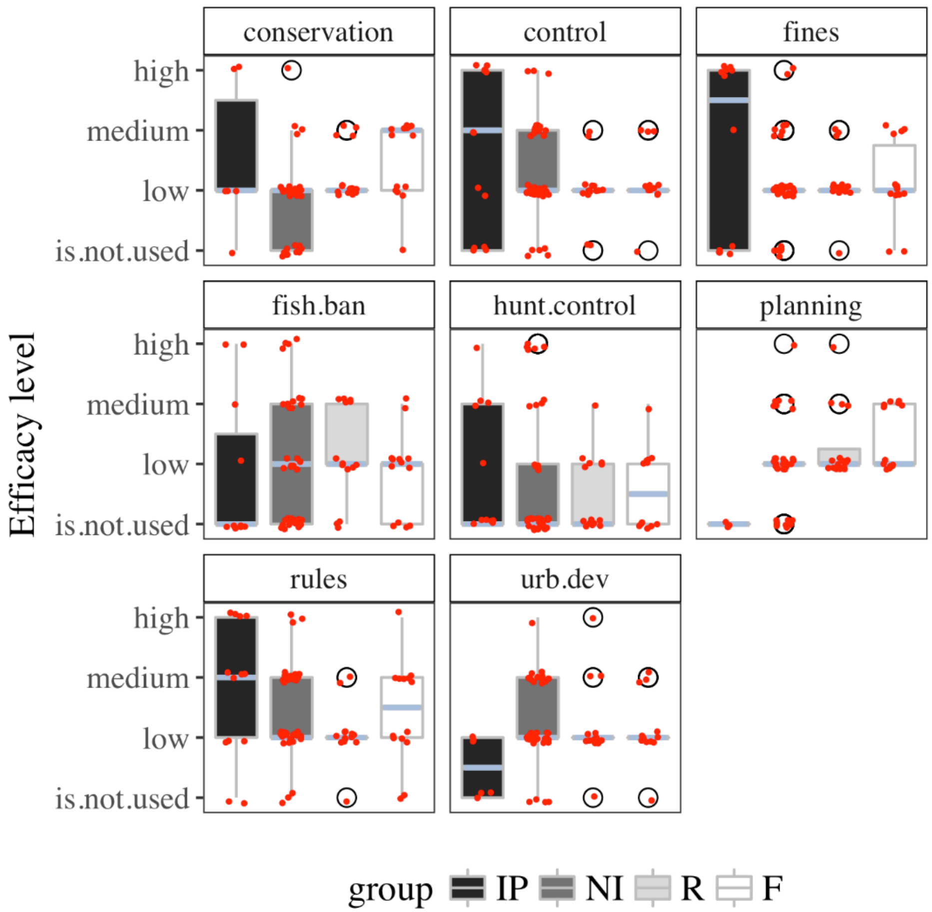
Figure 3-10. Distribution of answers to question 4B by group.
"What are the chances of conserving an ecosystem if it is located in different ownership regimes?"
IP: Indigenous People; NI: Non-Indigenous communities; F: Federal employees; R: Researchers



Pairs		Variable	χ^2
F	NI	Conservation	14.76
F	R	Conservation	5.65
IP	F	Conservation	8.69
IP	R	Conservation	10.36
IP	F	Control	11.45
IP	NI	Control	12.22
IP	R	Control	11.81
IP	F	Fines	17.03
IP	NI	Fines	21.51
IP	R	Fines	20.59
IP	F	Fish ban	7.54
IP	R	Fish ban	9.62
IP	F	Planning	16
IP	R	Planning	19
IP	R	Rules	9.55
NI	R	Conservation	8.97

Chi square (χ^2) values for pairwise comparisons with statistical differences

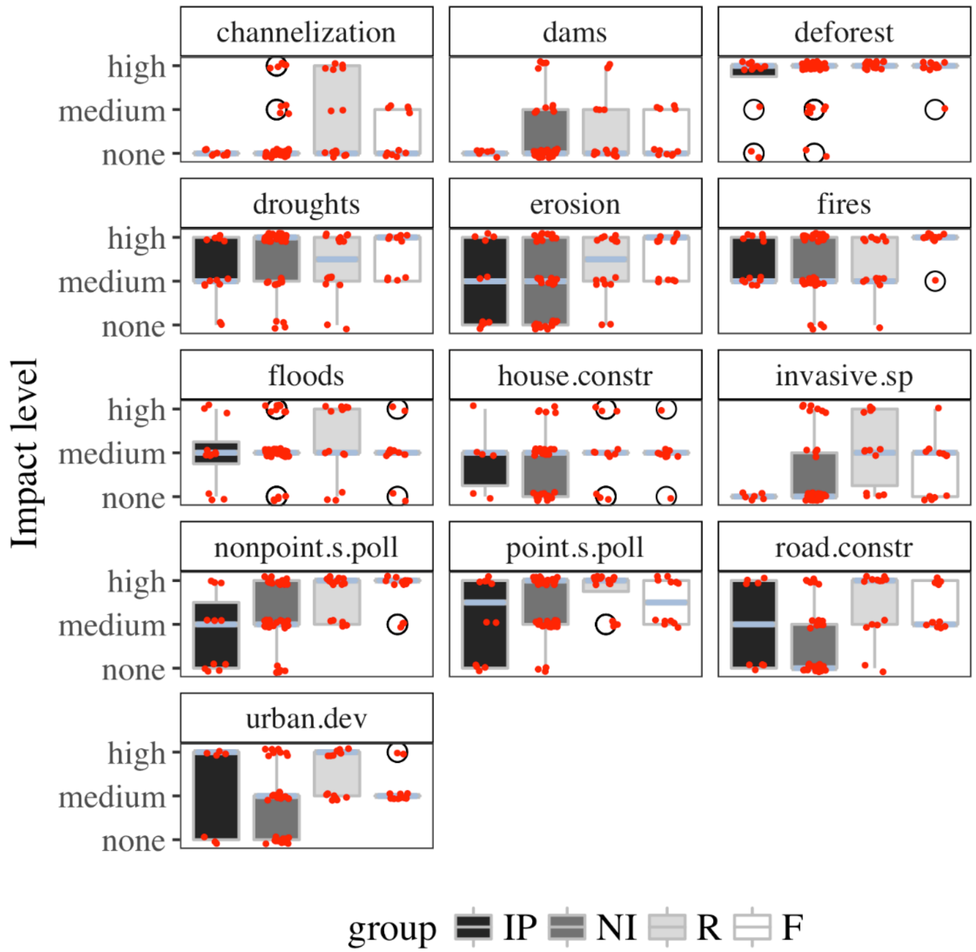
Figure 3-11. Distribution of answers to question 5A by group.
"What is the level of effectivity of formal governance strategies?"
IP: Indigenous People; NI: Non-Indigenous communities; F: Federal employees; R: Researchers



Pairs		Variable	χ^2
F	NI	Verbal agreements	10.12
IP	R	Cooperation with universities	10.52
IP	F	Conflict resolution	10.38
IP	NI	Conflict resolution	10.3
IP	R	Conflict resolution	9.2
IP	F	Verbal agreements	8.81
IP	NI	Verbal agreements	7.63
IP	R	Verbal agreements	9.88
IP	F	Cooperation within communities	15.41
IP	NI	Cooperation within communities	21.21
IP	R	Cooperation within communities	8.43
IP	F	Written agreements	10.31
IP	R	Written agreements	13.03
NI	R	Cooperation with universities	11.25

Chi square (χ^2) values for pairwise comparisons with statistical differences

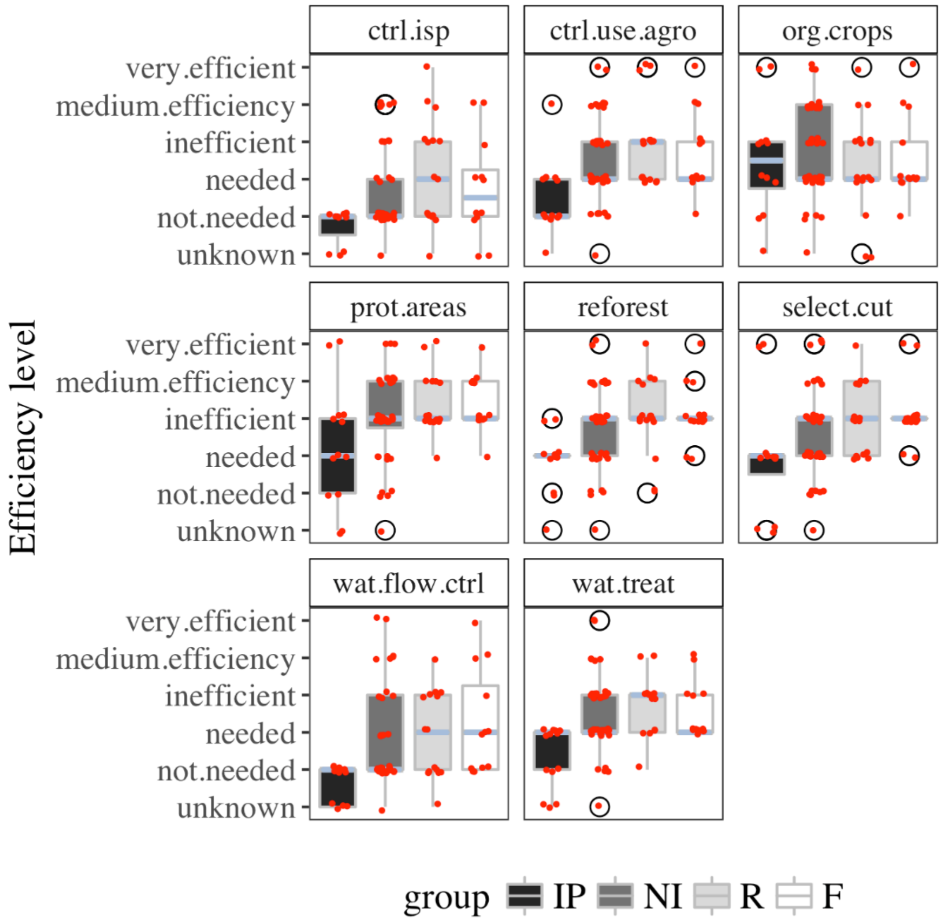
Figure 3-12. Distribution of answers to question 5B by group.
“What is the level of effectivity of informal governance strategies?”
IP: Indigenous People; NI: Non-Indigenous communities; F: Federal employees; R: Researchers



Pairs		Variable	χ^2
F	NI	Channelization	7.68
F	R	Channelization	6.1
F	NI	Fires	8.99
F	R	Fires	6.71
F	NI	Invasive species	8.92
F	NI	Road construction	11
F	NI	Urban development	8.36
IP	F	Channelization	4.94
IP	F	Nonpoint source pollution	8.66
IP	R	Nonpoint source pollution	9.47
IP	F	Erosion	7.5
IP	F	Fires	6.5
IP	R	Invasive species	8.57
IP	NI	Point source pollution	6.45
IP	F	Road construction	10.74
IP	F	Urban development	13.27
IP	R	Urban development	9.71
NI	R	Invasive species	8.17
NI	R	Road construction	10.63
NI	R	Urban development	9.26

Chi square (χ^2) values for pairwise comparisons with statistical differences

Figure 3-13. Distribution of answers to question 6 by group.
"How much each of these factors impact the ecosystems?"
IP: Indigenous People; NI: Non-Indigenous communities; F: Federal employees; R: Researchers



Pairs		Variable	χ^2
F	R	Selective cut	7.9
IP	R	Controlled use of agrochemicals	17.47
IP	NI	Control of invasive species	10.15
IP	F	Protected areas	10.73
IP	R	Protected areas	11.24
IP	F	Reforestation	14.04
IP	R	Reforestation	14.89
IP	F	Selective cut	15.72
IP	NI	Selective cut	15.32
IP	R	Selective cut	12.09
IP	F	Water treatment	11.07
IP	NI	Water treatment	12.53
IP	R	Water treatment	15.68
IP	F	Water flow control	11.69
IP	NI	Water flow control	12.74
IP	R	Water flow control	9.87

Chi square (χ^2) values for pairwise comparisons with statistical differences

Figure 3-14. Distribution of answers to question 7 by group.
"What is the efficiency level of current management practices (or the urgency level to develop new ones) for ensuring a healthy environment and securing the provision of ecosystem services?"
IP: Indigenous People; NI: Non-Indigenous communities; F: Federal employees; R: Researchers

Except for Indigenous peoples, the other groups of actors agree that the main economic activities in the watershed are ranching, subsistence crops and fishing (Table 3-7). Also, they agree that construction is not an important form of income. Regarding the governance strategies, NI, R, and F groups agree that control strategies, rules strategies, and written agreements have low to middle levels of effectiveness. Also, they agree that cooperation with universities is low, and that the best cooperation is within members of the same community.

Table 3-7. The rank order of economic activities.

Economic activity	**IP**	**NI**	**R**	**F**	**Overall rank**	**Scale**
Cattle	4	1	1	1	1	Most important
Subsistence crops	1	2	2	3	2	
Fishing	2	5	3	2	3	
Commercial crops	5	3	5	4	4	
Hunting	3	6	6	3	5	
Construction	7	4	7	5	6	
Mining	8	9	4	7	7	
Tourism	6	8	8	6	7	
Fish farming	8	7	10	8	8	
Petroleum	8	10	9	9	9	Least important

Regarding the effectiveness of management practices used in the watershed, there is a general agreement between NI, R, and F that the most important practices are water treatment, reduced use of agrochemicals, selective cuts, and reforestation. They also agree that current practices are ineffective, particularly reforestation and protection of important ecosystems.

3.3.3.1 Disparities regarding Indigenous peoples' perspectives

Fundamentally, the differences found between Indigenous peoples and other groups are related to four critical aspects: (1) their economy that is highly dependent on common-pool resources, but because of their interactions with other groups it has been transitioning into new forms of production, (2) their traditional practices, particularly regarding traditional medicine, hunting and gathering, (3) their perceptions of the processes influencing the social-ecological system that are limited by their experiences in their interaction with their territory, and (4) their social structures that ultimately defines how they organize, make decisions, and interact with other groups. Here, each of these aspects is discussed in-depth.

3.3.3.1.1 Indigenous economies

Indigenous peoples' economies are very different from what others perceive as the main economic activities in the watershed. Figure 3-15 illustrates the level of dissimilarity between Indigenous people and all other groups on this subject. The lower portion of the figure contains the activities with no or little dissimilarity and the middle and upper portion are the activities for which Indigenous peoples' perceptions have the largest differences.

At all visited locations, Indigenous peoples mostly grow food for their own survival, and only some of them are hired for working on commercial crops, or on non-Indigenous people's lands. Indigenous peoples in urban areas are the most marginalized of the communities, and they often live in conditions of extreme poverty.

"You can see Jiw girls begging in the streets, older men and women collect waste food. They are the ones that eat the mangoes that grow around the city, not we" (Towner from San Jose del Guaviare – GSJ08)

"Indigenous peoples are very poor, they do not have money for paying the transportation. The other day I drove four of them to the city, but I make them pay me at the beginning, otherwise, they do not pay. They are thieves too, they need to survive somehow" (Taxi driver – GSJ20)

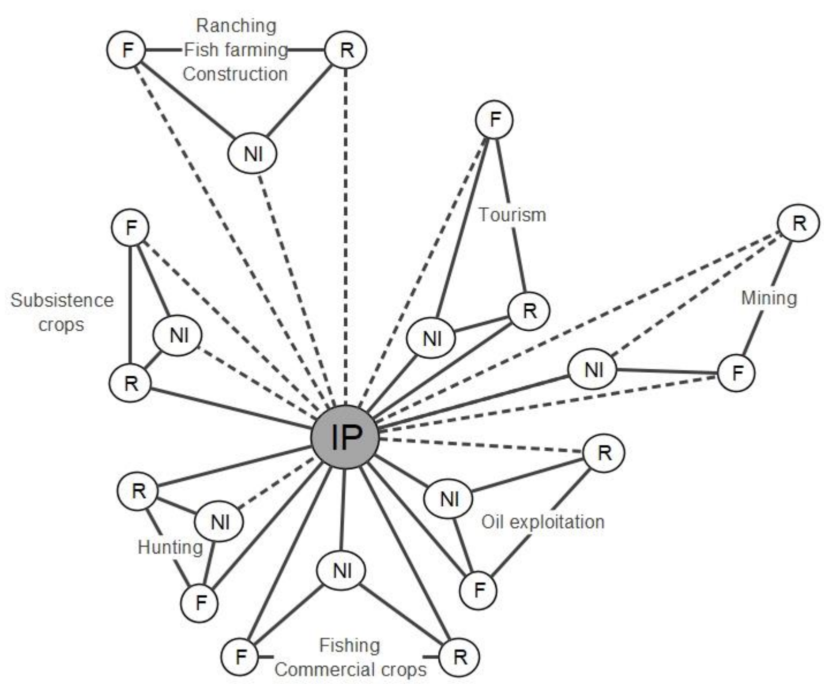


Figure 3-15. Differences between actors regarding economic activities.
IP: Indigenous peoples; NI: Non-Indigenous communities; R: Researchers; F: Federal

Some try to sell their products in the streets. In Puerto Carreño for instance, non-Indigenous people normally buy cassava flowers from Sikuany women. But in other regions they do not have lands for growing cassava, due to poor soil quality, occasional periods of water scarcity, and competition for the use of the land within densely populated reserves. In the Department of Guaviare, there are cases in which Indigenous families rent small pieces of land for growing cassava (del Cairo, 2012).

Ranching is also a predominant activity in the ORW, but for Indigenous peoples, it is substantially less important than for all other groups. There are two important reasons why IP do not engage in these activities in the same proportions as non-Indigenous people do. First, raising cattle is foreign to most Indigenous peoples and second, in reserves with poor soils, cattle would compete with the production of food. Only those Indigenous groups that for decades have interacted with the Llaneros, in the savanna, and peasants, in the Andean region, have learned and adopted this practice. One of the guides that assisted the field work in 2015, commented that "When the government has donated cows for the communities at the Guaripa Reserve (Municipality of Puerto Carreño) they do not know what to do with them." (VPC03). Often, these Indigenous communities do not have a tradition of cattle production; therefore, selling or eating the donated animal is common.

For Indigenous peoples in isolated areas, fishing is another important economic activity. Even though they compete for fish with non-Indigenous fishermen, there are creeks and flooded areas within their reserves where they can still fish. However, even when Indigenous peoples catch enough fish for selling some, there are limited means for traveling to the market by river. The money they make is just enough for covering the costs of gas and basic supplies (e.g., salt, sugar, soap, and oil).

Fish stocks in Inírida are affected by two other important activities, gold mining in rivers and ornamental fishing (Trujillo et al, 2014); Indigenous peoples actively participate in both. During the interviews, they explained how boats and specialized machinery that suction or dredge sands from the bottom of the river are used for extracting gold. Then, the sand is processed to separate the gold using mercury. Dredging boats, gas, engines, and other materials are often rented or provided by people who live in Inírida. Miners, most of them Indigenous, obtain a commission for the gold. The lack of regulations over this activity, which has been taking place over the last 30 years (Ajiaco-Martínez et al., 2012), is greatly responsible for the degradation of the riparian ecosystems in the Inírida river and for the threats to the public health due to the bioaccumulation of mercury in fish (Ajiaco-Martínez et al., 2012; Lasso et al., 2011). During this time, Inírida has experienced a rapid and disorganized growth, also affecting terrestrial ecosystems (Trujillo et al., 2014).

Unlike artisanal river gold mining, ornamental fishing is a legal activity. It is an important source of income for poor communities in the ORW such as Indigenous peoples (Ajiaco-Martínez et al., 2012). It was estimated that 13 million fishes from more than 40 different species were extracted from this watershed in 2009; 30% of which came directly from the natural systems (Ajiaco-Martínez et al., 2012). The commercialization of ornamental fish supplies markets in the USA, the EU and Japan (Mancera-Rodriguez & Alvarez-León, 2008). It is poorly managed, and the process of capture, reproduction and transportation is inefficient.

