Spatial patterns of natural resource depletion among rain forest communities in the Peruvian Amazon: the role of protected areas and indigenous territories in the conservation of key species

by

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Abstract

Human-induced environmental change is not a new phenomenon in biologically rich areas of western Amazonia. Rain forest communities have long modified their environments, pursuing a diverse portfolio of economic activities for subsistence and income generation. Globally, protected areas (PAs) are the chief conservation strategy. While the effectiveness of different PA models continues to be debated, recent research acknowledges the significance of extractive PAs and indigenous territories to the conservation of biodiversity in human-modified landscapes. Using community census data collected from rain forest communities in the data poor region of the Peruvian Amazon (N=919), spatial clustering and regression analyses are applied to evaluate the effect of proximity to extractive PAs and indigenous territories on relative availability of key species. Controlling for important environmental, market, and community characteristics, our research indicates that extractive PAs and indigenous territories have helped to preserve the availability of key species by certain measures that we isolate in the work.

Acknowledgments

This thesis is dedicated to my grandfather, the late William Vetrano, who encouraged me in my earliest years to find magic in nature, and to my grandmother, Therese Vetrano, whose aya oya pasta recipe has never failed to nourish me. I would like to express my deepest gratitude to my supervisor, Dr. Christian Abizaid, whose insights and genuine curiosity served as a driving force throughout the production of this thesis. I greatly appreciate the exceptional patience and generosity with which he approached our collaboration. I would also like to extend my sincerest thanks to the principal investigators of the PARLAP project—Dr. Oliver Coomes, Dr. Pablo Arroyo, and Dr. Yoshito Takasaki. In particular, I would like to thank Dr. Pablo Arroyo for his support on the spatial analysis component. At the University of Toronto, I would like to thank the Map & Data Library technicians for bearing with me through endless questions; Dr. Tat Smith for the support he showed during the early stages of the development of this thesis; Dr. Michael Widener for his support on spatial analysis techniques; and Xiaojun Su for her friendship during our time together in the program. I would also like to thank my four loving parents who have gone above and beyond to make me feel infinitely supported throughout my academic and professional endeavors. I wouldn't be who I am today without you. Last but not least, I would like to thank my two beautiful sisters for always finding a way to get a chuckle out of me. I hope that our competition for the title of Goofiest Human never outgrows us, and I would like to take this opportunity to confirm that the title is, and shall always remain, mine.

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1 Introduction & Background

Tropical rain forests are revered for their role in sustaining biodiversity, providing ecosystem services, and maintaining associated cultural values and livelihoods (Chhattre & Agrawal 2009). The Amazon basin is the largest and most biologically diverse tropical rain forest worldwide, making it a region of primary interest among conservationists (Salo & Toivenon 2009; Antunes *et al.* 2016). Protected areas (PAs)—i.e., defined geographic areas managed for the long-term conservation of nature—are the leading global conservation strategy, yet they are considered inadequate in meeting Amazonian conservation targets (Silveira Soares-Filho *et al.* 2006; Fajardo *et al.* 2014). The effectiveness of PAs depends on a number of factors, including external development pressures and local socioeconomic and political conditions (Oldekop *et al.* 2016). Despite notable progress on the development of PA systems (Jenkins *et al.* 2009), Amazonian biodiversity continues to be threatened by multiple interrelated factors, such as infrastructure development, extractive industries, hunting practices, and agricultural expansion (Rodrigues *et al.* 2009; Bass *et al.* 2010; Antunes *et al.* 2016). Historically, biologically rich areas of western Amazonia remained relatively untouched due to their remote, complex geography (Oliveira *et al.* 2007; Salo & Phyälä 2010) and only more recently has the region come under greater threat (Finer *et al.* 2015).

Conventional exclusionary conservation (e.g., “fence and fine”) approaches are based on the principle that anthropogenic activity compromises biodiversity conservation, and thus that select areas should be reserved and restricted in use (Kubo & Supriyanto 2010). However, the view that anthropogenic activity is incompatible with conservation objectives fails to acknowledge the complexity of social and market pressures driving land use change, especially within rural economies where the share of environmental income (i.e., income generated from wild and uncultivated resources) is significant (Angelsen *et al.* 2014). There is growing recognition that human-modified landscapes, including indigenous and community conserved areas (ICCAs), contribute meaningfully to the conservation of biodiversity and provision of ecosystem services (Chazdon *et al.* 2009; Dudley *et al.* 2014). While justified criticisms of community-based conservation schemes exist (Dressler *et al.* 2010), the most effective natural resource management programs in Amazonia, and in developing countries more broadly, reportedly involve local communities directly in co-management processes (Andrade & Rhodes

2012; Antunes *et al.* 2016). Key questions remain to be investigated, such as how to integrate scientific and local knowledge to improve conservation efforts without compromising the rights of rural resource users (Chazdon *et al.* 2009).

The effectiveness of conservation policy has typically been measured in terms of forest cover change (Bruner *et al.* 2001; Sánchez-Azofeifa *et al.* 2003; Nepstad *et al.* 2006; Oliveira *et al.* 2007; Andam *et al.* 2008; Nelson *et al.* 2011; Vuohelainen 2012; Miranda *et al.* 2015; Jusys 2016; Weisse & Naughton-Treves 2016), an approach that provides indispensable insights into landscape-level biodiversity loss and the relative performance of different types of PAs—e.g., uninhabited national parks versus inhabited extractive reserves. Additionally, a growing body of literature draws attention to social measures of PA impact, such as changes in livelihood opportunities or income (West *et al.* 2006; Andam *et al.* 2010; Ferraro & Hanauer 2014; Hanauer & Canavire-Bacarreza 2015; Oldekop *et al.* 2016). Fewer studies, however, consider the role of locally- and regionally-managed extractive PAs and indigenous territories in conserving biodiversity. Given that the vast majority of tropical regions are actively managed for subsistence and commercial purposes, Chazdon and colleagues (2008) call for a greater understanding of biodiversity patterns in human-modified tropical landscapes and the relationships between local communities, resource use, and sustainable management.

This thesis seeks to complement existing knowledge of biodiversity change in western Amazonia by examining spatiotemporal patterns of natural resource availability among rain forest communities, and determining the role of extractive PAs and indigenous territories in shaping those patterns. The study focuses on key aquatic and terrestrial species harvested by local communities in the Peruvian Amazon (N=919). Historical status (i.e., presence/absence) of key species, which is typically overlooked in studies of biodiversity change (Wilson *et al.* 2004), is incorporated to enable consideration of changes in natural resource availability over time. The regional scale of analysis captures heterogeneity in rain forest communities and habitats and allows inclusion of previously unstudied PAs, contributing to our understanding of conservation and development challenges in one of the most biologically rich areas of Amazonia. Given the potential conservation value of different types of PAs—from strictly protected nature reserves to Indigenous and Community Conserved Areas (ICCAs)—it is essential for researchers to consider alternative measures of conservation effectiveness that incorporate local knowledge of species availability.

Indeed, lessons from historical conservation policy and practice demonstrate that effective and equitable conservation outcomes require ecological and social objectives to be carefully balanced (Andrade *et al.* 2012; Van Wilgin & McGeogh 2015).

2 Research objectives

The present study is being carried out as part of the Peruvian Amazon Rural Livelihoods and Poverty (PARLAP) project, an international collaboration between researchers at the University of Toronto (Dr. Christian Abizaid), McGill University (Dr. Oliver Coomes, Dr. Pablo Arroyo, and Dr. Margaret Kalacska), and the University of Tokyo (Dr. Yoshito Takasaki). PARLAP seeks to improve our understanding of rural livelihoods and poverty among rural and indigenous communities in biologically rich areas of Western Amazonia. It is the first large scale survey of its kind conducted to date in the data poor region of the Peruvian Amazon. The results of the project will inform conservation and social policy to improve the well-being of the rural poor residing in rain forests. The primary objective of the present study is to examine the degree to which natural resources are protected by their proximity to protected areas and indigenous territories. This research is guided by four questions:

1. How has the availability of natural resources among rain forest communities changed over time, with respect to key fish, game, and timber species extracted?;

2. What are the spatial patterns in natural resource availability, initially (i.e., at the time of community establishment), in the present, and in terms of change over time? Have certain communities experienced greater depletion than others, and how are these patterns manifested spatially?

3. Which factors are likely to effect natural resource availability?; and importantly,

4. What is the role of protected areas and titled indigenous territories in shaping natural resource availability? Does proximity to protected areas and indigenous territories explain variation in availability of key species?

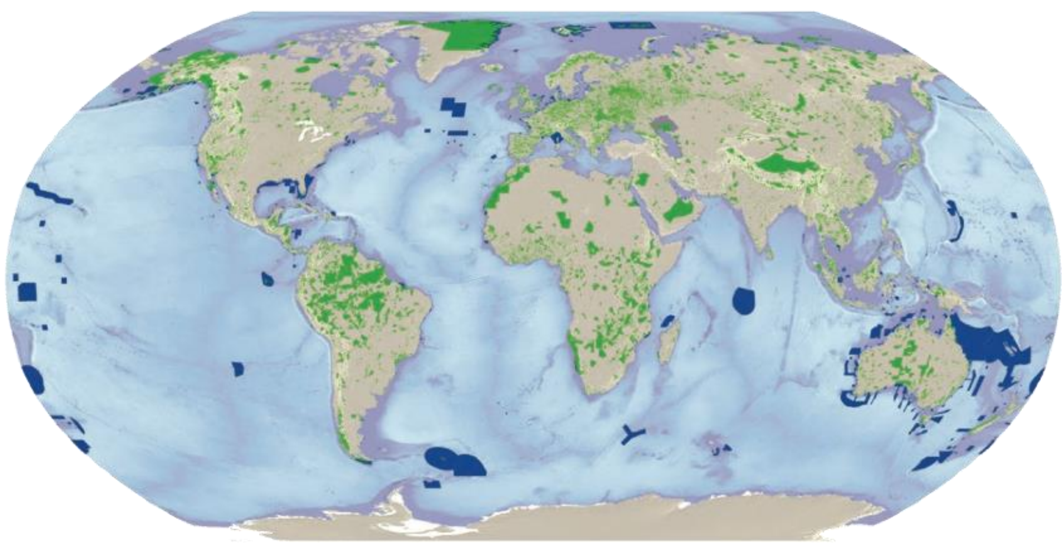
This research aims to expand our understanding of patterns of resource depletion among rural Amazonian communities, which will have practical implications for initiatives to reduce environmental degradation while preserving the right of communities to pursue sustainable livelihoods.

3 Literature Review

3.1 The evolution of the protected area (PA) model

PAs are considered the centerpiece of global conservation strategy. According to the International Union for the Conservation of Nature (IUCN) definition, PAs are intended "[…] to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (IUCN 2008). Figure 1 illustrates the global distribution of PAs. The extent of PAs has increased from 2.4 million to over 32.8 million square kilometers since 1962 (Deguignet *et al.* 2014), although this has not necessarily been met with positive biodiversity trends (Coad *et al.* 2015). At present, 15.4% of terrestrial areas and 8.4% of marine areas are protected under national-level jurisdiction (Watson *et al.* 2016).

Figure 1. Global distribution of terrestrial and marine protected areas (Source: Deguignet 2014)



For over forty years, the IUCN has been developing and updating a classification scheme for PAs, which categorizes land area by varying management and governance types. Generally speaking, the classification scheme can be understood as a spectrum from strictly to non-strictly protected, based on allowed levels of human resource use, visitation, and occupancy. Table 1 provides a broad overview of the seven IUCN PA management categories. The wide breadth of PA categories and their respective conditions points to the complex nature of land management classification, given the diversity of ecological features and human activities within reserve boundaries. It has been argued that less restrictive categories (e.g., category VI, which permits sustainable extraction of natural resources) undermine the original intent of PAs—to preserve biodiversity. However, it is now generally accepted that all categories, including traditionally-managed indigenous territories, make important contributions to conservation efforts (Dudley *et al.* 2014). Conservationists also stress the significance of buffer zones—i.e., areas immediately adjacent to PAs where land use restrictions provide an additional layer of protection—to landscape-level conservation, particularly as PAs are becoming increasingly isolated in human-modified landscapes (Shafer 2015; Weisse & Naughton-Treves 2016). Buffer zones are not a distinct IUCN PA management category but are subject to IUCN classification standards; for example, IUCN categories V and VI may serve as buffer zones to more strictly protected core areas (Dudley 2008).

Table 1. IUCN PA management categories

Categories	Description
Ia: Strict Nature Reserve	Protected area that is strictly controlled, primarily for scientific research and monitoring
Ib: Wilderness Area	Protected area that is unmodified or largely unmodified and managed in such a way that preserves natural conditions
II: National Park	Protected area managed primarily for ecosystem protection and recreation
III: Natural Monument or Feature	Protected area managed primarily for conservation of specific natural or cultural features
IV: Habitat/Species Management Area	Protected area managed primarily for conservation of specific habitats or species, typically through direct management intervention
V: Protected Landscape/Seascape	Protected area managed primarily for landscape/seascape conservation and recreation
VI: Protected area with sustainable use of natural resources	Protected areas managed for the conservation of ecosystems and habitats together with associated cultural values and traditional natural resource management systems

The broadened scope of the conservation agenda to include consideration of cultural values and traditional natural resource management systems reflects lessons learned from historical conservation policy and practice. Traditionally, PAs were modeled after Yellowstone National Park's exclusionary, protectionist approach to conservation (Andrade & Rhodes 2012). Particularly in the developing world, this strategy has been heavily criticized for negatively impacting communities within or neighboring reserve boundaries. The costs of PA establishment—which inform broader inquiry into the compatibility of biodiversity conservation and poverty alleviation objectives—range from restrictions on resource access, and in more extreme cases, displacement of entire communities (Brockington & Igoe 2006). The economic and social costs of PA establishment are not trivial, and are underrepresented and insufficiently treated in the literature (West *et al.* 2006). Cernea & Schmidt-Soltau (2006) investigate 12 case studies from Central African countries, citing total displacement of 100,000 residents due to national park establishment. Forced displacement without clear determination of alternative settlement agreements was found in all but two cases. Beyond physical separation of people from their homes, Ferraro (2002) draws attention to foregone agricultural and forest product opportunities related to the establishment of Ranomafana National Park in Madagascar. Costs were substantial, given the relatively low income of residents, and were unevenly distributed between households. Although resistance to exclusionary conservation policy has gained much ground, the effects of PAs continue to be absorbed by local communities due to involuntary economic displacement (Cardozo 2011).

Inequities associated with exclusionary practices spurred the development of an alternative model—participatory conservation—that seeks to balance biodiversity conservation and poverty alleviation objectives. In the broadest sense, the concept is founded on the tenet that long-term conservation requires involvement from, and creates benefits for, local populations (Brooks *et al.* 2013). Participatory conservation—also known as community-based conservation—is subject to multiple interpretations, depending on the context (Bixler 2015). Rodríguez-Izquierdo and colleagues (2010) propose that conservation is an iterative process that creates opportunities for involvement of multiple stakeholders at different stages including park establishment, management plan development, and management implementation. Using the Cordillera National Park in the Peruvian Amazon as a case study, the authors illustrate how park establishment was not a participatory process and involvement of local communities in development of the park's management plan was limited. Moreover, the success of community-based conservation schemes is locally specific. By way of example, residents located within the Pacaya-Samiria National Reserve depend on aquatic resources as a primary economic activity and food source. Within the reserve, subsistence fishing is allowed, but commercialization of resources requires an approved sustainable management plan. Data from interviews and biological monitoring suggest that community-based management plans improved the status of palm and aquatic species and the well-being of participants. Important tradeoffs are reported, however, such as loss of access to resources during recovery periods and conflict between community members and illegal extractors (Kilbane Gockel & Gray 2009). Another study by Horn and colleagues (2012) reports that sustainable management of aguaje (palm) by two indigenous communities in the Peruvian Amazon is hindered by multiple interacting factors including low resource stocks, market barriers, lack of access to relevant technology and training, and lack of community-level organizational experience. Community-based approaches will inevitably face tradeoffs; however, enormous insights are to be gained from their successes and failures, and solutions must be sought that balance effective action with inclusive decision-making processes.

Dudley and colleagues (2014) argue that the criticism of PAs on the basis of their social costs is overstated, and that newer thinking has supplanted the original PA model on which such criticisms are based. In fact, there is evidence that PA establishment has the potential to generate valuable socioeconomic benefits. For example, a study by Andam and colleagues (2010) attributes poverty reduction to PA establishment in Costa Rica and Thailand. A complementary study demonstrates that poverty reduction in Costa Rica resulted from tourism business opportunities, rather than changes in infrastructure or land cover (Ferraro and Hanauer 2014). Further, evidence from Bolivia maintains that PAs are not associated with poverty traps, nor do they differentially impact indigenous communities (Hanauer & Canavire-Bacarreza 2015). While win-win outcomes will not always be achievable, such studies indicate that there is an appropriate—and attainable—balance to be struck between biodiversity conservation and poverty alleviation. For conservation strategy to be effective, it will need to account for regional and local characteristics such as the level of economic and political stability and empowerment of rural populations in national politics (Oldekop *et al.* 2016). Strict protectionist policy will continue to be necessary and preferred under specific circumstances—such as in the remote, uninhabited interior of PAs—but local community involvement should be maximized to ensure that conservation activities are equitably managed.

3.2 Measuring the effectiveness of PAs in tropical rain forest conservation

The term "paper parks" was coined to describe PAs that fail to achieve conservation agendas due to limited financial and managerial resources. In 1999, an IUCN-commissioned study reported that less than 25% of PAs in 10 developing countries were properly managed (Bonham *et al.* 2008). In the Brazilian Amazon, for example, official PAs frequently lack inspectors, unit managers, and legally recognized management plans (Hall 2011). Similarly, mis- or unmanaged PAs have been reported within the Peruvian system of national PAs due to insufficient funding and staff numbers and inefficient centralized management from Lima (Rodríguez & Young 2000; Bury 2006). While these claims should not be dismissed, evidence from a pantropical assessment conducted by Bruner and colleagues (2001) suggests that the "paper parks" claim is not entirely justified. The results are based on questionnaire responses regarding the severity of five threats—land clearing, hunting, logging, fire, and grazing—covering 93 strictly protected areas across 22 tropical countries. The authors report that PAs have been relatively effective at protecting tropical biodiversity, especially considering limited resources and substantial land-use pressure. Despite such claims, insufficient or unstable funding remains a real, and in some cases formidable, barrier to effective conservation in developing countries (Segerstedt & Grote 2014).

The effectiveness of conservation policy has typically been measured in terms of land cover change—the leading driver of biodiversity loss globally. A regional-scale study from Costa Rica examines the effectiveness of national parks and biological reserves—where land-cover change is explicitly prohibited—as instruments of rain forest conservation (Sánchez-Azofeifa *et al.* 2003). The authors conclude that while deforestation within PA boundaries is negligible, forest loss within 10-km buffer zones is significant. The latter can be detrimental to the PAs, themselves, which function best when connected geographically to other PAs. In cases where buffer zones are both forested and contiguous, the result is a network of PAs and greater biodiversity. However, when buffer zones are deforested, increasing ecological isolation may undermine the ability of adjacent PAs to participate in the network. Similarly, data from the Brazilian Amazon points to evidence of a 'substitution effect', whereby deforestation is shifted from PAs to surrounding buffer zones. This finding could be considered a success if the objective of buffer zones is to relocate activity away from ecologically important areas, but it raises questions about the long-term potential for buffer zones to effectively serve their purpose

(Jusys 2016). A recent study from the Peruvian Amazon corroborates the contribution of buffer zones to landscape-level conservation (Weisse & Naughton-Treves 2016). Based on data from 13 PAs, the authors conclude that buffer zones are measurably reducing deforestation in regions where the pressure of land use change is highest, despite constraints such as ambiguous authority, insufficient budgets, and lack of coordination between national and regional institutions. These examples highlight the tension between economic development and environmental conservation, and thus the need to sharpen our understanding of the precise factors that enable non-exclusionary PA models to deliver conservation benefits.

