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## Assessing householder social-ecological resilience in transboundary conditions: The case of the MAP region in southwestern Amazonia

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# Assessing householder social-ecological resilience in transboundary conditions: The case of the MAP region in southwestern Amazonia

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Abstract

Land use change is continuously accelerating in the Amazon basin, intensified by road network expansion, farming, ranching, and mining activities, all major drivers of change. This pattern is expected to spread across the continent, fuelled by the economic benefits that road building provides. However, the extent of regional trade-offs regarding ecological stability and the provision of ecosystem services is generally unaccounted for, despite narratives on the loss of resilience and even the imminent trespassing of tipping points becoming common. In the PRODIGY project, we evaluate the social-ecological resilience of rural smallholders in the transboundary MAP (Madre de Dios – Acre – Pando) region in the southwestern Amazon, where the construction of the first transcontinental highway culminated a decade ago. This paper sets a baseline for this endeavour, by distinctively profiling the three country-sites constituting our sample; elucidating the complex system and disturbance and change approaches on which we rely to tackle the challenge; and detailing the implementation of our work. Our preliminary findings confirmed the intrinsic differences among the three country-sites, but also pinpointed crucial ones, like the triggering role of political polarization in Brazil, the mono-dependence on Brazil nut in Bolivia, and the uncertain effects of economic diversification in Peru.

Keywords: Rural livelihoods; human-environmental systems; trans-border situation; complexity; participatory systems analysis; disruption and change; tipping point.

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# List of Acronyms

| | |
|---|---|
| ACTO | Amazon Cooperation Treaty Organization |
| AIDER | Asociación para la Investigación y Desarrollo Integral |
| FAO | United Nations Food and Agriculture Organization |
| GDP | Gross Domestic Product |
| IBAMA | Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis |
| IBGE | Instituto Brasileiro de Geografia e Estatística |
| ICMBio | Instituto Chico Mendes de Conservação da Biodiversidade |
| IIRSA | Iniciativa para la Integración de la Infraestructura Regional Suramericana |
| INE | Instituto Nacional de Estadística |
| INEI | Instituto Nacional de Estadística e Informática |
| IPE | Instituto Peruano de Economía |
| MAP | Madre de Dios – Acre – Pando region |
| MINCETUR | Ministério de Comercio Exterior y Turismo |
| NGO | Non-Governmental Organization |
| NTFP | Non-Timber Forest Products |
| OECD | Organisation for Economic Co-operation and Development |
| PRODIGY | Process-based & Resilience-Oriented management of Diversity Generates sustainability project |
| RESEX | Reserva Extrativista |
| SERNANP | Servicio Nacional de Áreas Naturales Protegidas por el Estado |
| SERNAP | Servicio Nacional de Áreas Protegidas |
| SES | Social-Ecological Systems |
| SPA | Science Panel for the Amazon |

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# 1 Introduction

The Amazon basin encompasses about 6 million km$^2$ and is inhabited by around 28 million people. Three quarters of this area corresponds to lowland evergreen rainforests, about 15% to a mixture of seasonal forest, savanna, montane forests and alpine formations, and 7% to farm and grazelands in constant expansion. The basin is an important provider of ecosystem services of different types. It holds both the largest biomass reservoir and the highest biodiversity in the world, sustains regular rainfall patterns and regulates the global climate. It contains enormous reserves of freshwater, stores huge amounts of carbon and plays an important role in sequestering anthropogenic $CO_2$ emissions (FAO, 2015; Nagy et al., 2016; SPA, 2021).

It is also a source of many products of anthropogenic value, including timber and non-timber forest products, metals and hydrocarbons. Indeed, massive reserves of oil and gas have been found recently (Bebbington & Unerman, 2018; Finer & Novoa, 2015; Lopes et al., 2019; Rumrill et al., 1986; Sonter et al., 2017). The exploitation and commercialization of these goods and services have generated numerous social and environmental trade-offs (Lindert & Verkoren, 2010; Nepstad et al., 2008). Notorious examples are the repeated and increasing occurrence of forest fires (Cereceda, 2019). Concurrently, the Amazon rainforest is recognized as one of at least 15 tipping elements of the earth's climate system (Lenton et al., 2008). By surpassing such a 'tipping point', the system may abruptly and possibly irreversibly change its state, which may trigger severe and unforeseen repercussions on global, regional and local systems.

Besides, the Amazon geographically involves eight countries, all of which are interconnected, despite their national peculiarities, through a compact rainforest and rivers flowing across, and therefore subject to intense economic and cultural exchanges (ACTO, 2018). One of those transboundary areas is the MAP (Madre de Dios, Peru; Acre, Brazil and Pando, Bolivia) region. A transboundary area is one where intense exchanges occur across the formal borders, leading to common benefits but also generating challenges in the involved countries (Hataley & Leuprecht, 2018). Which is the case of the MAP region. Formerly marginalized, it has undergone considerable socio-economic development in recent decades due to the successive emergence of economic opportunities (mainly related to natural resources exploitation), related immigration waves and the recent construction of the interoceanic highway (Mendoza et al., 2015).

Since April 2019, the project Process-based & Resilience-Oriented management of Diversity Generates sustainabilitY (PRODIGY, https://prodigy-biotip.org/ has sought to identify and analyze the tipping points in the MAP region, and to question whether and how the crossing of a tipping point in a given element may lead to a cascade of other tipping elements. At the core of this endeavor is the analysis of resilience of social-ecological systems, since changes can equally occur on natural and/or socio-economic levels.

This publication aims to provide the basis and preliminary findings of our ongoing research. The following section gives a detailed account of the background of the MAP region, since its characteristics are decisive for understanding the functioning of local social-ecological systems. Section three identifies and reviews a suite of scientific approaches that can be applied to investigate such systems. Section four returns to the specific challenges in the MAP region and details the operationalization of our research framework through the sketching of a specific set of methods and presenting preliminary outcomes. Section five wraps up and outlines the upcoming steps.

# 2 The MAP region and its transboundary challenges

## 2.1 A historical glimpse

The recent history of the MAP region has been influenced by two main conditions: its relative remoteness from power and decision centers and its vast wealth of natural resources of high economic value; both of which have determined successive waves of colonization and migration aiming to "extract" those valuable resources.