Fish harvest in urban regions has a different dynamic. There the competition for fish resources is voracious and Indigenous peoples have little opportunity. Fishermen and other groups control locations with large fish population, and Indigenous peoples' incursions into these areas are forbidden; they can only attempt fishing in little creeks where fish populations are very small. All actors have similar opinions about the importance of fishing in the region. Also, there is general agreement that fish populations are highly decimated, and this concerns participants.

3.3.3.1.2 Indigenous traditions

An important aspect of Indigenous traditions is medicinal plants. Some Indigenous peoples grow medicinal herbs in their reserves, but many of these plants can only be found in the forest and other ecosystems. The Indigenous participants mentioned that most attempts to reproduce these plants in their reserves have failed. They also stated that elders do not have the means to transmit their knowledge on the use of these plants, because of the ecological degradation of the forest that is causing the decimation of medicinal species and because young generations are not prepared to learn, and that because of that this aspect of their traditional knowledge is quickly disappearing.

As mentioned before, wood is essential for Indigenous peoples and in this study, they expressed deep concern for this resource. Sometimes, members of Indigenous communities in San José del Guaviare must travel for days to find places in the jungle that still have the trees species needed for building their houses. Consequently, these communities are transitioning into pre-constructed houses provided by the government.

According to the results of this research, for Indigenous people wildlife is currently not considered a vital resource. Even though Indigenous peoples in the Orinoco have ancestrally consumed bushmeat as their primary source of protein (Matallana et al., 2012), sedentary Indigenous groups have changed this practice. One possible explanation is that Indigenous reserves are not large enough for supporting large wildlife populations. Also, the historical decimation of original wildlife has forced Indigenous peoples to change their habitual consumption of bushmeat. It has been reported by historians and anthropologists that during the conquest of the Orinoco in the 20th century there was an intense extraction of resources and wildlife that caused a great reduction of wildlife populations (del Cairo, 2012; Molano, 1989). Back then, Indigenous peoples had to compete with non-Indigenous for bushmeat, and, pressured by resources scarcity, they learned how to raise pigs and cows. Finally, the reduction of wildlife resulted in Indigenous peoples becoming more aware of what species they can or cannot hunt (IP03), and also there are certain internal rules that regulate hunting behaviors in some Indigenous communities.

3.3.3.1.3 Indigenous perceptions of the processes influencing the social-ecological system

The perception that Indigenous peoples have about factors that are currently transforming natural resources in the watershed is based on their experience and on the issues they face within the reserves. For instance, deforestation, fires, and droughts are the major impacting factors for Indigenous peoples, which are the same problems they are trying to overcome in their reserves. At the Refugio Reserve (San Jose del Guaviare municipality), Indigenous authorities are creating new mechanisms for controlling the occasional fires that have been more frequent with the arrival of new families. Similarly, the people of the Indigenous reserves in the La Uribe Municipality are cutting trees to grow food, and one of the projects they hope to carry out is the reforestation of deforested areas. They also indicate how fires and the accelerated deforestation around their reserves are impacting their water resources and wildlife.

Within Indigenous reserves the main sources of water are wells and rivers. Some of the Indigenous participants mention that water levels in their wells are dropping. Changes in levels of local precipitation are also impacting their crops. These reductions of groundwater and rainwater contrast with the fact that floods ranked fourth among the list of impacting factors for Indigenous peoples. This is consistent with observations during the field work and my conversations with Indigenous leaders. Many of the Indigenous reserves are located next to the river's flood zones and year after year they experience floods that destroy their crops; an issue that also affects non-Indigenous communities.

Differences between IP and actors from the R and F groups, regarding factors that impact natural resources may be partly explained by differences in their capacities to perceive processes at different scales. Non-point pollution is affecting the quality of the water in the watershed (IDEAM, 2014) and is due to the deforestation and erosion in the headwaters, expansion of urban areas, and heavy use of agrochemicals. Yet, Indigenous peoples do not perceive any of these stressors other than deforestation as important agents of transformation in their environments. Beside this, there are differences in the way Indigenous people interact with the territory, that make them perceive the problems in a unique way. Their values, lifestyles, and ideas are focused on the territory and intimately linked to the resources they obtain from nature.

However, when comparing IP and NI, they have similar opinions about the main factors that affect their resources; only point source pollution was found to be statistically different (χ^2=6.45, p=0.04). These two groups of actors are being affected in similar ways by the dynamics of transformation that is taking place in their territories, and both groups are limited by their experiences and interactions at local scales.

3.3.3.1.4 Social structures and Indigenous institutions

Indigenous peoples' visions about the governance of common-pool resources are linked to their Indigenous institutions and their perceptions about which are critical issues are based on their own social-ecological interactions. It was correctly stated by one of the researchers who participated in this research that "conservation for the Indigenous person has a different meaning than the one we have defined" (GSJ11), because for these peoples conserving is part of their identities. Indigenous peoples conserve for their survival and out of cultural values and world views, but non-Indigenous groups conserve for maintaining the sustainable development of the society.

There are significant differences between Indigenous peoples and all other groups, concerning governance of common-pool resources (Figure 3-16). Indigenous peoples, more than any other group, believe that conservation is possible in communal areas or lands where the resources are available for everybody's use. Even though some of the Indigenous peoples' responses indicated that conservation in communal areas is low, none of the participants from this group said that it is not possible. Furthermore, the answers were skewed towards believing that it is very likely that resources will be conserved in this type of land.

Significant differences in perceptions about the effectiveness of governance strategies were also found. Indigenous peoples differ from the other groups in the perception about the effectiveness of formal strategies that restrict and control fishing and hunting activities. They believe that these mechanisms are not as effective as the informal strategies designed by the communities. One possible issue with formal strategies is that these do not consider the context in which the use of resources is taking place. Also, formal strategies are imposed on the communities and users perceive them as foreign, illegitimate, and often inappropriate.

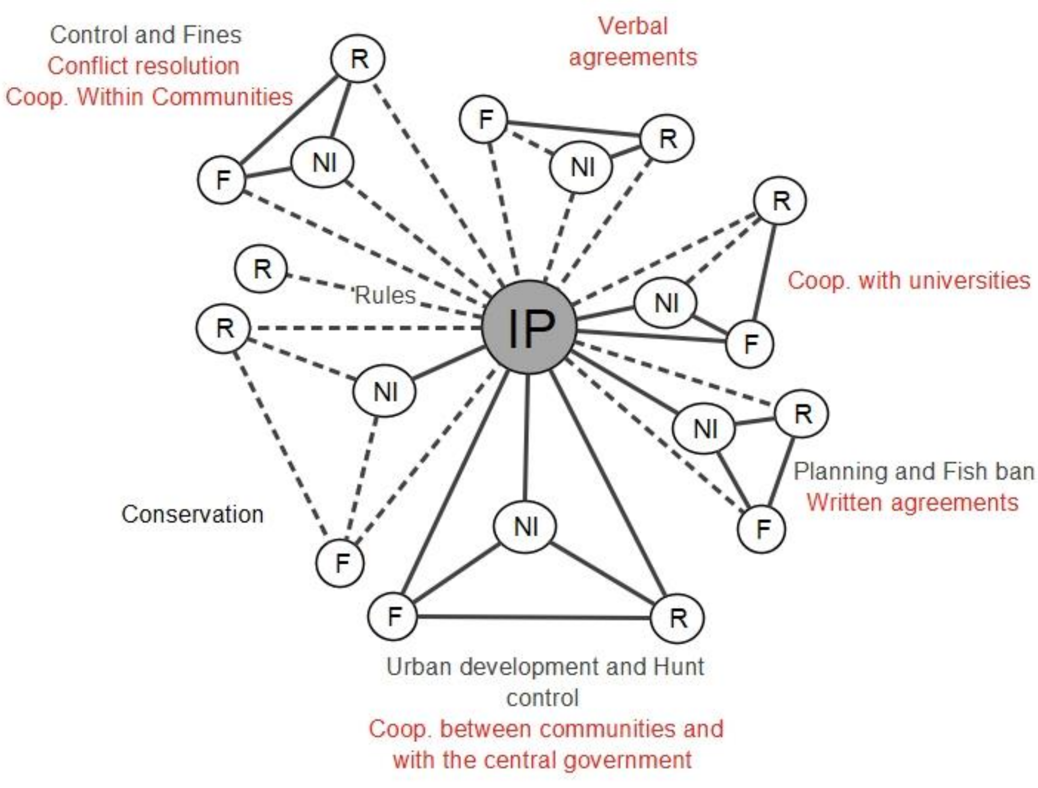


Figure 3-16. Differences between actors about governance strategies from the IP perspective. Black letters for formal strategies and red for informal
IP: Indigenous peoples; NI: Non-Indigenous communities; R: Researchers; F: Federal

Indigenous peoples' answers about controls and fines vary widely among participants. Three factors explain this variation. First, Indigenous peoples have the autonomy to govern their territories, therefore none of these outside rules can be used for controlling the behavior of the member within their community. Second, Indigenous peoples have their own mechanisms control and penalize those who do not follow the internal rules. Third, while it is the nation's responsibility to protect Indigenous peoples' territories from external agents, the laws that should control and penalize aggressors are not always implemented. Consequently, opinions about the efficacy of these formal rules vary between reserves, in part depending on the availability and resources demand.

Cooperation within the community obtained a high rank among Indigenous peoples. Even in the cases of the Indigenous reserve in San Jose del Guaviare, where resources are scarce and new families are constantly arriving, all members of the community believe they must support each other and work together. Often, they also work with other communities.

For management practices, Indigenous communities have less knowledge of many practices, particularly those concerning treatment plants for wastewater, agrochemical control, and protected areas. IP and NI think that reforestation is needed. However, answers provided by Indigenous peoples contrast to what actors at the regional scale believe (i.e., that reforestation's efficiency is low to medium). Indigenous peoples think also that selective cutting of trees is needed. Here they differ from both the regional and local scale actors.

3.3.3.2 Disparities from the perspective of the non-Indigenous communities

For non-Indigenous communities, the most persistent disparities were with Indigenous peoples, particularly concerning dependency on natural resources and the economic activities (Figure 3-17). Non-Indigenous communities' perceptions about levels of dependency on natural resources are correlated to their economic activities. They raise cattle, and they are commonly employed in growing commercial crops and in the construction industry. For non-Indigenous communities, the use of medicinal plants is unessential for curing illnesses, although, many of them use them.

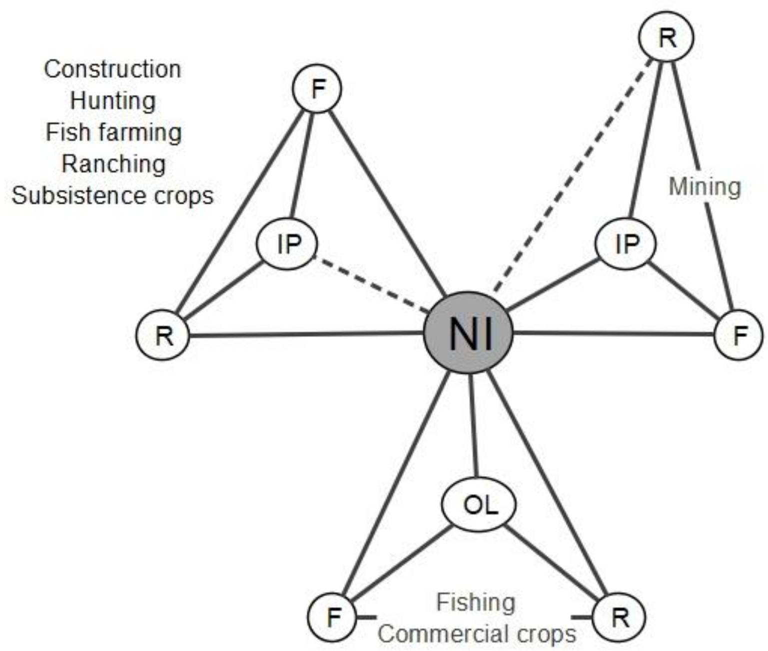


Figure 3-17. Differences between actors about economic activities from the NI perspective.
IP: Indigenous peoples; NI: Non-Indigenous communities; R: Researchers; F: Federal

Like Indigenous peoples, for non-Indigenous communities subsistence crops are the most important economic activities. Non-Indigenous communities however, depend less on their own internal food production for their food supply than Indigenous peoples. They are less concerned about the situation of fruits and vegetables because a substantial proportion of the food that is consumed by these communities is imported.

Despite these differences, non-Indigenous communities' concern over the state of natural resources, and perceptions about high impact factors are alike with Indigenous peoples', probably indicating that ecosystem transformations in the ORW are affecting both groups in similar ways.

Another important discrepancy from the perspective of non-Indigenous communities is found when comparing NI to R and F groups. They have different perspectives about the importance of minerals and mining. Minerals are thought to be slightly more meaningful by both R and F than by NI. Two thirds of the participants from non-Indigenous communities say that minerals are not important for their livelihoods and the other third thinks that it has little importance. However, 27% of the respondents showed high concern about mining and oil extraction. This is higher than R and F groups, who showed little concern.

In this study, it was important to make a distinction between mining and oil exploitation. Mining relates to the extraction of minerals other than carbon-based-energy resources such as oil and gas. Oil extraction has been for decades an important economic activity in the ORW, and hence oil extraction will be discussed separately from mining and mineral exploitation.

Mining activity in this watershed is difficult to assess because it is informal (Trujillo et al., 2014). Most of the minerals are extracted, circulated, and commercialized by illegal means. There are well known cases of gold mining, mostly in the southern portion of the watershed (Trujillo et al., 2014), and some reported cases of tantalum, chrome, sulfur, and iron mining in isolated areas (Sanz, 2016).

Participants from R and F groups also said that there are companies extracting rock materials from the rivers in the piedmont with permits for their operation. Though legal, this is perceived to be a problem. One of the interviewed researchers said that "It might not seem to be a problem, but the extraction of sands and rocks is transforming the river" (CY018). Two federal employees were consulted about this issue, and they agreed that this type of mining is affecting riparian ecosystems. Nonetheless, if extracting companies fulfill the environmental requirements of their practices these activities are considered legal.

Data collected in the field indicate that these mining issues are better known among participants within F and R groups. Even though the region where they work is not directly affected by mining activities, they learn about these issues during regional meetings, through the news or through official reports. On the other hand, Indigenous peoples and non-Indigenous communities do not have access to this information. They are not aware of the other mining activities because these do not occur in their territories, therefore their perception about the regional level of dependence that ORW's communities have on minerals is restricted to their knowledge of their own territories. However, non-Indigenous communities' concerns about minerals differ for several reasons.

About 60% of the non-Indigenous communities think that state of minerals is not a concern. These participants do not interact with minerals issues because mining is taking place in isolated areas and they live either within or close to towns. However, the other 40% of the non-Indigenous communities group who live in the same conditions, have low to medium levels of concern about minerals. This is because these communities have either experienced or heard about the impacts of similar industries in the Orinoco.

Some participants within the non-Indigenous group are aware of the social and environmental impacts of the oil industry and have resisted the incursion of petroleum companies into their territories. Because of this, they worry that impacts from mining industries will resemble the ones from the oil industry. Besides this, some locals are aware of exploration for minerals because they have been hired to guide the crew of experts in the field (VPC03). There is a conviction that extraction of minerals is linked to social and environmental impairment: "rumors are that water pollution, landscape fragmentation, and incremental socio-economic disparities are inevitable consequences of these types of industries" (MLU08).

Additional statistical differences were found in the answers about incentives. Among respondents, NI considered landscape and ecological types of incentives more impactful than R and F did. According to this, NI participants believe that conserving landscape and ecological functions are highly appreciated by local communities, and consequently local people feel motivated to protect natural resources when these two attributes remain well-preserved. Contrarily, R and F groups think that local communities do not feel motivated to conserve and protect an area with good landscape and ecological attributes.

3.4 Bridging disparities

Multilevel interactions between actors are affected by mismatches across levels (vertical) or within the same level (horizontal), and by the unique temporal scale at which each group operates. These two dimensions translate into differences in the actors' perceptions and opinions about their territory, limiting the potential to develop integral solutions to environmental issues. Even when actors at different scales share common interests for the protection and conservation of important resources, vertical and horizontal barriers are persistent challenges for regulating the rational and equitable use of common-pool resources.

Solving the mismatch presented in the interaction between actors is important for creating alliances, protecting local knowledge, and improving the chances of adopting future adaptive collaborative management practices (Crona & Parker, 2012; Brondizio et al., 2009; Olsson et al., 2007). Links between local groups and regional organizations, such as NGOs, have been fundamental in protecting the rights of minority groups (Susskind & Anguelovski, 2008) and ensuring healthy environments for local communities. Furthermore, integrated management practices in watersheds have increased social learning capacities (Rica et al., 2012), augmenting the capacity of the social-ecological systems to respond to uncertainty and sudden changes (Olsson et al., 2004).

Working to resolve horizontal and vertical differences is necessary for promoting local participation and for increasing the capacity of local institutions to govern common-pool resources. Local governance is only possible if members of a single community work together for developing autonomous institutions and norms for the use of their common resources, and if they successfully adapt to the changes in the system derived from processes at larges scales. Vertical differences limit access to information available at larger scales (Susskind et al., 2012) and prevent local communities from participating in the formulation of plans and projects that will define the use of the natural resources.

Links between actors solidify the network of interactions at multiple levels (Ostrom, 2005, 1990), for this, one of the most commonly used strategies is the identification or creation of bridging organizations that mediate in the resolution of conflicts between actors, incentivize social learning, promote trust by bringing together different actors, and create links that strengthen networks (Crona & Parker, 2012; Berkes, 2009). Bridging organizations play an important role in providing the space where multiple forms of knowledge and disciplines come together (Crona & Parker, 2012; Berkes, 2009).

Given the nature of each of the groups of actors involved in this research, their perspectives are not expected to be similar, but rather diverse. It is this diversity what adds value to the network of interactions that take place in multilevel systems (Allen et al., 2011; Berkes, 2009), therefore, bridging differences between groups within the ORW is not to reduce this variety, but rather bringing together these groups so that social learning can take place.

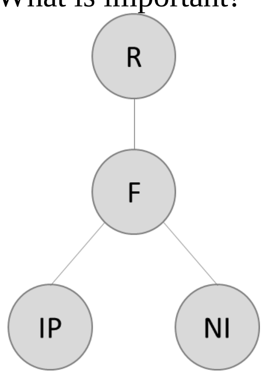
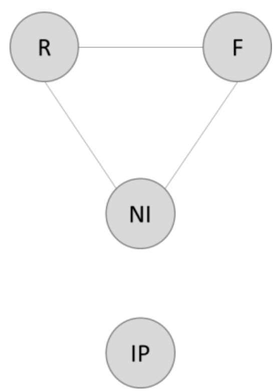
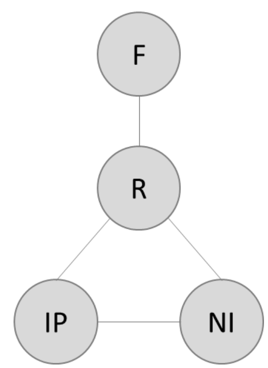
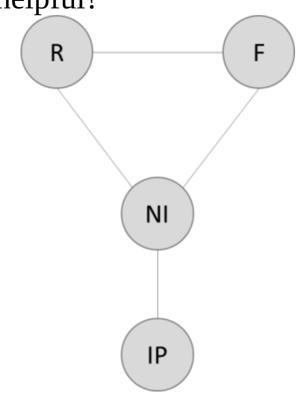
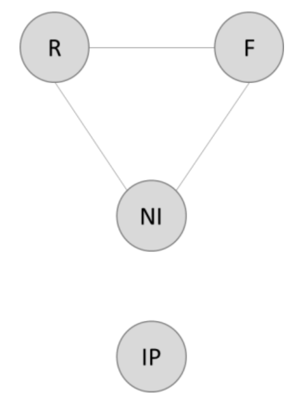
3.4.1 Identification of opportunities for bridging actors

Each of the questions used in the survey relates to socio-ecological characteristics and the differences between actors denote mismatches (Table 3-8).