To this end, researchers have assessed how alternative management strategies perform on a comparative basis in preventing deforestation. For example, Porter-Bolland and colleagues (2011) provide evidence that community-managed forests (CMFs) may be equally, if not more, effective at preventing land clearing than strictly protected forests. The results—based on a meta-analysis of published case studies across the tropics—do not hold for all case studies, highlighting the context-specific nature of PA performance. The authors suggest that deforestation rates in certain CMFs may potentially be due to CMF allocation to regions where the perceived threat of deforestation is lower. Even in the presence of deforestation pressures, certain CMFs were successful at preventing land clearing—e.g., ejidos in Mexico demonstrate the potential for strong working rules to help maintain forest cover in CMFs. Another study, by Nepstad and colleagues (2006), compares the outcomes of inhabited parks versus uninhabited reserves in the Brazilian Amazon and concludes that restriction of deforestation and fires between parks and indigenous territories is not substantially different. That study examines the rate of deforestation and fire incidence at both internal and external boundaries of PAs and calculates their ratios to assess performance of uninhabited parks and inhabited reserves. While parks tend to be established in remote areas where the pressure of deforestation is lower, indigenous territories are established in the active agricultural and logging frontier. Despite high "land use change" pressure at their borders, many indigenous communities effectively inhibit deforestation. Similarly, Nelson & Chomitz (2011) employ matching methods to compare the effectiveness of strict and multiple use PAs. The results indicate that in Latin America and Asia, multi-use PAs are more effective than strict PAs in reducing fire incidence. Where indigenous areas are identified in Latin America, these areas are reported to reduce fire incidence more than any other form of protection. Overall, there is compelling evidence to suggest that the contribution of extractive PAs and indigenous territories to biodiversity conservation is significant.

Oliveira and colleagues' (2007) regional assessment of forest degradation and deforestation rates in the Peruvian Amazon demonstrates that land cover change within forest concessions, native communities, and natural PAs is negligible compared to surrounding areas. While this particular study shows that the performance of native territories is worse than that of PAs, the authors caution that conservation outcomes are site specific and depend on multiple, interacting factors that collectively contribute to deforestation. The authors conclude that land use allocation in combination with remoteness and a complex river network help guard against deforestation. In fact, the tropical rain forest ecosystem of Western Amazonia—which includes parts of Bolivia, Colombia, Ecuador, Peru, and western Brazil—has remained largely intact compared to the eastern Brazilian Amazon. While extractive activities are not new to western Amazonia, recent research draws attention to the intensity of hydrocarbon exploration and production, and the spatial overlap between hydrocarbon concessions and less strictly protected areas and indigenous territories in the region (Finer *et al.* 2008). Current studies evaluating the effectiveness of different types of PAs highlight that understanding the effectiveness requires attention to measures beyond land cover change, and that results vary locally as a function of decision-making processes between multiple stakeholders. Thus, more needs to be understood about the role of locally- and regionally-managed PAs and indigenous territories—those forms of land allocation that are most marginalized within the wider balancing act between conservation and development.

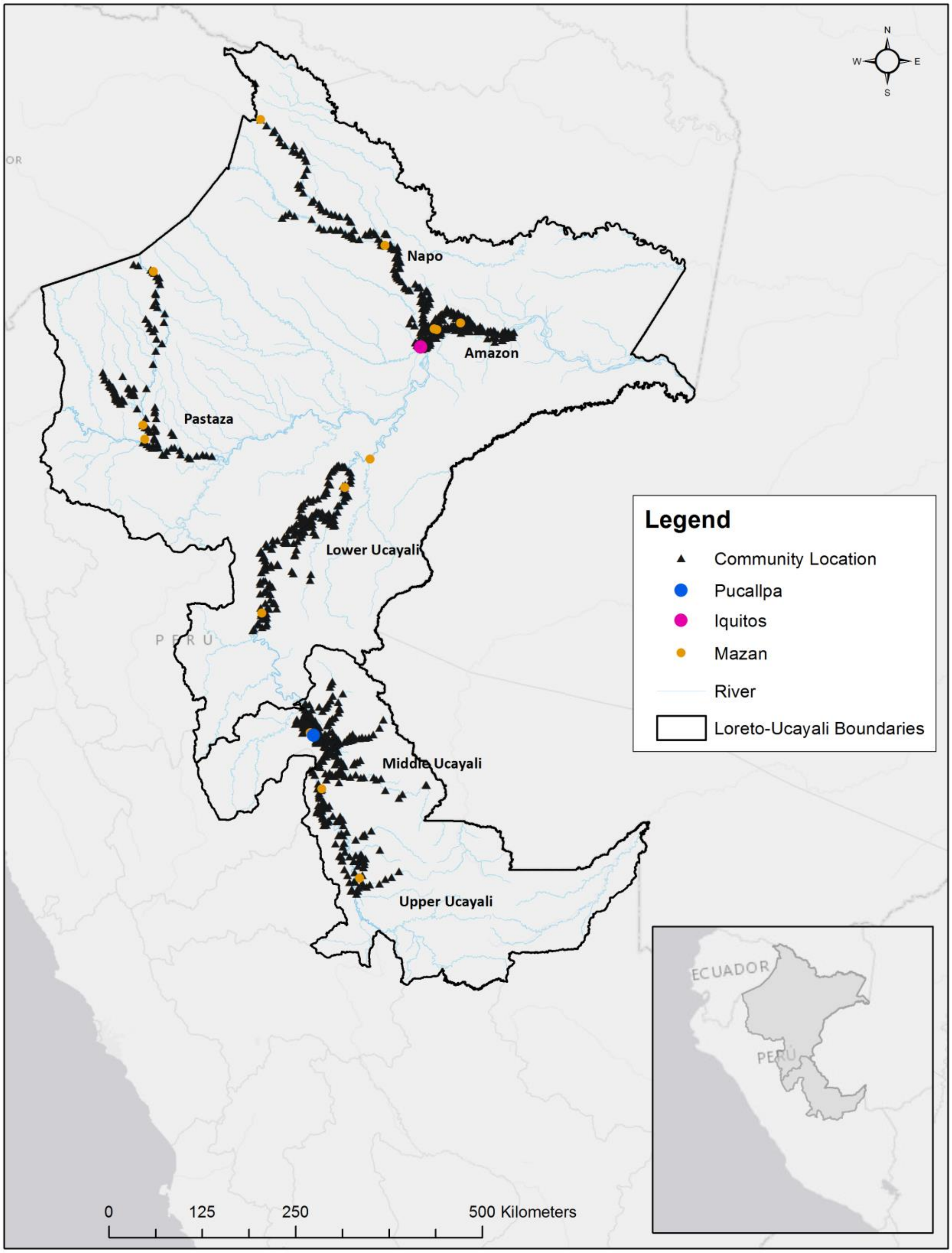
4 Study area, data, and methods

4.1 Study area

The study area is situated in the lowland rain forest of northeastern Peru along four major Amazonian rivers—the Amazon, Napo, Pastaza, and Ucayali—in the administrative regions of Loreto and Ucayali (see Figure 2). The region's physical geography is characterized by tropical forested and riverine ecosystems, which have been shaped by natural and anthropogenic processes (Arce-Nazario 2007). Historically, settlement patterns reflect the region's river network, particularly the annual and seasonal flooding of the Amazonian floodplain (Denevan 1996). The upland and floodplain are ecologically distinct (Arce-Nazario 2007). The floodplain provides fertile soil for agriculture and efficient access to aquatic resources, yet regular flooding makes permanent settlement risky. By comparison, lower soil fertility in the upland is less conducive to agriculture, however there is no risk to flooding and greater access to forest products. The areas where the floodplain and upland meet are thus considered most relevant to permanent settlement.

Intact lowland tropical forest dominates the study area. By 2013, only about seven percent of the region had been deforested and one-quarter is currently under some form of protection. Roads are scarce and thus riverboats serve as the major form of transportation. The two primary urban centers are Iquitos, which is accessible only by air or riverboat, and Pucallpa, which has been connected to Lima by road since the 1940s. Communities include primarily self-identified Amerindian (native) groups and campesinos (i.e., people of mixed descent who have been residing in the Amazon for generations, typically as farmers), as well as small number of colonos (i.e., colonist settlements). Roughly 11% of the region's population self-identify as native, the most populous ethnic groups being Asháninka, Cocama-Cocamilla, Shipibo-Conibo, and Quichua. Communities participate in a variety of subsistence and market-oriented activities, including agriculture, livestock production, fishing, hunting, and timber and non-timber forest product (NTFP) extraction (Coomes *et al.* 2016).

Figure 2. Map of PARLAP study area



4.2 PARLAP data

The present study is based on a community census conducted as part of the PARLAP project—the most extensive survey of rural communities in western Amazonia to date. Data collection at the community level was undertaken in 2013-2014. Survey teams visited 919 communities within the four river sub-basins (see Figure 2) to obtain information on community characteristics (e.g., location in the upland or lowland, ethnicity, etc.), history of settlement and relocation, economic orientation, natural resource endowments, means of communication and transportation, and access to education and health services. The study's regional-scale coverage enabled a diverse range of biophysical and socioeconomic conditions to be captured. Community locations were determined using the 2007 National Census and satellite imagery, and revised as necessary during surveying. Two teams of four Peruvian interviewers conducted the surveys, visiting each community to interview leaders and village elders in a structured questionnaire format.

The questions that pertain most directly to this thesis are related to natural resource endowments. Specifically, informants were asked about the availability (presence/absence and typical harvest yields) of key terrestrial and aquatic species—both at the time of community establishment and at present. Year of community establishment varies widely between communities, with the earliest record of establishment dating back to the middle 16th century and the mean decade of establishment in 1970. Table 2 below lists the local and English names for game, timber, and fish species included in the analysis. These data will serve as metrics for assessing the depletion of natural resources over time.

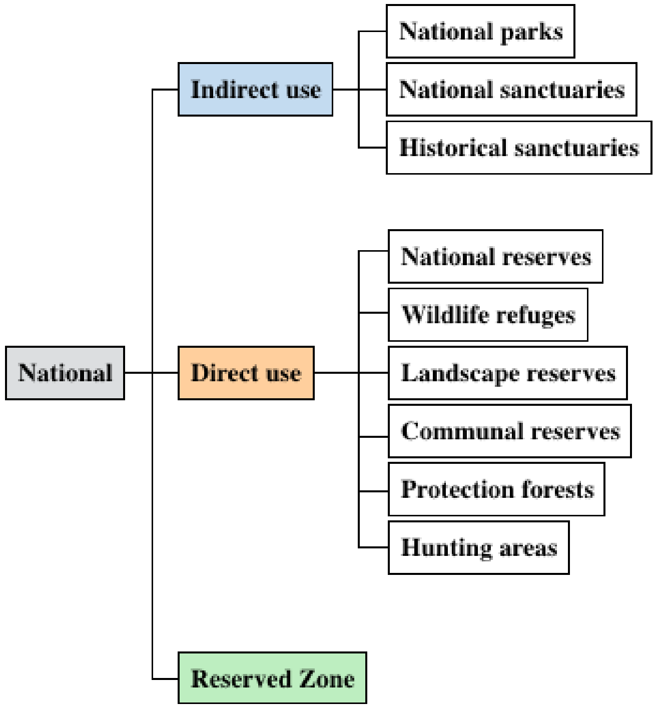
Table 2. Key terrestrial and aquatic species extracted by surveyed communities

	Local Name	English Name
Fish species	Paiche	Arapaima
	Gamitana	Tambaqui
	Paco	Red-bellied pacu
	Tucunare	Peacock bass
	Fasaco	Wolf fish
Game species	Sacha vaca	Tapir
	Huangana	White-lipped peccary
	Sajino	Collared peccary
	Ronsoco	Capybara
	Venado	Brocket deer
	Mono coto	Red howler monkey
	Mono choro	Woolly monkey
	Mono maquisapa	Spider monkey
	Majas	Paca
Timber species	Caoba	Mahogany
	Cedro	Spanish cedar
	Moena	Moena
	Tornillo	Tornillo
	Cumala	Cumala
	Lupuna	Kapok

4.3 Protected area and indigenous territory data

Peru has an extensive system of PAs, administered nationally, regionally, and privately. Figure 3 provides an overview of Peru’s nationally administered PA system, which is managed by the Peruvian National System of Protected Areas, Servicio Nacional de Áreas Naturales Protegidas por el Estado (SERNANP).

Figure 3. Peru's nationally administered PA system



At the national level, PAs are classified as indirect use, direct use, or reserved zone. Indirect use PAs correspond most closely to IUCN category II, permitting research, recreation, and tourism activities, while prohibiting modifications to the natural environment (e.g., natural resource extraction). Direct use PAs, on the other hand, permit natural resource extraction in specific sites, as defined by the PA's management plan. Reserved zones are areas awaiting designation under national protection status. Regional and private conservation areas serve as complementary PAs to Peru's national system of PAs. Regional conservation areas are areas that harbour significant levels of biodiversity but do not qualify for national-level jurisdiction and therefore are managed at the regional (departmental) level (Solano 2009). Private conservation areas (ACPs) include individually-owned and community-based ACPs. As of 2001, the Law on National Protected Areas enables individuals or communities that own land to create ACPs. Under this instrument, indigenous communities may voluntary request that land under their collective ownership be legally recognized (Barnhart 2015). Community-based ACPs correspond closely to national-level communal reserves but are legally distinct. Additional avenues for conservation through Peru's legal system include ecotourism and conservation concessions, which were introduced as part of a forestry law in 2000 (Vuohelainen *et al.* 2012).

Figure 4 shows the location of all the PAs identified within the administrative regions of Loreto and Ucayali, highlighting those that were included in the analysis. PA shapefiles were obtained from the World Database on Protected Areas (WDPA), which is currently the most comprehensive global spatial dataset on PAs available. Information from the Peruvian government was used to verify and complement data from the WDPA on protection status within the study area. PAs were selected for inclusion in the study based on their proximity (in terms of Euclidian distance) to communities. Private conservation areas were excluded due to their small size and given that they are typically managed more for economic development than conservation purposes (Shanee *et al.* 2015). Table 3 provides the name, classification, and year of establishment of those PAs and buffer zones included.

Figure 4. Protected areas selected for inclusion

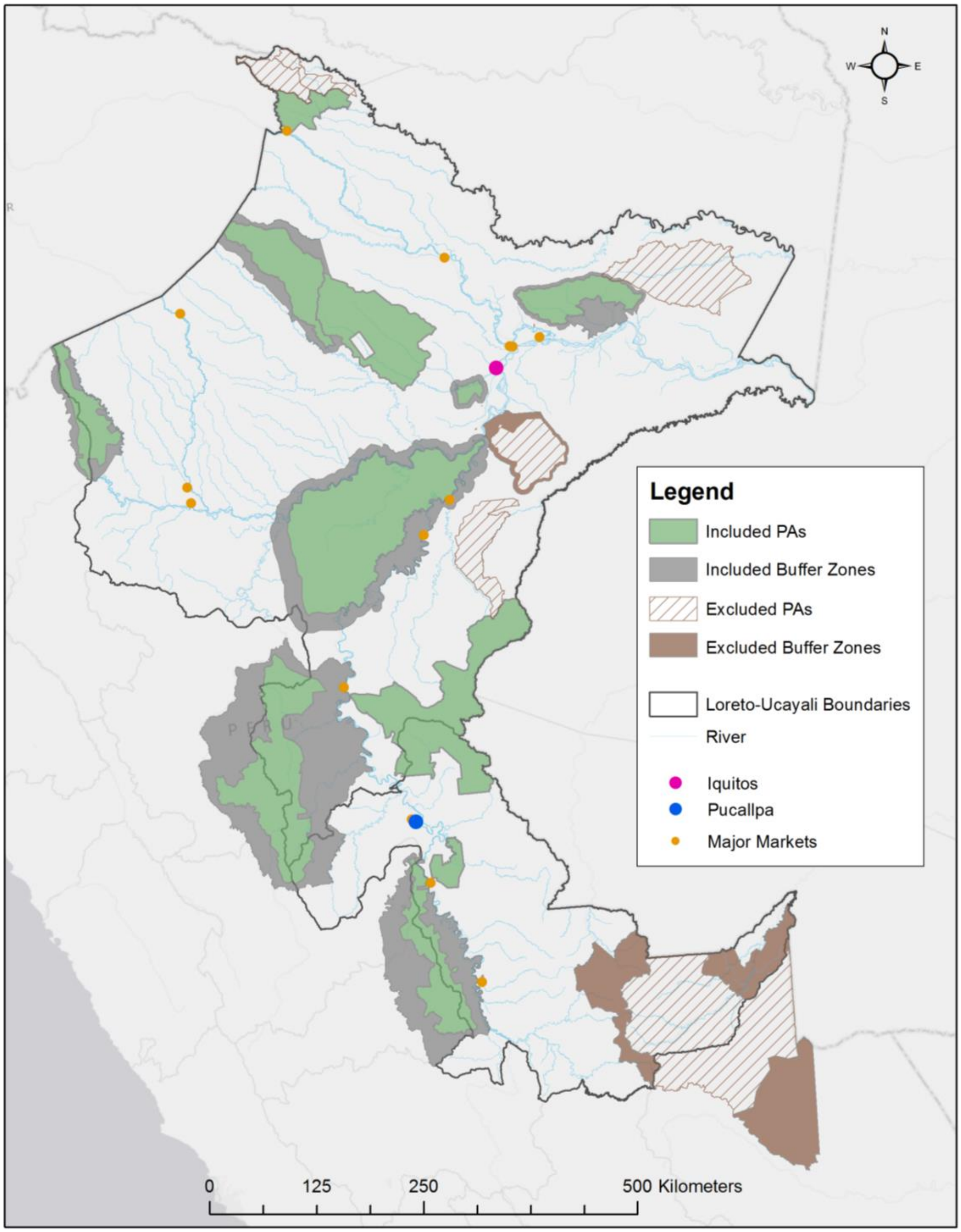


Table 3. List of PAs included in the analysis, their classification, and year of establishment