In the last decades of the XIX century, tree species like *Castilla ulei* and *Hevea brasiliensis*, providers of 'wild gum' or rubber, were high demand inputs for the manufactured products of the industrial revolution. Many *caucheros*, local and foreign entrepreneurs, rushed to the region seeking rapid wealth. Some succeeded and became 'rubber barons', key players in the region's governance (García, 1982; Rumrill et al., 1986).

Because of the aforementioned remoteness, the delimitation and enforcement of national borders was poorly handled, and with the emergence of economic opportunities, the area became the battleground of disputed sovereignties (Garay Vera, 2008; Rumrill et al., 1986). The current borders of the MAP region were established after a period of conflicts that raged between 1899 and 1912, including wars, revolutions, treaties, and even the ephemeral instauration of an independent state (García, 1982).

At the onset of the first world war, the international prices of rubber declined due to the establishment of plantations in Asia (Lindert & Verkoren, 2010). This caused a decrease in the MAP region's attractiveness. However other economic activities had already emerged and several cities, such as Rio Branco and Cobija, had become established.

Remnants of rubber exploitation, supplemented by farming, ranching and timber extraction, underpinned the regional economy until the mid-XX century. Around that time, national governments, wanting to take advantage of the enormous amount of 'unused' land, encouraged colonization ventures by offering large extensions of land at no cost (Lindert & Verkoren, 2010; Rumrill et al., 1986). Descendants of these colonists became landowners, such as the *barraqueros*, large-scale Brazil nut collectors in Bolivia, and livestock ranchers in Brazil.

The second half of the XX century is characterized as a time of intensified extractive activities of renewable and non-renewable resources. Several forest products were 'discovered' and larger markets for these products later developed. Precious timber and the Brazil nut (*Bertholletia excelsa*) became flagship products, and cities like Rio Branco, Riberalta and Puerto Maldonado evolved into regional markets and export hubs (Assies, 2002; Cronkleton et al., 2008; Dourojeanni, 2001). At the same time, cattle ranching was intensely promoted in Brazil, becoming Acre's economic keystone (Godfrey, 1990; Lindert & Verkoren, 2010).

In the 1970s gold and other minerals were re-discovered in some parts of the MAP region. As the opportunity for occasional and quick profit emerged, small mining operations mushroomed, which triggered an important influx of migrants, mainly from neighboring regions (García, 1982). This process continued and intensified until mining became the economic backbone of the Madre de Dios department in Peru (Alfaro, 2012). Later, in the 1980s and 1990s, in Bolivia and partially also in Peru, several public and private investors encouraged the emulation of the Brazilian ranching model with minor success, which also accelerated the conversion of forests into grazelands (Campell et al., 2010; Chávez Michaelsen et al., 2013; Killeen et al., 2008; Lindert & Verkoren, 2010; Perz et al., 2016).

The above-described socioeconomic changes together with a growing global awareness of environmental problems created pressure on the respective national governments to act. This crystallized in the creation of national parks, which besides their conservationist mandates, also allow the restricted operation of other economic activities.

Over the years, the diversification of economic activities, the change of land-property regimes, and the installation of national parks, allowed many short-term immigrants to become permanent residents. Establishing peasant communities, they sustained their livelihoods with a strategic combination of productive and extractive activities (Assies, 1997).

At the turn of the XXI century, a major infrastructural project was set up to revamp the region: the construction of the Interoceanic Highway. Completed in March 2012, the highway extends for 2 600 km starting at the Peruvian coastline on the Pacific Ocean, traversing the Andes and the southwestern Amazon, and ending at the Atlantic Ocean's coast in Brazil. About a decade after its completion, the overall intention of the highway to dynamize the economy and trade and integrate the region seems to have succeeded: cities, markets, entrepreneurship and migration have grown and intensified; but social and environmental drawbacks have also arisen (Mendoza et al., 2007; Perz et al., 2010).

## 2.2 The study sites

### *2.2.1 Acre, Brazil*

After successive occupations by the Viceroyalty of Peru, the Peru-Bolivian confederation, Bolivia, and a few attempts at independence, Acre became a state of Brazil in 1903 (Treaty of Petrópolis, 2019). Acre is the most western of Brazil's states and one of the most distant from its economic and administrative centers. With an area of 164 124 km² and a population of 881 935, it is the Brazilian Federation's 16$^{th}$ largest and fourth least densely populated state (IBGE, 2019). It generates about 14,2 million R$ year$^{-1}$ (about 2,4 million €), which contributes a tiny 0,2% of the national GDP, surpassing only the state of Roraima (IBGE, 2018).

Although services and industry have become more important in recent times, Acre's location in the Amazon rainforest makes nature- and rural-related activities the determinants of its economy (Acre (State), 2019). Thus, at the end of the XX century, Acre was branded as a state dominated by timber, agriculture and the traditional extraction of forest products, such as rubber and Brazil nut (Rumrill et al., 1986).

Subsequent rapid colonization has posed a challenge to the balancing of conservation, economic production, and people's well-being. Existing land use regimes compete by resources, land and economic profit (Perz et al., 2012). For instance, some s*eringeiros* and *castanheiros* (rubber and Brazil nut collectors, respectively) left their traditional activities to concentrate on livestock rearing and/or agriculture on deforested lands. With time this process intensified, leading to the acquisition and renting of land for the establishment of large cattle ranches, and the simultaneous expansion of the road network. In 2004, it was estimated that there were two million head of cattle in Acre (IBGE, n.d.; Mendoza et al., 2007), grazing in areas almost exclusively converted from natural forests (França Maia et al., 2016; Lima et al., 2013).

Conflicts between small-scale rubber collectors, subsistence farmers, conservationists and large-scale loggers and cattle ranchers scaled-up in the 1970s and 1980s. This led to the expulsion of settlers, and the prosecution and even assassination of some leaders, which brought the conservation movement national and international attention. As a result, and to prevent further conflicts, the government proposed alternatives to regulate landownership and land use (França Maia et al., 2016).

Thus, in 2000, the National System of Natural Conservation Units was established and two types of conservation zones were created: (i) the *Unidades de Proteção Integral*, where no economic activity and only conservation is allowed, and (ii) the *Unidades de Uso Sustentável*, also known as 'Extractive Reserves'. In Acre, two of the latter were implemented: Chico Mendes and Alto Juruá (Figure 1).