Table 3-8. Percentage of differences between actors by subject.

Pair of actors	Management needs	Interest	Economic activities	Governing strategies	Solutions	Interaction
IP – NI	50%	50%	50%	33%	15%	Horizontal
IP – R	75%	50%	50%	73%	23%	Vertical
IP – F	63%	13%	50%	60%	46%	Vertical
NI – R	0%	50%	10%	13%	23%	Vertical
NI – F	0%	25%	0%	13%	38%	Vertical
R – F	13%	13%	0%	7%	15%	Horizontal

Table 3-9. Major differences between groups of actors by subject.
Questions 1,3 and 6 reveal differences related to use behavior, 5 to governance strategies and 7 to management practices.

Interests	Economic activities	Management needs	Governing strategies	Solutions
Question 1: - What is used? - What is available? - What is important?	Question 3: - What is needed? - What is in demand?	Question 6: - What are the main environmental issues?	Question 5: - What informal and formal strategies are helpful?	Question 7: - What practices work? - What is needed?
				

By comparing the level of agreement and disagreement, it was possible to infer horizontal and vertical strengths and weaknesses; respectively known as bounds and gaps (Crona & Parker, 2012). Figures in Table 3-9 outlines the specific findings.

The strongest subject of interaction between IP and NI was found to be around the main factors that create disturbances on natural resources (Question #6). Here, IP and NI had the lowest percentage of disagreement (15%), followed by IP-R and NI-R (23%), and IP-F and NI-F (46% and 38% respectively). Even though local actors had similar opinions about the environmental issues that need to be managed, they have large differences regarding interests in different natural resources (Question #1) and economic activities (Question #3). The percentage of disagreement was 50% in both cases.

Future bridging efforts have to acknowledge the big gap between IP and NI regarding their economies, this is pivotal because based on their economic dynamics actors make decisions about how to use the resources. Besides, finding ways in which both local economies can co-exist is indispensable for advancing towards better horizontal connection at local scales. Part of this process consists of identifying common interests for natural resources but also in knowing what aspects they do not overlap because these will represent an opportunity to solve future conflicts for natural resources.

The Question #5 is about the level of efficacy of different formal and informal strategies that are involved in the governance of natural resources. For this question IP and NI disagreed 33%, NI-R and NI-F 13%, IP-R 73%, IP-F 60%, and R-F 7%. In this case, the role of a bridging organization should be to identify the potentials for developing cooperative work as the main informal strategy, mediate the differences between actors regarding formal strategies, and assist with the design of governing strategies that are better suited to overcome specific environmental issues.

Information about governance strategies from question #5 is useful in identifying what tools can be helpful in the process of creating and enforcing rules and regulations that limit the use of common-pool resources. For instance, among informal strategies, verbal agreements and cooperative efforts had similar results for both groups of local actors. This implies that the use of these strategies could result in effective mechanisms for achieving equity in the use of common-pool resources at local scales. Having the capacity of building verbal agreements could be useful in solving conflicts derived from the use of resources and effective cooperation between actors at local scales is essential for narrowing the gaps that keep groups of actors separated.

Question #7 refers to the effectiveness of different management practices for solving environmental issues. There, Indigenous peoples had very distinctive perceptions from all other groups, which could be explained by two main reasons. First, their ancestral interaction with the ecosystems enable them to develop their own mechanisms to deal with environmental issues, and currently, none of these practices are used by environmental authorities in the ORW. Second, the survey used words that might not be meaningful for the Indigenous participants.

Overall, Indigenous peoples and non-Indigenous communities have several commonalities. They share concerns about the availability of natural resources; particularly among poor people that depend on farming, fishing, and ranching. They are similarly affected by the expansion of monocrops (e.g., rice and palm oil) and extractive industries; these are economic activities that stimulate new processes of immigration and rapid transformation of the ecosystems. Another common aspect is in their concern for the land tenure. With the arrival of big industries, non-Indigenous communities are experiencing the same process of invasion of their territories that Indigenous peoples did, and the adoption of new legislation threatens their rights over the lands. These commonalities could incentivize future collaborations between the two of them.

3.5 Conclusions

Globalization is impacting local commons (Randhir, 2016) and the ORW is one of the regions where these transformations are taking place. Interactions between governing levels will be important for the future development and conservation of the watershed, therefore, this research focused on analyzing the underlying factors that disrupt vertical and horizontal interactions between regional and local groups. A multi-scale approach can be used for creating coalitions across scales for the improvement of local governance. More equitable and effective interactions across scales require the adoption of bridging strategies. The evidence collected in this study provides important information about the nature of the differences between actors in multi-scale systems, but it also identifies opportunities to strengthen the governance of common-pool resources in this watershed.

The main discrepancies found in this study show that horizonal differences at local scales are larger than at regional scales, also, vertical differences are larger between regional actors and Indigenous peoples than with non-Indigenous communities. Differences between local groups regarding use-behavior (direct and indirect use of natural resources) are the largest. This implies that future efforts for bridging these two actors will have to address issues about priorities of conservation. For instance, for Indigenous peoples, medicinal plants is one of the most important resources but it only has a medium to low importance for non-Indigenous communities, therefore, it is very likely that in future conservation agendas these two actors will disagree about how much priority it should be given to the protection of medicinal plants. Similarly, Indigenous peoples consider that ranching is not important for sustaining their livelihoods but for non-Indigenous communities is one of the most important activities.

Therefore, the findings about local mismatches from this research represent milestones for the future governance of common-pool resources in the ORW, and by analyzing the divergent points, at which local groups have fundamental disagreements, will contribute to the formulation of strategies for building trust and for advancing towards collaborative actions.

Regarding the flow of information, it was found that vertical mismatches is affecting how actors build mental models about the impacts that different stressors have on the socio-ecological dynamics within the watershed. The differences found between IP-F and IP-R regarding non-point pollution support the idea that, current multi-scale disarticulation is impeding Indigenous peoples to perceive the impact of processes at large scales. The same can be said about non-Indigenous communities regarding invasive species. This means that actors at regional scales, such as researchers and federal employees, can provide information that otherwise is not perceptible by local communities and raise the awareness of all actors. Also, by improving channels of communication, locals can be better informed about important transformative and impacting dynamics that are taking place at larger scales, such as climate change and the future development of the watershed, and together can work to develop mechanisms of adaptation and mitigation for these upcoming challenges.

In certain regions of the ORW, different Indigenous ethnic groups work together, and are organized for achieving common goals; however, throughout the region, many of them lack political representation. Despite this, Indigenous peoples have survived centuries of colonization. They have a profound knowledge of the ecosystems in this region and large coordination capacity.

On the other hand, it was found that some non-Indigenous communities in the ORW use different types of institutions for making decisions in neighboring areas. Such is the case of the JACs in various villages in La Uribe, and in the case of environmental organizations in San Jose del Guaviare; these are families that live in the same area and work together for the use and protection of the common-pool resources in open-source lands. Compared to Indigenous peoples, non-Indigenous communities have a better knowledge of regional economic dynamics, but they have lower cohesion and their capacity to organize varies depending on the groups of people found in a single territory.

A coalition between Indigenous peoples and non-Indigenous communities could be mutually beneficial, however, competition for resources, unequal distribution of power, and lack of stable incomes among Indigenous peoples are major burdens for the consolidation of cooperative work.

Besides articulating actors and coordinating efforts, it is important to keep advancing towards a better understanding of the socio-ecological and economic dynamics that take place at multiple scales in this watershed. As suggested by Olsson and collaborators, when communities learn about the limits of the system, they are better prepared for governing the system and for overcoming sudden changes in the future (Olsson et al., 2007).

CHAPTER 4

INTEGRATING INDIGENOUS PEOPLES' TRADITIONAL KNOWLEDGE FOR SUSTAINABLE DEVELOPMENT OF THE ORINOCO RIVER WATERSHED

4.1 Introduction

Life Plans are documents that present Indigenous peoples' visions of their territory and their objectives for development. Some researchers have considered these Life Plans to be important for improving the interaction between Indigenous peoples and governmental institutions (Cayon, 2012; Bottazzi, 2009; Houghton, 2008). Promoting the articulation of Indigenous peoples' Life Plans with the development plans designed by the government (here called National Plans of Development) is very much needed for Indigenous peoples' survival. Furthermore, governance of common-pool resources will benefit from intercultural dynamics, which are important for social learning (Brondizio et al., 2009), help find different solutions and alternatives to problems (Islam & Susskind, 2013; Berkes & Turner, 2006; Folke, 2006), and maintain cultural diversity.

The objective of this research is to analyze attributes that influence the governance of Indigenous peoples over their territories using a qualitative analysis of 11 Indigenous peoples' Life Plans in the Orinoco River Watershed (ORW). This will help answer three main questions: (1) Are there significant differences in the quality of knowledge, equity, and internal organization between communities of Indigenous peoples in the Orinoco River Watershed? (2) How do Indigenous peoples' Life Plans compare to

National Development Plans? and (3) Could Indigenous peoples' Life Plans be used for articulating local governance with the national government?

The hypotheses for the research are that differences in knowledge, equity, and internal organization quality among Indigenous peoples are smaller when compared to national actors, that Indigenous peoples' Life Plans have different characteristics (e.g., principles, goals, and methods) when compared to National Development Plans, and that Life Plans are useful tools for articulating local governance with the national government.

The unique contribution of this research is to the comparative analysis of Indigenous peoples within the Orinoco River Watershed using their Life Plans. Most of the research on Indigenous governance in South America has been focused on the Amazon and the Andean region. Little is known about the Indigenous peoples in the Orinoco and their environmental governance is deeply unexplored (Gasson, 2002). This research is unique in studying Indigenous institutions through the qualitative analysis of Life Plans from the environmental sciences perspective and potential implementation of the ultimate findings to inform management practices, such as co-management of priority and protected areas.

This research starts with the definition of three categories of analysis that influence social resilience: knowledge and learning, social equity and infrastructure, and social structure and organization (Bergamini et al., 2013; Carpenter et al., 2012). These categories are used in this research to describe and evaluate each Life Plan. Through this initial characterization, it is possible to compare Life Plans and to identify main differences and commonalities throughout the region. Commonalities are then used to compare the notions of development from the Indigenous peoples' perspectives and government's National Development Plans. Lastly, past experiences of Indigenous peoples in South America are reviewed for studying harmonization between scales of governance. and factors are influential for the successful articulation of Indigenous and governmental institutions.

4.2 Use of social resilience indicators for the description of Indigenous peoples' Life Plans

Resilience is the capacity of a system to absorb shocks while maintaining its function, renewing its components and relationships, and re-organizing and developing the system (Folke, 2006). In a socio-ecological context, resilience depends on intrinsic characteristics of human communities that influence the community's capacity to respond to the transformation of natural systems. For instance, social learning and memory (an attribute of social groups) contribute to people's experiences and increase their capacity to make decisions about the use of resources (Berkes & Turner, 2006; Folke, 2006). Another example is social networks that facilitate communication between social groups and help communities in overcoming traumatic events (Islam & Susskind, 2013; Carpenter et al., 2012).

Biophysical and socioeconomic indicators are becoming useful tools for measuring attributes that confer resilience capacity and for the identification of its impacting factors (Bergamini et al., 2013). Socioeconomic indicators are used in this study for describing Indigenous peoples' knowledge and learning, social equity, and social structure and organization through the Life Plans.

The reason for selecting resilience indicators for the analysis of the Life Plans is because of the ample body of literature that demonstrates that Indigenous peoples' practices lead to regions with high resilience (Stevens, 2014, 2013; Nunn, 2009; Berkes et al., 1998). This is because, through their cumulative knowledge of the region they have maintained a dynamic balance with their environments, and their social institutions have evolved and adapted to new conditions.

Traditional ecological knowledge is one of the most important aspects that have enabled these adaptations (Moller & Liver, 2010) and today, Indigenous institutions play an important role in the conservation of biodiversity around the world (Stevens, 2013; Berkes et al., 1998; Stevens, 1997).

Applying socioeconomic indicators will allow us to analyze characteristics that are linked to Indigenous institutions' resilience and their impacting factors. For assessing the variability of Life Plans across a region, three fundamental aspects that influence local governance are assessed across all Life Plans: knowledge and learning, social equity and infrastructure, and social structure and organization (Bergamini et al., 2013; Carpenter et al., 2012). These three form the main categories for studying the Life Plans, and their assessment uses 12 social resilience indicators (Table 4-1).

4.2.1 Knowledge and learning

Social resilience is highly reliant on the transmission of knowledge, through formal and informal mechanisms, and on the process of social learning (Berkes, 2009). Learning is influenced by the exchange of knowledge and experiences derived from the interaction of individuals with the environment (Allen et al., 2011). Considering this, the first category of analysis is knowledge and learning. The indicators used for this category focus on the evaluation of important factors that influence social learning such as: (a) ways of transmitting knowledge through informal education (i.e., primary socialization that takes place within the community), and formal education (i.e., education in academic institutions), (b) existing cultural traditions highlighting the importance of conserving nature, (c) levels of interaction with the natural world that are fundamental for the acquisition of ecological knowledge through experience, and (d) exchange of knowledge between ethnic groups and systems used for storing knowledge.

Table 4-1. List of indicators by category

Category	Indicator
Knowledge and learning	a) Transmission of traditional knowledge b) Cultural traditions that promote conservation or harmonious interaction with the environment c) Physical interaction with nature d) Documentation and exchange of knowledge
Social equity and infrastructure	a) Autonomy b) Health c) Basic services d) Risk
Social structure and organization	a) Internal social organization b) Conflicts with other social groups c) Articulation with state institutions d) Planning

4.2.2 Social equity and infrastructure

The second analytical category refers to social equity and infrastructure. Social equity is an important condition for attaining the goals of sustainable development (Timmer & Juma 2005), for effective management and governance of common-pool resources (Ostrom et al., 2007), and for long-term resilience of social-ecological systems (Olsson et al., 2014).

Four characteristics measured for equity are: (a) Autonomy, that measures the level of independence that Indigenous peoples have to govern their land, the access to their ancestral territories, and the level of recognized autonomy by non-Indigenous social groups; (b) Health security, that measures how much access communities have to health services provided by the state, but also, the status of their traditional medicine including knowledge to practice the medicine and the access to medicinal plants; (c) Risk, that is subdivided into health risk, from exposure to pollution and harmful elements in the environment, and physical risk that measures both level of exposure to natural hazards (e.g., floods, droughts, slides), and how these communities are affected by social unrest, riots, and armed conflict between external parties (i.e., illegal armed groups and drug gangs); (d) Basic services that measures access to basic services, other than health and education (e.g., drink water, sewage system, and electricity).

4.2.3 Social structure and organization

The third analytical category is social structure and organization. This refers to the internal organization of Indigenous institutions. Social institutions are composed of the members of the community bestowed with special functions, and the norms and rules for the use of common-pool resources. Norms describe patterns of behavior accepted within a community, whereas rules not only define how the resources will be distributed, but also the mechanism used to implement these rules (e.g., surveillance and coercive methods), the ways to resolve conflicts for the use of resources, and penalties (Ostrom, 1990). Social structure and well-functioning social organizations improve the capacity of a social-ecological system to self-organize after disturbance (Carpenter et al., 2012).

The indicators used for this category help analyze four aspects: (a) organization capacity, that measures the structure of power within the Indigenous institutions, principles of organization, and the existence of rules and norms, (b) conflicts with other groups, an indicator that measures levels of aggression against Indigenous peoples as external conflicts can threaten members or the whole community depending on the level of aggression, (c) articulation with state institutions that helps assess the capacity of the leaders in communicating needs of the community and also to identify gaps, and (d) planning as a measure of the level of organization in terms of the capacity of the community to identify core areas for their future development, priorities, and potential solutions.

4.3 Indigenous peoples' Life Plans

> *A Life Plan is where we gather the projects and goals that we have as a unique Indigenous people. They show our knowledge and the group of ideas that we use to preserve our way of life. The goal of the Saliba people's Life Plan is to preserve our way of life, maintaining the cultural balance according to the way of understanding, expressing, and looking at the paths; this is the Saliba, it is the way of transmitting the knowledge through generations using our own vision of the world.*
>
> *Saliba people's Life Plan*

> *Life Plans have recently become a fundamental instrument for initiating a continuous process of reflection on the future of Indigenous peoples, who are culturally recognized as "different" and seek to live in their natural environment with their own identity and their particular form of seeing the world; which is far from the vision of most of the society*
>
> *U'Wa people's Life Plan – Chaparral Barronegro*

A Life Plan is the instrument of permanent transformation that pulls and organizes the community to reach quality levels and conditions of life, to transform practice into awareness (participation), consciousness into efficiency, (organization) and efficiency into autonomy (self-management)

World Bank

4.3.1 The origins

Life Plans are part of what Indigenous peoples are, they have always had Life Plans (Berkes et al. 2000, Blaser, 2004; Villegas-Arias, 2008) and they have always pursued them. Blaser mentioned that "it is in the white person's mind where Indigenous peoples seemed to be wild, without social structure or goals" (Blaser, 2004). Furthermore, western ideas and schemes of development have been imposed on Indigenous peoples for centuries, impacting their livelihoods and reducing their ancestral territories. Worldwide, between 1960's and 1970's, Indigenous organizations started to emerge, claiming their rights over their ancestral territories. During the following decades, these Indigenous organizations obtained support from environmental and human-rights organizations and gained important international recognition (Stevens, 2014; Susskind & Anguelovski, 2008). The shift in the predominant perception about Indigenous peoples' rights, has been one of the most important victories of the Indigenous peoples around the world (Stevens, 2014).

In the 1980's, Indigenous peoples, mostly in South America, started to present their Life Plans in documents, communicating to the state what their thoughts were about the development of their territories, opposing dominant ideas about development. In their Life Plans, Indigenous peoples talk about their own thoughts, their own ways of doing things, thinking, learning, their interpretations of the reality, and their ways of solving problems. During the 1980's Life Plans started to be partially accepted by the international community as alternative visions of the future (ONIC et al., 2000; Blaser, 2004). Currently, the initiative of these Life Plans is spreading around the world, sometimes with different names but always with the same purpose of protecting Indigenous peoples' ethnic identities and autonomy over their ancestral territories.

Life Plans have been used in different ways: as political instruments for claiming the state's recognition of their rights and autonomy (Espinosa, 2014; Saavedra, 2014; Cayon, 2012; Bolaños & Pancho, 2008), as an internal mechanism to improve self-governance (ONIC, 2014; Cayon, 2012), and as a form of communication with other state institutions (Cayon, 2012; Sobrevila, 2008). Through their Life Plans, Indigenous peoples accept the existence of other ways of thoughts and organization systems (Cayon, 2012; Caviedes, 2008), and they build forms of adaptation to predominant rules and logic.

4.3.2 Life Plan as an alternative to development

> *The word "development" has no place among our traditional concepts, it is Western: it simply does not exist…*
>
> *… We must understand that change and permanence are phenomena linked to the historical development of our culture. The "development" for us is to flow and remain in the territory, to grow and to transit in it, to come and go from the inside out and from the outside in, like the snail. Always following the footsteps of the grandparents that tells us where to go, in harmony with nature and the cosmos. Therefore, we cannot address the issue of economic development from the idea of linear progress, indefinite growth, or only as material growth, but from the character of an Indigenous people that insist on building their own history in their permanence and survival*
>
> *Misak people's Life Plan*

As a basin principle, Indigenous peoples' Life Plans conserve nature, this is part of their politics of resilience (Blaser, 2004). Indigenous peoples know that after a disturbance the ecosystem might not return to its pre-disturbance condition, which in turn will affect their livelihoods. Since the knowledge they have about these ecosystems is limited, they strive to protect their own ability to respond to changes in nature (Blaser, 2004). However, the reduction of their territories and degradation of the ecosystems impairs their capacity for maintaining the balance between their needs and the needs of nature. Therefore, the alternatives of development presented in the Life Plans reflect these interactions and show how Indigenous peoples have used the land to sustain the livelihoods, acknowledge the contradictions between their principles for conserving nature and their practices of production, how this affects their traditions, and also present their reflections about the best ways in which they can solve these dilemmas.