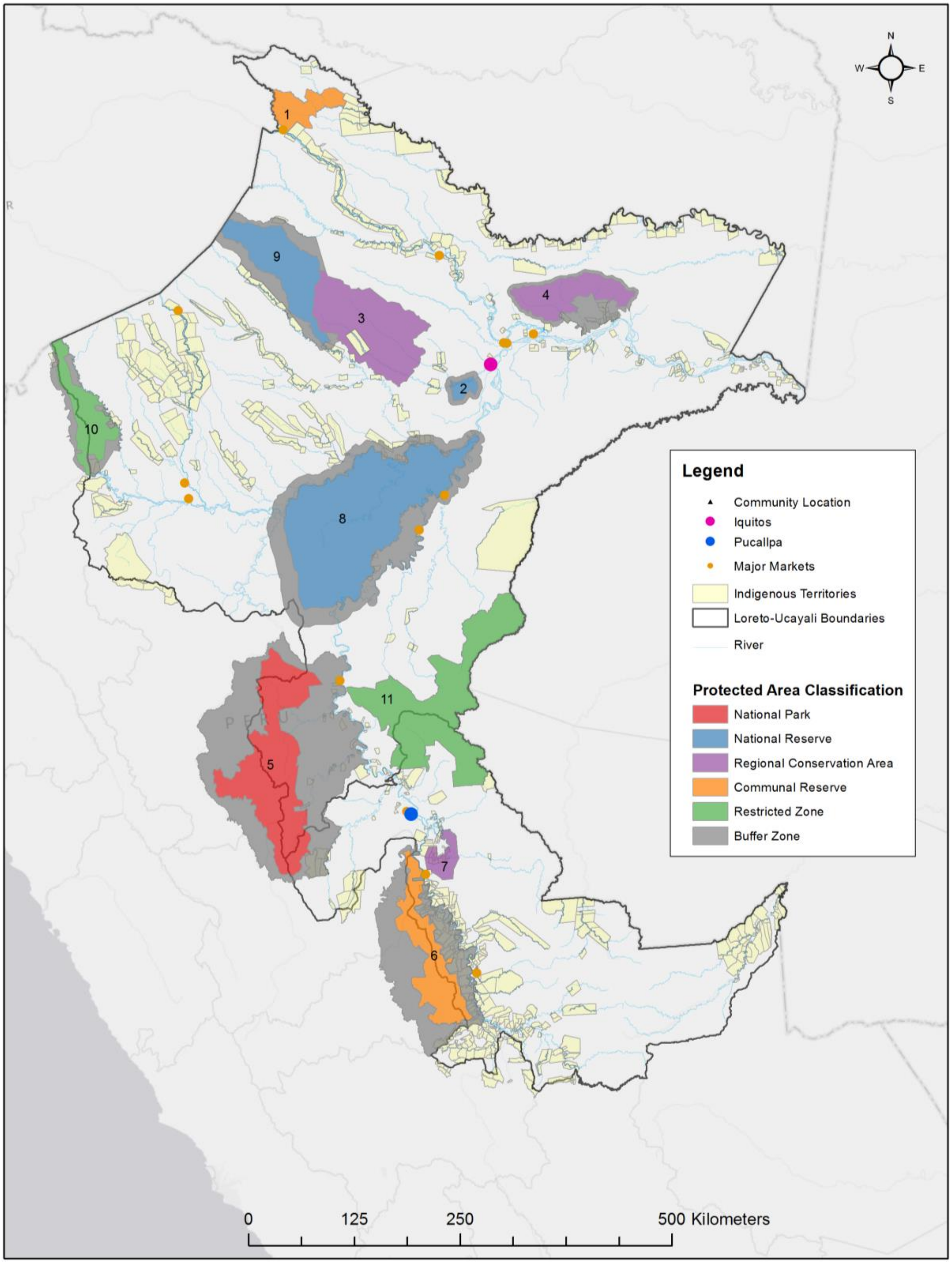
Protected Area	Classification	Year of Establishment
Airo Pai (1)	Communal reserve	2012
Allpahuayo Mishana (2)	National reserve	2004
	Buffer zone	2007
Alto Nanay-Pintuyacu Chambira (3)	Regional conservation area	2011
Ampiyacu Apayacu (4)	Regional conservation area	2010
	Buffer zone	2011
Cordillera Azul (5)	National park	2001
	Buffer zone	2011
El Sira (6)	Communal reserve	2001
	Buffer zone	2009
Imiria (7)	Regional conservation area	2010
Pacaya-Samiria (8)	National reserve	1972
	Buffer zone	2009
Pucacuro (9)	National reserve	2010
	Buffer zone	2013
Santiago-Comaina (10)	Reserved zone	1999
	Buffer zone	2007
Sierra del Divisor (11)	National park; reserved zone	2006

Note: The numbers in parentheses listed next to the PA names above correspond to the label numbers in Figure 5.

Data on indigenous territories, known as *comunidades nativas*, were obtained from the Instituto del Bien Común (IBC). In particular, data is available on whether or not native communities have formal title to their land. In Peru, native community titling was granted following the 1974 Law of Native Communities, which provided legal recognition of indigenous rights over traditionally occupied lands. The majority of land titles were granted immediately following the 1974 law to indigenous communities seeking to secure land tenure and develop sustainable land management strategies (Cuba *et al.* 2014). Since then, legal titling has fluctuated with the ebb and flow of national development policies (Greene 2006). By 2001, 15% of the Peruvian Amazon was formally titled or reserved for indigenous communities (Smith *et al.* 2003), however, these claims continue to be challenged by overlapping agricultural, forestry, and mining interests (Cuba *et al.* 2014).

Within the PARLAP study area, 718 of 919 total communities (78%) are formally recognized by the Peruvian government and roughly half of all native communities have formal title to their land. Figure 5 shows the location of—and in some cases, overlap between—communities, indigenous territories, and PAs selected for inclusion in the study. Of the 919 communities, 174 (18.9%) are located within PAs, including buffer zones. If buffer zones are excluded, only 40 communities (4.4%) are located within PAs.

Figure 5. Location of PARLAP communities, indigenous territories, and protected areas



Note: The label numbers correspond to the following PAs: (1) Airo Pai; (2) Allpahuayo Mishana; (3) Alto Nanay-Pintuyacu Chambira; (4) Ampiyacu Apayacu; (5) Cordillera Azul; (6) El Sira; (7) Imiria; (8) Pacaya-Samiria; (9) Pucacuro; (10) Santiago-Comaina; and (11) Sierra del Divisor.

4.4 Analytical framework

4.4.1 Exploratory analysis of natural resource availability

As an initial step, this study examines general trends in the evolution of natural resource availability over time. Drawing on information from the community census described in section 4.2, proportional values, or indices, were calculated to reflect availability of key natural resources for each community (i.e., the number of species, relative to the total number of key species, that are available) both initially (i.e., at the time of community establishment) and in the present (i.e., at the time of survey in 2013-2014). A third set of indices representing change over time were calculated from initial and present indices. Natural resource availability was compared between communities and sub-basins in terms of terrestrial (game and timber only), aquatic (fish only), and game, timber, and fish species, separately. The indices were further explored based on location within/outside of and proximity to PAs and native territories. In effect, the possible index values range from 0 to 1, where "0" represents "complete absence of key species" and "1" represents "complete presence of key species." In terms of change over time, index values range from -1 to 1, where negative values indicate "depletion" of key species over time and positive values indicate "accretion". Change indices with values close to zero indicate little to no change. Results are discussed in section 5.1.

4.4.2 Cluster analyses

Spatial and cluster analyses were performed in ArcGIS 10.4. The indices represent relative availability of natural resources among rural communities, initially and in the present, allowing spatiotemporal patterns of presence/absence and depletion/accretion of key species to be explored. In order to examine the spatial distribution of natural resource availability, cluster analyses were performed in two stages. To ensure the accuracy of distance values, the data layers were projected using the South America Albers Equal Area Conic projection. Cluster analysis measures the degree of spatial autocorrelation between communities and their associated index values, identifying "clusters" of communities with similarly high or low values, as well as "spatial outliers" whose values are significantly different from their nearest neighbours. Unless otherwise specified, a default distance is automatically computed to ensure that every value is considered with respect to at least one nearest neighbour. The Global Moran's I statistic indicates whether values are clustered, random or dispersed. The statistic ranges from -1 to 1, where a positive statistic indicates clustering and a negative statistic indicates dispersion.

During the first stage, the Spatial Autocorrelation (Global Moran's I) tool was employed to determine whether statistically significant clusters exist across the dataset—e.g., whether there are clusters of communities with relatively low initial availability of certain resources, or that have experienced significant depletion of certain resources. Cluster analyses were performed separately for each of the six sub-basins—the Amazon, Napo, Pastaza, Lower Ucayali, Middle Ucayali, and Upper Ucayali—to ensure that the large distance between sub-basins did not affect the default distance chosen for determining nearest neighbours.

The test for global spatial autocorrelation provides only one measure of clustering for each sub-basin, thus it is important to test for local clustering that contributes to the spatial pattern observed overall at the sub-basin scale. During the second stage, the Cluster and Outlier Analysis (Anselin Local Moran's I) was employed to determine where statistically significant clusters of high or low values and spatial outliers exist in the dataset. The tool returns a Local Moran's I statistic and defines the cluster type as "high-high", "high-low", "low-high", and "low-low". A community classified as "high-high" has a relatively high index value compared to other communities in the dataset and its nearest neighbours (as defined by the default distance) have similarly high values. A community classified as "high-low", on the other hand, is a spatial outlier; it has a relatively high value but is surrounded by communities with low values. The Z score is used for interpretation: if a community has a high positive Z score, it is surrounded by communities with similar values and classified as a "high-high" or "low-low" cluster type. If a community has a low negative Z score, it is a spatial outlier and classified as a "high-low" or "low-high" cluster type.

4.4.3 Correlation and regression analyses

In the final stage of analysis, Pearson correlation and Ordinary Least Squares (OLS) regression analyses were carried out to assess the role of PAs and formal land titles more explicitly in shaping natural resource availability. Aquatic, game, and timber indices for present-day and change over time were taken as dependent variables. Distance to the nearest PA and native land title were taken as predictor variables. Additional control variables and their expected effect on the dependent variables were identified (Table 4). Given the highly migratory nature of certain freshwater aquatic species, it is not unlikely that conservation activities have a differential effect on aquatic versus terrestrial species (Suski & Cooke 2007). If the predictor variable was expected to have a differential effect on resource types, this was noted. Communities were excluded from the correlation and regression analyses if they are colonist settlements (N=13). Additionally, for the correlation analyses, communities that reported positive changes in natural resource availability were excluded to aid interpretation (aquatic: N=19; timber: N=97; game: N=1). Note that these exclusions were made for the correlation and regression analyses only; the exploratory analyses include all 919 samples. The range of change indices was transformed from negative to positive values in order to simplify interpretation; higher values indicate greater depletion. The relationship between predictors and present-day and change indices was assumed to be consistent—i.e., if a positive correlation was expected between a given predictor and a given present-day index, a negative correlation was expected for that same predictor and its associated change index (negative change implies lower levels of depletion when the indices range from 0 to +1).

Change indices were included in the correlation analyses only due to uncertainties inherent in assessing changes in the availability of key species based on community census data. By way of example, community land size and access to upland or lowland are included as control variables, however, the study cannot account for changes in community land size or land access over time. The Pearson correlation test for association—which is appropriate for evaluating the degree of correlation between two or more continuous variables, or between continuous and dichotomous variables—was used to identify the most suitable predictor variables for inclusion in the regression models. While correlation analyses examine crude associations between predictors and dependent variables, regression analyses examine joint associations—that is, the relationship between a given predictor and dependent variable that is conditional on the effect of other predictors. Correlation and regression analyses were performed using STATA 13.1. Robust standard errors, which deal with minor violations of OLS assumptions, and Variance Inflation Factors (VIF), which describe whether multi-collinearity is present, were also computed. According to the rule of thumb, there is evidence of multi-collinearity if the largest VIF is greater than 10 or the mean of all VIFs is significantly larger than 1 (Chaterjee & Hadi 2012).

Table 4. Explanatory variables and their expected effect on natural resource indices

Predictors: Variables of Interest	**Expected Effect on Dependent Variables**
Distance to the nearest PA (km)	***Negative:*** As distance increases, natural resource availability likely decreases. The strength of correlation may be lower for aquatic resources, given that certain freshwater aquatic species may travel beyond PA borders.
Formal land title (0 or 1)	***Positive:*** Indigenous communities solicit legal title to their territory, in part, to implement sustainable land management strategies. Thus, communities that have been granted a formal land title are expected to have higher natural resource availability.
Year of establishment of the nearest PA	***Positive:*** Park management is assumed to improve over time, thus older PAs are likely to be more effective than more recently established PAs. As the age of PAs increases, protection afforded to key species increases, thus natural resource availability likely increases.
Predictors: Control Variables	
Distance to the nearest urban center (km)	***Positive:*** As distance increases, or as a community becomes more remote, natural resource availability likely increases. Given the 'riverscape' nature of the region and the relative importance of fishing to the communities' economies, this correlation is perhaps less evident for aquatic resources.
Community land size (km)[1]	***Positive:*** As community land size increases, natural resource availability likely increases, particularly in terms of terrestrial species.
Access to land in the upland only, lowland only, or both[2] (0 or 1)	***Varying:*** In Amazonia, the distinction between upland and lowland is an important environmental control, given that their ecological and biophysical characteristics differ greatly. Communities with access to upland only are likely to have lower aquatic resource availability, while communities with access to lowland only are likely to have lower terrestrial resource availability. Communities with access to both types of land likely have access to a wider range of species overall, however, it is not clear how this affects access to fish, game, and timber species individually.
Type of community: campesino or native (0 or 1)	***Negative:*** Resource use practices may vary between different ethnicities, thus it is important to control for broad ethnicity-driven variations. Campesino communities are ineligible for land titles and are thus likely to have lower natural resource availability.
Decade of community establishment	***Negative:*** Communities that were established more recently have greater competition for land access and therefore are likely to have lower present-day natural resource availability, particularly in terms of terrestrial species.
Government recognition (0 or 1)	***Negative:*** Communities that have received formal government recognition are likely to have greater integration with the market and lower natural resource availability.
Decade of government recognition	***Negative:*** Based on the above assumption, communities that have had government recognition for a longer period of time are likely to have lower natural resource availability.
Importance of fishing, hunting and timber extraction to the communities' economic activities historically (0 or 1)	***Negative:*** Communities where fishing was historically the most important economic activity are likely to have lower present-day aquatic resource availability and higher depletion of aquatic resources over time. The same logic applies to communities where hunting and timber extraction were historically the most important economic activities.

Notes:
1. The variable for 'community land size' was missing too many values (N=458), therefore 'distance to the nearest community' was used as a proxy for community land size.
2. Two variables generated from the PARLAP survey, 'access to land in the upland' and 'access to land in the lowland' were used to create three dummy variables—'access to land in the upland only', 'access to land in the lowland only', and 'access to both types of land'.

Distance to the nearest PA was calculated for each community as a relative measure of the level of protection afforded to key species by PAs. In doing so, the assumption was made that communities within or in close proximity to PAs benefit from spillover effects of conservation activities, and that this effect can be measured as a function of distance. The assumption is based on the concept of distance-decay, which describes the effect of increasing distance on spatial interactions: generally, as the distance between two locations increases, there is less interaction—or influence—between them. Under this assumption, it is expected that communities within or in close proximity to PAs are likely to report higher natural resource availability, even after controlling for remoteness of community location. Similarly, native communities that have been granted formal land titles are likely to report higher natural resource availability relative to native communities that have not received land titles and campesino communities that are ineligible for land titles. In this way, it is possible to assess the influence of PAs and native land titles separately as avenues for the conservation natural resources.

In terms of proximity to the nearest PA, three measures were calculated for each community: (1) distance to the nearest buffer zone boundary, (2) distance to the nearest PA core area boundary, and (3) distance to the nearest PA centroid. Distances were calculated based on Euclidian distance. PAs are not homogenous entities but rather dynamic socio-ecological systems, deeming it necessary to compare results between multiple measures of distance. Given that management activities of older PAs are likely to be more efficient than those of recently established PAs (Andrade & Rhodes 2012), it is important to consider the date of establishment of neighboring PAs. A similar assumption could be made for land titles, however, the date that communities received formal land titles was not included in the analysis due to issues related to insufficient metadata for the spatial information retrieved from the IBC. Further, the types of activities (e.g., human habitation, resource extraction, etc.) permitted within PA boundaries directly impact the quality of habitat available for key species, and thus it is important to consider classification type of near PAs. Among the PAs selected for inclusion, all are classified as ‘direct use’ regional conservation areas, national reserves, communal reserves, or buffer zones, with the exception of Cordillera Azul National Park, thus PA classification type was not included in the correlation and regression analyses. Given the extent of land use pressure beyond

Cordillera Azul's boundaries and the fact that resource extraction is permitted within certain zones, it was not deemed unreasonable to exclude PA classification from further analysis.

5 Results

5.1 Evolution of natural resource availability: initial, present, and change over time

Figures 6-10 provide an overview of the distribution of the natural resource indices across the study area. The data is presented for all key species and separately for aquatic, game, and timber species. Note that all 919 surveyed communities were included in the exploratory and cluster analyses, while certain communities are excluded from the correlation and regression analyses as described in section 4.4.3. For each category, the number of communities is plotted against index ranges, as listed in the legend. By way of example, slightly fewer than 600 communities reported availability of 75-100% of all key species at time of community establishment. Grouping the data based on index ranges allows us to compare initial and present indices, and a clear trend emerges. The data in Figure 6 show that, at the time of community establishment, a significant proportion of communities reported availability of 75-100% of key species. The data for present-day, on the other hand, are spread more equitably between index ranges, indicating that far fewer communities reported availability of 75-100% of key species in the present. Importantly, as illustrated in Figure 7, the change indices suggest that the vast majority of communities experienced relatively significant depletion of key resources over time. The decline appears to be greatest for fish species (Figure 10). Limited but noteworthy cases of positive change are observed, prompting important questions about wider-scale social and ecological changes that may have contributed to such trends.