### 2.2.2 Pando, Bolivia

Pando was officially founded in 1938. With an area of 63 827 $km^2$ and a population of 110 436, it is the least populated, connected and developed department of Bolivia (INE, 2012). Its annual GDP reached about 350 million € in 2018, corresponding to 0,91% of the national GDP (INE, 2019a). Similar to Acre and Madre de Dios, Pando's historical development was determined by waves of pioneers and entrepreneurs seeking rapid wealth via the exploitation of natural resources, especially rubber in the early XX century, followed by Brazil nut (Lindert & Verkoren, 2010; Rumrill et al., 1986).

Pando's economic diversification was arrested by its relative isolation from Bolivia's and the late government's degree of reticence to the market economy. Its economy continues to overwhelmingly depend on the Brazil nut. As a consequence, well developed social and economic structures exist for the collection, postharvest and storage of Brazil nut; and to ensure forests and ecosystems are relatively well looked after (Lindert & Verkoren, 2010; Marsik et al., 2011).

Nevertheless, deforestation remains an issue in Pando. 180 792 ha, about 3% of its total area, has been deforested, which constitutes over one third of the total area deforested at the national level. The drivers are livestock rearing (50%), mechanized agriculture (30%) and peasant and indigenous agriculture (20%) (Larrea-Alcázar, 2015; Quiróz Claros & Vos, 2017).

Similar to the Brazilian and Peruvian cases, Bolivia's legislation allows for two types of conservation areas: (i) Parks, Sanctuaries and Natural Monuments, where only scientific research, ecotourism, environmental education and provision of means of subsistence for native communities are allowed, and (ii) National Reserves of Wildlife, where economic activities are also allowed. In Pando, the Manuripi Amazon National Wildlife Reserve was created in 1973 (D.S. Nº 24781 Reglamento de areas protegidas, 1997; SERNAP, 2012), and it is traversed from north to south on its eastern flank by the unpaved road 16 that extends until the shore of the Madre de Dios river (Van Damme, 2018) (Figure 1).

Brazil nut makes up more than half of the total income of community members, although its harvesting is constrained to just four months each year (García, 2016; INE, 2019b). However, there is an untapped potential for the collection of products from other species in the area, such as *açaí* (*Euterpe precatoria*), *majo* (*Oenocarpus bataua*), rubber (*Hevea* spp.), and *jatata* (*Geonoma deversa*, *Geonoma stricta*) (SERNAP, 2012). Recently, after a long hiatus and driven by an increase in its international price, rubber collection has regained importance (SERNAP, 2012); as has the collection of the *açaí* palm fruits (García, 2016).

### 2.2.3 Madre de Dios, Peru

Madre de Dios, the third largest department of Peru but one of the least populated, was officially created in 1912 after the trilateral Acre border litigation was solved (Dourojeanni, 2013). Until recently, it was considered a marginal region, as its economic weight and political relevance were minor: it contributes barely 0,5% to the national GDP (about 1 017 million €) (MINCETUR, 2019) and elects only one representative to the parliament (OCI, 2017).

However, a recent economic boom has enhanced its reputation as a place that is undergoing development, and its population has correspondingly grown steadily: from 20 000 in 1970, to 100 000 in 2010, to more than 150 000 today (Brack et al., 2011; *MADRE DE DIOS, RESULTADOS DEFINITIVOS*, 2018). Currently, domestic and international immigrants make up more than 60% of its population (Sánchez Aguilar, 2017). About half of its GDP depends on the extraction of non-renewable resources: oil, gas and minerals (IPE, 2018). Gold mining is the department's major economic pillar, and its over-spill effects have propelled other economic activities such as construction, trade and hosteling, and the reinforcement of precedent activities, like timber, NTFP extraction and farming (INEI, 2018). Lately, supported by non-governmental organizations (NGOs) and launched by private entrepreneurs, productive and industrial activities have more recently broadened: i.e., diversified agroforestry systems, pisciculture, furniture construction, fruits and nuts processing, essential oil production, etc. (Brouwer, 2018; Rumrill et al., 1986).

Still, natural resources remain the major assets of Madre de Dios, which led the government to set forest conservation policies that evolved into conservation initiatives. The Tambopata and Manu national reserves, and the Alto Purus and Amarakaeri communal reserves were created to be used for conservation and research, though allowing restricted tourism and some extractive activities (Alfaro, 2012; Dourojeanni, 2013), which has led to the growth of ecotourism as a prominent activity in the region. Although the sector is nominally significant by its growing scale and the high per-capita spending, its overall impact on the local economy is limited, as it is run primarily by larger non-local companies (Doan, 2013).

However, this fast development also implies tradeoffs. The expansion of gold mining in the 1980s and 1990s triggered a large influx of artisanal and small-scale miners. By 2010, more than 1 500 requests for regularization of operations, involving about 30 000 miners, were approved (Brack et al., 2011). Because of the region's remoteness, the government implemented a *laissez faire* approach with the entrepreneurs. The absence of control and monitoring led to massive environmental and social impacts. It is estimated that the clearing of forests, topsoil removal and mercury release affect more than 4 000 ha $year^{-1}$ (Asner & Tupayachi, 2016). Furthermore the mushrooming of miner settlements triggered an abrupt surge in child labor and sexual exploitation (Salo et al., 2016). Various initiatives to curb and formalize artisanal and small mining have had limited impact, due to their inadequacy, volatility, inconsistent implementation, and overall, inability to offer economic alternatives to miners (Salo et al., 2016) (Figure 1).

## 2.3 The MAP initiative

The MAP region encompasses about 300 000 $km^2$ and is inhabited by approximately one million people (Rioja et al., 2015). It is considered a promising case for cross-border partnership and economic integration because of the similar geopolitical, environmental and social-economic roles the region plays for its three respective countries (Lindert & Verkoren, 2010; Mendoza et al., 2007) (Figure 1). Therefore, its situation is considered archetypical for transboundary studies.