The World Bank has a policy to ensure that Indigenous peoples will not be affected by the execution of projects. It also has a policy for the Conservation of the Biodiversity in which Indigenous peoples play a central role (Sobrevila, 2008; Stevens, 1997). In the intersection between these two policies are found the Indigenous peoples' Life Plans. The World Bank has participated in different stages of the construction of multiple Indigenous peoples' Life Plans and has traced guidelines for the elaboration of these documents. The World Bank promotes Latin American governments' adoption of elements from the Life Plans as part of the governance and co-management of natural resources (Sobrevila, 2008), and suggests acknowledging the impact that governments' development projects might have on Indigenous peoples' livelihoods.

Paradoxically, groups like the World Bank play an important role in the construction of development plans with neoliberal agendas (Saavedra, 2014). The World Bank supports projects that have had a dramatic impact on Indigenous peoples (Finer, et al., 2008) and the environment (Park, 2010). With its participation in these projects, the World Bank promotes the adoption of development plans with a neoliberal agenda, that will always be against Indigenous peoples' life trajectories (Fast, 2012; Blaser, 2004). The Neoliberal model supported by the World Bank enforces the idea of sustainable development through capitalism, even though the capital accumulation deepens the differences between social groups. With its Indigenous peoples' Policy, the World Bank seeks to improve efficiency in the execution of its projects and protection of their investments as well as to safeguard the tights of Indigenous peoples.

4.3.3 Life Plans in Colombia

Understanding how Life Plans are used in Colombia requires understanding the struggles and victories of Colombian Indigenous peoples. In the decade of the 1960's, Indigenous peoples started to establish organizations that claimed their rights over ancestral territories. Collective action and decades of struggles helped Indigenous peoples to gain public recognition. The new constitution of 1991 finally acknowledged Indigenous peoples' political, social, cultural, and territorial rights, and recognized Indigenous reserves (also called '*resguardos*') as Indigenous collective territories. Each of these territories is then recognized as Indigenous Territorial Entities that are governed by Indigenous peoples' authorities. These Indigenous Territorial Entities are autonomous in defining their own governance and use natural resources, and they receive economic resources from the state for the execution of their plans and projects.

The creation of Indigenous Territorial Entities also represented a challenge for Indigenous peoples, whose territories are fragmented and disarticulated from other territorial entities. To improve their capacities, Indigenous Territorial Entities subsequently started to work in collective organizations (Associations of Traditional Indigenous Authorities and 'cabildos') to improve their governing mechanisms (Rivera and Gomez, 2006). Individually or collectively, Indigenous Territorial Entities have been able to use the resources assigned to them in projects for the development of their territories using their Life Plans to guide their goals.

Despite the victories attained by Indigenous peoples in Colombia, there are several challenges such as the lack of legal instruments (statutory or common laws) that define Indigenous Territorial Entities' functions, rights, and responsibilities (Baena, 2015), difficulties in the communication within and between Indigenous Territorial Entities (Rivera & Gomez, 2006), and communication issues between Indigenous authorities and other state authorities (Cayon, 2012; Rivera & Gomez, 2006).

State representatives conceive Indigenous Territorial Entities as a way of articulating Indigenous peoples to civil society and to the state, consequently they impose their ideas about governing systems and future development of the territory (Cayon, 2012). Conversely, Indigenous peoples are constantly fighting to maintain their autonomy and cultural traditions (Cayon, 2012). They do not want to follow imposed development plans, they instead want to use their ancestral Life Plans that are based on their own perceptions and identities (ONIC et al., 2000). These radically different approaches to the principles that guide the governance of the territory are major hurdles to communication between these two actors. Without legal instruments that define the Indigenous Territorial Entities, state agents will continue assuming that Indigenous territories are under the same scheme of development as the rest of the territory (Cayon, 2012), compromising Indigenous peoples' autonomy (Baena, 2015).

In this context, Indigenous peoples' Life Plans have an important function in protecting Indigenous peoples' ethnic and cultural integrity. According to the ONIC, the Indigenous National Organization of Colombia, Life Plans are meant to be tools for protecting their future development as ethnic groups with distinctive cultural features (ONIC et al., 2000). On the other hand, state agencies recognize these plans as "… an important instrument that helps to materialize Indigenous peoples' autonomy while improving the dialog between Indigenous communities and state institutions" (Programa Presidencial Indígena, 2013).

Life Plans have begun to be incorporated in planning documents to improve communication with other social institutions and governments; however, there are two challenges to overcome with these plans: first, the intermediaries interpret Indigenous thoughts in a way that will support others' interests and which eventually will favor government policies and external projects, and second, communities specify what their needs are but can't articulate these needs in other institutions' plans and projects (Villegas-Arias, 2008).

4.4 Methods

4.4.1 Study area

The Orinoco River Watershed (ORW) is shared by Colombia and Venezuela; this research focuses on the Colombian portion of the watershed. The Colombian portion of ORW is subdivided into five Departments (Arauca, Meta, Casanare, Vichada, and Guaviare) and two main biomes: Savanna and Rainforest; the transition between these two is known as the Orinoco-Amazonas transition. Figure 4-1 shows the location of the Indigenous reserves included in this study.

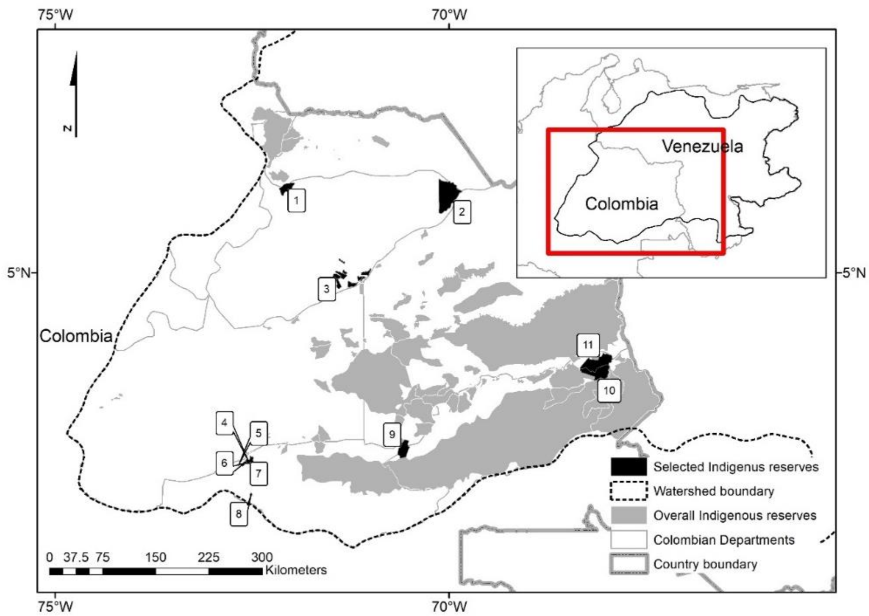


Figure 4-1. Indigenous reserves in the Colombian portion of the Orinoco River Watershed.
The numbers indicate the Indigenous reserves included in this study (Table 4-2)

Indigenous peoples' Life Plans were obtained through the Colombian Indigenous Information System (SIIC in Spanish). Even though the Indigenous reserves reported in the Ministry of Interior of Colombia for this watershed are 25, only 11 Life Plans are available through the SIIC (Table 4-2).

Predominant savanna ecosystems are found in Casanare with forests towards the west along the piedmont. Indigenous reserves in the savannas are dominated by sandy and poor soils. There, the ecosystems are heavily degraded by and the landscape is fragmented, creating islands of strategic ecosystems that are rapidly disappearing.

Table 4-2. Indigenous reserves included in this research.

Department	ID	Reserve	Ethnic groups
Casanare	1	Médano, Macucuana, Saladillo, Paravare, San Juanito, El Concejo, El Duya y El Suspiro	Saliba
	2	Chaparral - Barronegro	U'Wa
	3	Caño Mochuelo	Saliba
Guaviare	4	Barrancon	Guayabero
	5	La Asunción	Tucano
	6	Corocoro	Curripaco, Cubeo, Puinave
	7	El Refugio	Siriano, Piratapuyo, Nukak, Yuruti, Desano
	8	La Fuga	Tucano, Guayabero, Desano, Piratapuyo, Guanano, Carapana, Cubeo
	9	La Maria	Guayabero
Guainia	10	Caranacoa – Yuri - Laguna Morocoto	Puinave
	11	Paujil	Puinave

Source: SIIC, 2016

In the piedmont, reserves count with nutrient-rich soils that are highly productive and their ecosystems are predominantly forested. The combination of forest and hilly topography provides niches for a diverse number of species; however, deforestation is impacting these ecosystems. Wildlife in both savanna and forest has been reduced, impacting Indigenous peoples' ways of livings and traditions.

Indigenous reserves in Guaviare are in the Orinoco-Amazonas transition (between the savanna and the rainforest). There, soils are poor in nutrients, flooded in the alluvial plains, well drained in the high flatlands, and highly erodible, characteristic that is being exacerbated by the loss of forest. Forested ecosystems in Guaviare are rapidly transitioning into savannas, causing the loss of biodiversity; however, in more isolated areas of the Department, Indigenous reserves still count with large fish and wildlife populations. In Guainia, Indigenous reserves are located next to the river, surrounded by rainforest, and their soils are acid and poor in nutrients. Biodiversity is being affected by deforestation, in the case of remote areas, and by the combination of deforestation and large demand for resources in the case of Indigenous reserves closer to the urban area.

Economic activities within Indigenous reserves in Casanare are based on agriculture and ranching, and some have domesticated minor species. Prevailing economic activities for the reserves in Guaviare are domestication of animals, there is relatively little agriculture due to the poor quality of the soil. The soils in the Transitional region into the rainforest and in the rainforest, are acid and poor in nutrients. Indigenous peoples in Guaviare and Casanare compete intensively with non-Indigenous communities for fish and bushmeat. The Indigenous people in Guanía are hunters and gatherers, and they also grow manioc and occasionally participate in the extraction of resources such as gold and ornamental fish.

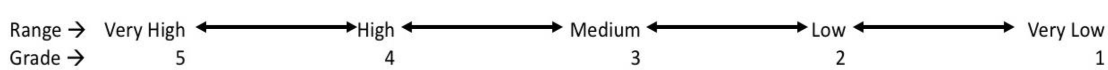
Levels of isolation also vary between Departments. Indigenous reserves in Casanare have access to roads that connect them to near villages and some use the river for transportation. Mobilization times to the closest village are between one and two hours, and public transportation is available; although some must walk an hour to the main road. Indigenous reserves in Guaviare has similar conditions, they are next to or within a short distance to the capital, and they also have access to public transportation. Studied Indigenous reserves in Guainia are in remote areas where communication is only possible by boat. Some Indigenous communities have their own boats and engines, but the cost of gas is high and public transportation is infrequent.

4.4.2 Social resilience indicators

Three main categories of analysis are used for the measurement of social resilience through the selected Life Plans: (1) Knowledge and learning, (2) Social equity and infrastructure, (3) Social structure and organization. For each of these categories, four resilience indicators were used for a total of twelve indicators (Table 4-3).

These indicators are adapted from: (a) resilience indicators used to measure socio-ecological production in landscapes (Bergamini et al., 2013), and (b) the list of attributes that confer general resilience in social-ecological systems presented by Carpenter and collaborators in 2012. Grades for each indicator are presented in Appendix B.

Factors affecting the results are presented by analytical category and each indicator was assigned a rank based on the following ranges:



4.5 Results

The results show large variation between Indigenous reserves (Figure 4-2), with an average value of 3.3. This can be interpreted as a medium-low capacity to cope with transformations in the system. Table 4-4 shows the results for each of the twelve indicators used in this study.

Table 4-3. Resilience indicators used in this research by category of analysis.
In parenthesis are the codes used for the analysis

Category	Resilience indicator	Evaluation criteria
Knowledge and learning (KN)	Transmission of traditional knowledge (T)	Number of generations involved Formal and informal mechanisms of transmission Language in which the knowledge is transmitted Cultural background of the teachers that teach at the schools
	Cultural traditions that promote conservation or harmonious interaction with the environment (C)	Existing activities related to nature Specific ceremonies that celebrate nature Use of symbols to represent the material world through natural elements
	Physical interaction with nature (I)	Number of generations involved Level of interaction
	Documentation and exchange of knowledge (D)	Documents communicating traditional knowledge Exchange of knowledge with other Indigenous communities
Social equity and infrastructure (EQ)	Autonomy (A)	Level of autonomy in relation to land and resource management
	Health (H)	Access to health care provided by the state Use and propagation of medicinal plants Use of traditional medicine and protection of the knowledge
	Basic services (S)	Coverage of basic services other than health and education Quality of the services
	Risk (R)	Health risk due to malnutrition or pollution Physical risk due to social unrest, violence, or natural hazards
Social structure and organization (SO)	Internal social organization (O)	Level of internal organization Existence of well-defined social organization with clear roles
	Conflicts with other social groups (L)	Level of conflict
	Articulation with state institutions (A)	Level of interaction with national and regional state actors and policies
	Planning (P)	Clarity in the formulation of the projects contained in the Life Plan

Source: Adapted from Bergamini et al., 2013 and Carpenter et al., 2012.

Table 4-4. Average grade by indicator

Code	Indicator	Grade	Range
SS_O	Internal social organization	4.5	high – very high
KN_T	Transmission of traditional knowledge	3.8	medium – high
KN_I	Physical interaction with nature	3.8	medium – high
EQ_A	Autonomy	3.8	medium – high
SS_P	Planning	3.8	medium – high
EQ_R	Risk	3.5	medium – high
SS_C	Conflicts with other social groups	3.3	medium – low
SS_A	Articulation with state institutions	3.3	medium – low
KN_C	Cultural traditions that promote conservation	3.3	medium – low
EQ_H	Health security	3.0	medium
EQ_B	Basic services	2.6	low – medium
KN_D	Documentation and exchange of knowledge	2.3	low – very low

4.5.1 Knowledge and learning

The best results were obtained for transmission of traditional knowledge and physical interaction with nature, the lowest for cultural traditions that promote conservation or harmonious interaction for the protection of the environment and cultural documentation and exchange of knowledge.

4.5.1.1 Transmission of traditional knowledge

All Life Plans mention that for Indigenous peoples the process of learning takes place throughout their lives and it involves children, young people, adults (women and men), and elders. Life Plans explain how the responsibility of educating their children relies on the entire community and how specific aspects of their cultural lives, like values and behavioral clues, are taught directly by parents or elders.

Regarding the formal mechanisms of education, most of the communities have access to schools, but the school facilities often are poor with low availability of books and teaching materials, furniture, and other equipment.

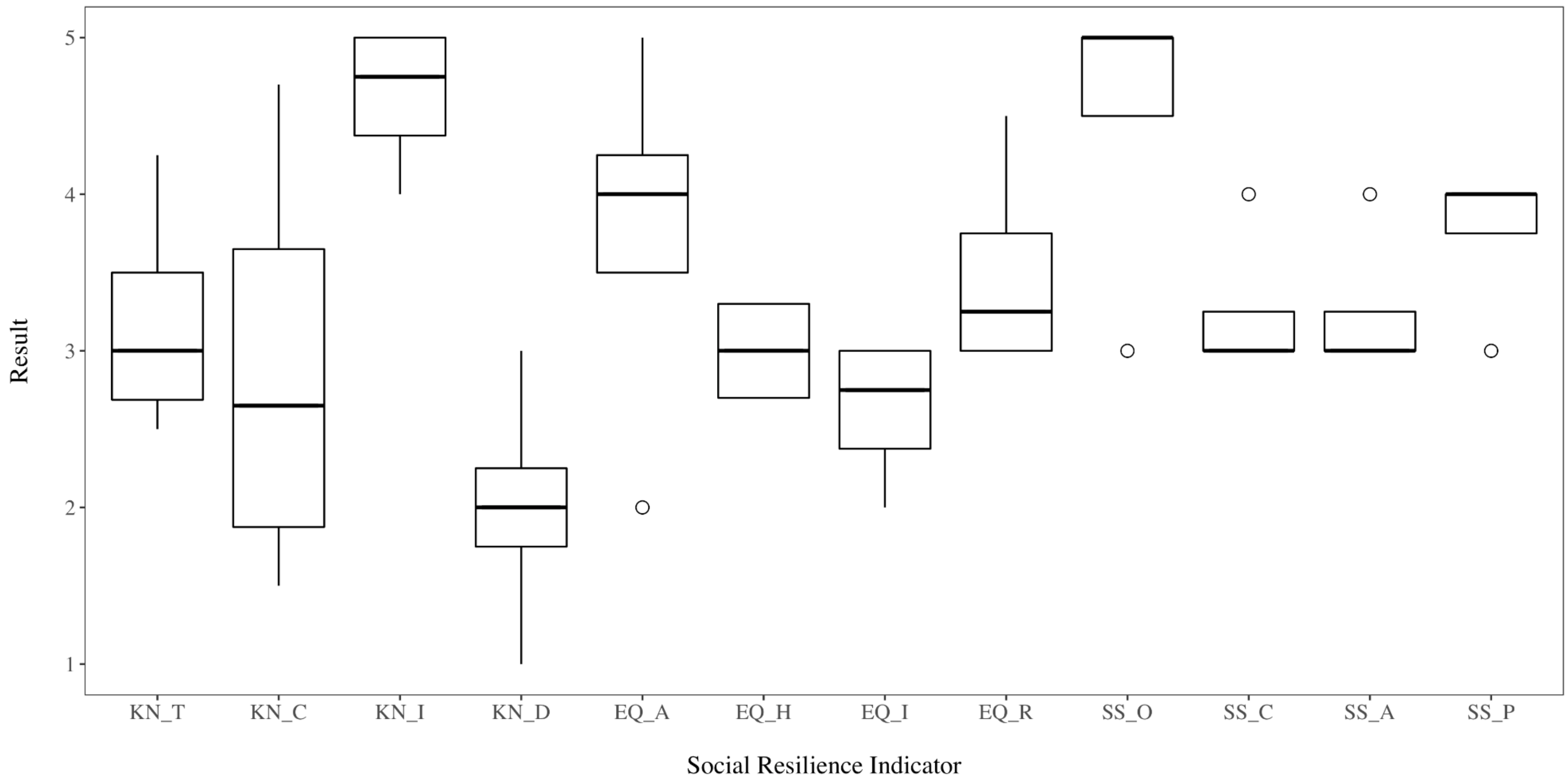


Figure 4-2. Variation within indicators.
Codes are presented in Table 4-4.

Very often, the teachers hired by the state to teach in Indigenous communities are non-Indigenous, they do not have cultural knowledge, and sometimes they disregard Indigenous peoples' culture and traditions (Villegas-Arias, 2008). Some schools have Indigenous teachers, but rarely do they belong to the same community. Most of the Indigenous peoples show concern for the loss of their language in their Life Plans. Children do not receive bilingual education in the school, because teachers either speak only in Spanish or in an Indigenous language different from their own.

4.5.1.2 Cultural traditions that promote conservation

Not all Life Plans present extensive descriptions of cultural traditions, and those that include it do not focus on specific practices of conservation but mostly on harmonious interaction with the environment; which often result in environmental conservation. These descriptions attempt to show the intimate links between Indigenous peoples and nature through myths and anecdotes of their daily lives.

4.5.1.3 Physical interaction with nature

Most Life Plans show how all members of their communities participate in practices that require interaction with the natural environment, and how this involves multiple generations. For instance, parents and children go out of the reserves to explore the region looking for food, often have more interaction with nature than those who stay in the reserve to grow food and raise domestic animals. Young adults, adults, and elders also interact and explore the territory when looking for medicinal plants.