Figure 6. Initial and present availability of all key species, PARLAP study area (N=919)

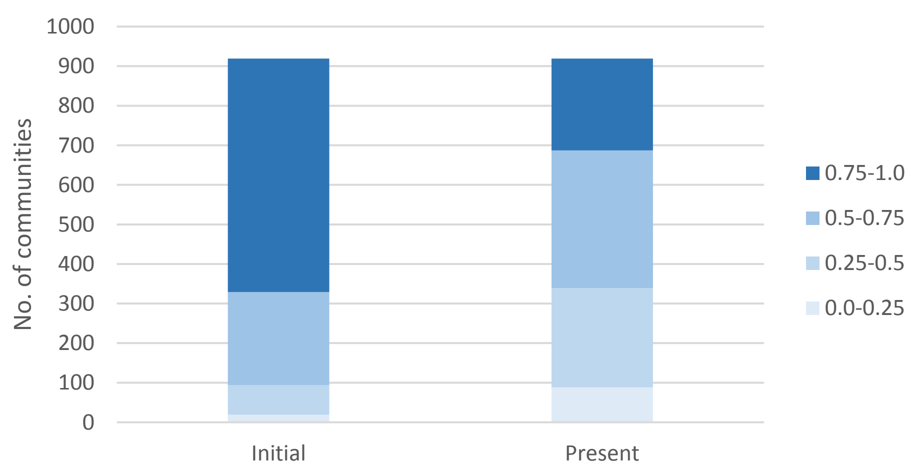


Figure 7. Change in availability of all key species, PARLAP study area (N=919)

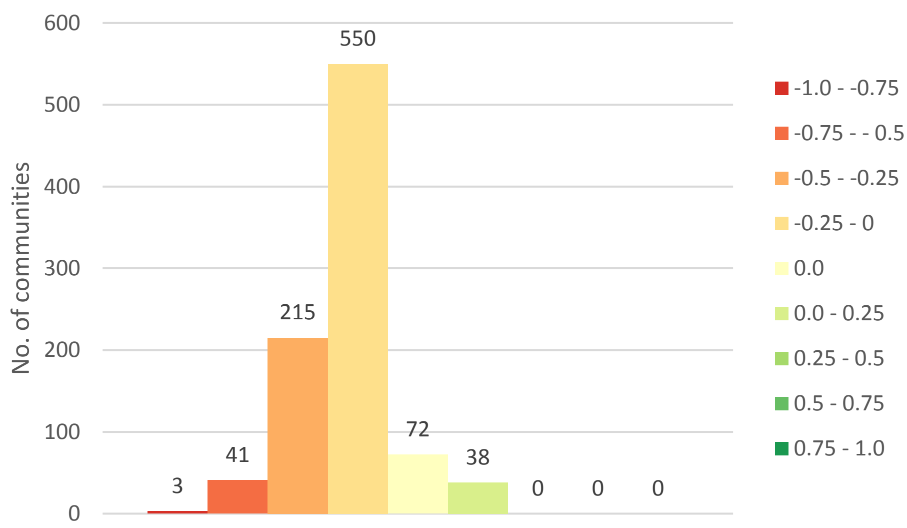
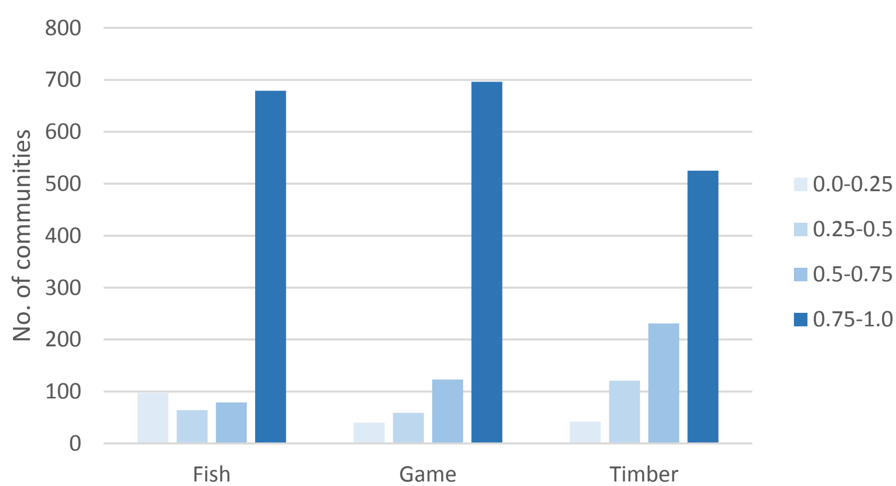
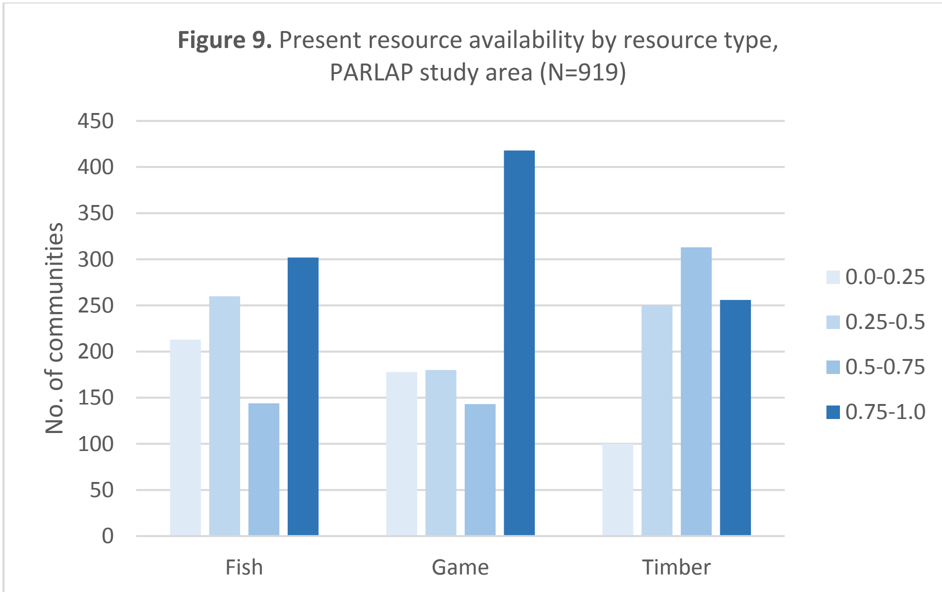
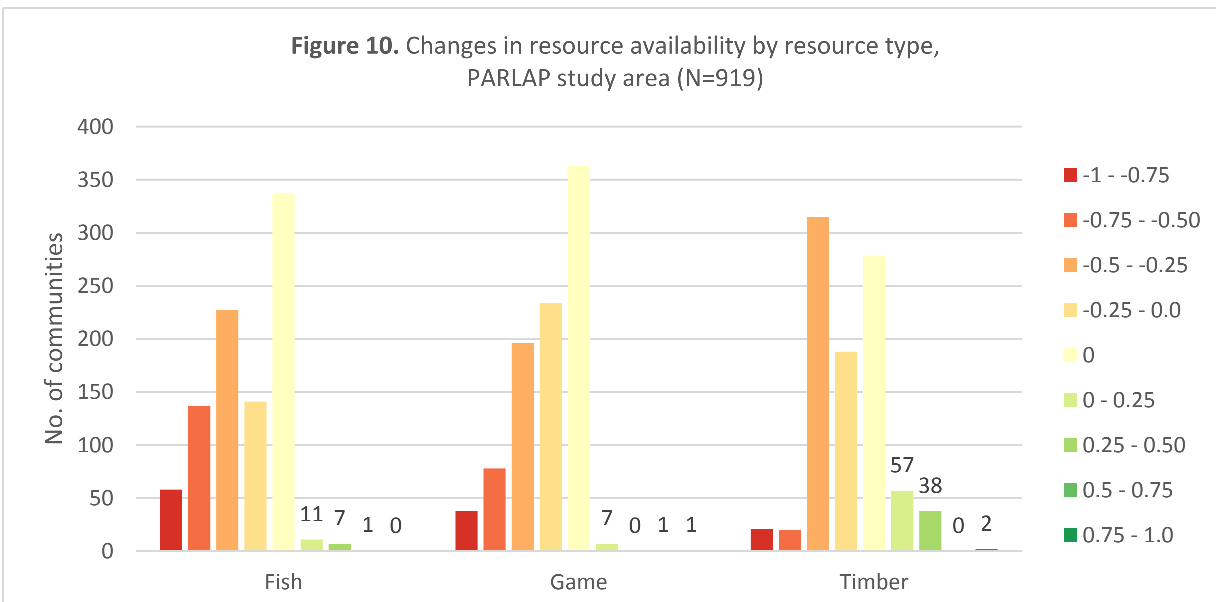


Figure 8. Initial resource availability by resource type, PARLAP study area (N=919)







Tables 5-9 summarize the mean and standard deviation values for initial, present, and change indices of natural resource availability for each sub-basin and for the entire study region. A paired samples t-test was conducted to compare initial and present means (Tables 5b-9b). There was a significant difference between initial and present means for each case, with the exception of timber species in the Lower Ucayali ($p < 0.01$).

Table 5a: Indices—All key species						
	Initial		Present		Change	
	Mean (μ)	Std. Dev. (σ)	Mean (μ)	Std. Dev. (σ)	Mean (μ)	Std. Dev. (σ)
Amazon (N=140)	0.67	0.22	0.40	0.23	-0.27*	0.17
Napo (N=177)	0.80	0.18	0.60	0.19	-0.19*	0.12
Pastaza (N=115)	0.92	0.10	0.77	0.18	-0.15*	0.12
Lower Ucayali (N=176)	0.81	0.11	0.67	0.20	-0.14*	0.16
Middle Ucayali (N=211)	0.80	0.21	0.52	0.21	-0.27*	0.20
Upper Ucayali (N=100)	0.86	0.15	0.67	0.17	-0.19*	0.13
Study Region (N=919)	0.80	0.19	0.59	0.23	-0.21*	0.17

Table 5b: Comparison of means—All key species Initial & Present			
	t	d.f.	p
Amazon (N=140)	18.14	139	0.0000
Napo (N=177)	20.92	176	0.0000
Pastaza (N=115	13.46	114	0.0000
Lower Ucayali (N=176)	11.18	175	0.0000
Middle Ucayali (N=211)	20.31	210	0.0000
Upper Ucayali (N=100)	14.12	99	0.0000
Study Region (N=919)	37.46	918	0.0000

Table 6a: Indices—Terrestrial species						
	Initial		Present		Change	
	Mean (μ)	Std. Dev. (σ)	Mean (μ)	Std. Dev. (σ)	Mean (μ)	Std. Dev. (σ)
Amazon (N=140)	0.66	0.24	0.41	0.25	-0.25*	0.20
Napo (N=177)	0.81	0.20	0.65	0.21	-0.16*	0.15
Pastaza (N=115)	0.94	0.11	0.82	0.18	-0.12*	0.14
Lower Ucayali (N=176)	0.76	0.13	0.64	0.21	-0.12*	0.17
Middle Ucayali (N=211)	0.78	0.25	0.50	0.25	-0.28*	0.21
Upper Ucayali (N=100)	0.88	0.17	0.71	0.20	-0.17*	0.15
Study Region (N=919)	0.79	0.21	0.61	0.26	-0.19*	0.19

Table 6b: Comparison of means—Terrestrial species Initial & Present			
	t	d.f.	p
Amazon (N=140)	14.71	139	0.0000
Napo (N=177)	14.98	176	0.0000
Pastaza (N=115)	8.91	114	0.0000
Lower Ucayali (N=176)	9.34	175	0.0000
Middle Ucayali (N=211)	19.52	210	0.0000
Upper Ucayali (N=100)	11.32	99	0.0000
Study Region (N=919)	30.90	918	0.0000

Table 7a: Indices—Aquatic species						
	Initial		Present		Change	
	Mean (μ)	Std. Dev. (σ)	Mean (μ)	Std. Dev. (σ)	Mean (μ)	Std. Dev. (σ)
Amazon (N=140)	0.68	0.42	0.37	0.29	-0.31*	0.31
Napo (N=177)	0.75	0.32	0.47	0.33	-0.29*	0.27
Pastaza (N=115	0.87	0.25	0.62	0.31	-0.25*	0.26
Lower Ucayali (N=176)	0.95	0.18	0.77	0.29	-0.18*	0.25
Middle Ucayali (N=211)	0.81	0.30	0.52	0.29	-0.29*	0.28
Upper Ucayali (N=100)	0.75	0.33	0.48	0.33	-0.27*	0.27
Study Region (N=919)	0.81	0.32	0.54	0.33	-0.26*	0.28

Table 7b: Comparison of Means—Aquatic species Initial & Present			
	t	d.f.	p
Amazon (N=140)	11.63	139	0.0000
Napo (N=177)	14.21	176	0.0000
Pastaza (N=115)	10.52	114	0.0000
Lower Ucayali (N=176)	9.46	175	0.0000
Middle Ucayali (N=211)	15.27	210	0.0000
Upper Ucayali (N=100)	9.95	99	0.0000
Study Region (N=919)	28.98	918	0.0000

Table 8a: Indices—Game species						
	Initial		Present		Change	
	Mean (μ)	Std. Dev. (σ)	Mean (μ)	Std. Dev. (σ)	Mean (μ)	Std. Dev. (σ)
Amazon (N=140)	0.64	0.28	0.36	0.28	-0.28*	0.25
Napo (N=176)	0.80	0.23	0.68	0.28	-0.12*	0.21
Pastaza (N=115)	0.95	0.12	0.88	0.23	-0.07*	0.18
Lower Ucayali (N=176)	0.83	0.14	0.60	0.26	-0.24*	0.23
Middle Ucayali (N=211)	0.80	0.25	0.50	0.31	-0.30*	0.26
Upper Ucayali (N=100)	0.90	0.16	0.75	0.23	-0.15*	0.17
Study Region (N=918)	0.81	0.23	0.61	0.31	-0.20*	0.24

Table 8b: Comparison of means—Game species Initial & Present			
	t	d.f.	p
Amazon (N=140)	12.93	139	0.0000
Napo (N=176)	7.61	175	0.0000
Pastaza (N=115)	4.20	114	0.0000
Lower Ucayali (N=176)	13.49	175	0.0000
Middle Ucayali (N=211)	16.62	210	0.0000
Upper Ucayali (N=100)	8.83	99	0.0000
Study Region (N=918)	25.70	917	0.0000

Table 9a: Indices—Timber species						
	Initial		Present		Change	
	Mean (μ)	Std. Dev. (σ)	Mean (μ)	Std. Dev. (σ)	Mean (μ)	Std. Dev. (σ)
Amazon (N=140)	0.70	0.28	0.49	0.29	-0.21*	0.24
Napo (N=177)	0.84	0.23	0.61	0.21	-0.23*	0.22
Pastaza (N=115)	0.93	0.16	0.74	0.21	-0.19*	0.20
Lower Ucayali (N=176)	0.65	0.18	0.70	0.20	0.05	0.21
Middle Ucayali (N=211)	0.75	0.30	0.49	0.28	-0.26*	0.26
Upper Ucayali (N=100)	0.86	0.22	0.66	0.24	-0.20*	0.20
Study Region (N=919)	0.78	0.26	0.60	0.26	-0.17*	0.25

Table 9b: Comparison of means—Timber species Initial & Present			
	t	d.f.	p
Amazon (N=140)	10.55	139	0.0000
Napo (N=177)	13.92	176	0.0000
Pastaza (N=115)	10.19	114	0.0000
Lower Ucayali (N=176)	-3.30	175	0.9994
Middle Ucayali (N=211)	14.50	210	0.0000
Upper Ucayali (N=100)	9.87	99	0.0000
Study Region (N=919)	20.60	918	0.0000

*p < 0.01

Per community reports, availability of natural resources across the entire study region has, on average, declined by approximately 21% since the time of community establishment (Table 5). Availability of terrestrial and aquatic resources, specifically, has been reduced by 19% and 26%, respectively (Tables 5a & 6a). Historically, relatively wide variations in availability of key resources exist between sub-basins. Reports from the Amazon sub-basin indicate that initial availability of all key resources ranges between 64 and 70%, compared to 65-95% across the other sub-basins. Across all categories (e.g., all key species, terrestrial, aquatic, etc.), the data indicate that natural resource availability in the Amazon, both initially and in the present, is lower relative to the other sub-basins. However, there is considerable variation between communities within the Amazon, particularly with respect to initial availability of aquatic resources ($\mu = 0.68$; $\sigma = 0.42$), although this variability is less relevant in the present ($\mu = 0.37$; $\sigma = 0.29$). By comparison, initial availability of aquatic resources in the Lower Ucayali is quite high, on average, and there is less variation between communities ($\sigma = 0.18$). Interestingly, present availability of aquatic resources in the Lower Ucayali is less equitable across communities ($\sigma = 0.29$). In terms of game and timber species, it appears that initial abundance was highest in the Pastaza and Upper Ucayali. For present-day, however, timber abundance is highest in the Pastaza and Lower Ucayali (Tables 8a and 9a).

Across the study region, the change indices are consistently negative values, demonstrating that natural resource availability is lower in the present (at the time of survey) compared to initially (at the time of community establishment). The sole exception is with respect to timber resources in the Lower Ucayali, which experienced a slight positive change overall. Greatest depletion among communities in the Amazon and Middle Ucayali highlights the potential role of proximity to urban markets in driving such changes, and thus the implications of location for rainforest conservation and poverty. In terms of conservation efforts, it is important to consider which species contributed most to the observed declines. Table 10 below summarizes the percentage of communities that reported declines by species, based on those that had access to the resource at the time of community establishment. Decline in mahogany and arapaima is most striking, with 45% and 41% of all communities reporting declines in each, respectively. Notable declines are also observed in white-lipped peccary, tapir, Spanish cedar, and red-bellied pacu species.

Table 10. Percentage of communities reporting declines by species

Resource Type	English Name	Percentage (%) of communities reporting declines
Fish	Arapaima	41.02
	Red-bellied pacu	34.97
	Tambaqui	29.41
	Wolf fish	15.14
	Peacock bass	14.92
Game	White-lipped peccary	33.01
	Tapir	32.68
	Brocket deer	25.82
	Collared peccary	25.49
	Spider monkey	19.17
	Woolly monkey	17.86
	Capybara	13.40
	Red howler monkey	13.07
	Paca	8.93
Timber	Mahogany	44.83
	Spanish cedar	35.69
	Moena	21.98
	Cumala	11.43
	Kapok	11.43
	Tornillo	7.51

5.2 Evidence for spatial clustering

Tables 11-16 summarize the results from the test for global spatial autocorrelation, indicating whether statistically significant clustering of similar values occurs in each sub-basin—for example, whether communities with relatively high or low initial natural resource availability, or that have experienced considerable positive or negative change, tend to be spatially clustered. As shown in tables 11-16, statistically significant clustering is detected within every sub-basin, with the exception of the Upper Ucayali. However, the degree (or strength) of clustering varies widely across resource types (e.g., terrestrial, aquatic, etc.), time periods (initial, present, or change), and sub-basins. By way of example, where clustering is detected in the Amazon sub-basin, the strength of that clustering is greater than in other sub-basins, with an average Moran's Index value (I) of 0.42. In the Napo and Lower Ucayali sub-basins, on the other hand, the strength of clustering is relatively weak, with a maximum Moran's Index value of 0.18 and 0.17, respectively. It is important to note that all datasets were tested individually for skewness and a skewness threshold of +/- 2 was applied (George & Mallery 2010). If skewness was found to beyond the acceptable threshold, results of the cluster analyses were not interpreted, as specified in the 'Interpretation' column in the tables below.