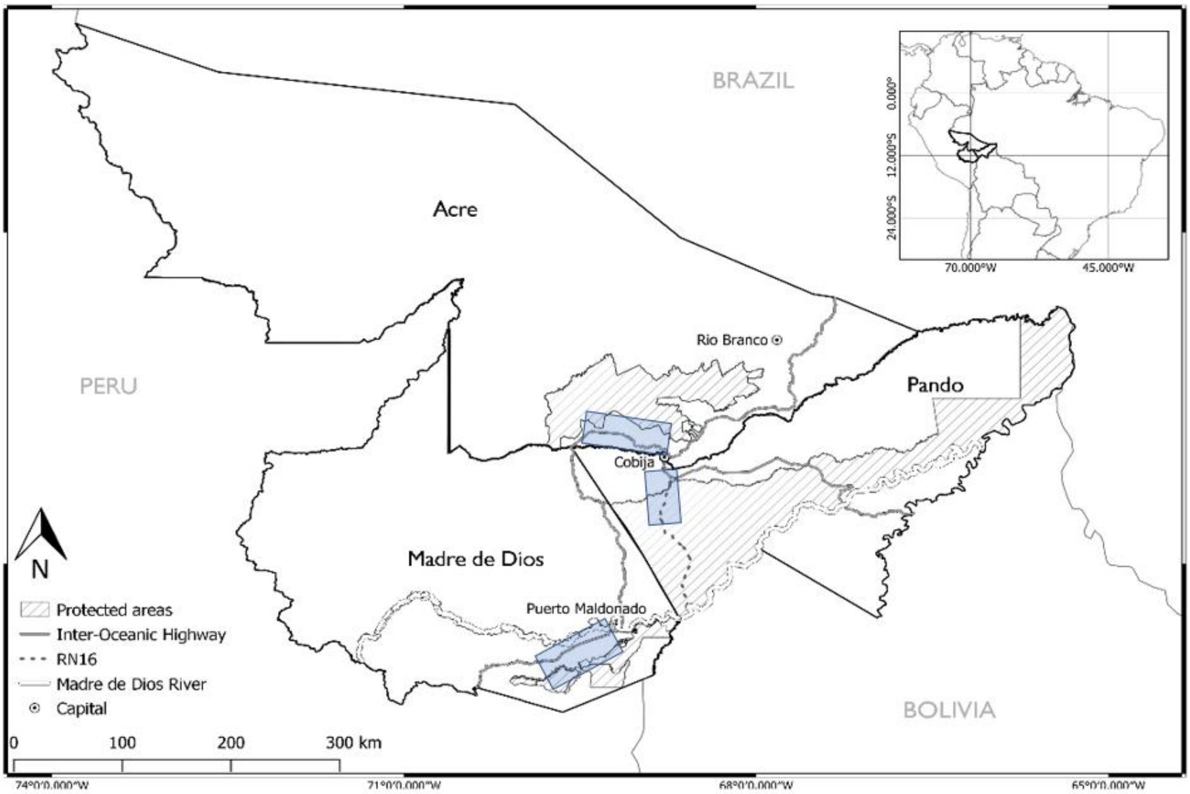


Figure 1: The MAP region. The PRODIGY research area stretches across the interoceanic highway, including the protected and neighboring areas alongside (marked polygons)

Trans-border situation and transboundary regions have gained importance as globalization and interconnectedness across countries and political demarcations evolved and grew (Perkmann & Sum, 2002). A transboundary situation occurs when neighboring countries impact and influence each other directly, or indirectly through the use of public goods or commons (OECD & Joint Research Centre - European Commission, 2021). In the case of the MAP region, both occur as the efforts to build partnerships to meet common regional demands, such as to increase connectivity and economic development, and challenges, like to tackle deforestation and land degradation, have existed since the early 1990s (Gudynas, 2007; Lindert & Verkoren, 2010; Perz et al., 2010).

Under those premises, the MAP initiative was created in 2000 as a politically neutral platform where stakeholders of varying positions but similar interests could productively interact and form coalitions for action. The idea was envisioned in a 1999 multilateral gathering organized by the University of Rio Branco in Acre, where they agreed that the region's environmental fragility was the major regional challenge, and that only joint actions could address it. Hence, the *Declaración de Rio Branco* was signed, giving birth to the 'MAP' acronym, standing for Madre de Dios, Acre and Pando.

The MAP initiative led to further projects, including one on road connectivity integration and administration improvement, sponsored by the United States cooperation (Mendoza et al., 2007); and another on developing measures to promote international trade, supported by the Union of South American Nations (Chávez et al., 2005; Parimbelli, 2016). Of late the MAP initiative's leadership and leverage has progressively declined, due to the uneven level of involvement of its counterparts and a corresponding decrease in their stakes and capabilities.

## 2.4 Some of the MAP region transboundary challenges

As described above, the MAP region as a whole is confronted with common challenges including deforestation, land use change, conflicts among land users and fast urbanization (Dourojeanni, 2013; Duchelle, 2007; Lindert & Verkoren, 2010; Mendoza et al., 2007; PRODIGY Proposal, n.d.; Rumrill et al., 1986). However, its three constituent countries are also marked by historical and contemporary social and political differences. In the handling of common issues such as the Brazil nut collection and the national protected areas, these differences among countries become evident.

### *2.4.1 The Brazil nut*

Brazil nut (*Bertholletia excelsa*) is the most important non-timber forest product in the MAP region. Bolivia, Brazil and Peru are the top world producers, with a joint production volume of 120 000 ton year$^{-1}$ and an economic inflow above 45 million € year$^{-1}$ (TRIDGE, n.d.). Currently Bolivia holds 42,8% of the global market share, followed by Brazil (35,5%); and Peru (5,2%) (TRIDGE, n.d.).

The harvesting of Brazil nut is seasonal; its collection, pre-processing and storage are generally artisanal, and appeal to traditional technologies, techniques and even infrastructures, which have been recognized as being socially and ecologically sustainable (Guariguata et al., 2017). Brazil nut trees can reach heights of 50 m, diameters of 2 m and have life spans of 500 years, and require, to prosper, an ecologically diverse surrounding. The species is thus acknowledged as an indicator of the adjacent forest's health. Its logging is banned, due to the species' symbolic character, economic importance and ecological significance, nevertheless it still often occurs (Brouwer, 2018; Capurso, 2018; Chávez Michaelsen et al., 2013; Hellström, 2017; Marsik et al., 2011; Rumrill et al., 1986; Soares-Filho et al., 2006) (Figure 2).

The regional production of Brazil nut is affected by broad and diverse challenges. For instance, in 2005, there was an abrupt rise in international prices, likely due to the 're-discovery' of Brazil nut as a super food by western consumers, which led to high demand and increased the benefits for collectors. Oppositely, in 2008, the El Niño Southern Oscillation caused droughts in the Amazon region, which seems to have halted Brazil nut tree flower pollination and severely diminished the development of nutshells and the final production of Brazil nuts themselves. At the same time, the international Brazil nut market is quite volatile, since buyers can react to a limited supply by increasing the international price, which occurred in 2017; but longer shortages can incite buyers to diverge and seek other types of nuts, such as macadamia (*Macadamia integrifolia*) and cashew (*Anacardium occidentale*), more broadly cultivated, which ultimately can cause a fall in the Brazil nut price (Terazono, 2017).