Another factor that influences the level of interaction with nature is the health of the ecosystems. Without well-preserved ecosystems, it is very difficult for the members of the community to have an interaction with the natural elements in the region, mostly because they must travel long distances to encounter healthy ecosystems that can provide the resources they need. But this requires the investment of resources of the community, therefore, residents of Indigenous reserves in very transformed environments opt to look for local jobs or alternative sources to sustain their livelihoods.

4.5.1.4 Documentation and exchange of knowledge

Some Indigenous reserves have started to document their knowledge through poems and written myths. The Life Plan itself constitutes a document that contains important aspects of their traditional knowledge. However, Indigenous institutions have not created a system of knowledge documentation. Regarding the exchange of knowledge, there are Indigenous peoples that interact and cooperate regionally. Occasionally, there is some cultural exchange.

4.5.2 Social equity and infrastructure

For this category, the indicator with the higher rank was Autonomy, followed by Risk. Health services and Basic services were the lowest in this category.

4.5.2.1 Autonomy

Even though Indigenous peoples have autonomy to govern their territories, Life Plans show how they do not have full access to their ancestral territories and sacred places. Also, they mention that some non-Indigenous groups do not recognize the rights that Indigenous peoples have over their reserves. Occasionally, Indigenous peoples report outsiders entering their territories without previous authorization or even consultation, or invasion of portions of their territories that are used for building infrastructure (e.g., roads and military facilities) without their consent. This exemplifies how Indigenous peoples' autonomy is being compromised.

4.5.2.2 Health security

The availability of health services provided by the state is low in almost all communities. Some Indigenous reserves have health facilities, but these are out of service most of the year. Depending on the reserve, every six months or every year, the community is visited by a health commission sent by the state to evaluate the health conditions of the members of the community. Members of the community travel to the closest health attention center, but in some cases, it is too far from the reserve. Traditional medicine is also used, but it is in rapid decline due to the loss of traditional knowledge, that relies on medicinal plants and in the transmission of knowledge. The traditional doctor or *paye* not always finds someone to teach this knowledge. They are also losing the medicinal plants with the transformation of the ecosystems.

4.5.2.3 Basic services

Basic services in Indigenous reserves are not fully covered. Most of them have issues related to sanitation and housing. In their Life Plans, Indigenous peoples refer to the need for better infrastructure, especially in those Indigenous reserves with longest settlement history. For instance, Saliba and U'wa peoples have been living in these lands for almost a century, they have adopted sedentary lifestyles and yet, their infrastructure is not adequate for sustaining their new needs. They do not have floors in their houses and other facilities inside their reserves have structural problems. On the other hand, the main concern for Puinave people (semi-nomadic group) is the lack of potable water for their communities.

4.5.2.4 Risk

None of the Indigenous reserves have sanitary systems or organized trash systems, increasing the risk of contracting water-borne and vector-borne diseases. Other predominant factors that increase health risk are malnutrition, diarrhea, exposure to polluted water, and exposure to mercury poisoning through fish consumption. Physical risk is mostly due to armed conflict, but there are also some communities which are exposed to floods and bank erosion.

4.5.3 Social structure and organization

In this category, the internal social organization indicator had the highest rank, and it is the highest among all indicators. Conflict with other social groups, articulation with state institutions, and planning have medium to low ranks.

4.5.3.1 Internal social organization

With only a few exceptions, Indigenous peoples show a clear structure in their internal organization. Their internal rules are fully defined, they are adopted by the entire community, and officers are regularly elected for enforcing these rules; these officers are also in charge of making decisions and of representing the community with external actors.

4.5.3.2 Conflicts with other social groups

The most common cause of conflicts is external cultural influences, that cause loss of their language, alcoholism, and cultural erosion, and contribute to the decrease of the youth population through migration. Another very important source of conflict is the competition for natural resources. Life Plans mention reduction of natural resources for overexploitation and deforestation. Also, there were cases of intense competition for fish resources that led to fishing prohibitions imposed by non-Indigenous, and sporadic violent attacks on members of the community. Less frequently, there have been recent events of violent expulsion from their original territories and assassination of Indigenous leaders.

4.5.3.3 Articulation with state institutions

Most of the Life Plans do not represent very well the level of interaction with state institutions. A few of them mention that their interaction with the state institutions is frustrating and that the employees in the federal agencies are not efficient in processing their claims. Other Life Plans do not say anything about their interaction with the state.

4.5.3.4 Planning

All Life Plans define their main lines of action, some just mentioned actions that they thought could be useful for advancing towards specific goals, and only a few developed a full plan with projects, activities, sources of financial support, and set time goals.

4.6 Analysis of the variation found between Life Plans

Common aspects found in the analysis of the Life Plans were that all Indigenous peoples' trajectories are intertwined with the territory and they all see it as the place where their heritage persists. Indigenous peoples in all Life Plans constantly go back to the territory as a guide for the future of their communities, and because of this their plans and projects are always emphatic about recovering their ancestral territories and their traditions, protecting their current territory and all the natural elements it contains, protecting their identities, increasing their autonomy (particularly regarding food security and traditional medicine) and improving their Indigenous institutions.

On the other hand, differences between Life Plans are derived from the different priorities that the various Indigenous peoples assign to their needs, which at the same time related to the geographical contexts where their Indigenous reserves are located. Some Life Plans focus more on Indigenous peoples' myths and life-trajectories, others on current interactions within the community and with their environment, or on their economy and political organization. These differences make it difficult evaluate certain social resilience indicators. Nonetheless, Life Plans contain rich information about Indigenous peoples' visions that are important for addressing the issue about how to harmonize these peoples' ideas with western ideas of development.

4.6.1 Knowledge and learning, and the influence of the context

All Life Plans mention that they have lost several traditions, particularly regarding ecological knowledge. Yet, some Life Plans are better at describing their traditional knowledge, ceremonies, and nature representation. U'wa people's Life Plans talk about rescuing their myths and traditions but they do not include descriptions of their symbolic representation of the natural world, other than the meaning of oil (petroleum) in their culture, and they are very emphatic about the impact of that oil extraction. They conceive oil as the earth's blood and that when it is extracted many natural dynamics are impacted.

The Saliba people include ample description of their interactions with their territory in their Life Plan. They believe that with the creation of the world, a territory was assigned to each people. Also, they think that there is an equilibrium between their culture with nature, and because of this, the loss of their culture threatens the balance in their territory. Their cultural identity is contained in their territory and in all its elements, and because of this their knowledge and traditions are fundamental for maintaining the natural equilibrium. They believe that sorrow and sickness arise with misbehavior. For the Saliba people, human conflict has its origins in social misbehavior with nature.

Puinave people use natural elements for describing and explaining their social organization and gender roles. Also, their myths explain that music and cooked food are two important elements for human evolution from a monkey (or from the animal world) into humans, and how those who break the rules are isolated and are not allowed to learn their musical traditions or participate in ceremonies. Under the Puinave culture, ancestral tradition is what makes humans different from animals, and by losing their traditions they will stop existing as humans and will go back to their animal form.

Tucano people believe that by learning from nature they are endowed with an special kind of understanding that defines their identities and makes them different from other ethnic groups. This is explained in detail through mythological narratives of their origins in their Life Plan. Except for the Tucano people, the Guayabero people and the various ethnic groups within the Indigenous reserve in the Guaviare did not explore their links with nature in detail, they only mentioned how important animals and plants were for their ancestors.

When comparing the Life Plans in the Guaviare to Life Plans in other locations, there is a noticeable lack of symbolic or cultural references about their forms of perceiving nature in the Guaviare region. The way in which the Life Plans were elaborated could explain this. All Life Plans in the Guaviare are very similar. They have the same content and only vary in certain portions of the document where Indigenous leaders' explanations are inserted and in the projects' formulation. It seems likely that these Life Plans were elaborated by a third party that assisted these Indigenous peoples. This way, it is probable that Indigenous peoples could not decide themselves what was going to be included in their Life Plans and therefore what is included in the document is only a small part of these Indigenous peoples' identities.

Despite the influence that western mediators have on the construction of the Life Plans, it was found that many Indigenous peoples, especially those in the Guaviare Department, are undergoing a process of cultural erosion, where their knowledge and ancestral rituals have been lost or transformed. This is related to the level of interaction that different Indigenous peoples have with their ancestral territories. For instance, the Puinave people's access to their territory (Guainia) is still unrestricted because they can access open-source areas (lakes, rivers, sacred mountains) without fearing of being expulsed. By contrast, the U'wa and Saliba peoples (Casanare) have limited access to these areas due to the competition with other local communities and the large concentration of private properties around their Indigenous reserves. These external factors could explain also why Indigenous peoples in the Casanare refer to their links with nature in past tense but the Puinave people in Guainia have more vivid descriptions, and why Indigenous peoples in Guaviare barely mentioned the interactions that their ancestors used to have with nature.

Internal and external social interaction and levels of social organization within the Indigenous reserves can also affect how much of the Indigenous peoples' cultural features are expressed in the Life Plans. The Saliba people's Life Plan includes eight different Indigenous reserves with an overall population of roughly 1,500 habitants, and yet they convey a clear explanation of their symbolic representation of the world in their Life Plan. In contrast, La Maria Indigenous reserve, composed of a population of 30 individuals of the Guayabero ethnic group, do not include many details about their cultural identities in their Life Plan.

Because the Saliba people have a much longer tradition of interaction with non-Indigenous people and with the government (since the 1920's) they have learned how to communicate their ideas, also they count with an Indigenous association that represents them in their interaction with governmental entities. But the Guayabero people in the La Maria and Barrancon Indigenous reserves, have a much recent history of settlement (since 1960's), their interaction with the government is infrequent, few of them speak Spanish, and due to the constant influx of new families to their Indigenous reserves their internal structure is weakening.

These comparisons show how internal and external factors can change the way Indigenous peoples communicate their thoughts and ideas through their Life Plans, and they explain why knowledge and learning is one of the categories with the largest variability.

4.6.2 Social equity and the discussion about autonomy

Equity in this research is analyzed through measurements of autonomy, health, other basic services, and risks. In their Life Plans, Indigenous peoples mix these four aspects using expressions such as "food autonomy" or "service autonomy", however, these expressions can be interpreted as them wanting to be self-sufficient in their economies, so they will not depend entirely on external assistance. This way, it was found that the concept of autonomy for Indigenous peoples is mixed with other factors that confer social equity. Autonomy relates to internal organization and formulation of rules for controlling social behavior, also known as social institutions, that are created by a group to make decisions about its territory.

For many of the Indigenous peoples involved in this research, autonomy refers to the capacity to produce their own food, for others it relates to the level of respect that other groups show for their cultural values and for their territories, it could also mean having better Indigenous leaders that will represent their communities in front of the government, or having the freedom to decide what to do with the money they get through financial transferences from the central government.

Differences in the levels of emphasis on autonomy between Life Plans could be explained by differences in the configuration of the territory (i.e., the combination of biophysical factors and urban development). For instance, Indigenous reserves closer to urban areas will identify invasion of their territories as the main threat to their autonomy but those in isolated areas often mention that deficient provision of basic services is the main challenge for maintaining their autonomy. Resource availability was also found to be important because most of the Life Plans mention that their “food autonomy” is a major issue, while only those Indigenous reserves in Guainia (the portion of the watershed covered by rainforest) have a different approach (even though the Indigenous peoples in Guainia also have malnutrition issues they do not relate this to their autonomy but to their security).

The Puinave people in Guainia discuss the problem of autonomy as a statutory issue that needs to be solved through the creation of administrative, judicial, and territorial tools to be able to govern their territories. Despite these differences, the programs and projects that focus on the improvement of Indigenous autonomy are similar in all Life Plans, and they all emphasize improving their knowledge about their Indigenous rights and other aspects that contribute to the formation of Indigenous leaders.

Lack of basic services is also considered in some Life Plans as a threat to their autonomy, however, this is more closely related to human rights' violation (Mehrotra et al., 2000). Importantly, those Life Plans that identified this as an autonomy issue also mentioned that the lack of resources for being self-sufficient in the acquisition of some of these services is another aspect affecting their autonomy. Access to financial resources for the execution of the projects that they have formulated through their Life Plans, is indeed fundamental for fostering their autonomy, however, it is the government's responsibility to provide fundamental services.

4.6.3 Social structure and organization, and the consolidation of the Indigenous communities

The structural organizations also vary between Life Plans. This is one aspect that is mostly influenced by internal dynamics and social cohesion. All Indigenous reserves have a person called "Capitan" who represents the community in front of the governmental agencies, but sometimes he or she has little power within the Indigenous reserve. In other cases, the Capitan oversees internal order, among others, it is "El Alguacil" (sheriff). In most cases, the supreme authority is "El Cabildo" which is the group of leaders that discuss and propose norms and rules within the community, and that gather all members for voting on fundamental decisions. Elders and traditional doctors are highly respected within Indigenous communities, and they are often consulted for solving issues.

Some Indigenous institutions are better structured than others. They have a clear and detailed regulatory system and they are well organized ensuring its enforcement. There are some other cases with authority issues, especially in those communities with constant migration where trust between families is compromised by internal dynamics and competition for resources. Almost all Life Plans mention how interpersonal relationships are affected by behavioral changes, the increment in the consumption of alcohol, and by the interaction with the western culture, but they also talk about how conflicts within the Indigenous reserve do not escalate and how they are usually solved through dialog or minor reprimands.

Independently of the level of internal organization, all Indigenous peoples develop detailed plans for the improvement of their Indigenous institutions and they constantly acknowledge the importance of having strong leaders with deep knowledge of the national law and about their rights. Some of them highlight the importance of interacting with other Indigenous communities to learn from their experiences and to form strategic alliances.

Interestingly, there is almost no description about Indigenous peoples' interaction with government agencies in the Life Plans. Only a few of them talk about how these interactions take place in an environment of inequity and disrespect, and how difficult is communicating with the state.

4.7 Indigenous peoples' vision of development

Different Indigenous peoples have different ideas about the future development of their territories. Even within a single community, there is variation in their ways of thinking and behaviors. It cannot be assumed that all Indigenous peoples promote and practice forms of production that are environmentally friendly or that they all have the same sense of collective action. Nowadays Indigenous peoples also struggle to find balance in their interaction with nature. Despite this, Indigenous peoples' fate is more deeply intertwined with the products and dynamics of the surrounding ecosystems than any non-Indigenous community in the ORW. In their Life Plans, Indigenous peoples not only present their plans and future projects for the development of their territories, but they present an alternative development future.

When comparing Indigenous peoples' Life Plans with the National Development Plans, fundamental differences are found in the underlying principles that drive and inspire each of these plans. Life Plans are inherently articulated to Indigenous peoples' relationship with the environment since they believe that their ancestral connection with the territory guides their path. On the other hand, Nation's Development Plans are aligned with economic interests and market-driven dynamics. This implies that the priorities for future development of the region are not the same. Indigenous peoples do not consider the economic growth as a guiding principle for the development of the territory, while governmental institutions do not have the protection of socio-ecological interactions as the most important criteria when formulating development projects. They both, however, recognize the importance of these two elements and they have them fully developed within their plans.

Regarding the protection of the environment, it was found that both Life Plans and Nation's Development Plans acknowledge current environmental issues and needs for adopting better environmental management strategies and regulations, but they have different goals. Life Plans' goals are the maintenance of a territory capable of sustaining their livelihoods, the protection of their identities and their heritage by reestablishing traditional practices linked to the environment, and the improvement of their autonomy by expanding their Indigenous reserves to include traditional territory with abundant natural resources. The main goal in Nation's Development Plans is sustainable development. Here, regulations are employed to restrict the use of natural resources for protecting ecosystems and regional dynamics that support ecosystem services for large groups of people; who not necessarily live and experience the territory and therefore do not know the territory like local people do. Besides this, Nation's Development Plans are rarely successful in incorporating local communities' needs, traditions, and cultural dynamics to the development projects.

Indigenous peoples build their Life Plans collectively, and they use their knowledge of the territory and their empirical knowledge for prioritizing and deciding what projects and activities should be developed in their reserves. On the contrary, decisions about the management of natural resources in Nation's Development plans are based on political agendas, legislative frameworks, and scientific knowledge.

One last fundamental difference is that Life Plans in the ORW conceive the resources in the region as necessary elements for achieving their goals of future development and many of them disagree with development projects that involve industrial extraction of resources, such as petroleum and gold. Contrarily, the Nation's

Development Plans has the expansion of extractive industries among the priority mechanisms for the growth of the national economy.

4.8 Cases of articulation between Indigenous peoples' vision of the future and the governmental vision

Most cases of articulation between Indigenous peoples and governments take place around the conservation of important species and strategic ecosystems through protected areas. The Yaigoje Apaporis Indigenous reserve in the Colombian Amazon is one of the cases in which Indigenous peoples from seven different ethnic groups, the GAIA foundation, and the Special Management Unit for the National Parks System of Colombia (UAESPNN) worked together for the creation of a national park within the Indigenous reserve.

Concerned by the threat of gold mining in their territory, Indigenous peoples filed a petition in 2007 for the inclusion of the Yaigoje Apaporis Indigenous reserve in the Colombian system of national parks, however, right after the UAESPNN enacted the resolution of creation of the park, a Canadian company obtained the mining permit for extracting gold from the Indigenous territories.

While the Indigenous reserve remained protected by the national park status, this company could not explore resources. In 2008, however, influenced by the mining company, one member of one of the Indigenous communities sued UAESPNN's resolution arguing that the petition that asked for the creation of the park was not legitimate and therefore the legal status of a national park could not protect the Yaigoje Apaporis Indigenous reserve. In 2015, after more than five years of legal contests, the

Colombian Court confirmed the creation of the park and declared illegal the execution of mining activities (Rhoades, 2015).

The management of the Yaigoje Apaporis National is now shared by the Yaigojé Apaporis Indigenous Captains Association and the UAESPNN. Their own Life Plan and ideas of development guide actions toward the conservation of their traditions and they maintain their autonomy (von Hildebrand, 2017). The Life Plan is articulated with the UAESPNN's goals of conservation of the biodiversity (Minambiente, 2009) and the GAIA foundation supports Indigenous peoples in developing endogenous research for the formulation of management guidelines (von Hildebrand, 2017). Even though other national parks in Colombia follow a co-management regime (Uribe, 2005), this is the first time that a coalition between Indigenous institutions, government, and a non-governmental organization, has been able to prevent the incursion of a mining company into a region with large biodiversity and exceptional cultural values (Rhoades, 2015).

Another case is Pilon Lajas Biosphere Reserve in Bolivia. Decades of conflict for the use of the resources within the Biosphere have resulted in one of the most emblematic cases of local sustainable development solutions in South America (UNDP, 2012), and it illustrates another example about how the integration of Indigenous institutions and governmental institutions through the Life Plans can be possible.

The Biosphere was created in 1992, and since then, state, and Indigenous peoples' institutions have had the opportunity to know each other and to build trust. The Tsimané Mosetene Regional Council (CRTM) is the Indigenous organization that represents Indigenous peoples from four ethnic groups living in the biosphere, and its administrative structure has been improving through time thanks to the experience gained by its leaders in their interaction with the state. Since 2003, the National Service of Protected Areas of Bolivia (SERNAP) and the CRTM co-manage Pilon Lajas (UNDP, 2012; Bottazzi, 2009).

Intense logging activities extracted fine wood from this region between 1970 and mid-2000s. During this time, settlers arrived from all around the country and this created specific socioeconomic dynamics that caused profound impacts on the Indigenous peoples' traditions, therefore, one of the main goals for the CRTM in the management of the Biosphere has been to recover and protect Indigenous peoples' traditional knowledge.

Derived from these historic interactions with the extractive sector, Indigenous peoples learned how to commercialize wood, and this became a source of conflict with both local communities and the state, but they also learned from these past experiences about how to adapt to new conditions and how to negotiate with the state using innovative solutions (UNDP, 2012; Bottazzi, 2009). CRTM has negotiated with SERNAP the adoption of endogenous ideas of development inside the Biosphere, including productive practices with minimum impact on the ecosystems (UNDP, 2012).