Table 11. Global Moran's I Summary: Amazon

	Moran's Index (*I*)	z-score	p-value	Interpretation
Terrestrial				
Initial	0.426198	2.021695	0.043208**	Clustered
Present	0.284784	1.358707	0.17424	Random
Change	0.274233	1.314091	0.188816	Random
Aquatic				
Initial	0.094776	0.473969	0.635522	Random
Present	0.44726	2.118345	0.034146**	Clustered
Change	-0.233206	-1.049948	0.293742	Random
Game				
Initial	0.409056	1.939642	0.052423**	Clustered
Present	0.255671	1.223791	0.221031	Random
Change	0.151227	0.738075	0.460469	Random
Timber				
Initial	0.2421	1.164261	0.244318	Random
Present	0.224455	1.077573	0.281224	Random
Change	0.157179	0.766736	0.443239	Random

Table 12. Global Moran's I Summary: Napo

	Moran's Index (*I*)	z-score	p-value	Interpretation
Terrestrial				
Initial	0.112773	5.360318	0***	Clustered
Present	0.071411	3.464575	0.000531***	Clustered
Change	-0.012566	-0.310769	0.755976	Random
Aquatic				
Initial	-0.013099	-0.33308	0.739074	Random
Present	0.039311	2.0137	0.044041**	Clustered
Change	0.066028	3.214227	0.001308***	Clustered
Game				
Initial	0.058749	2.903965	0.003685***	Clustered
Present	0.171787	7.955992	0***	Clustered
Change	0.018598	1.098896	0.271814	Random
Timber				
Initial	0.112954	5.344575	0***	Clustered
Present	-0.014185	-0.014185	0.701798	Random
Change	0.18411	8.550436	0***	Clustered

Table 13. Global Moran's I Summary: Pastaza

	Moran's Index (*I*)	z-score	p-value	Interpretation
Terrestrial				
Initial	0.274363	4.404427	0.000011***	No interpretation (skewed)
Present	0.296887	4.636173	0.000004***	Clustered
Change	0.111542	1.853189	0.063855*	Clustered
Aquatic				
Initial	0.207982	3.347735	0.000815***	No interpretation (skewed)
Present	0.309291	4.781557	0.000002***	Clustered
Change	0.033847	0.641162	0.521417	Random
Game				
Initial	0.217045	3.627161	0.000287***	No interpretation (skewed)
Present	0.299223	4.708863	0.000002***	No interpretation (skewed)
Change	0.18698	3.053957	0.002258***	No interpretation (skewed)
Timber				
Initial	0.162962	2.708352	0.006762***	No interpretation (skewed)
Present	0.175076	2.782846	0.005388***	Clustered
Change	0.130014	2.092837	0.036364**	Clustered

Table 14. Global Moran's I Summary: Lower Ucayali

	Moran's Index (*I*)	z-score	p-value	Interpretation
Terrestrial				
Initial	0.101033	1.655701	0.097782*	Clustered
Present	0.020841	0.410656	0.681325	Random
Change	0.11979	1.944101	0.051883*	Clustered
Aquatic				
Initial	0.054891	0.989786	0.322279	No interpretation (skewed)
Present	0.105943	1.728639	0.083874*	Clustered
Change	0.100126	1.638276	0.101364	Random
Game				
Initial	-0.018454	-0.198118	0.842953	Random
Present	-0.00164	0.062954	0.949804	Random
Change	0.031047	0.568644	0.569597	Random
Timber				
Initial	0.165389	2.656051	0.007906*	Clustered
Present	0.0565	0.96731	0.333389	Random
Change	0.12029	1.956778	0.050374*	Clustered

Table 15. Global Moran's I Summary: Middle Ucayali

	Moran's Index (*I*)	z-score	p-value	Interpretation
Terrestrial				
Initial	0.349049	8.111209	0***	Clustered
Present	0.388559	8.978427	0***	Clustered
Change	0.238292	5.558534	0***	Clustered
Aquatic				
Initial	0.197096	4.628353	0.000004***	Clustered
Present	0.108626	2.588385	0.009643***	Clustered
Change	0.258966	6.03352	0***	Clustered
Game				
Initial	0.256819	5.998988	0***	Clustered
Present	0.517583	11.915386	0***	Clustered
Change	0.329169	7.633043	0***	Clustered
Timber				
Initial	0.44426	10.290964	0***	Clustered
Present	0.202545	4.737493	0.000002***	Clustered
Change	0.154997	3.669514	0.000243***	Clustered

Table 16. Global Moran's I Summary: Upper Ucayali

	Moran's Index (*I*)	z-score	p-value	Interpretation
Terrestrial				
Initial	0.293851	0.684718	0.493522	No interpretation (skewed)
Present	-0.673733	1.450383	0.146952	Random
Change	0.421134	0.947716	0.343274	Random
Aquatic				
Initial	0.135812	0.317971	0.750507	Random
Present	-0.117995	-0.233727	0.815197	Random
Change	-0.053714	-0.094529	0.924689	Random
Game				
Initial	1.904991	4.355365	0.000013***	No interpretation (skewed; *I* outside acceptable range)
Present	-0.202547	-0.419337	0.67497	Random
Change	0.385689	0.863246	0.388002	Random
Timber				
Initial	-1.104936	-2.432354	0.015001	No interpretation *(I* outside acceptable range)
Present	-0.849405	-1.832352	0.066899*	Dispersed
Change	0.151576	0.355609	0.722134	Random

*p < 0.1; **p <0.05; ***p <0.01

Notes:

1. The data is interpreted as "clustered" only if the p-value is below the threshold value of 0.1.
2. Default distances were automatically generated for each sub-basin to ensure each feature had at least one neighbour, as follows: Amazon: 7.33 km; Napo: 47.98 km; Pastaza: 17.63 km; Lower Ucayali: 7.99 km; Middle Ucayali: 16.78 km; Upper Ucayali: 22.1 km

Figure 11 helps visualize the relative strength of clustering of present aquatic resources in the neighbouring Napo and Amazon sub-basins. In the Napo sub-basin (Figure 11A), clustering was found to be statistically significant with a Moran's Index value of 0.039. The strength of clustering is so modest that no clear spatial pattern is apparent from visual interpretation. In the Amazon sub-basin (Figure 11B), by comparison, a higher Moran's Index value of 0.45 is returned, indicating a greater degree of clustering. Although there are reports of low availability of present aquatic resources dispersed throughout most of the Amazon sub-basin, there appears to be lower availability of aquatic resources overall among communities in the western segment of the main river, closer to the urban center of Iquitos. These patterns are confirmed by the results from the test for local spatial autocorrelation, which detects where clusters exist locally (Figure 12). In the Amazon sub-basin, clusters of low values surrounded by similarly low values (i.e., low-low clusters) are detected in the western segment of the river. Additionally, high-high clusters are observed on the eastern segment of the river, south of Ampiyacu Apayacu regional conservation area. In the Napo sub-basin, low-low clusters are detected only midway downstream (about 180 km northwest of Iquitos) and high-high clusters are detected near Iquitos, suggesting that there are perhaps different factors shaping natural resource availability in each sub-basin, other than proximity to Iquitos.

Figure 11. Global clustering of aquatic resources in the Napo and Amazon (present)

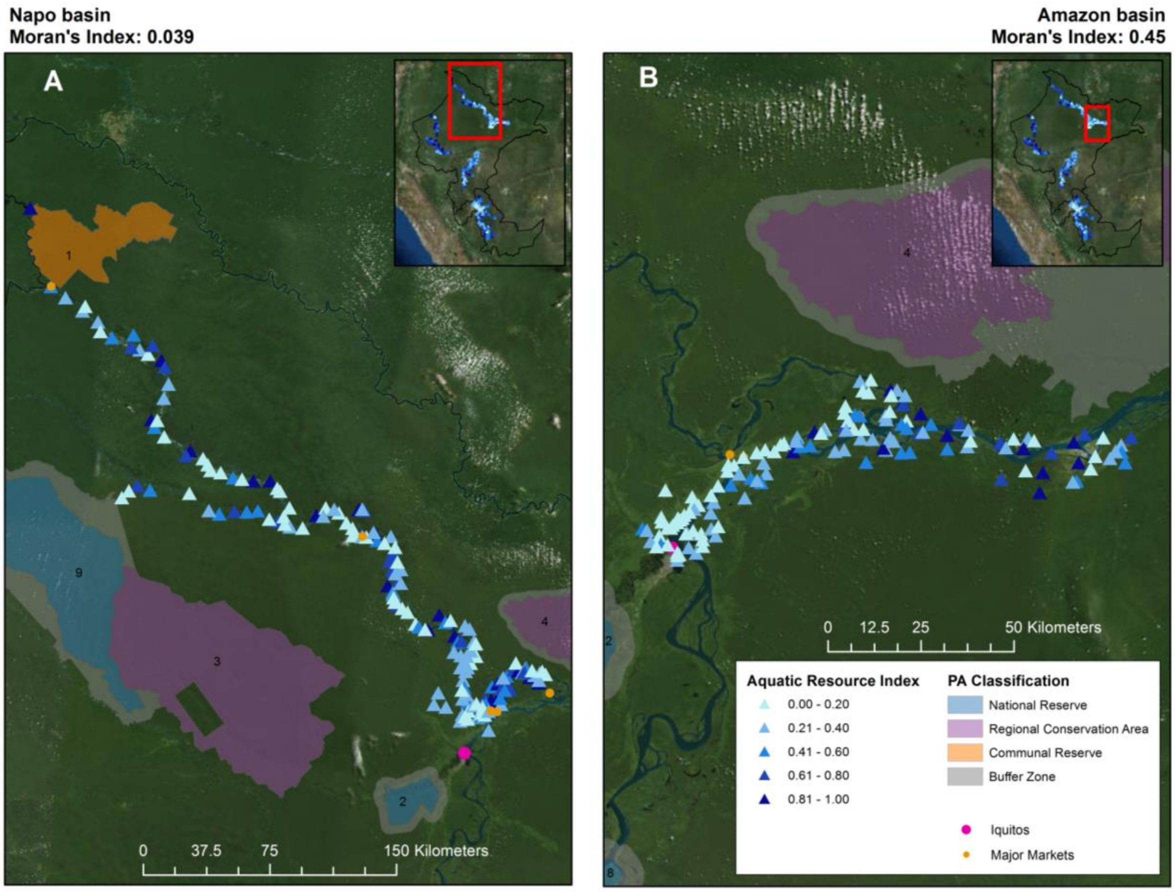
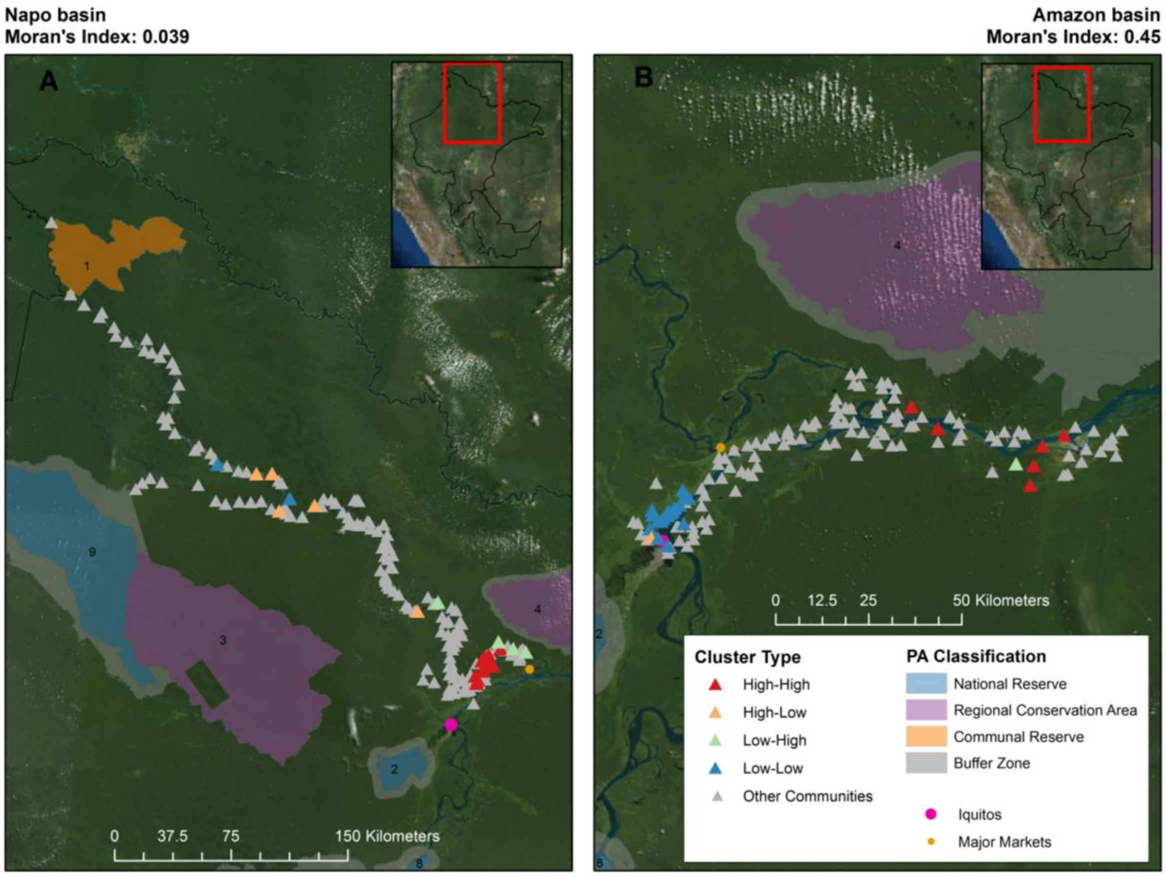
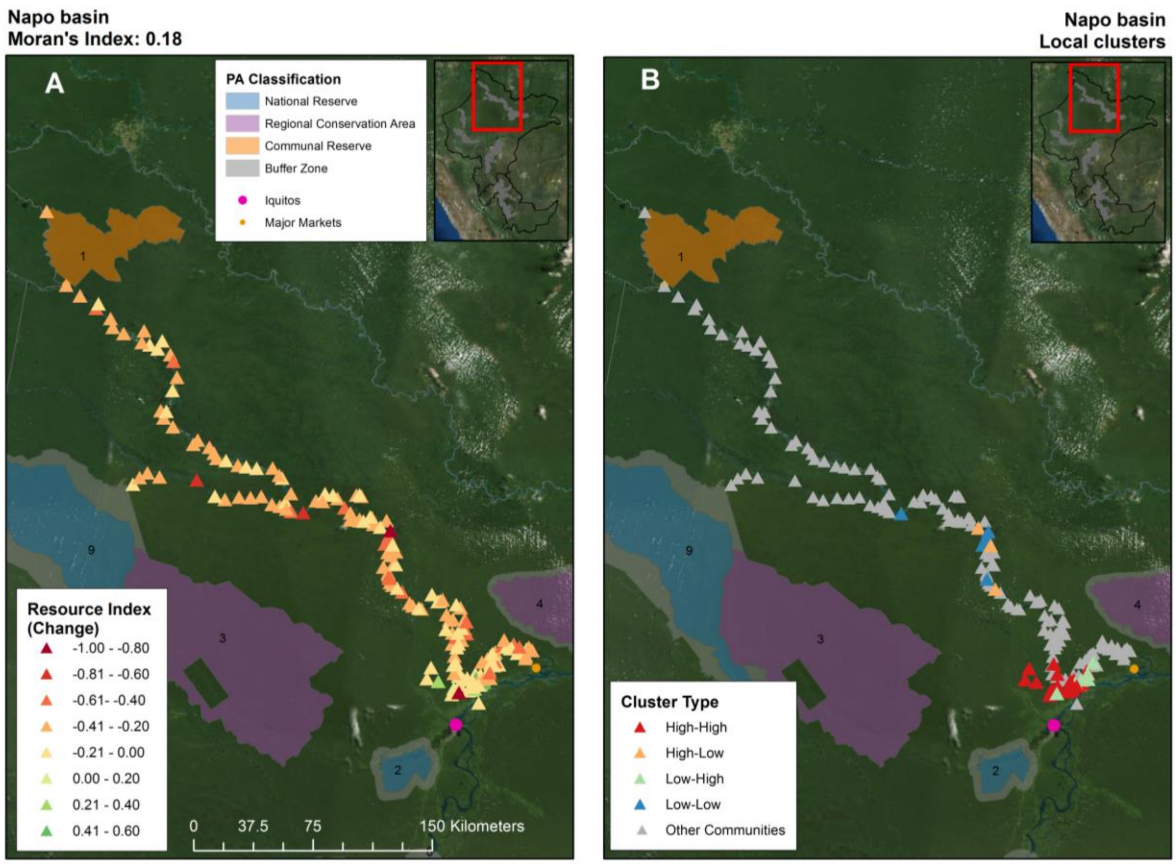


Figure 12. Local clustering of aquatic resources in the Napo and Amazon (present)



In the Napo sub-basin, clustering is detected across several resource types and time periods, however the strength of clustering remains low. The greatest degree of clustering is detected for change in timber resource availability (I = 0.18). Figure 13A illustrates how the change index varies across the sub-basin. Keep in mind that, in this case, the index values represent change over time (i.e. the difference between the time of community establishment and the present): a low negative value indicates "depletion" while a high positive value indicates "accretion", represented by red and green, respectively. Yellow represents little or no change in the presence of key timber species. Accordingly, a low-low cluster represents a community that experienced considerable negative change, surrounded by other communities that experienced similar negative change. Overall, the data indicates a decline in timber species availability among communities, yet particularly severe decline is observed among Nuevo Tiwinisa, Nuevo San Roque, Diamante Azul, and Nueva Bellavista communities. Interestingly, there appear to be significant reports of minimal depletion to no change of timber species near Iquitos, and a few instances of positive change. The results of the local test for spatial autocorrelation confirm this pattern, highlighting several high-high clusters (Figure 13B). In the same area, a few low-high outliers are noted. The results raise important questions about the factors contributing to the observed spatial patterns; again, if proximity to urban center plays a decisive role in shaping natural resource availability, high-high clusters would not necessarily be expected near Iquitos.

Figure 13. Global and local clustering of change in timber resources in the Napo



In the Middle Ucayali sub-basin, statistically significant clustering is detected for all key species categories, with the strength of clustering ranging widely from 0.11 to 0.52. The highest degree of spatial clustering in the Middle Ucayali, and across the entire study area, is observed for present game resources (I = 0.52). Visually, the strength of this clustering is apparent (Figure 14); communities reporting low present-day availability of game are densely concentrated along the main river channel, and availability gradually increases along the more remote tributaries spreading north- and south-east towards Sierra del Divisor restricted zone and Imiria regional conservation area. The test for local spatial autocorrelation decisively confirms this pattern (Figure 15). Importantly, several high-high clusters are observed within and in close proximity to Imiria regional conservation area, highlighting the potential role of conservation strategy within Imiria in protecting key species.