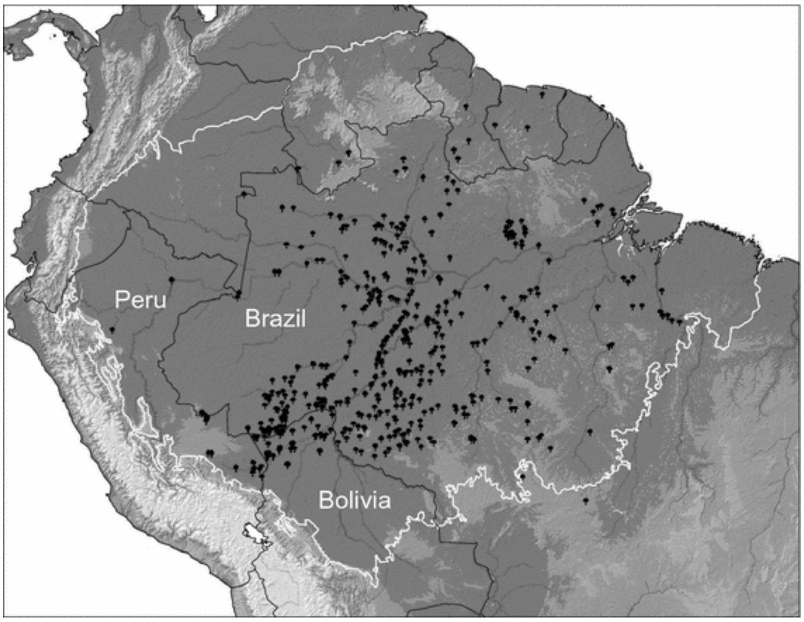


Figure 2: Distribution of Brazil nut trees in the Amazon basin (delineated in white). Notice the higher density in the MAP region (Source: Guariguata et al., 2017)

In addition, there are national differences regarding how the Brazil nut economy is affected across producing countries.

In Bolivia, slower economic growth and smaller trade scale has caused a persistent marginalization and under-competitiveness relative to neighboring countries; a situation lately enhanced by the alleged socialist and protectionist regime of Evo Morales (2006-2019). This contributed to the maintenance of pre-existing economic and organizational structures. Nevertheless, *ad-hoc* legislation by the government and institutional networks created by civil society have positively impacted the production of Brazil nut and the preservation of collection sites. Nowadays, Brazil nut accounts for almost 70% of the economy of Pando. The leading force are the *barraqueros*, inheritors of former regional landlords who were granted concessions by the government to operate the collection of Brazil nuts and rural communities. The methods and infrastructure upon which they rely for the collection, pre-processing and storage of nuts have barely changed throughout the last century. A beneficial side-effect of the 'over-dependence' on Brazil nut is the relatively good condition of the providing forests, as collectors acknowledge the importance of the tree for harvesting the nut.

In Brazil, similar edicts to protect forests and Brazil nut trees exist, but the profile of land users is evolving and diverging. For example, private ranchers are keen to expand their grazelands at the expense of forests, and inhabitants of the extractive reserves, supposedly allowed only to engage in extractive activities, are becoming small ranchers themselves, incentivized by the comparative high profits, the permissive regulations and weak control. Nowadays, the Brazil nut tree density has considerably decreased, and the surrounding ecosystems are poorly preserved, as the economic importance of Brazil nut shrank, and the priorities of locals drifted.

In Peru, due to the recent and fast diversification of work and business opportunities, land-users are exposed to several options, e.g., farming, ranching, agroforestry, pisciculture, and off-farm activities such as mining or urban-rural migration. Therefore, Brazil nut collection has become one option among many others. Hence, the *castanheiros* (Brazil nut gatherers) have started to widen their activities to increase their economic opportunities and livelihood resilience. This situation is widespread and may have an impact on the condition of Brazil nut trees, which are less cared for, although not to the extent of that observed in Brazil.

### *2.4.2 National protected areas*

In all three countries, the capital cities of the MAP region, Rio Branco, Pando and Puerto Maldonado, are relatively close to their respective national protected areas.

In Brazil, the Extractive Reserve (*Reserva Extrativista RESEX)* Chico Mendes covers an area of 970 570 ha and hosts about 10 000 inhabitants (França Maia et al., 2016; ICMBio, 2009). It was created in 1990 and is part of the protected areas created under the National System of Natural Conservation Units (França Maia et al., 2016). At the state level, these are administrated by the Chico Mendes Institute for the Conservation of Biodiversity (ICMBio), which is linked to the Ministry of the Environment; at the state and municipal levels, several *ad-hoc* organizations exist. At the local level a deliberative council, responsible for the RESEX administration, comprises representatives of local public entities, civil society organizations and traditional populations. In RESEX this council is chaired by ICMBio. Protected areas can either be classified as areas of integral protection or as areas of sustainable use. An Extractive Reserve is part of the latter and is defined as "(…) an area used by traditional populations whose survival is based on extractivism and, in addition, subsistence agriculture and small animal husbandry. Its basic objectives are to protect the livelihoods and culture of these populations, and to ensure the sustainable use of the Units of Conservation of natural resources" (Art. 18 of the law 9 985). By this, private areas in an extractive reserve must be expropriated and the areas occupied by traditional populations are to be regulated.

In Bolivia, the Manuripi Amazon National Wildlife Reserve of 747 000 ha was created in 1973 (Alfaro, 2012). National reserves aim to "(…) protect, manage and sustainably use, under official surveillance, wildlife. [They allow for] intensive and extensive uses, both non-extractive and extractive, according to its zonation, the latter subject to strict control and monitoring referred exclusively to wildlife management and use." (Decree Nº 24781 *Reglamento de areas protegidas*, 1997). The National Reserve of Manuripi was formerly managed by the National Service of Protected Areas (SERNAP), an entity dependent on the Ministry of Environment and Water. Since 2008 its administration is co-led by a management committee, formed by representatives of civil society and populations residing in the area.