CRTM's work has prevented and reversed several disturbing factors (e.g., illegal logging and hunting activities, reverse of a major timber concession, and the construction of roads). However, there are many ongoing threats, including the construction of the Bala dam and megaprojects for building roads across their territory (UNDP, 2012). These projects will affect not only Indigenous peoples' livelihoods but will cause the complete transformation of strategic ecosystems at the heart of the Amazon (Lavaud, 2016).

CRTM, in articulation with other Bolivian Indigenous organizations, actively denounce these projects, attracting international attention over these issues.

Indigenous peoples' victories in Pilon Lajas have been very important for the protection of an area that provides water to 8,000 people in Bolivia (UNDP, 2012), and with their participation as one element within the national system of governance, they started to advance towards the inclusion of Indigenous ideas in the national policies. Furthermore, the experience obtained by Indigenous peoples in Pilon Lajas is being replicated in other parts of the country (UNDP, 2012).

Protected areas and Indigenous territories have resulted also in the imposition of the state's ideas, as in the case of the Condor Park in Ecuador. This protected area was created with the support of the Binational Fund for the Peace and the Development, the International Tropical Timber Organization, and Conservation International with the goal of conserving the biodiversity, reducing poverty, and empowering the Indigenous peoples living in the area (Global Transboundary Conservation Network).

The process of creation of the Condor Park took over two years, during which the Ecuadorian Environmental Ministry and the Natura Foundation (an NGO present in different South American countries), consulted local communities and together defined management regimes and future management zones within the park. From the negotiations between the state and the Shuar people the Shuar territorial government was created with co-management purposes. In public meetings, the governmental institutions manifested their support for the Indigenous governance of the territory, and furthermore, the Park's management plan was elaborated jointly with the Shuar people and other local communities, and it included management zones with different use regimes in harmony with the traditional practices described in the Shuar Life Plan (Saavedra, 2014).

These negotiations demanded long meetings and arduous discussions, but once the management plan was finished and the resolution for the creation of the Park was ready, the government in 2007 unilaterally decided to exclude from the park 40% of the area. These areas corresponded to the zones where the traditional productive practices were allowed (Saavedra, 2014). Thanks to this decision, mining companies no longer had impediments to advance with their projects. Mining projects have intensified since 1994 and this has had tremendous impacts on Indigenous peoples' lives (Shuar Arutam People, 2017).

From the review of these and other cases, it is possible to conclude that the articulation of Indigenous peoples' Life Plans in the national policies and development plans, has at least five common main characteristics: (1) It is driven by a conflict about how to use natural resources, (2) Involves the participation of external actors that facilitate the communication between Indigenous peoples and government institutions (e.g., the GAIA foundation in the case of Yaigoje Apaporis, and multiple transnational organizations in the other two cases), (3) Strong Indigenous organizations are present in the process, (4) The Indigenous peoples execute actions that confirm their autonomy, and (5) Results in legally binding agreements. The last two characteristics were only found in the two first cases.

In the Yaigoje Apaporis Indigenous reserve, the future mining projects threatened the survival of multiple Indigenous peoples, and it was also a threat to UAESPNN's projects of conservation; this is the main resource-use conflict in this case. In Pilon Lajas and Condor Park, the conflict consisted in the imposition of rules for the use of natural resources that were against the Indigenous needs, this created resistance and discomfort among Indigenous peoples and affected the state's governability. In both cases threats from future mining projects and concerns about the governance of natural resources catalyzed the dialog and articulation of actors.

Regarding the third characteristic, Indigenous peoples' self-determination in the Yaigoje Apaporis reserve was expressed through the creation of the national park since this was a decision made by the Indigenous peoples, and also, as it was able to stop the mining projections, it set a precedent about their power to decide the future of their territory. In Pilon Lajas, demonstrations of Indigenous peoples' autonomy have included the expulsion of logging companies and outsiders that were illegally fishing and hunting in the Biosphere, and the advancement of projects for improving their living conditions.

The case of the Condor Park did not present any actions that demonstrated Indigenous peoples' autonomy, in fact, all efforts to articulate Indigenous peoples' traditional practices were in vain because the government did not protect the conditions under which Shuar people's autonomy was possible. This case shows how political regimes and economic interests are key factors for the successful articulation of the Indigenous peoples' Life Plans and the governments' projects.

Other limiting factors to the autonomy of the Indigenous peoples in these cases were their lack of knowledge and experience about the national system and legal instruments and their economic dependency on external organizations. Demonstration of

Indigenous peoples' autonomy is a necessary step in the consolidation of an effort to articulate Indigenous peoples and government organizations.

4.9 Conclusions

Indigenous peoples' traditional knowledge of the territory serves as a guide for the use of resources in their Indigenous reserves. Indigenous peoples are fundamental social actors in the management of ecosystems within many developing countries, however, harmonizing predominant ideas of economic development and environmental policies with Indigenous peoples' visions and ideas about sustainable development is a problem that has not been fully addressed in the literature. Furthermore, Indigenous peoples' survival is affected by internal and external dynamics that reduce their social resilience.

Through the analysis of Indigenous peoples' Life Plans, this research discussed the factors that could facilitate or impede the articulation of Indigenous peoples' views of their territories with predominant development ideas and attempted to quantify characteristics that confer or reduce their resilience capacity.

Results showed that thanks to their social structure, Indigenous peoples have a large self-organization capacity, they involve all members of their community in the decisions and activities that affect them all, and they transmit their knowledge between generations; these are all important resilience features. However, Indigenous peoples' knowledge of their territories is being transformed with the changes of the land and they are constantly working to maintain their cultural identities.

Social resilience differences between Life Plans indicate that not all Indigenous peoples or Indigenous reserves have the same characteristics. Exploring these differences in depth is important for the future of cooperative work between the State and these communities. Also, improving our understanding of the Life Plans and about Indigenous peoples' ideas and representations of the material world will improve communication.

The Life Plans showed that for Indigenous peoples the protection of the environment relies on their knowledge of the territory, and it depends on the level of interaction that they have with nature. Their social structures are highly linked to their territory and to the health of its ecosystems, and because of this, when resources in their territory start to decline their survival is compromised and their cultural identities start to decay. Currently, multiple Indigenous peoples that inhabit the ORW conserve great knowledge of the territories, but many are losing their ancestral knowledge.

Currently, in the ORW, Indigenous peoples' autonomy over their territory allows them to choose how to use their resources, and they might also oppose the exploration and exploitation of natural resources when these activities become threats to their survival. It is in this context that articulation with the government's institutions take place. Through their Life Plans, they are willing to harmonize their development visions with the Nation's Development Plans, but this is imperiled by the very same disarticulation between governmental institutions and Indigenous institutions.

It does not suffice to have dialogs and agreements on how the use of the resources is going to take place in their reserves. The materialization of these processes must result in statutory instruments and in actions that demonstrate Indigenous peoples' autonomies.

It was found that five conditions seem to influence the inclusion of Indigenous peoples' ideas of development in the national policies and development plans: (1) It is driven by a conflict about how to use natural resources, (2) Involves the participation of external actors that facilitate the communication between Indigenous peoples and government institutions, (3) Strong Indigenous organizations are present in the process, (4) The Indigenous peoples execute actions that confirm their autonomy, and (5) Results in legally binding agreements.

CHAPTER 5

STRATEGIES FOR THE PROTECTION OF ECOSYSTEM SERVICES IN THE ORINOCO RIVER WATERSHED

5.1 Introduction

Despite the efforts for governing common-pool resources in the Orinoco River Watershed (ORW), the governments of Colombia and Venezuela have not been able to successfully protect strategic ecosystems in this watershed (DNP, CONPES 3797 2014) and ongoing rapid transformations demand having adaptive management of the socio-ecological systems (Berkes, 2009). Cooperation between local institutions and the state has been important for regulating the use of common-pool resources in similar regions (Premauer & Berkes, 2015; Huber-Sannwald et al., 2012, UNDP, 2012), furthermore, the existence of robust local governing institutions is important for effective adaptive management (Berkes, 2009, Benegas et al., 2009).

Oftentimes, local governance in developing countries, like Colombia and Venezuela, faces two issues: first, the lack of social structures that allow the interaction of governing institutions at multiple scales, and second, national governments do not recognize people's rights to organize and regulate the use of local resources (Randhir, 2016; Ostrom, 2005). There are mismatches between and among resource-users and other actors at multiple scales in the ORW. Mismatches are one of the causes of disarticulation between multi-scale-governing institutions. They are stronger in multicultural environments (Berkes, 2009) and when information flow between scales is restricted

(Watson-Manheim et al., 2012). On the other hand, social inequalities in the ORW are affecting multiple local communities, including Indigenous peoples.

Little is known about the conditions that lead to these two issues and their characteristics in the ORW, specifically, the interethnic, social, and political relations and power dynamics, and their relationship with the socio-ecological outcomes. Furthermore, exploring new tools and innovative solutions is pivotal for improving local governance in developing countries (Gasson, 2002).

The objective of this research was to identify and characterize multi-scale socio-ecological dynamics and tools that promote (i.e., that provide opportunities) or impede the progress of local governance within a region undergoing rapid socio-ecological transformations. The study area was the Orinoco River Watershed (ORW), which is one of the most culturally diverse regions in South America (Gasson, 2002).

Based on the main findings from this dissertation, this chapter will focus on what strategies could help in overcoming fragmentation issues and lack of recognition of local organizations. Here, the objective is to define strategies for articulating multi-scale actors and creating governmental initiatives for the recognition of local institutions' rights to govern common-pool resources.

The uniqueness of this research is the definition of structural and non-structural strategies for maintaining multi-scale socio-ecological systems networks. Management practices are usually cited as a list of suggestions that lay outside of the context in which they are to be applied (Barnes & Van Laerhoven, 2015; Ostrom et al., 2007). A significant gap in environmental sciences is to use social-ecological knowledge as a basis for the formulation of management practices and to be able to articulate them to the real needs of complex socio-ecological systems. This research uses a multi-scale framework (Randhir, 2016) to articulate theory and practice aiming for integral management of ecosystem services in an important watershed system in South America.

The following section will present the main findings from the three previous chapters, then, the strategies are presented, followed by the challenges to the implementation of these strategies, future research, and final considerations.

5.1.1 Main findings related to opportunities for the progress of local governance

At the watershed scale, there were found regions with high potential for augmenting ecological capital and areas with large accumulation of ecosystem services, particularly in the Transitional and Guyana regions (Table 2-11). In the Andes and Piedmont region were found areas with high restoration potential. In the interface between regional and local scales, regional actors (researchers and federal employees) share a common vision about main economic activities with non-indigenous communities (Figure 3-17), and, they disagree little about needed management practices and the efficiency of informal, formal, and cooperative governing strategies (Tables 3.8 and 3.9).

Although, it was found that there are large disagreements between local actors (Indigenous peoples and non-Indigenous communities), it was also found that Indigenous peoples and non-Indigenous communities have little disagreement about potential solutions to the environmental issues in the watershed (Tables 3.8 and 3.9). Through the analysis of the Life Plans it was found that Indigenous institutions are strong regarding their internal organization, and thanks to their high interaction with the environment and transgenerational transmission of their traditional knowledge, they have high potential for preserving their knowledge. Also, Indigenous peoples are successfully communicating their needs and visions about the future development of the territory through their Life Plans.

There are cooperation opportunities between Indigenous peoples and governmental institutions in areas where Indigenous reserves overlap national parks and other protected areas. Similarly, there is great potential for the formation of coalitions between Indigenous peoples and organizations at regional, national, and international scales, for the protection of hotspots of biodiversity in the White Sands region and the Flooded Llanos. The definition of these hotspots was the result of a collaborative effort between several institutions and researchers from Colombia and Venezuela in 2010 (Lasso et al., 2010), but the national governments have not adopted legal mechanisms for the protection of these areas.

5.1.2 Main findings related to the impediments for the progress of local governance

Preliminary observations at the watershed level started to reveal contradictions between national development plans, Indigenous peoples' plans of development, and other communities' needs. Most Indigenous peoples' territories in the Colombian portion of the watershed are overlapped by current and future economic projects, and by polygons that indicate the availability of land for future oil exploration and extraction according to the national government. In the Venezuelan portion of the watershed, the overlap of economic projects and Indigenous territories happens in the northern portion of the Guyana region and in the most eastern side of the Llanos and Plains region.

In the interface between regional and local scales, the results showed that non-indigenous communities and regional actors differ in opinions about the predominant needs and interests regarding current use of common-pool resources, and what governing strategies are more efficient. Importantly, this assessment revealed that Indigenous peoples' opinions largely differ from all other groups, but mostly when compared those of federal employees. Social inequalities and threats to the autonomy of Indigenous peoples were revealed during the qualitative analysis of Indigenous peoples' Life Plans. These results also show that the national government does not provide guarantees to foster Indigenous peoples' autonomies over their territories.

At local scales, Indigenous peoples and non-indigenous communities have strong disagreements about management needs, interests, and predominant economic activities, with lower disagreement about governing strategies.

Two main mechanisms could help overcome these impediments, these are the improvement of social capital and the development of governmental initiatives. The following section will present strategies within each mechanism and suggestions about how these could be implemented in the ORW.

5.2 Social capital

Creating rules and norms to define social behavior is a central piece for effective governance of common-pool resources, furthermore, societies invest in their future welfare when they devote present time and resources in activities for the construction and adoption of these rules and norms (Brondizio et al., 2009), and it is fundamental having a network of connections between distinct groups within the society, also known as bridging social capital. For this, the main strategy consists in creating bridging organizations that work on linking groups with different backgrounds and interests (Crona & Parker, 2012).

Once the connection is established and actors start to interact, social learning takes place. Actors use the acquired knowledge for making decisions about governance policies and practices (Crona & Parker, 2012), however, lack of trust is problematic for this process. Social learning helps in creating trust among and between groups, equally, trust is a catalyzer for social learning (Allen et al., 2011). Another constituting element in the strategy is having reliable and useful information.

Given these characteristics, enhanced, strengthened social capital could be an effective mechanism for solving issues derived from the disarticulation between actors in the ORW. The main suggested strategies are bridging organizations, social learning, and conflict management.

5.2.1 Bridging organizations

Bridging organizations that link groups of actors within or across scales (Crona & Parker, 2012). They are formed by non-local actors, such as individuals or NGOs that use mechanisms for improving the communication between actors, aid mutual understanding, track down solutions to problems that hamper collaborative efforts, and facilitate the solution of conflicts (Ashcraft, 2017). Also, they guide the community in the creation of management plans, introduce scientific elements to the community (Gruby & Basurto, 2014), and promote the recognition of non-scientific forms of knowledge among decision-making circles (Allen et al, 2011).

Bridging organizations contribute to the formation of polycentric governance systems (Choe, 2004), which is a concept developed by Elinor Ostrom in 1991 to explain how the interaction of nested institutions could offer bottom-top and top-bottom advantages to multi-scale governing systems (Ostrom, 2005). This concept acknowledges the existence of governing institutions at different scales (such as the national governments of Colombia and Venezuela at a watershed scale, federal agencies that act a more regional level, combined with social organizations), that organize to carry out common goals.

Resulting links are fundamental for social learning and for building trust among actors (Allen et al., 2011), however, this is a long-term process that needs continuity and the constant presence of these organizations. Consequently, the articulation of actors is costly and can be highly dependent on these organizations. For this, bridging organizations must also help with improving social capital by involving members of the community and contributing to the development of leaders (Berkes, 2009).

Linking strategies used by bridging organizations consist in connecting different groups in meetings to start dialogs around environmental management issues, identifying and coordinating activities (including management activities) in which groups can work together (e.g., plantation of trees, environmental assessments, formulation of management plans) (Allen et al., 2011), facilitating co-management (e.g., local and governmental institutions contribute jointly to the management of national parks, biodiversity hotspots, or areas that without being protected are recognized as important reservoirs of ecosystem services).

Not all bridging organizations are equally successful in connecting groups and building nested networks for the governance, they can produce interactions without fostering real polycentric institutions (Gruby & Basurto, 2014), or support locals without building institutions for local governance or supporting stronger collective action (Barnes & Van Laerhoven, 2015). Bridging organization can try to influence effective collective action by providing examples to the communities, building pilot projects, and using incentives for collective action (Barnes & Van Laerhoven, 2015). Also, involving bridging organizations with local experience and recognition is important for demonstrating commitment to the local processes, also, this type of bridging organizations can create effective coordination with organized groups in the region for the execution of activities (e.g., intergroup workshops and meetings) (Barnes & Van Laerhoven, 2015).

Bridging organizations should know how to work with various technological tools to coordinate online groups, model biophysical dynamics with stakeholders, and encourage the construction of tools that suit the needs of the concerned actors. They should further identify and provide necessary information for solving problems (Barnes & Van Laerhoven, 2015), take responsibility for searching for alternatives that will engage diverse groups, and be capable of coordinating trans-disciplinary collaborations (Allen et al., 2011).

Bridging organizations in the Orinoco could improve local governance, particularly for Indigenous institutions. Currently, non-local organizations are involved in actions that help communicate Indigenous peoples with government institutions. Although researchers, consultancy firms, and NGOs are often involved in projects with the community, they do not focus on bringing together diverse groups as bridging organizations. For instance, in the construction of their Life Plans, all Indigenous Peoples included in this research received the support of external actors that helped Indigenous peoples to fulfill requirements for accessing financial support from the state, but outside actors did little to link Indigenous institutions with other local groups and governmental institutions.

5.2.1.1 Case 1: Arauca and Meta sub-watersheds

Indigenous territories, farmers, two national parks, and biodiversity hotspot areas are found together within the Andes and Piedmont region, in the Arauca and Meta sub-watersheds' headwaters (Figure 5-1). During the last 50 years, the competition for the use of common-pool resources and the incursion and expansion of the petroleum industry has caused a lot of social conflicts, affecting not only human populations but also ecosystems that provide fundamental services.

The analysis of the spatial distribution of ecosystem services in this research showed medium and medium-high accumulation of four ecosystem services, specifically to the south of the Cocuy National Park and to the north of the Tama National Park. The headwaters have a medium-high and high accumulation of surface runoff, which is beneficial for the adoption of management practices such as water harvesting, ecological restoration, and afforestation.

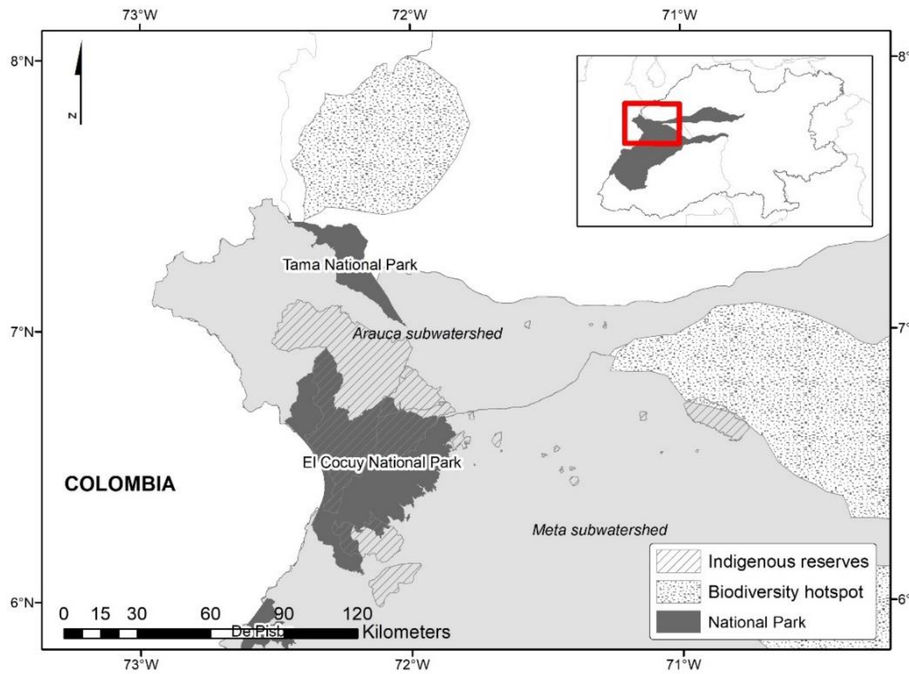


Figure 5-1. Map with overlapping public and Indigenous properties at the headwaters of two important tributaries of the Orinoco river.