Figure 14. Global clustering of game resources in the Middle Ucayali (present)

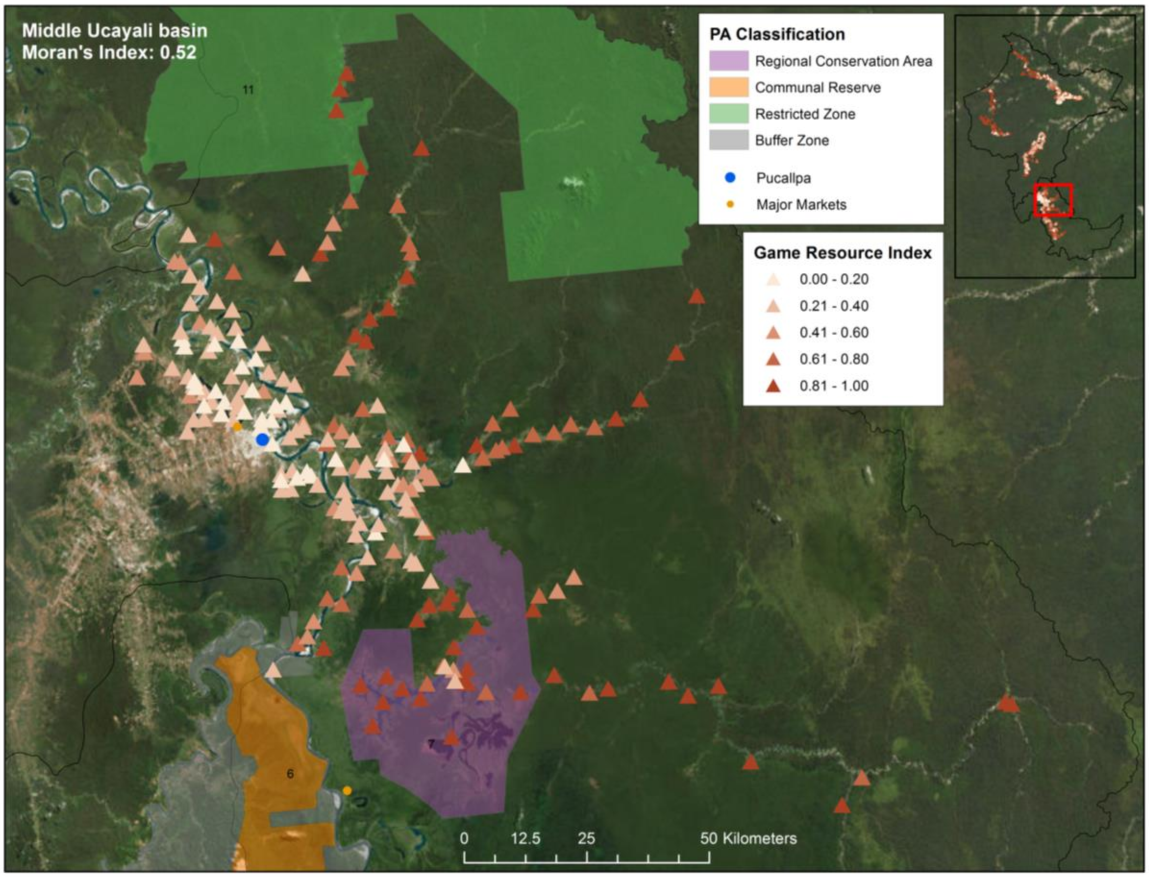
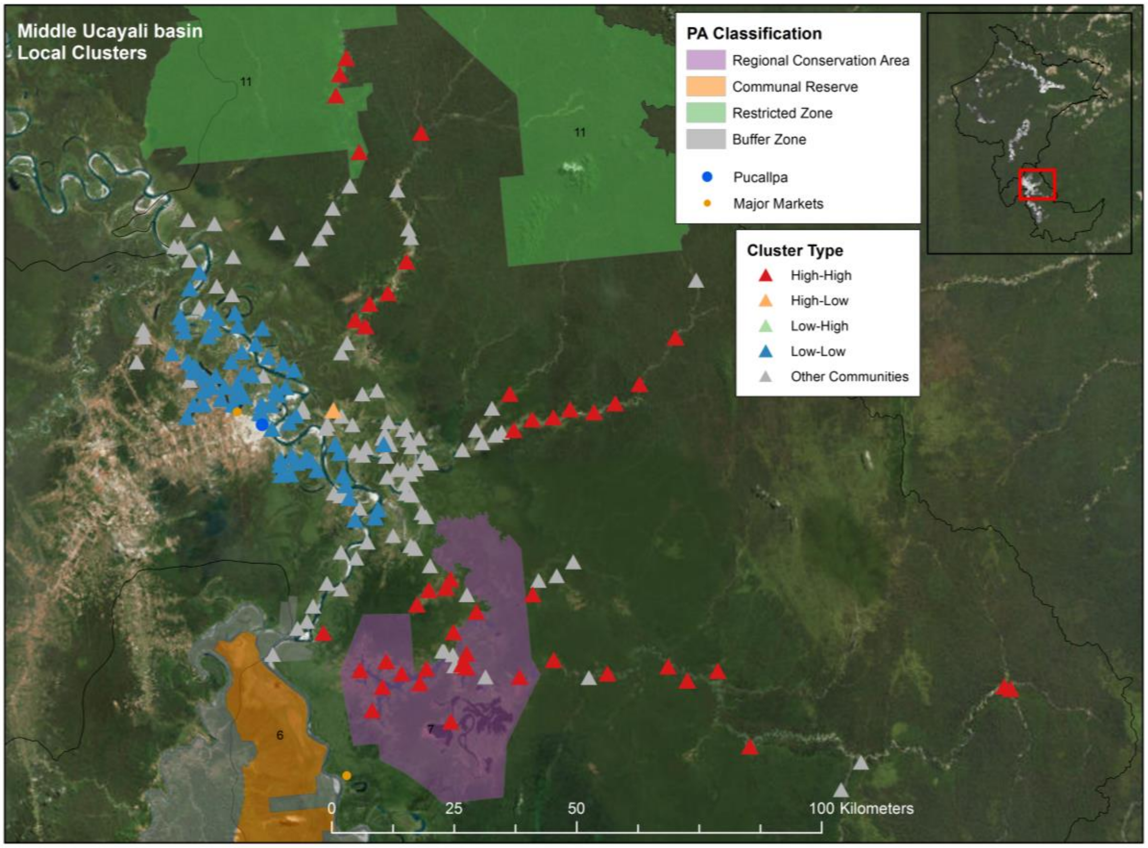


Figure 15. Local clustering of game resources in the Middle Ucayali (present)



The results for the Pastaza sub-basin are similar, however, the strength of clustering is not nearly as high, with Moran's Index values ranging from 0.13 to 0.31. The highest degree of clustering within the Pastaza sub-basin is detected for present aquatic resource availability (I = 0.31). Figure 16 shows how the index varies across the sub-basin. The strength of clustering is less easily discerned, visually, compared to the patterns observed in Figure 11B (Amazon) and Figure 14 (Middle Ucayali). It appears that, overall, availability of aquatic resources is highest in the westernmost segment of the sub-basin. The test for local spatial autocorrelation reveals low-low clusters (i.e., communities with low present aquatic resource availability, surrounded by communities with similarly low present aquatic resource availability) close to the major markets of Ullpayuco, Andoas Nuevo, and San Lorenzo (Figure 17). High-high clusters are detected in more remote riverine areas, off the main channel of the Pastaza and about 25 kilometers from the boundary of Santiago-Comaina reserved zone.

Figure 16. Global clustering of aquatic resources in the Pastaza (present)

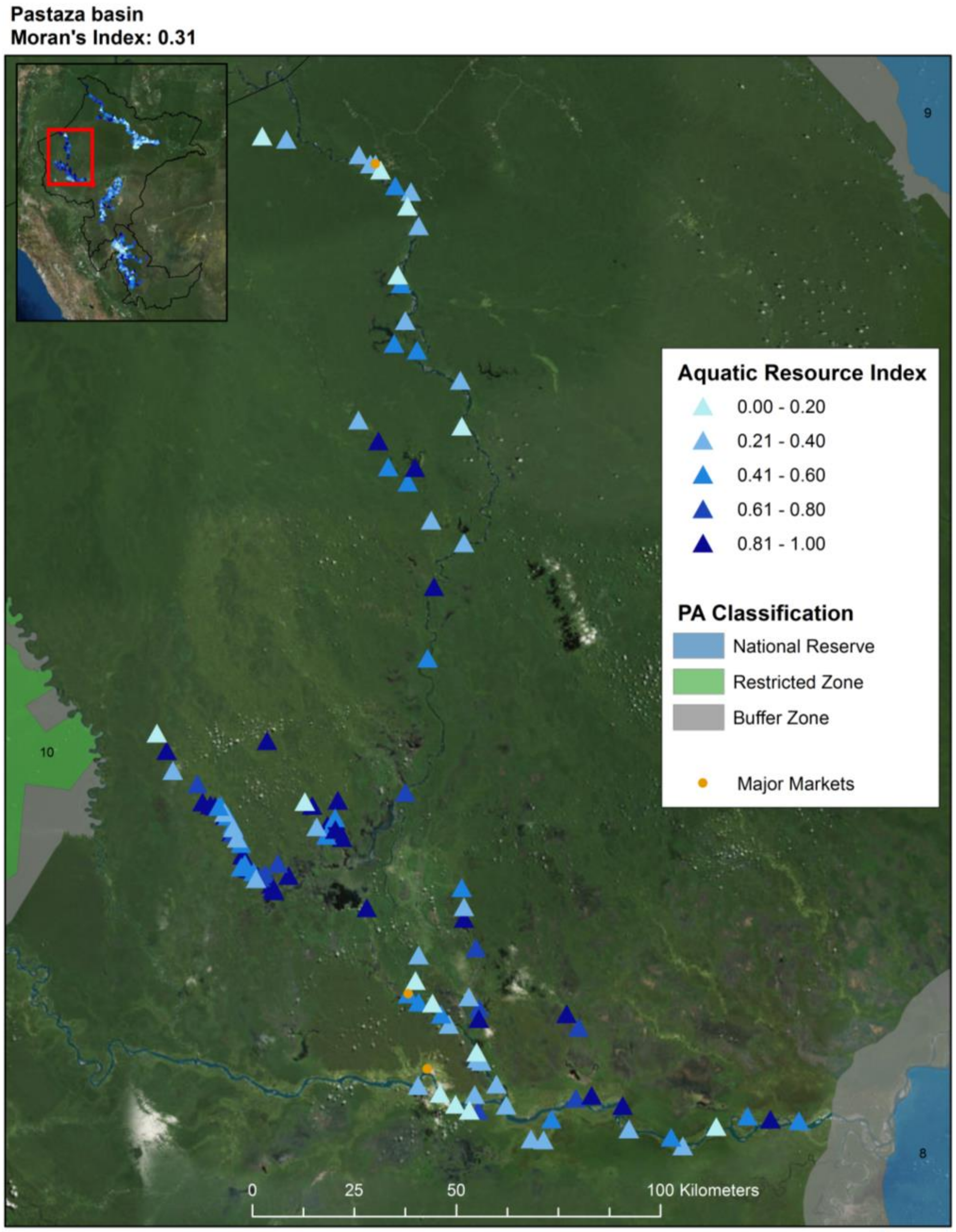
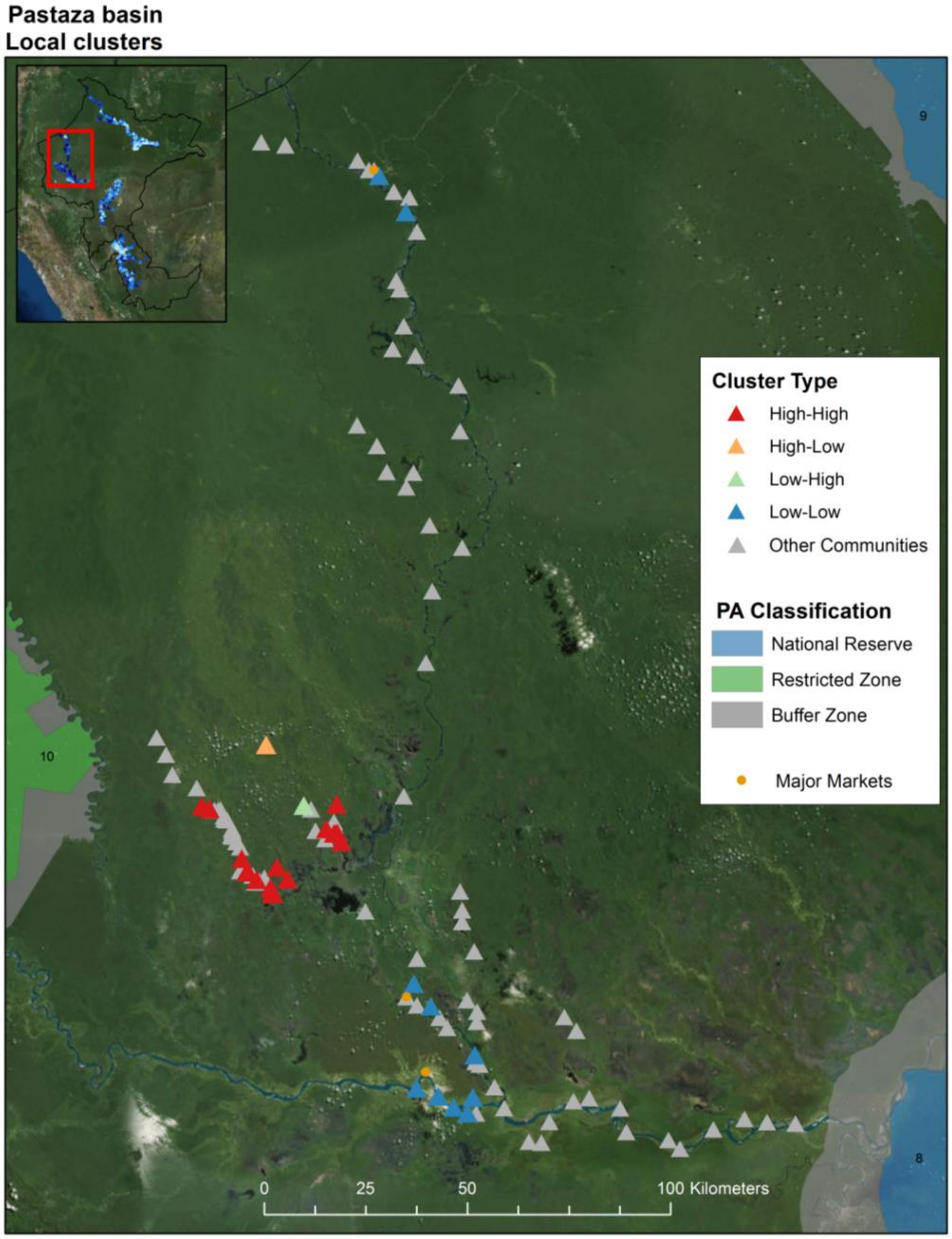


Figure 17. Local clustering of aquatic resources in the Pastaza (present)



In the Upper Ucayali sub-basin, statistically significant clusters are detected for initial timber resources, however, the respective Moran's Index values fall outside the acceptable range from -1 to 1 and thus cannot be interpreted. Further, the only instance across the entire set of results where a Moran's Index value was statistically significant and highly negative is for present timber resources in the Upper Ucayali. In this case, the spatial pattern is interpreted as being highly dispersed.

In terms of change in natural resource availability over time, several instances of statistically significant clusters are detected across the study area. The strength of those clusters is relatively low, ranging from 0.06 to 0.19 in the Napo, Pastaza, and Lower Ucayali sub-basins. In the Middle Ucayali sub-basin, the degree of clustering is slightly higher, ranging from 0.15 to 0.33. Figure 18 illustrates the moderate degree of clustering in the Middle Ucayali with respect to changes in game resource availability between the time of community establishment and the present. Generally speaking, and consistent with the spatial pattern observed in Figure 14, communities that experienced the highest levels of negative change (i.e., substantial decline in availability of game resources) are concentrated along the main channel of the river, near Pucallpa. Communities characterized by minimal or no change in game resource availability are dispersed throughout the sub-basin. Only two instances of positive change (i.e., greater availability of game resources in the present, relative to the time of community establishment) are observed, near Pucallpa. Results from the local spatial autocorrelation test provide insight into the makeup of the global statistic. As shown in Figure 19, low-low clusters (i.e., communities that experienced significant decline, surrounded by other communities that experienced significant decline) are visible northwest of (or downstream from) Pucallpa. Fewer but detectable low-low clusters are also present southwest of (or upstream from) Pucallpa. Earlier investigation of present game resources pointed to lower relative availability along the more remote river channels north- and south-east of Pucallpa, particularly within Imiria regional conservation area. In terms of change, high-high clusters (i.e., communities that experienced minimal to no change) are observed only south-east of Pucallpa within Imiria, further highlighting the potential role of Imiria’s management strategies in conserving key game species.

Figure 18. Global clustering of game resources in the Middle Ucayali (change)

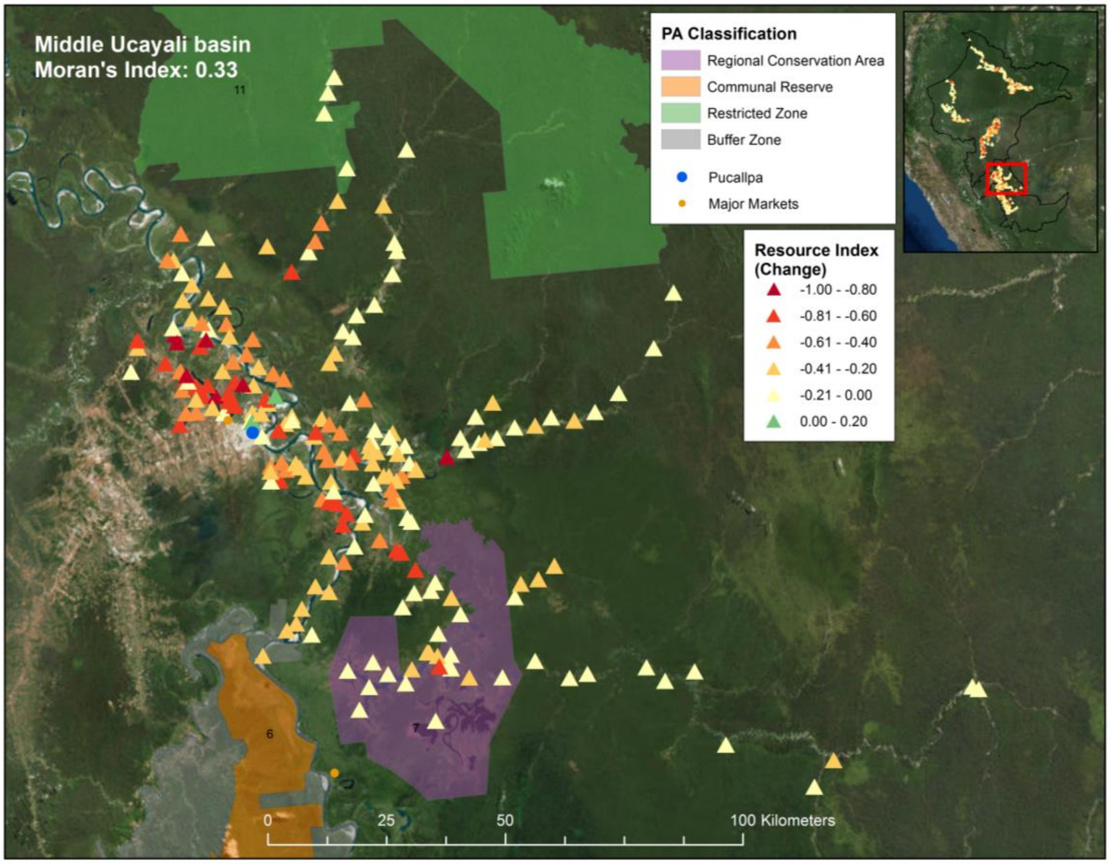
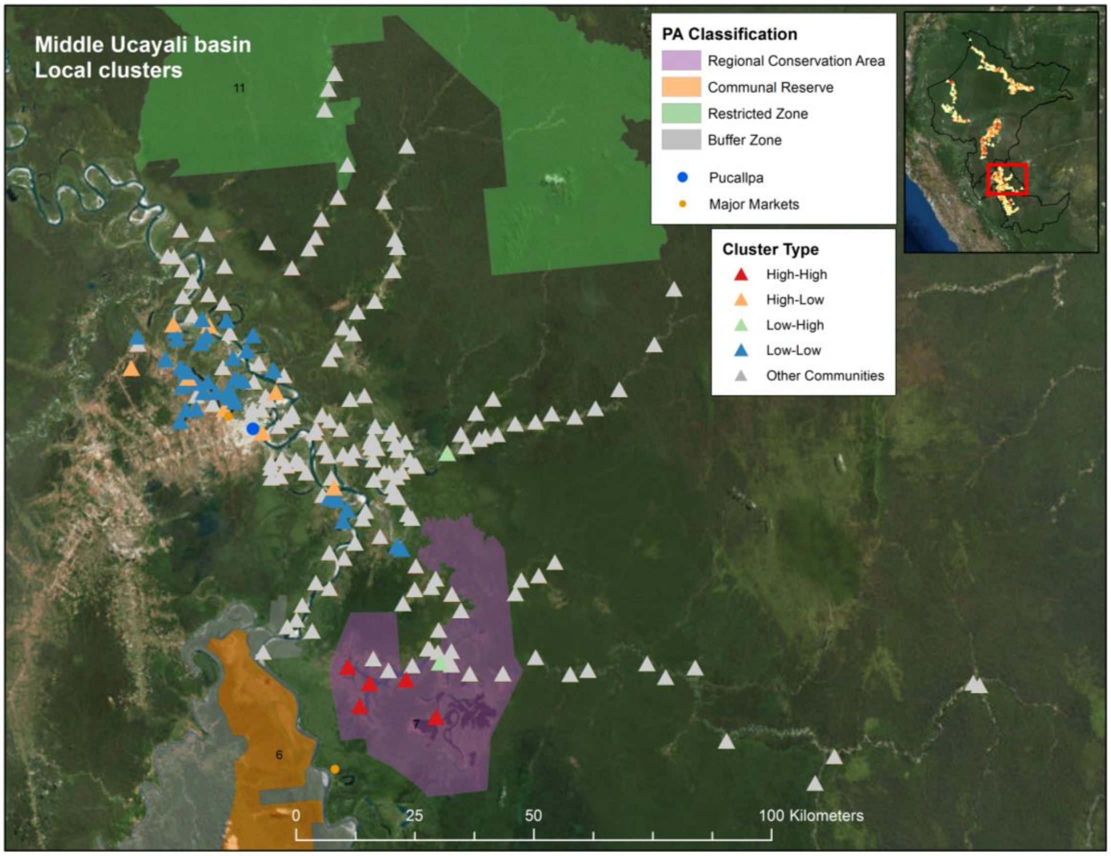


Figure 19. Local clustering of game resources in the Middle Ucayali (change)



The data points to a clear consensus that availability of key terrestrial and aquatic resources in the study area has measurably diminished among communities between the time of community establishment and the present. Cluster analyses elucidate whether resource depletion among communities tends to be spatially clustered and where. The global statistic expresses the degree of clustering at the sub-basin-scale: overall, the strength of clustering is found to be greatest in the Amazon and Middle Ucayali sub-basins, where perhaps proximity to the urban centers of Iquitos and Pucallpa play an important role in shaping natural resource availability. Clustering of communities with high present-day availability of and low changes over time in game species within the boundaries of Imiria regional conservation area draws attention to the potential impact of PAs on natural resource conservation. The test for local spatial autocorrelation identifies clusters and outliers, locally, explaining the makeup of the global statistic and clarifying observed spatial patterns that may not be immediately evident. The results bring to light potential geographic factors shaping spatial patterns in natural resource availability, while also serving as a poignant reminder of the wide variation in and locally specific character of natural resource availability among rain forest communities in the Peruvian Amazon.