In Peru, the National Reserve of Tambopata of 274 690 ha was created in 1977 and established in 2003 by the law n°26834, with the objectives of protecting, conserving and evaluating the wild natural and cultural resources, as well as investigating and promoting their sustainable use and management (Alfaro, 2012). As in Brazil and Bolivia, Peruvian protected areas are divided into two categories: areas of indirect use, e.g. National Parks, and areas of direct use intended for the conservation of biological diversity and the sustainable use of wild flora and fauna. National Reserves are part of the latter and allow the commercial exploitation of natural resources under management plans which are approved, supervised and controlled by a competent national authority (Ley de Areas Naturales Protegidas Ley Nº 26834, 1997). Locally, the National Reserve of Tambopata is managed by the National Service of Protected Areas (SERNANP), a public institution under the Ministry of Environment, together with the NGO Association for Research and Integrative Development (AIDER). A supervising management committee comprises representatives of civil society groups and traditional populations residing in the area.

All three reserves suffer from illegal deforestation and forest degradation, but at different rates. Between the creation of the RESEX Chico Mendes (in 1990) and 2010, 8,19% of the reserve's total area was deforested, a total of 76 430 ha (Wallace et al., 2018). In the same time period, the Manuripi reserve lost 3 390 ha (SERNAP, 2012), which does not account for the area affected by fires, e.g. 5 000 ha in 2005 alone (HERENCIA, 2010). Inside the Peruvian reserve of Tambopata, 750 ha were lost to mining activities in 2017 alone (Finer et al., 2017) and since then until 2019, deforestation continued at a rate of 6,5 ha per month (Finer & Mamani, 2020).

Brazil's RESEX reserve is meant to support extractive activities (mainly rubber and Brazil nut extraction), however many locals live off cattle ranching, which is also the main driver of land conversion. RESEX is actually the most permissive of the three reserves when it comes to allowing farming. Indeed, the RESEX management plan allows for each resident to use up to 10% of their land for non-extractive activities, i.e. agriculture, small livestock rearing, fish farming and agroforestry. The total area dedicated to these activities cannot exceed 30 ha per concession; and in lands with no extractive potential, this number can be extended to 20% of the land, not exceeding 40 ha in total. Big animals -like cows- can only be bred on half the area dedicated to non-extractive activities. This means that grazelands should not surpass 15 to 20 ha per concession (IBAMA, 2006). In practice, these measures have proven to be insufficient. The deforested area between 1988 and 2014 reached 67 200 ha, corresponding to 6,9% of the reserve area (França Maia et al., 2016); by 2009 the socioeconomic census counted 21 000 heads of cattle which by 2016 increased to 29 000 (França Maia et al., 2016). In 2010 15% of RESEX households named livestock rearing as their main economic activity (Fernandes, 2017; França Maia et al., 2016), and the area used for it was estimated to be 52 900 ha; according to the Management Plan, the maximum area should have been 30 000 ha, meaning that the area dedicated to cattle was 76% above the maximum legal limit (França Maia et al., 2016).

In comparison, the national reserves of Bolivia and Peru are prohibiting all farming activities on land that was not owned or used by local people before the reserves' creation. In Bolivia, 25% of the Manuripi National Reserve (about 747 000 ha) is legally owned by local people: 23% by communities and 2% by *barraqueros* (SERNAP, 2012). Agriculture is only allowed for subsistence and as long as it does not weaken the reserve's conservation goals (SERNAP, 2010), it can be practiced on a very limited (1,3%) proportion of the Manuripi reserve. In the Tambopata reserve, agriculture is only allowed in zones which were already cultivated before the creation of the reserve. These represent 1,23% of the total area, and their expansion is not allowed (SERNAP, 2012).

Nevertheless, the Manuripi and Tambopata protected areas face a different challenge: mining. It is notable that 49% of the Manuripi national reserve area is allocated to the national state for hydrocarbon exploration (SERNAP, 2010), which began with the construction of a highway that aims to connect the Pando region with Bolivia's economic and political centers (Ruta 16 (Bolivien), 2020). In Peru, gold mining concessions exist just across the Tambopata reserve's border, along the buffer zone, and intrusions of illegal miners into the reserve are not uncommon (Asner & Tupayachi, 2016).

Although the highest proportion of Tambopata reserve is devoted to zones of strict protection (49%), a considerable part (6,8%) is used for ecotourism. Recently, the reserve became an important tourist attraction, receiving over 50 000 visitors year$^{-1}$ and generating around 35 million € year$^{-1}$ (Vilela et al., 2018). The situation is different in Manuripi, where tourism is much less developed, and less than 2% of the total area of the reserve is dedicated to it.

# 3 Conceptual and methodological basis

To operationalize our aim to assess the social-ecological resilience of rural householders, we rely to the premises set by transboundary research, and for its implementation on two scientific approaches: complex systems, and approaches to disruption and change. For the latter we draw on the conceptual models: adaptive cycle and panarchy, to elucidate the occurrence of tipping points.

## 3.1 Transboundary research

Borders are much more than divisions between neighboring countries. Rich social and material dynamics occur across them. Exchange and integration but also exclusion and conflict, are intrinsic phenomena to national political boundaries (Hataley & Leuprecht, 2018). Therefore, the study of boundaries has transited beyond geography and political science, towards a diversity of social and environmental disciplines and interfaces among them, aiming to tackle the challenges that societies confront in those situations (Paasi, 1998; Popescu, 2011).

Operationally, the fundamental questions that **transboundary studies** address are: how do societies evolve in such a situations, which are the actors and factors that determine the societies' operation, and finally, how can they be steered to promote the parties' cooperation and overall prosperity (Castanho et al., 2018).

The Peru-Brazil-Bolivia hub, as it is called the commercial confluence of these three countries for commercial purposes (Figure 3a), contains the MAP region. It is singled out as one of the 10 integration and development hubs in South America, as it accounts for 10.5% of the area of the region, 4.5% of its population, and 2.1% of its GDP (IIRSA, 2010, 2011). Studies previous to the construction of the transoceanic highway, have shown the trade balance of the MAP region strongly oriented towards extra-regional exports: in 2000, 98% of exports reached destinations outside the region, and in 2008, it reached 96.6% (IIRSA, 2011). Must be noted that those exports were essentially of natural resources.