Concerned local actors, such as associations of farmers, Indigenous peoples, NGOs, and local business, could join efforts for the protection of areas with high ecological values, but as shown in this research, cultural differences, geographic isolation, and conflicts that have developed through time, are barriers for the articulation. Bridging organizations in this scenario could help connecting local groups concerned with the rapid loss of ecosystem services; they could also link these groups with regional governmental institutions and research groups interested in the protection of strategic ecosystems, such as Andean paramos and cloud forest, and in the conservation of the biodiversity.

5.2.2 Social learning

Social learning helps actors within each group to understand broader processes (Allen et al., 2011) and to solve problems by adapting foreign concepts to their conditions (Crona & Parker, 2012). Social learning is highly reliant on the level of interaction and integration between groups, it does not suffice to have common interests and goals as only through meaningful interactions groups learn from each other (Barnes & Van Laerhoven, 2015), and these happen when groups of actors meet and join forces. For instance, during restoration projects, actors from distinct groups work together for carrying out common goals.

However, preconceptions, prejudices, and ideas about the world and diverse cultural backgrounds will affect how much of the knowledge gained through meaningful interactions will be used (Crona & Parker, 2012), because of this, social learning is difficult in transdisciplinary and multicultural environments. For instance, preconceptions and prejudices between distinct cultural groups also cause social inequality. During this research, some non-indigenous participants expressed negative feelings about Indigenous peoples and their traditions, while others were impartial in their opinions, and only a few participants referred to them with respect or were concerned about the conditions in which they live in this watershed. Misconceptions about Indigenous peoples are not only the result of historic dynamics of colonization, indifference, and the lack of recognition of Indigenous peoples' rights by national authorities have played a significant role in reinforcing these ideas (Houghton, 2008).

Loss of traditional knowledge is a significant obstacle to social learning in the ORW. This research showed that Indigenous peoples' traditional knowledge is declining due to the transformation of the environment and the ecosystems in the Orinoco. Also, the transformation of the regional economy, from ranches into oil fields, have dramatically changed non-indigenous communities' traditional practices (e.g., Llaneros and farmers); some of them remarked how new generations lack knowledge about old ways of production. Other factors that accelerate the loss of traditional knowledge are migrations and emerging cultural values (Gadgil et al., 1993).

5.2.2.1 Case 2: Social learning in the interaction between Indigenous peoples and actors at national scales

One opportunity for improving social learning among Indigenous peoples in the Orinoco is through the exchange of experiences about their interactions with governmental institutions, particularly when negotiating about extractive and productive practices in Indigenous territories.

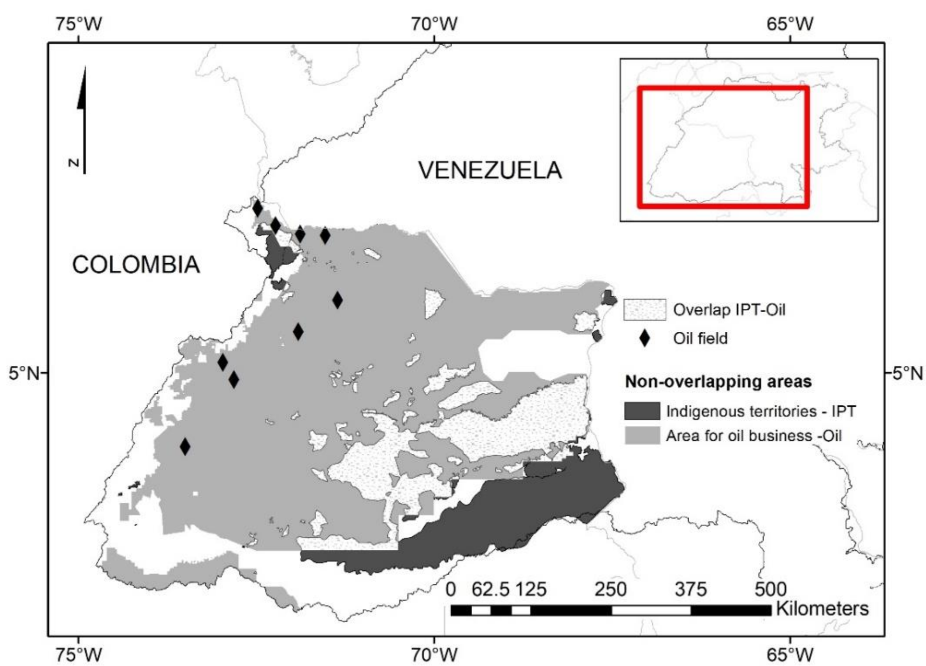


Figure 5-2. Map of Indigenous territories and current and future projects of oil extraction.

In the Orinoco, there are planned economic projects in areas which overlap Indigenous territories (Figure 5-2). Indigenous peoples with little or no experience in negotiating and overcoming conflicts with companies interested in extracting resources within their territories can learn from those who have gone through this process, such as the U'wa people living in Arauca river headwater, Nasa peoples in Guaviare river headwater, and Guahibo people along the Meta river.

5.2.2.2 Case 3: Growing trust between actors that share common interests through social learning

The livelihoods of non-indigenous communities and Indigenous peoples who share the Orinoco region, are equally threatened by the ongoing process of land-use transformation and intensification of extractive industries. Unlike non-indigenous communities, Indigenous peoples have ample experience in resisting and surviving colonization processes. Thus, a collaboration between these two groups could improve their chances to successfully negotiate with the government for the future development of the region, but achieving this requires solving cultural differences, communication issues, and building foundations for potential future collaborations.

In addition to local communities, other actors within regional and national institutions in charge of the protection of the environment (e.g., researchers and federal employees) are interested in promoting more sustainable productive practices. Even when actors within and across scales share interests for the conservation, protection, and effective management of natural resources, successful interactions for social learning is not easy, due to preconceptions.

These disarticulations could be eased in the execution of restoration projects in areas with good restoration potential within protected areas, or influence areas, or biodiversity hotspots. All actors with interest in working for the effective and inclusive management of the ecosystems should be invited to do hands-on work; this is how social learning takes place, that is why it is also called “learn by doing” (Allen et al., 2011). However, before that, bridging organizations need to work with these groups for creating a baseline about each other’s interests and to promote interactions that recognize and respect cultural and ideological differences. Acknowledging what are the different motivations that in first place incentivized the groups to organize and collaborate is necessary when promoting social learning (Crona & Parker, 2012).

Each positive interaction between these actors can foster more collaborative environment in which actors can learn to appreciate the visions and ways in which the other groups interact with their surroundings. These relationships promote the acquisition of knowledge because actors start to learn from each other. Trust is built once they start noticing that this knowledge is improving their practices, that others respect them, and that they are not being exploited.

5.2.3 Conflict management

Social interactions around the use of common-pool resources can develop into conflicts if groups of actors perceive an inequality in their access to these resources, and unresolved conflicts deepen gaps between groups within the community (Ashcraft, 2017). Because of this, investing in productive strategies to improve social capital hinges on effective management of these conflicts. Resolving these conflicts involves an agreement between actors about governance, use, and benefits obtained from natural resources through dialog and negotiation.

Effective conflict management strategies are inclusive (the exclusion of actors from the negotiations process intensifies the conflict and disrupts collaborative efforts) (Ashcraft, 2017), and result in long-term solutions through agreements that include negotiators' expectations for the future (Ashcraft, 2017).

5.2.3.1 Case 4: Characteristics of social conflicts between local actors and the state's influence

Actors living in the ORW are highly dependent on common-pool resources and the reduction of available resources, combined with the rapid increment of the population, is causing competition between local users, while discrimination between different local groups aggravates the competition. For instance, in the region around Guaviare river, some fishermen have greater power and control over fresh-water resources, and they impede or restrict Indigenous peoples' access to fish. Another example is the pollution of creeks that cross Indigenous territories in this same region. Riparian corridors in the upstream are used for recreational purposes by non-indigenous actors. Indigenous leaders that participated in this research commented that these activities result in littering and in the pollution of water by soap and other products, and that this affects their welfare. They feel powerless because local authorities have offered little support, and because they fear retaliation if they express their dismay.

Power differences also affect other local communities. Visited regions close to the Meta river, farmers described how massive industrial production of rice is impacting their livelihoods. Rice production uses large areas of land, changes land cover, and pollutes water, soils, and nearby ecosystems. Pesticides are sprayed using ultralight aircrafts that overfly the rice fields, a technique with little precision. These chemicals affect adjacent parcels where people grow their food and pollute the land and freshwater ecosystems. Most rice producers show little concern for these complaints. They have more economic and political power, and they make clear their superiority by imposing their resource-use behaviors.

These issues do not receive much attention from the national government, and without the intervention of external organizations (e.g., humanitarian institutions and international courts) there are little hopes for resolving these conflicts anytime soon. Progressing towards nested and functional polycentric systems requires the support of the government for controlling local control of the power by one or few individuals, and the engagement of organizations with experience in managing resource use conflicts.

5.3 Governmental initiatives

Successful local governance hinges on the recognition by the state of local organizations and on the multi-scale structure (Randhir, 2016; Ostrom, 2005). These are necessary conditions for improving local governance, and therefore, for attaining the goals of conservation and adaptive management of ecosystem services (Berkes & Turner, 2006). For advancing towards this end, the state must provide conditions for better local governance, it must recognize resource rights and confer autonomy to local institutions (Berkes et al., 2006; Ostrom, 2005). The state also must ensure that individual interests stay aligned with the sustainability of the ecosystems (Berkes et al., 2006).

Here, two mechanisms are presented through which states could work for better local governance in the ORW; these are co-management incentives and development of legal instruments for local governance.

5.3.1 Adoption of incentives for co-management

Efficiency in the governance of social-ecological systems is improved when governments adopt co-governance or shared governance (Borrini-Feyerabend et al., 2013) along with strategies for improving social capital and adaptive management (Berkes & Turner, 2006). Co-governance consists in sharing the power and responsibilities between the government and local resource users (Borrini-Feyerabend et al., 2013; Berkes, 2009), and it is used in the governances of protected areas that overlap with Indigenous territories (Borrini-Feyerabend et al., 2013). Governments that had adopted co-management use incentives to stimulate local participation, facilitate the creation of rules and regulations by the community itself (i.e., recognize the legitimacy of such rules), promote bridging social capital, share information with the public, are willing to give concessions to the communities during negotiation processes, give proper compensation to co-management leaders, and acknowledge the importance of locals' knowledge.

Governments must acknowledge complexity and cultural diversity when working in multiethnic environments (Premauer & Berkes, 2015). For instance, Indigenous peoples in the Orinoco are particularly vulnerable to permanent ecological transformations, they have a decentralized governing system (decisions are made collectively) and communicate in their native language. Their visions about the future development of the territory aim for the conservation of their links with natural elements in their territory.

Indigenous institutions together with the Special Management Unit for the National Parks System of Colombia (UAESPNN) could join efforts for the conservation of ecosystems in protected areas and for improving the recognition of Indigenous institutions. Protected areas in Colombia have held a scheme similar to co-management called Special Management Regimes, that build agreements between state and Indigenous authorities (Uribe, 2005). Local communities and governmental institutions also have opportunities for jointly managing common-pool resources.

5.3.1.1 Case 5: Co-management with Indigenous institutions in the ORW

The overlap of Indigenous territories and protected areas in the ORW offer great opportunities for the conservation of strategic ecosystems (Figure 5-3) and improving Indigenous peoples' living conditions. With the construction of their Life Plans, Indigenous peoples in Colombia have found a way to communicate their needs and plans for managing their territories. No other social group in the watershed has longer experience in the management of their territories, or better recognition for their cooperative and organization capacities than Indigenous peoples (Table 3-3 and Table 3-4).

Despite this, Indigenous peoples are very isolated; they are the group with largest mismatches according to the results from this research. Because of this, the work for building social capital between Indigenous peoples and all other groups, within and across scales, is an urgent task. The advantages for society when recognizing Indigenous peoples' role in the governance of common-pool resources, have been widely demonstrated, as they have contributed to the solution of technical problems in the construction of infrastructure (Berkes et al., 2000). Their participatation in co-governance has improved local governance and adaptive management (Berkes et al., 2006, 2009), social equity, and protected areas environmental and biological conditions (Zulu, 2013; Berkes, 2009).

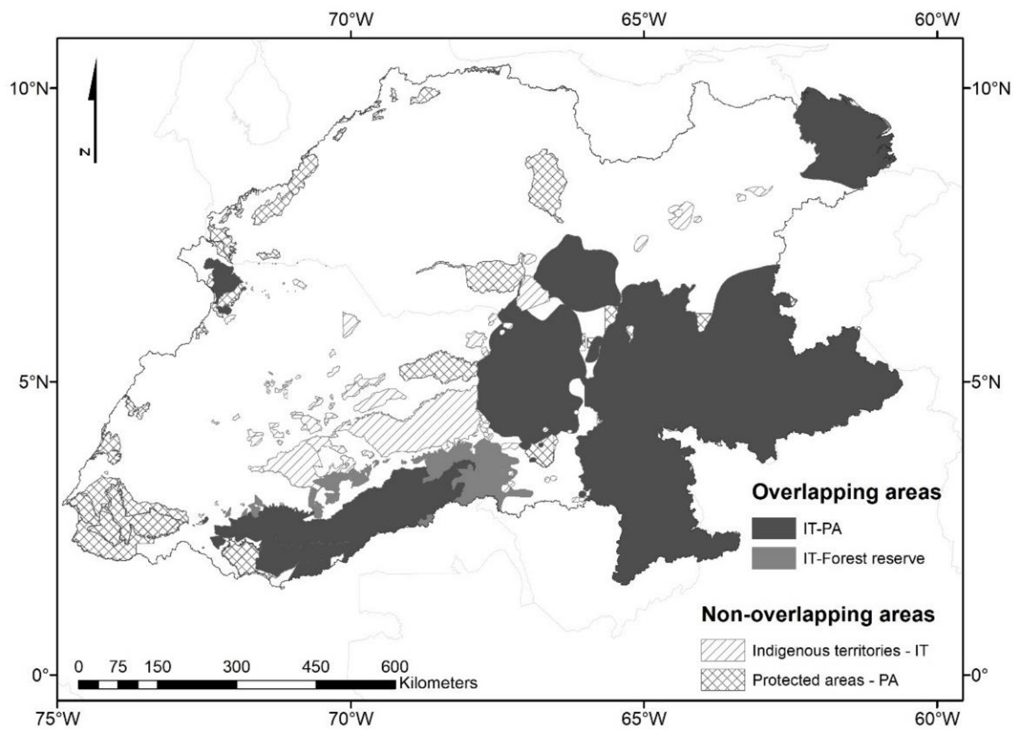


Figure 5-3. Distribution of Indigenous territories and protected areas in the Orinoco River Watershed – ORW

The Matavén forest is a special case in the Orinoco. It is located between the Vichada and the Guaviare rivers (Figure 5-4) and hosts high biological diversity and well-preserved ecosystems (Villareal-Leal et al., 2009). Indigenous peoples have occupied this region ancestrally, and in 2003, 16 Indigenous reserves joined as the

Matavén Indigenous reserve (INCORA, Res. 037 2003). Nowadays, the Association of Cabildos and Indigenous Authorities of Matavén Forest (ACATISEMA) represent six ethnic groups living in this territory.

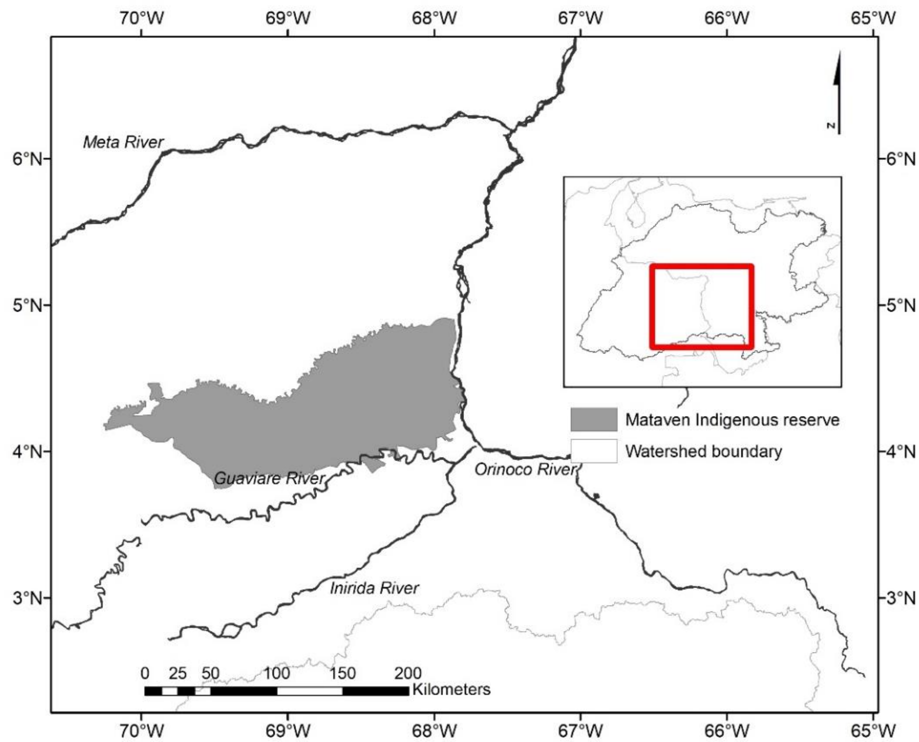


Figure 5-4. Matavén

ACATISEMA and the UAESPNN, with the collaboration of national and international organizations, have worked to declare this reserve a national park, but they have not been successful. Several reasons lay behind this failure, including the encroachment of settlers that grow crops of coca (an illegal activity), national plans for large projects for agribusiness which will overlap with the reserve, and corruption of governmental actors (Hyde, 2005). Colombia’s National Department alerted the government about the threats to the Matavén forest in 2014 (DNP, CONPES 3797 2014) and mentioned the need to advance collaborative efforts for the environmental management of this region with local communities and other national organizations. Growing concern in public circles is revitalizing this initiative, which could be the first case of co-management in the Colombian portion of the ORW.

5.3.1.2 Case 6: Opportunities for the local governance of fresh-water resources

The national government and non-indigenous communities also have opportunities for collaborative work in the ORW, particularly for managing freshwater resources. Beyond collaborative work with watershed management activities (e.g., afforestation, restoration of ecosystems, and water harvesting), the national government could explore the possibility of encouraging local users to create their own rules for using freshwater resources, such as fish.

Puerto Carreño is a municipality located at the intersection of the Meta and the Orinoco river, at the boundary between Colombia and Venezuela. The governments of Colombia and Venezuela have been advancing projects for future infrastructure megaprojects for improving the navigability of the Orinoco river, and with, new actors have been emerging. Environmental organizations and research institutes have worked for decades in Puerto Carreño and neighboring municipalities to expand knowledge of wildlife populations and ecosystems, and to raise awareness among local and regional actors about the importance of conserving strategic ecosystems.

These efforts have attracted the interest of academic institutions, like the Llanos University which created a post-graduate program for the education of environmental leaders in the region. Environmental NGOs in the region are working with regional, national, and international organizations for the declaration of new protected areas, such as for the Bita river, which is a stream with great biological diversity. This social movement has started to gain momentum, and environmental leaders in the region are promoting practices for the sustainable use of common-pool resources, such as fish. For instance, a rule created by the community for regulating sports fishing and protecting the Peacock bass (a fish of the genus Cichla), was legitimized and adopted by the municipality in 2015 (Concejo Municipal del Municipio de Puerto Carreño, Acuerdo 010).