5.3 Results of correlation analyses

The results of the Pearson correlation test for association between dependent and independent variables are shown in Tables 17 and 18. Note that sample sizes vary due to the exclusion of colonist communities and positive change indices. Distance to the nearest urban center (Iquitos or Pucallpa) is the only independent variable that is statistically significant for all six resource indices. Not unexpectedly, distance to nearest urban center is positively correlated with present-day availability of aquatic, game, and timber species, confirming the expected relationship that natural resource availability generally increases as communities become more remote and isolated from urban activity. Distance to nearest urban center is negatively correlated with change indices, suggesting that communities further from Iquitos or Pucallpa experienced lower levels of natural resource depletion over time. For present-day indices, the relationship is strongest for game and timber species, and for change over time, the relationship is strongest for game species. These results are consistent with the hypothesis that the effect of distance is less evident for aquatic species.

The relationship between resource indices and distance to the nearest PA is less straightforward in interpretation. For present aquatic species, there appears to be a weak negative correlation with distance to the nearest buffer and PA boundaries—as distance increases, availability of aquatic species decreases. These results are in agreement with the expectation that proximity to PAs affords greater protection over natural resources. For game and timber species, however, the results run counter to the expected relationship: there appears to be a weak positive correlation that is strongest for distance to the PA centroid. In other words, communities' reported availability of game and timber increases with greater distance to the PA centroid. In terms of change indices, there is a weak positive correlation between aquatic resources and distance to the nearest buffer and PA boundaries, a weak negative correlation between game resources and all three PA distance measures, and a weak negative correlation between timber resources and distance to the PA centroid. Again, the results for game and timber species run counter to the expected relationships. The relationship between proximity to PAs and resource indices is inconclusive for the reasons that follow:

1. Correlations between resource types and distance measures are inconsistent; even if PAs afford differential levels of protection to aquatic versus terrestrial species, one would expect the sign of correlation to be consistent between resource types and the strength to vary. However, this is not found to be true.

2. Correlations between distance and terrestrial resource indices run counter to the expected relationship.

It is important to reiterate that correlation analysis examines the crude association between independent and dependent variables, while regression models examine conditional associations that may vary based on the effect of additional independent variables. Distance to centroid is assumed to be the most conservative measure, given that the intensity of land use pressure is likely highest within buffer zones and close to the PA borders relative to the PA core area. For the purposes of this study, distance to the nearest PA boundary was selected for inclusion in the regression models, given that it is the most conservative measure that was also statistically significant for all resource indices. Interestingly, where a statistically significant correlation between resource indices and the control variable 'Year of establishment of near PA/buffer' is observed, the correlation is negative for present-day indices and positive for change over time, suggesting that newer PAs are associated with lower present-day natural resource availability and higher levels of depletion. This finding corresponds with the hypothesis that more recently established PAs are less effective than older ones, however, this interpretation is meaningful only with respect to its relationship with PA distance measures.

Results from the correlation analyses provide evidence for a weak to moderate positive correlation between native land titles and present-day availability of fish, game, and timber species. In terms of change indices, only the correlation for game species is statistically significant (r = -0.22, p = 0.0000). Overall, correlations with game resource indices are the strongest. These relationships are consistent with the expectation that communities with formal land titles afford greater protection over natural resources compared to those without. While a causal mechanism cannot be concluded, further inquiry is required to understand the particular conditions that enable effective conservation vis-à-vis indigenous territories. The control variable 'community type'—whether a community identifies as native or campesino—is related to the land title variable in the sense that only native communities are eligible for titles, however it is included as a separate variable to capture broad ethnicity-related variations that may influence resource indices. Community type is found to correlate with all six resource indices, with the exception of change in timber species. The correlation is positive for all present-day resource indices, indicating that native communities have higher natural resource availability compared to campesino communities. The strength of correlation is highest for present availability of game species (r = 0.34; p = 0.0000) and close to zero for fish species (r = 0.069; p = 0.0366). In terms of change indices, community type correlates negatively with fish and game species. Again, the strength of correlation is highest for game species (r = -0.23; p = 0.0000) and close to zero for fish species (r = 0.068; p = 0.044). The results are consistent with the expectation that natural resource availability is higher among native communities, raising questions about how to explain the differential outcome between aquatic and terrestrial species.

Results point to a weak negative correlation between government recognition and present-day indices, suggesting that communities that are formally recognized by the government are associated with lower levels of natural resource availability. The correlation is strongest for game resources (r = -0.14, p = 0.055). In terms of change over time, weak positive correlations are detected only for fish and game species. These findings prompt questions about the differential effect of government recognition across resource types, particularly with respect to timber resources. Results for the related control variable 'decade of government recognition' were inconsistent with expectations and excluded from further analysis due to collinearity with government recognition. Decade of community establishment was also excluded from further analysis due to lack of evidence for substantial correlation between two out of three resource indices.

Community land size is found to positively correlate with present terrestrial resource indices, particularly game species (r = 0.22; p = 0.0000). Without controlling for potential changes in community land size between time periods, a negative correlation is found between land size and change in availability of game species, reinforcing the significance of land size to the availability of game. The results raise questions about potential mechanisms driving the differential impact of community land size on availability of game versus timber species. A related but distinct control variable is land access—whether or not communities have access to land in the upland only, lowland only, or both. In terms of present-day indices, communities with access to upland only are associated with higher terrestrial resources and lower aquatic resources, and the opposite is true for communities with access to lowland only. Communities with access to both, on the other hand, are associated with lower aquatic and timber resources and higher game resources—a finding that is not straightforward in interpretation.

Finally, correlation analyses between resource indices and the control variable accounting for historical importance of fishing, hunting, and timber extraction yielded inconclusive results. It was expected that present-day availability of fish species would be relatively low and depletion over time would be high among communities where fishing was one of the top three economic activities historically. The same line of logic applies to communities where game or timber extraction was considered one of the top three economic activities, historically. However, where a statistically significant correlation is observed, those correlations are positive for present-day resources and negative for change over time. Despite that the results run counter to the expected relationship, historical economic activity is expected to be an important explanatory variable for current resource indices.

Table 17. Results of Pearson correlation test for association between present-day dependent and independent variables

	Dependent Variables					
Independent Variables (N=906, unless otherwise specified)	**Aquatic (present)**		**Game (present)**		**Timber (present)**	
	r	**p**	***r***	**P**	***r***	**p**
Distance to the nearest PA buffer boundary (km)	-0.21***	0.0000	0.12***	0.0004	0.015	0.6466
Distance to the nearest PA boundary (km)	-0.18***	0.0000	0.14***	0.0000	0.060*	0.0720
Distance to the nearest PA centroid (km)	0.021	0.5290	0.20***	0.0000	0.22***	0.0000
Year of establishment of nearest PA buffer	-0.11***	0.0006	0.012	0.7204	-0.049	0.1372
Year of establishment of nearest PA	-0.30***	0.0000	-0.050	0.1302	-0.23***	0.0000
Formal land title (0 or 1) (N=727)	0.079**	0.0325	0.39***	0.0000	0.20***	0.0000
Distance to the nearest urban center (km)	0.22***	0.0000	0.47***	0.0000	0.36***	0.0000
Community land size (km)	0.041	0.22	0.22***	0.0000	0.10***	0.0016
Access to land in the upland only (0 or 1)	-0.055*	0.0960	0.20***	0.0000	0.12***	0.0005
Access to land in the lowland only (0 or 1)	0.17***	0.0000	-0.37***	0.0000	-0.18***	0.0000
Access to land in the upland and lowland (0 or 1)	-0.14***	0.0000	0.25***	0.0000	-0.11***	0.0006
Type of community: campesino or native (0 or 1)	0.069**	0.0366	0.34***	0.0000	0.19***	0.0000
Decade of community establishment (N=900)	-0.015	0.65	-0.0088	0.79	-0.11***	0.0006
Government recognition (0 or 1)	-0.12***	0.0002	-0.14***	0.0000	-0.064*	0.055
Decade of government recognition (N=781)	-0.046	0.2027	0.071**	0.0461	-0.0013	0.9702
Historically, fishing/hunting/timber extraction was one of the communities' top three economic activities (0 or 1)	0.075**	0.0249	0.25***	0.0000	0.052	0.12

*p < 0.1; **p <0.05; ***p <0.01

Table 18. Results of Pearson correlation test for association between change dependent and independent variables

	Dependent Variables					
Independent Variables	**Aquatic (change)**		**Game (change)**		**Timber (change)**	
(Aquatic: N=887; Game: N=896; Timber: N=809, unless otherwise specified)	***r***	**p**	***r***	**p**	***r***	**p**
Distance to the nearest PA buffer boundary (km)	0.11***	0.0014	-0.11***	0.0006	0.072**	0.041
Distance to the nearest PA boundary (km)	0.087***	0.0098	-0.12***	0.0002	0.019	0.5875
Distance to the nearest PA centroid (km)	-0.0062	0.8535	-0.15***	0.0000	-0.099***	0.0050
Year of establishment of nearest PA buffer	0.074**	0.0279	-0.030	0.3785	0.081**	0.0207
Year of establishment of nearest PA	0.14***	0.0000	-0.020	0.5429	0.23***	0.0000
Formal land title (0 or 1) (Aquatic: N=710; Game: N=718; Timber: N=651)	-0.0071	0.8495	-0.22***	0.0000	0.048	0.2234
Distance to the nearest urban center (km)	-0.11***	0.0009	-0.29***	0.0000	-0.11**	0.0011
Community land size (km)	-0.0241	0.4738	-0.17***	0.0000	-0.042	0.2091
Access to land in the upland only (0 or 1)	-0.057*	0.0925	-0.16***	0.0000	0.021	0.5526
Access to land in the lowland only (0 or 1)	0.046	0.17	0.19***	0.0000	-0.23***	0.0000
Access to land in the upland and lowland (0 or 1)	-0.013	0.7072	-0.093***	0.0051	0.21***	0.0000
Type of community: campesino or native (0 or 1)	-0.068**	0.044	-0.23***	0.0000	-0.0091	0.7956
Decade of community establishment (Aquatic: N=881; Game: N=890; Timber: N=803)	-0.0011	0.9732	-0.083**	0.0130	-0.028	0.44
Government recognition (0 or 1)	0.089***	0.0079	0.12***	0.0003	-0.051	0.15
Decade of government recognition (Aquatic: N=763; Game: N=772; Timber: N=699)	-0.030	0.4026	-0.12***	0.0007	-0.13***	0.0007
Historically,fishing/hunting/timber extraction was one of the communities' top three economic activities (0 or 1)	-0.039	0.25	-0.15***	0.0000	0.096***	0.0061

*p < 0.1; **p <0.05; ***p <0.01

In summary, regression models for present-day aquatic, game, and timber resource indices were specified based on the results of the Pearson correlation tests to ensure that the most theoretically-sound explanatory variables were accounted for. Among the distance measures, distance to the nearest PA boundary was selected for inclusion. Despite unexpected results, land access was included in the regression analyses to ensure that the environmental distinction between upland and lowland was controlled for. Finally, and as previously mentioned, decade of community establishment and decade of government recognition were excluded. Results from the regression analyses are presented in the section that follows.

5.4 Results of regression analyses

OLS regression was employed to examine the effect of each predictor on present-day aquatic, game, and timber availability among communities. For each regression model, the R-squared value and number of observations are reported. For each predictor, the coefficient, p-value and VIF are reported. Robust standard errors are reported in parentheses. In order to aid interpretation, descriptive statistics for resource indices and explanatory variables are included in Table 19 below.

Table 19. Descriptive statistics for resource indices and explanatory variables

Variable (N=906, unless otherwise specified)	**Mean (μ)**	**Std. Dev. (σ)**	**Range**
Aquatic resource index (present)	0.54	0.33	0 – 1
Game resource index (present)	0.60	0.31	0 – 1
Timber resource index (present)	0.60	0.26	0 – 1
Distance to the nearest PA boundary (km)	32.88	25.96	0 – 120.39
Year of establishment of nearest PA boundary	2000	14.03	1972 – 2012
Formal land title (N=727)	60% titled; 30% untitled	N/A	0 or 1
Distance to the nearest urban center (km)	263.23	227.83	3.15 – 925.85
Community land size (km)	4.08	3.79	0.20 – 49.05
Access to land in the upland only	9.3% upland only	N/A	0 or 1
Access to land in the lowland only	44% lowland only	N/A	0 or 1
Access to land in the upland and lowland	46.7% both	N/A	0 or 1
Type of community: campesino or native	52% campesino; 48% native	N/A	0 or 1
Government recognition	80% government recognized	N/A	0 or 1
Historically, fishing/hunting/timber extraction was one of the communities' top three economic activities	Fishing: 89.4%; Hunting: 46.2%; Timber extraction: 49.3%	N/A	0 or 1

Based on the results presented in Table 20, the selected predictors explain 15% of the variance in present-day aquatic indices. Distance to the nearest PA, land title, distance to the nearest urban center, land access, and government recognition are all statistically significant and consistent with the expected effect. Importantly, there is evidence to suggest that distance to the nearest PA has a negative effect on fish availability, controlling for all other predictors. As distance to the nearest PA increases by 1 km, aquatic resource availability decreases by 0.0035. In other words, an increase in distance by roughly 57 km from the PA boundary corresponds to a decline in aquatic resource availability by 0.2 (or the loss of one species). Land title status and distance to the nearest urban center are found to have a positive effect on fish availability, controlling for all other predictors. Present aquatic indices are higher, on average, among communities that are formally titled and more remote, while indices are lower among communities that have government recognition and access to the upland only. Interestingly, although both are positive, the magnitude of the effect of distance to the nearest PA is 8.75 times greater than that of distance to the nearest urban center.

Table 20. Regression analysis of present-day aquatic resource availability

Predictor Variables	Coeff.	p	VIF
Distance to nearest PA boundary (km)	-0.0035*** (0.00057)	0.000	1.51
Year of establishment of nearest PA	-0.0015 (0.0013)	0.231	2.03
Land title	0.105* (0.059)	0.077	4.95
Distance to nearest urban center (km)	0.00040*** (0.000082)	0.000	2.82
Community land size (km)	-0.0030 (0.0033)	0.368	1.18
Access to land in the upland only	-0.13*** (0.048)	0.007	1.32
Access to land in the upland and lowland	-0.073*** (0.025)	0.003	1.25
Type of community: campesino or native	-0.029 (0.056)	0.600	4.97
Government recognition	-0.066* (0.038)	0.080	1.09
Historical importance of fishing	0.054 (0.040)	0.178	1.03
Intercept	3.65 (2.55)	0.152	N/A
F-value	19.56***	0.000	
R-squared	0.1554		
No. of observations	727		

*p < 0.1; **p <0.05; ***p <0.01

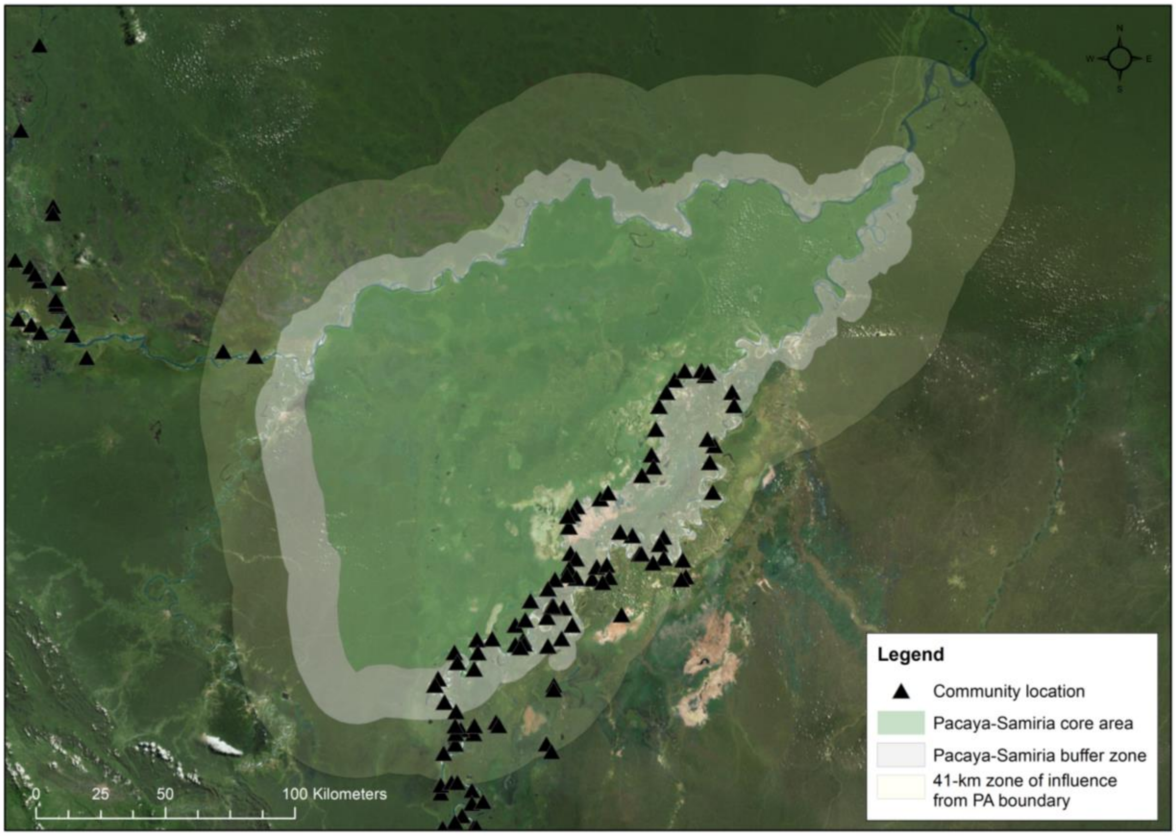
Based on the results presented in Table 21, the selected predictors explain 40% of the variance in present-day game indices. Distance to the nearest PA, year of PA establishment, distance to the nearest urban center, community land size, land access, and the historical importance of hunting are all found to be statistically significant. Again, distance to the nearest PA is found to have a negative effect on game availability, controlling for all other predictors. As distance to the nearest PA increases by 1 km, game resource availability decreases by 0.0027. To put this in perspective, an increase in distance from the PA boundary by roughly 41 km corresponds to a decline in game resource availability by $0.\overline{1}$ (or the loss of one species). Figure 20 helps visualize this effect, using Pacaya-Samiria National Reserve as a hypothetical example. A 41-km buffer or "zone of influence" from the reserve boundary is highlighted to show how game resource availability might vary among communities within the zone versus those beyond it. Of course, the results do not necessarily hold true for this specific example, but the figure helps visualize how proximity to the PA hypothetically influences game availability based on the results of the regression model.