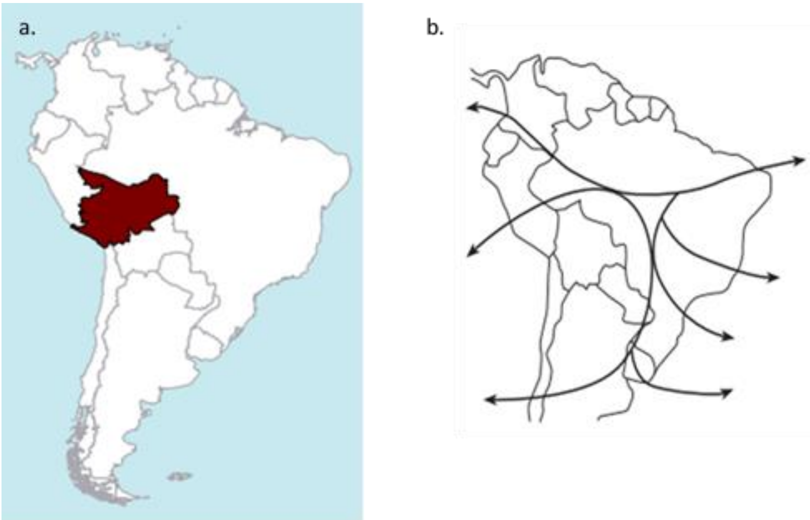


Figure 3: a. The 'Peru-Brazil-Bolivia hub' containing the MAP region and b. the proposed transport corridors to prop economic integration (Sources: IIRSA, 2011; Gudynas, 2007)

Situations like this are widespread in Latin America, evidencing the need to ease trade (mostly via roads), which has been heavily promoted by national governments and multilateral organizations, like the Initiative for the Integration of Regional Infrastructure in South America (Figure 3b). In the case of the MAP region, this has led to the construction of the intercontinental highway finalized in 2010.

Historically, the institutional and regulatory conditions were thought to benefit the more powerful actors, and most of the population, mainly rural, remained marginalized in terms of the provision of basic services such as health, education and justice. Thus, it remains unclear whether the benefits of this transboundary effort will overpower its tradeoffs, and not hampering the sustainable development of the region on the long run (Gudynas, 2005, 2007).

Therefore, the distinctive evaluation and analysis of the three country-sites involved, with respect to their peculiarities as well as their commonalities is crucial, as well as the relationships between and among country-sites, expressed in cross-border flows and exchanges. Hence, in this research variables such as migration, cross-border traffic and road network expansion gain special preponderance, and are therefore evaluated and compared among countries.

## 3.2 The complex systems approach

A situation is called 'complex' when several elements, apparently disconnected from each other, together exhibit more and different properties than those possessed by the elements alone. For many real-world systems, this should be obvious, as most phenomena do not occur in isolation but are rather related to other elements and phenomena. Nevertheless, in applied research, there is a strong tendency to simplify a situation by opting for pre-existing and reductionist approaches, methods and tools. By acknowledging **complexity** as an inherent quality of the research subject, the selection of premises, approaches and methods to handle them is relativized to the problem itself (Callo-Concha, 2014).

Related to complexity is the notion of a **system**, as a collection of components intrinsically interconnected, and whose interaction determines the performance of the whole (Bertalanffy, 1950). It has become clear that complexity is an inherent feature of most systems. Indeed, components, while performing their own actions, interact with one another and define the system's overall functioning. Hence, complexity becomes the most important characteristic of systems, subsequently referred to as **complex systems** (Callo-Concha, 2014; Folke, 2006).

To operationalize the analysis of complex systems in applied research, the definition of an integrative unit of analysis is key. The concept of **Social-Ecological Systems (SES)** underlines the inherent interconnectedness of humans and their surroundings; hence, the adoption of SES as a unit of analysis has been favored by studies that prioritize the harmonization of social development and conservation, such as the provision of ecosystem services and the prevention of disturbances (Adger, 2006; Berkes & Folke, 1998; Gallopín, 2006; Ostrom, 2009).

In research on social-ecological systems, stakeholder **participation** is important to increase the quality of collected information, and to understand the systems' actors' viewpoints and actions, and the underlying structures behind them. Moreover, participation increases the legitimacy of outcomes, reduces the biases of centralized approaches, and promotes co-learning among participants (Stringer et al., 2006; Walker et al., 2002).

## 3.3 Resilience et al.: disruption and change approaches

The ability of systems to fit into changing surroundings is often taken as a surrogate of sustainable behavior. Thus, the use of concepts such as resilience, vulnerability, adaptation, adaptability and transformation, was extended to the analysis of social-ecological systems. These complementary concepts are part of the disruption and change approach, and target situations where progressive change and/or sudden disruptions hit the systems, and how the systems seek ways to soften their impacts and return to a stable stage (Adger, 2006; Callo-Concha, 2014).

**Resilience** was first identified in biology and defined as the capacity of living systems to absorb shocks and recover functions across temporal and spatial scales (Holling, 1973). Later, adopted by social science, other features like renewal and reorganization were attributed to the resilience of cultural-, economic- and political systems (Adger, 2000). The connection between natural and social systems was made with the coining of the concept **social-ecological resilience.** Including premises associated with operation and purpose, the concept underlines the abilities of systems to undergo changes and retain their function, structure and identity (Carpenter et al., 2001; Cumming & Peterson, 2017; Davidson et al., 2016; Sinclair et al., 2017; Walker et al., 2002). Differently to resilience, the application of **vulnerability** is generally associated with social issues and specifically with hazards (Adger, 2006; Turner et al., 2003). For instance, the vulnerability of a community to droughts will relate to the particular characteristics of that population, i.e., its exposure, susceptibility and coping ability (Gallopín, 2006), vulnerability can also be elicited as a condition that needs to be strengthened to prevent undesired effects, e.g., making a population less vulnerable to the effects of global warming (Acosta-Michlik & Espaldon, 2008; IPCC, 2007; Kasperson et al., 2005; Liu et al., 2008; Van der Leeuw, 2001).

**Adaptation** was applied in biology to refer to the features that contribute to a species' survival and reproduction (Douglas J, 1997), and in social sciences to the capabilities of individuals, groups and institutions to adjust to change (Denevan, 1983; Smit & Wandel, 2006). Different than resilience and vulnerability, adaptation offers many linguistic and semantic variations, i.e. **adaptive capacity** referring to a system's intrinsic ability to retain its characteristics and configuration throughout the duration of a disturbing event (Brooks et al., 2005); **adaptability**, relates to the capabilities of a system to change itself to cope with changes; and in the implementation arena, **adaptive management** alludes to the measures and review of their effects to refine subsequent decisions (Gunderson, 2002; Stringer et al., 2006), and if embodied on all operative levels, we would be speaking of a **complex adaptive system** (Folke et al., 2003).