Under these conditions, the national government has great opportunities for the creation of collaborative initiatives for improving the governance over fish resources. Existing commercial fishing bans and regulations are not strictly enforced, and this is causing the decimation of fish populations (Lasso et al., 2010). However, if the multi-scale governmental institutions articulate with groups of local-users, the chances are that new local institutions will form. Also, other local groups must be an active part of these initiatives (e.g., Indigenous peoples, army, and commerce), these must be linked to avoid conflicts and social inequities.

5.3.2 Technology and information tools

Reliable information sources inform decision-makers when building policies and adopting management practices, and technology tools improve communication across diverse groups of actors. For instance, the use of spatial models for representing biophysical processes is amply used for decision making (McCall, 2014), web-based application programs are used for monitoring environmental variables (Holmberg et al., 2015), and specialized mapping tools are available to Indigenous peoples (Digital democracy, 2017); who use these tools to produce necessary information for supporting their demands over their ancestral territories, and it is part of the international network of Indigenous peoples.

Producing technological tools and facilitating information flow across scales is costly, it needs maintenance, robust structures to disseminate information, and reliable sources of information. Within the multi-scale structure, it is common to find organizations at higher levels leading the construction, management, and circulation of these instruments.

Technology and information tools are also necessary for social learning, but unlike the scientific information used in policy processes, here relevant and useful information is more important. “Actors consider information to be relevant and useful if it is congruent with their experience and interests” (Flora et al., 2006). Actors need this type of information for solving problems at local scales and for rapidly adapting to unexpected shifts within the socio-ecological systems (Allen et al., 2011). Once more, organizations at higher levels need to produce or enable the acquisition of this information and make it available to the public (Berkes et al., 2006).

Difficulties met during the construction of the spatial models in this research included restrictions on the climatologic and hydrologic historic data, which indicates weaknesses in the national information system. On the other hand, databases and other information tools needed at local scales are non-existent, and actors learn about political decisions and upcoming projects by word of mouth without regard for the accuracy of this information. Bridging social capital hinges on the availability of reliable and understandable information (Flora et al., 2006) and if multi-scale, nested, and polycentric institutions are going to be created in the future, the state must first resolve these communication issues.

5.4 Challenges

Even though it is important to improve the conditions for better multi-scale governance of the commons, complying with the principles that have been defined in the literature as general characteristics of robust institutions do not assure successful governance. Ostrom warned that factors such as rapid exogenous changes, imposed solutions, large dependency on external funding, lack of support from institutions at higher levels, and corruption threaten local governance (Ostrom, 2005).

One of the largest challenges for building local governance in the ORW is the conflict created by illegal business (e.g., illegal extraction of wood, gold, fish, and wildlife, and cocoa plantations) and violence in certain regions, which create divisions in local communities. Many regions in the Altillanura and Transitional regions, for example, cannot be accessed due to security issues. This situation demoralizes the population and impedes the progress of national initiatives.

The massive transformation of the ecosystems in the ORW and the loss of ecosystem services have their origins at local scales, but most importantly national, and international economic dynamics have caused these changes. Being able to negotiate with powerful stakeholders (e.g., national and international companies dedicated to the extraction and commercialization of natural resources) and state-actors with their own economic interests is a major challenge.

Many social actors in the ORW are also migrating. People seek stable living conditions in safe and healthy environments. Migrations in both directions are one of the major threats for supporting and creating new local institutions; this reduces trust and reciprocity among actors at local scales (Ostrom, 2005). Also, social dynamics within local groups are changing, causing divisions, and loss of human capital for sustaining traditional productive practices. Social inequity enhances differences between Indigenous peoples and non-indigenous communities, reducing bridging social capital.

Finally, there exists the risk that bridging organizations will not be able to create functional links. Multi-scale links can become rigid structures that only impose more burden on the institutions (Barnes & Van Laerhoven, 2015). Implementation of programs that have not been adjusted to the local conditions and aspirations is, therefore, another big challenge; it wastes economic and human resources and exhausts local actors.

5.5 Future research

While the results of this research can be used to define areas where improved management practices could have better impact on the retention of sediments, water harvesting, afforestation, and restoration projects, the special and temporal scales used here limit their use for the formulation of specific projects. The runoff and soil loss models, for example, are based on average monthly values, and while this time scale is enough for analyzing seasonal differences it is insufficient for a more thorough measurement of extreme events that cause erosion, stream sedimentation, and water pollution. Planning watershed management practices for solving these issues needs hourly time-step information and higher spatial resolution.

Furthermore, the results from the runoff model indicate that more complex hydrological dynamics are taking place in the watershed, and that other factors, such as water withdrawal and ground water dynamics, should be included in the model for better efficiency and consistency.

The results from the Ecosystem Service Index, used for analyzing the spatial distribution of cumulative services, were based on four proxies (runoff, soil loss, carbon storage, and biodiversity) to measure provision of water, regulation of water quality, mitigation of atmospheric CO_2, and provision of habitat. Because of this, the ESI analysis does not offer a description of many other important ecological values in the region. Future research should incorporate vital ecosystem services such as provision of ground water and micro and regional climate regulation, instream buffering and attenuation of mass flows, provision of wild animals as food sources, and biomass provision with nutritional value.

Studies for the assessment of ecosystem services that include land use and land cover changes are very useful for measuring the impact that these transformations have on ecosystem services and will be of great value for the sustainable development of the watershed. These models use at least 30 years of baseline data, thus, future research should help in consolidating and organizing recharge and runoff measurements for the ORW, and in creating dynamic models that combine existing information about land use and land cover changes with regional water balance models.

Mismatches identified in this research can guide future research for better understanding of what kinds of information are needed for bridging groups (Table 3-9). It was found that differences among local groups regarding natural resources use behavior and local economic dynamics impose major constrains in the interaction between local actors, however, this research does not provide information about what aspects can be manipulated to improve these connections. It is important to keep advancing our understanding of specific socio-economic and socio-ecologic dynamics that provide a common context enabling conditions for the articulation of local actors.

The study of Indigenous peoples' Life Plans in the ORW highlights what internal characteristics contribute to the resilience of these communities and which are detrimental, also, it helped to adjust social resilience indicators for similar cases. Research projects for the assessment of social resilience that involve the participation of Indigenous peoples promote the creation of endogenous indicators (Verschuuren et al., 2014), therefore future research should involve the evaluation of the indicators used in this research by the communities themselves and data should be obtained using participatory and ethnographic methods.

The comparative analysis of the Indigenous peoples' Life Plans presented alternatives to the incorporation of Indigenous peoples' views and traditions in the management of protected areas in South America and for the consolidation of co-management systems. However, a more extensive comparative analysis could bring to light specific mechanisms through which effective and equitable future co-governance can take place in the watershed. This research showed differences between Indigenous peoples' Life Plans throughout the watershed. A next step should be to identify the underlying factors that drive these differences and to point out under what conditions Indigenous institutions are likely to be stronger and to have one voice in co-governance.

5.6 Final considerations

Developing countries are facing big challenges in their sustainable development, protection of natural resources, and biological conservation. Much of it depends on socio-politic and economic dynamics at both national and international levels. Governing common-pool resources requires the participation of not only state institutions, but the involvement of multiple stakeholders at multiple scales. Throughout this research it was found that groups of actors at multiple levels are involved in activities for the conservation of natural resources, but the lack of communication and cultural gaps are undermining these efforts and putting at risk the survival of local communities.

Within Indigenous territories and inside of national protected areas are found the largest accumulation of ecosystem services, but in the day to day life, Indigenous institutions and state institutions have very little interaction. Even though the disarticulation between these two institutions has been reported in the literature, in this research were quantified levels of disarticulation and compared to those presented between other local and regional actors. These findings show that Indigenous institutions share very little commonalities with other groups, not only in their natural resources use behavior but in their governing strategies.

A road map, with strategies for growing mutual respect and collaborative work, was suggested in this last chapter, however, there are multiple challenges that complicate the implementation of these practices as they correspond to an ideal multi-scale model.

The political reality of both Colombia and Venezuela and the international demand of resources, affect the socio-ecological dynamics in the watershed. The ideas exposed in this research constitute a proposal and their implementation will largely depend on the socio-political and socio-economic dynamics. Currently, Colombia is redefining its political structure with the signature of peace agreements with one of the guerrillas' groups, and the power is being redistributed across the nation. This portrays a scenario with important uncertainties. These political transformations will have their larger impact on those with little power, such as Indigenous peoples and other local communities.

An additional factor related to the market of natural resources, imposes a larger challenge. The results from this research could rising awareness about the need of a more integrated and multi-scale coalition to protect local commons, and this vision could be embraced by the government. Future political conditions could align with the ideas developed in this research. Polycentric and nested institutions could be formed, and stronger network of interactions could grow, but still, the demand for resources by international companies will keep playing a major role in the conservation of the ecosystems.

Mining, oil, and palm oil businesses will remain in the territory. Even if the state has the necessary governing instruments, these companies will continue to be involved in the extraction of natural resources, and if there is corruption and political links to these businesses, there will be great environmental degradation. Because of this, there is vulnerability in this watershed's conservation. Worldwide, governments do not respond to the needs of the population but to the market's needs, and this is true even with the intervention of international conservationist institutions. Is because of this, that the market of natural resources is the biggest challenge of all.

APPENDIX A

SURVEY

Part I: Use behavior

1) For each of the natural elements in the list, please describe the level of dependency that the communities have for sustaining their livelihoods.

Natural Element	**(0) No dependency**	**(1) Little dependency**	**(2) Medium dependency**	**(3) Large dependency**
Wood (timber)				
Fruits and vegetables				
Wildlife (Bushmeat)				
Fish				
Medicinal Plants				
Water				
Minerals				
Soil				

2) Describe your concern level about the availability of each of the natural elements in the list

Natural Element	**(0) Not concerning**	**(1) Somehow concerning**	**(2) Very concerning**
Wood (timber)			
Fruits and vegetables			
Wildlife (Bushmeat)			
Fish			
Medicinal Plants			
Water			
Minerals			
Soil			

3) For each of the activities in the list, indicate the dependency level that communities have for their livelihoods.

Activities	(0) There is no dependency	(1) Little dependency	(2) Medium dependency	(3) Large dependency
Subsistence crops				
Ranching				
Fishing				
Fish farming				
Hunting				
Mining				
Tourism				
Masonry				
Commercial crops				
Oil extraction				

Part II: Common-pool resources governance

4) Different cultural values and property regimes influence the protection of natural resources. From the following values and ownership types indicate how likely it is that a person or a community would protect natural resources.

Value	(0) Unlikely	(1) Indifferent	(2) Likely	(3) Very likely
Region with a cultural value				
Region with a landscape value				
Region with an ecological value				
Region with an economic value				
Protected Area				
Private property				
Public property				
Indigenous reserves				
Open source areas				

5) Different regions have different forms of collective organization for the use and protection of natural resources. Please select the organizing and collective-action strategies that are currently being used in this territory and their level of efficiency.

Formal strategies

	(0) Not used	**(1) Inefficient**	**(2) Efficient**	**(3) Very efficient**
Conservation				
Planning				
Urban development				
Rules				
Fines				
Control				
Hunt ban				
Fish bans				

Informal strategies

	(0) Not used	**(1) Inefficient**	**(2) Efficient**	**(3) Very efficient**
Verbal agreement				
Written agreement				
Conflict resolution				
Internal cooperation				
Within cooperation				
Cooperation with the state				
Cooperation with Universities				

Part III: Management of Natural Resources

6) From the factors in the list, select the level at which each of them negatively affects natural resources

Factor	**(0) Does not affect**	**(1) Affect little**	**(2) Greatly affect**
Point source pollution			
Non-point source pollution			
Deforestation			
Fires			
Droughts			
Floods			
Road construction			
House construction			
Urban development			
Erosion			
Channelization			
Invasive species			
Dams			

7) The following management practices are used to address the factors that impact natural resources. Select the alternative to rate the efficiency of each practice.

Management Practice	**I don't know it**	**It is not needed**	**It is needed**	**(0) Not efficient**	**(1) Efficient**	**(2) Very efficient**
Wastewater treatment						
Organic crops						
Reduced use of agrochemicals						
Selective cut						
Reforestation						
Protected areas						
Control of invasive species						
Waterflow control						

Part IV: Demographics

What is your relationship with the Orinoco River Watershed?

I live in the watershed	
I work in the watershed	
I do research in the watershed	
Other	
Age	
Gender	
How many people live with you?	
How many people depend on you?	

What is your ethnicity?	
Where were you born?	
For how long you have been interacting with the Orinoco River Watershed	

What is your monthly average income? (Minimum income is $689,454 COP)

Less than the minimum	
The minimum	
2-3 times the minimum	
More than 3 times the minimum	

What is your profession?

Fishermen	
Farmer	
I provide transportation services	
Rancher	
I work for a palm-oil plantation	
I work for an oil company	
Miner	
Education	
Researcher	
State employee	
Unemployed	
Various activities	
Housewife	
Other	

APPENDIX B

RESILIENCE GRADING RUBRIC

These indicators were adapted from the indicators presented by Bergamini and collaborators (marked as UN) (Bergamini et al., 2013) and Carpenter and collaborators (marked as Carpenter) (Carpenter et al., 2012).

Category	**Resilience indicator**	**Evaluation criteria**	**High value (5)**	**Middle/High (4)**	**Middle (3)**	**Middle/Low (2)**	**Low (1)**
Knowledge and learning	Transmission of traditional knowledge (UN)	Generations involved	All generations are involved in the transmission of knowledge	Only adults and elders can participate in the acquisition of knowledge	Only certain members of the community can access to the knowledge	Only elders hold the knowledge	The knowledge of the community is lost
		Mechanisms of transmission	Schools are in good conditions, and informal mechanisms have permanent influence	Schools are under regular conditions, and informal mechanisms have permanent influence	Schools in bad conditions and informal mechanisms have permanent influence	Schools in bad conditions and intermittent informal mechanisms	No schools and weak informal education
		Language in which the knowledge is transmitted	Good bilingual	Bilingual that needs to be improved	Very poor bilingual	Only Indigenous language	No Indigenous language

Category	**Resilience indicator**	**Evaluation criteria**	**High value (5)**	**Middle/High (4)**	**Middle (3)**	**Middle/Low (2)**	**Low (1)**
		Teachers	Teachers are members of the community	Some teachers belong to the community and others from other Indigenous communities	Some teachers belong to other Indigenous communities and other to non-Indigenous communities	All teachers are non-Indigenous	Community has no teachers
	Cultural traditions that promote conservation or harmonious interaction with the environment (UN)	Existence	There are descriptions of cultural traditions that involve socio-ecological interactions, and they are essential for the community	There are descriptions of cultural traditions that involve socio-ecological interactions but only somehow important	There are descriptions of cultural traditions that involve socio-ecological interactions, but they are rarely used	There are descriptions of ancient cultural traditions involving socio-ecological interactions, but they are not used	There is no recollection of cultural traditions related to socio-ecological interactions
	Physical interaction with nature (UN)	Generations involved	All members interact	All but children	Only certain groups interact	Only young adults interact	There is no interaction
		Level of articulation	Full articulation and interaction with state	Articulation with state institutions and medium interaction	Articulation with state institutions and low interaction	No articulation with state some interaction	No articulation or interaction

Category	Resilience indicator	Evaluation criteria	High value (5)	Middle/High (4)	Middle (3)	Middle/Low (2)	Low (1)
	Documentation and exchange of knowledge (UN)	Documents communicating traditional knowledge	Institutions and systems for knowledge documentation and exchange are present and well-functioning	Institutions and systems for knowledge documentation and exchange present but can be strengthened	Some knowledge documentation and exchange taking place but need to be strengthened	Only a small fraction of knowledge documented	Documentation of knowledge does not take place
		Exchange of knowledge with other Indigenous communities	Indigenous communities have installed a formal system of knowledge exchange, and it is currently working	Indigenous communities have informal and frequent interaction for the exchange of knowledge	Indigenous communities have informal but infrequent exchange of knowledge	Indigenous communities have casual interaction with other groups for the exchange of knowledge	There is no exchange between Indigenous communities
Social equity and infrastructure	Autonomy (UN)	Level of autonomy	Community has access to its traditional lands and resources and autonomy in their management	Community has access to its traditional lands and resources and partial autonomy in their management	Community has limited access to their traditional lands and resources and limited decision power over their management	Community has limited access to its traditional lands and resources and no decision power over their management	Community has neither access to nor decision power over traditional lands and resources

Category	Resilience indicator	Evaluation criteria	High value (5)	Middle/High (4)	Middle (3)	Middle/Low (2)	Low (1)
	Health security (UN)	Health care provided by the state	Excellent health care is available to the community	Basic health care is available to the community	Accessibility to basic health care is either intermittent, or the facilities are difficult to access	Basic health care is almost always absent, or facilities are very difficult to access	Health care not accessible
		Medicinal plants	Community has access to medicinal plants and the knowledge for its use	Community has access to some medicinal plants and some knowledge for its implementation	Community has limited access to medicinal plants is facing the risk to lose the knowledge to use it	Community has limited access to medicinal plants and it has lost most of the knowledge	Community has no access to medicinal plants or to the knowledge
		Traditional medicine	Traditional medicine is very important They have traditional healers, full transmission of knowledge between generations	Traditional healers are often consulted and their knowledge is well preserved but the mechanisms for transmitting this knowledge needs to be improved	Traditional healers are often consulted but they have been losing their knowledge	Traditional healers are not commonly consulted and their knowledge is disappearing	Community does not use traditional medicine

Category	Resilience indicator	Evaluation criteria	High value (5)	Middle/High (4)	Middle (3)	Middle/Low (2)	Low (1)
	Basic services (UN)	Coverage of basic services other than health and education	Community has coverage of basic services and they meet all its needs	Community has coverage of basic services	Community has less than basic services covered but the ones in place are providing working well	Community does not have all basic services covered and they are not working properly	Community has no access to basic services
		Quality	The existing infrastructure to supply services to the community is in excellent conditions	The existing infrastructure to supply services to the community is in good conditions and minor problems need to be solved	The existing infrastructure to supply services to the community is very damaged and needs to be repaired	The existing infrastructure to supply services to the community needs to be replaced	There is no infrastructure
	Risk (UN)	Health risk due to malnutrition or pollution	Very low risk due to malnutrition or pollution	Low risk due to malnutrition or pollution	Medium risk due to malnutrition or pollution	High risk due to malnutrition or pollution	Very high risk due to malnutrition or pollution
		Physical risk due to natural hazards or violent confrontations	Very low risk of having physical damage	Low risk of having physical damage	Medium risk of having physical damage	High risk of having physical damage	Very high risk of having physical damage

Category	Resilience indicator	Evaluation criteria	High value (5)	Middle/High (4)	Middle (3)	Middle/Low (2)	Low (1)
Social structure and organization	Internal social organization (UN and Carpenter)	Level of internal organization	Institutions in place and resources effectively managed	Institutions in place and some resources effectively managed	Institutions in place but need to be strengthened	Institutions not effective	Institutions not present
	Conflicts with other social groups (Carpenter)	Level of conflicts	There is no conflict between Indigenous Peoples and other non-Indigenous groups	Rising problems due to the influence of other groups in the environment or the culture	Verbal or behavioral aggression towards members of the community or invasion of their territories	Sporadic violent attacks against members of Indigenous communities	Assassination of Indigenous leaders and expulsion of Indigenous Peoples from their territories
	Articulation with state institutions (Carpenter)	Level of interaction with national and regional state actors and policies	Full articulation and constant interaction with federal employees and resource management agencies	Articulated but with communication issues	Articulated in paper but not in practice	Interact occasionally	No interaction
	Planning (Carpenter)	Clarity in the formulation of the projects contained in the Life Plan	Plan with thematic lines, projects, funding and timeline	Thematic lines and projects defined	Loose projects or main lines without specific projects	Vague definition of how to implement the Life Plan	No definition of themes or projects

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