Table 21. Regression analysis of present-day game resource availability

Predictor Variables	Coeff.	p	VIF
Distance to nearest boundary PA (km)	-0.0027*** (0.00047)	0.000	1.54
Year of establishment of nearest PA	0.0041*** (0.0012)	0.001	2.09
Land title	0.074 (0.050)	0.144	4.95
Distance to nearest urban center (km)	0.00071*** (0.000078)	0.000	2.83
Community land size (km)	0.0070** (0.0030)	0.019	1.19
Access to land in the upland only	0.14*** (0.038)	0.000	1.35
Access to land in the upland and lowland	0.18*** (0.022)	0.000	1.27
Type of community: campesino or native	0.022 (0.049)	0.653	4.97
Government recognition	-0.030 (0.030)	0.315	1.09
Historical importance of hunting	0.036* (0.020)	0.074	1.18
Intercept	-7.80*** (2.41)	0.001	N/A
F-value	52.99***	0.000	
R-squared	0.4016		
No. of observations	727		

*p < 0.1; **p <0.05; ***p <0.01

Figure 20. Hypothetical visualization of the effect of distance on game availability



Distance to the nearest urban center, community land size, and land access are all found to have a positive effect on game availability, as expected. On the other hand, communities where hunting was historically one of the top three economic activities are found to have higher present game resource availability. This is surprising given our expectation that communities which relied heavily on hunting in the past would experience greater levels of depletion over time and thus have lower present game availability. However, it is possible that over-exploitation did not occur due to relative local abundance and renewability of game species or other factors. It is worth noting that communities with land titles are not found to have different levels of game availability compared to those without. Finally, although both are positive, the magnitude of the effect of distance to the nearest PA is 3.8 times greater than that of distance to the nearest urban center.

Lastly, as per the results presented in Table 22, the selected predictors explain 16% of the variance in present-day timber indices. All of the predictors are statistically significant, with the exception of community land size, community type, and government recognition. Distance to the nearest PA is found to have a negative effect on timber availability, controlling for all other predictors. As distance to the nearest PA increases by 1 km, timber resource availability decreases by 0.00079. In other words, an increase in distance from the PA boundary by roughly 211 km corresponds to a decline in timber resource availability by $0.\overline{16}$ (or the loss of one species). Further, land title status and distance to the nearest urban center are found to have a positive effect on timber availability, controlling for all other predictors. Present timber availability is higher, on average, among communities that are formally titled and more remote. Again, although both are positive, the magnitude of the effect of distance to the nearest PA is 2.7 times greater than distance to the nearest urban center.

Table 22. Regression analysis of present-day timber resource availability

Predictor Variables	**Coeff.**	**p**	**VIF**
Distance to nearest PA boundary (km)	-0.00079* (0.00045)	0.079	1.57
Year of establishment of nearest PA	-0.0025** (0.0010)	0.013	2.03
Land title	0.11*** (0.042)	0.010	4.96
Distance to nearest urban center (km)	0.00029*** (0.000062)	0.000	2.82
Community land size (km)	0.0015 (0.0027)	0.583	1.18
Access to land in the upland only	0.080** (0.036)	0.024	1.32
Access to land in the upland and lowland	0.091*** (0.021)	0.000	1.25
Type of community: campesino or native	-0.058 (0.043)	0.172	4.96
Government recognition	-0.0037 (0.031)	0.902	1.09
Historical importance of timber extraction	0.013 (0.018)	0.491	1.08
Intercept	5.46*** (2.0)	0.006	N/A
F-value	16.14***	0.000	
R-squared	0.1597		
No. of observations	727		

*p < 0.1; **p <0.05; ***p <0.01

In summary, the results of the regression analyses indicate that, controlling for important environmental and market factors, proximity to PAs and indigenous territories are partially responsible for variation in present availability of key species among communities. Examination of the VIFs confirm that multi-collinearity between predictors is not present in any of the models. The results demonstrate that communities that are closer to PAs have, on average, higher availability of fish, game, and timber species. Further, communities that have formal land titles have, on average, higher present-day availability of fish and timber species. Surprisingly, land title status is not found to have an effect on game availability, which raises questions about the differential effect of native territories on game versus fish and timber species. Although distance to urban center has a positive effect on resource availability, the effect of distance to the nearest PA is greater in magnitude for all resource indices, suggesting that whether or not land is formally protected may matter beyond remoteness.

6 Limitations

All methods of scientific inquiry are subject to limitations, and it is worth noting the analytical caveats relevant to this study. First, the indices that were generated as proxies for natural resource availability are based on the reports of community members, and human reporting introduces the potential for error due to, for example, selective memory. Moreover, given the economic value of key species to the surveyed communities, it is not unreasonable to suggest that respondents have an incentive to tailor their responses to reduce the risk associated with sharing potentially sensitive information. Future research might address this limitation by, for example, including a number of quality control survey questions—the answers to which are already definitively known—and comparing those against survey responses. In cases of pronounced variation between known information and a community's responses, those communities could be excluded from the analysis to improve reliability of data. There is a tradeoff here between precision and practicality; for example, while conducting ecological surveys may be a more precise method for capturing information on species diversity, this method is prohibitive given the size of the study area. Further, ecological surveys were not carried out in the past, which would prevent the initial status of species from being considered in the analysis.

Another limitation of the study is related to the data on native territories retrieved from the IBC. Due to insufficient metadata, it was not possible to determine the title status of 179 native-identified PARLAP communities, which reduced the sample size of the regression analyses to 727. For the same reason, two potentially important control variables—date of titling and size of the titled territory—could not be incorporated. The size of titled territory is relevant to the specification of the regression models, given that the effect of titling may vary based on the extent of land area under title for each community. In order to improve the results of the regression analyses, future research could involve confirming the status of land titles of all surveyed PARLAP communities and ensuring inclusion of relevant control variables. It would be especially useful to test whether the unexpected effect of titling observed for game availability might vary with this added information.

A few limitations with respect to the spatial analyses should be noted. The first is related to the use of Euclidean distance measures to estimate communities' proximity to nearest PAs.

Given that communities in the study area depend on river transportation for access to natural resources, Webster and colleagues (2016) propose that travel distance calculations based on fluvial networks provide more accurate estimates. Future work may wish to evaluate whether distance measures based on this methodology, rather than Euclidean distance, improve the accuracy of the regression analyses. However, given that conservation benefits afforded by proximity to PAs do not necessarily vary as a function of precise travel distance, measures based on Euclidean distance serve as a useful initial approximation.

Another limitation that should be noted is the use of default distance values computed by ArcGIS to detect spatial clustering. Default values are automatically generated to ensure that every feature has at least one neighbor, as discussed in section 4.4.2. This may affect the accuracy of the results if the data are highly skewed. In order to address this, a threshold distance can be computed to ensure that each feature has at least eight features. Given that the datasets which were found to be highly skewed were left uninterpreted, this was not considered problematic. Future work may wish to consider the appropriateness of different threshold distances for each sub-basin.

Finally, it is important to note that the results of the OLS regression may be biased due to spatial autocorrelation. A natural avenue for future research is to perform spatial regression analyses to address potential bias linked to spatial autocorrelation.

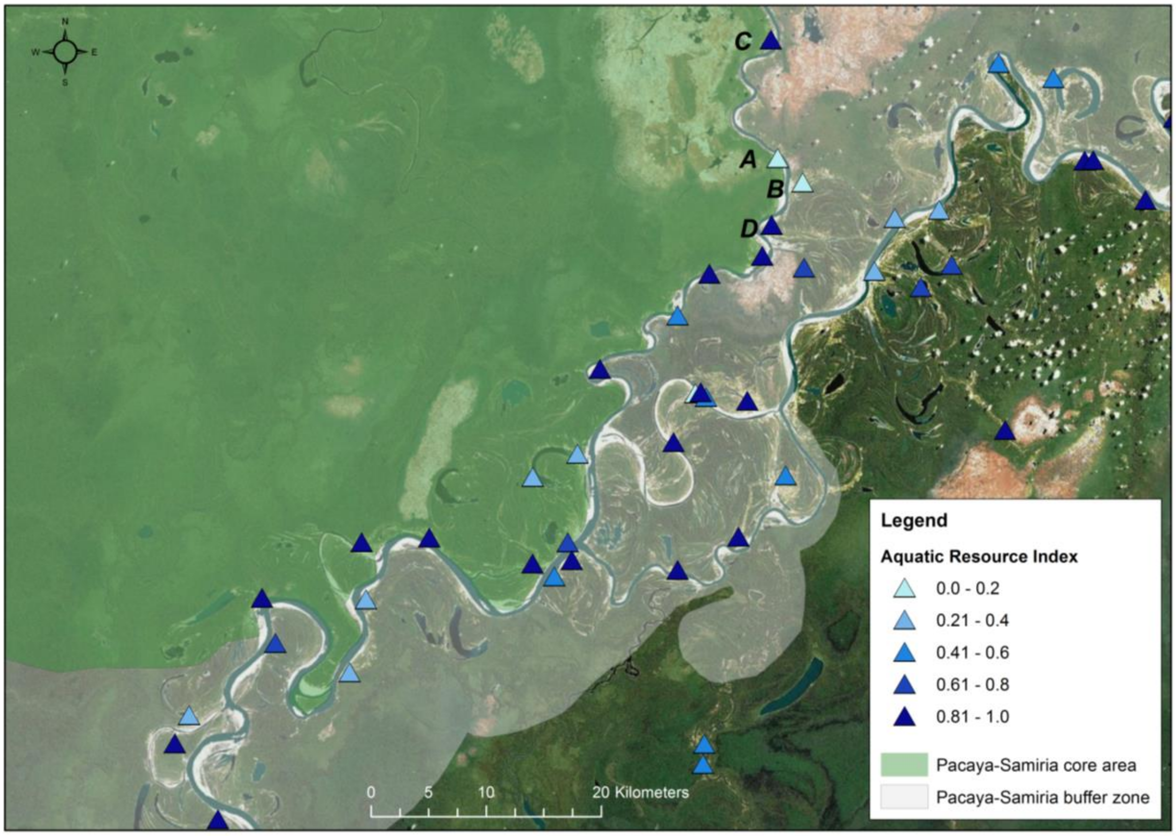
Despite these analytical caveats, the PARLAP data provide important information on the relative abundance of species from the perspective of communities whose livelihoods depend, in part, on the ability to access those species. Certainly, remote sensing techniques provide critical information on historical land cover change in Amazonia; however these techniques are limited to forest coverage and coarse spatial scales. The PARLAP data, on the other hand, covers nearly 160,000 square kilometers and was collected using consistent survey techniques that provide species-level information on aquatic and terrestrial resources. Even if biological inventories of the study region's natural resource base existed, this data would serve as complementary knowledge in two respects: first, expert opinion among local communities could inform gaps in those inventories, and second, the data allows us to consider natural resource availability from the perspective of local communities, rather than solely in terms of physical change. Interestingly, a study conducted by Holt and colleagues (2010) suggests that local knowledge of game abundance in the Bolivian Amazon generally agrees with results from wildlife harvest models and other ecological research. Thus, the benefits of including these perspectives are considered to outweigh costs associated with potential subjective biases in the data.

7 Discussion & Conclusion

This thesis examines spatiotemporal changes in natural resource availability among rain forest communities in the Peruvian Amazon, and the role of locally- and regionally-managed extractive PAs and indigenous territories in the conservation of key species. Using community census data, initial and present availability of fish, game, and timber species are evaluated to elucidate patterns of change over time. Relatively significant depletion is observed among surveyed communities; results show that availability of key species declined, on average, by 21% since the time of community establishment. This decline appears to be greater for aquatic than terrestrial species—a finding that is consistent with results of a study from the Brazilian Amazon (Antunes *et al.* 2016), which suggest that greater loss of aquatic species can be attributed to spatial clustering of communities along rivers. Thus, river and floodplain habitats and consequently, aquatic species, are more easily accessed by hunters, while terrestrial species populations are buffered by less accessible forest interiors. Moreover, results show that the availability of key species varies widely between and within sub-basins. The Amazon sub-basin is found to have the lowest availability of key aquatic and terrestrial species both initially and in the present, while the Amazon and Middle Ucayali sub-basins are found to have the greatest depletion over time. At the species level, reported declines are most significant for mahogany and Spanish cedar timber species, white-lipped peccary and tapir game species, and arapaima and red-bellied pacu fish species.

Results from the tests for global and spatial autocorrelation indicate whether communities with similar resource availability tend to be spatially clustered—for example, whether depletion is found to be particularly concentrated in certain geographic areas. Statistically significant clustering is detected within each sub-basin; however, the strength of clustering varies widely. Visually, clustering is imperceptibly low except within the Middle Ucayali and Amazon sub-basins. The results of the cluster analyses draw attention to the likely effect of remoteness from urban centers, while also highlighting significant heterogeneity of resource availability between communities. This heterogeneity is illustrated in Figure 21, which shows a subset of communities in the Lower Ucayali located within Pacaya-Samiria's buffer zone. Significant variation in present aquatic resource availability between communities is observed over relatively short distances. For example, two communities (listed on the map as 'A' and 'B') reported no present availability of key aquatic species, while neighboring communities (listed on the map as ‘C’ and ‘D’) reported 100% availability. Similarly wide variation between communities is evident throughout the study region, highlighting the locally specific nature of resource depletion. This finding has important implications for conservation policy, which, to be effective, should be tailored to local ecological and social conditions.

Figure 21. Heterogeneity of present aquatic resource availability



To isolate the effect of proximity to PAs and native territories, OLS regression was employed in the final stage of analysis. Correlation analyses were performed, initially, to evaluate the relationships between resource availability and explanatory variables, including distance to the nearest PA, land title status, and relevant environmental, market, and community control variables. Results from the correlation analyses align with those of the cluster analyses, underlining the positive correlation between distance to the nearest urban center and all resource indices. Results from the regression analyses, on the other hand, demonstrate that proximity to urban center is a relevant but insufficient explanation for variation in resource availability on its own. Overall, the regression models explain 15%, 40%, and 16% of variation in fish, game and timber availability, respectively. Distance to the nearest PA is found to have a negative effect on fish, game, and timber availability, controlling for all other predictor variables. In other words, communities that are closer to PAs have higher present-day availability on average. Importantly, the magnitude of this effect is at least twice that of distance to the nearest urban center and is greatest for game, followed by fish, then timber. These findings are consistent with the expectation that PAs may afford differential levels of protection on terrestrial versus aquatic species. The magnitude of the effect is smallest for timber resources—a finding that may be related to forest policy changes in the early 2000s that assigned more than 7 million hectares in the Peruvian Amazon as forest concessions (Salo & Toivenon 2009). As forested areas were assigned to either permanent production, reserves for future use, or communal reserves managed by indigenous communities, certain communities may have lost access while others gained access. This may also explain why certain communities reported positive changes in timber species availability. It is important to distinguish between the concepts of access and availability; if communities lost access to resources due to land use restrictions, the implications for biodiversity conservation are entirely different than if communities experienced lower availability due to depletion of the resource base. Further research is needed to clarify the how policy interventions targeted at specific resource types or species may have influenced the results.

Moreover, results from the regression analyses suggest that land title status has a positive effect on fish and timber availability only. The absence of an effect on game availability is surprising and warrants further attention. Despite this minor deviation, the results presented here point to a clear role for PAs and indigenous territories in ensuring the availability of key species among rain forest communities in the Peruvian Amazon. While causal mechanisms cannot be confirmed, evidence from this study joins the existing literature in implying that locally- and regionally-extractive PAs and titled indigenous territories are currently making, and will continue to make, important contributions to the conservation of biodiversity in Peru and elsewhere in Amazonia.

Avenues for future research may focus specifically on evaluating the effectiveness of PAs and indigenous territories in conserving key aquatic species. Recent research from the PARLAP study region emphasizes a shift among communities from resource extraction to agriculture, though fishing remains a critical subsistence activity (Coomes *et al.* 2016). This shift is not unique to the Peruvian Amazon; in the nearby Ecuadorian Amazon, for example, Gray and colleagues (2015) report substantial declines in participation of extractive activities among households. While fish species may be subject to higher renewability rates compared to game and timber, longer-term sustainability of the aquatic resource base may be undermined by current levels of depletion coupled with communities' continued reliance on fisheries both for everyday subsistence and for stability during environmental shocks (Coomes *et al.* 2010). The establishment of locally- and regionally-managed extractive PAs and the titling of indigenous territories helps create pathways for local communities to participate in and develop effective conservation strategies. By way of example, research from the Brazilian Amazon comparing abundance of arapaima fish populations in community-based management (CBM) and non-CBM areas makes a compelling case for the effectiveness of CBM tools in recovery and conservation efforts (Campos-Silva & Peres 2016).

As rural, economically-disadvantaged communities in western Amazonia become increasingly exposed to the effects of urbanization and macro-scale social and economic changes, attention and resources should be devoted to ensuring that indigenous territorial rights are respected, and that the diverse local perspectives of indigenous and campesino communities alike are factored into conservation policy. At the end of the day, the effectiveness of conservation policy depends on the behavior of multiple stakeholders in the system, and those behaviors will be more aligned with policy to the extent that local perspectives and claims have been considered in crafting it. The effort required to balance such local dynamics with existing broader-scale understanding of biodiversity change is not trivial; however, the systemic character of natural resource conservation demands it of us.

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