When a change or shock is so great that a system is unable to cope, i.e. it is insufficiently resilient, or unable to adapt, a system experiences what is called **transformation** or regime shift, that is the conversion to a fundamentally new system when ecological, economic, or social conditions make the precedent system non-viable (Anderies et al., 2006; Berbés-Blázquez & Scott, 2017; Folke, 2006; Löf, 2010; Walker et al., 2004).

## 3.4 Towards the detection of tipping points

The **adaptive cycle** has been proposed to represent the evolution of complex systems across disturbances and changes. In four successive phases: exploitation (r), conservation (K), release (Ω) and reorganization (α), it shows the stages that a system experiences during a hazardous situation, e.g., a forest growth in biomass accumulation (exploitation), the reaching and maintenance of its climax (conservation), the sudden loss of it by an undesirable event, like a fire (release), and its subsequent recovery (reorganization) (Figure 4).

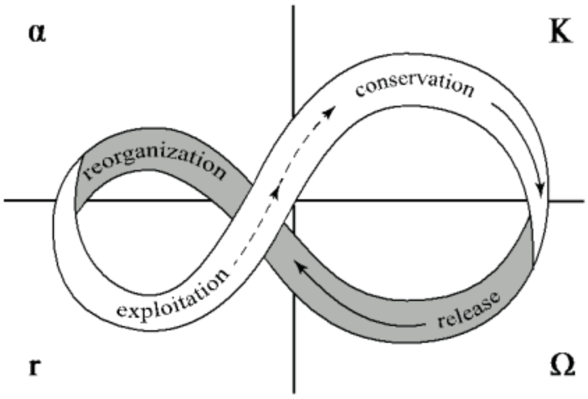


Figure 4: The adaptive cycle indicating its four phases and their succession
(Source: Gunderson and Holling, 2002)

All the concepts of disruption and change are implicit in the adaptive cycle. Resilience and vulnerability are the forces that drive the transitions and adaptability across the whole cycle. Transformation is more punctual, and if it occurs, it happens during the transition from the conservation to the release phase (Anderies et al., 2006; Berkes et al., 2002; Holling & Gunderson, 2002; Tversky & Kahneman, 1974; Ulrich & Probst, 1990; Walker et al., 2002).

**Tipping points** are the situations in which a small but constant perturbation triggers a major change in an overall complex system (Lenton, 2013). Although the first insights into tipping points were made in natural systems, more recent attention has targeted social-ecological systems, especially at the earth system scale, as they are at the center of major concern related to their large-scale impacts (Lenton et al., 2008). Tipping points are generally caused by an active force, such as soil erosion, that trigger a recognizable feedback loop on a tipping element, like vegetation mass in the Amazon. A control parameter, for the example, volume of soil loss per ha, indicates the status of the system; and if it reaches a critical point, e.g., +5 ton $ha^{-1}$ of soil loss, it indicates the approach and eventual triggering of a tipping point (Lenton, 2013; Lenton et al., 2008) (Figure 5).

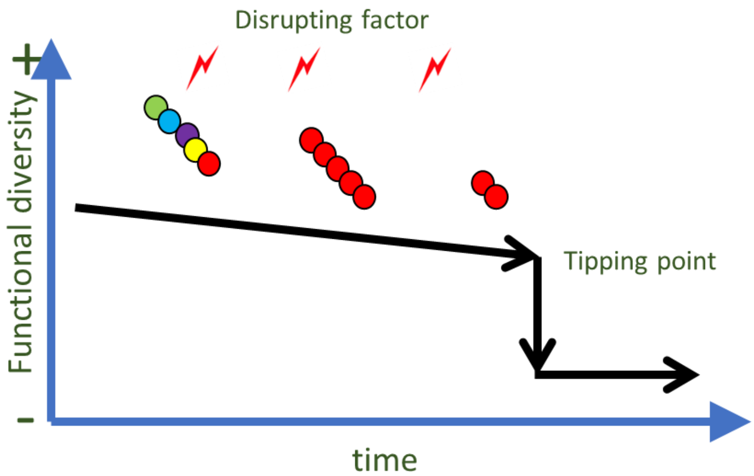


Figure 5: Trajectory of a gradually less diverse system towards its tipping point (Source: Jungkunst, 2019)

As tipping points are mostly abrupt and mostly irreversible, a major concern is their anticipation, to enable the softening of their impacts when they are harmful, or to encourage them when they are beneficial (Lenton, 2013). In this regard, early warning indicators are avidly researched for the diagnosis of the system, forecasting of the tipping points occurrence, and possibly their prevention (Liehr et al., 2017; Scheffer et al., 2009; Thonicke et al., 2019).

As can be implied, the concept of tipping points has been predominantly applied in biophysical systems, but lately its application is been stretched to the social and social-ecological domains. By the same there is not a clear-cut acknowledgement of the boundaries of the concept and of what should involve (Russill and Nyssa 2009; Kopp et al. 2016). But a review of its application suggests a compromised definition: "(…) *a tipping point is a threshold at which small quantitative changes in the system trigger a non-linear change process that is driven by system-internal feedback mechanisms and inevitably leads to a qualitatively different state of the system, which is often irreversible*" (Milkoreit et al. 2018) which will be considered along this research.

# 4 Operationalizing the analysis of Social-Ecological Systems and prevention of tipping points

Having outlined the real-life conditions of our research subject, and the conceptual trenches in which we stand, this section describes the operationalization of our work within the context of the PRODIGY project.

## 4.1 Research question and objective

Aligned with Lenton et al. (2008), PRODIGY targets four sub-systems, i.e., soil ecosystem, economic livelihoods, social/institutional cohesion, and regional climate (Lenton et al., 2008). It is hypothesized that when a hazardous event occurs such as the loss of biodiversity, it operates via a cascade effect by striking these tipping elements successively amplifying their effects, which may eventually lead to the reaching of an overall system tipping point. Accordingly, the four sub-systems are assessed via *ad-hoc* approaches and tools, and their outcomes integrated to offer a comprehensive view on the resilience of the MAP system (Figure 6) (PRODIGY Proposal, n.d.).

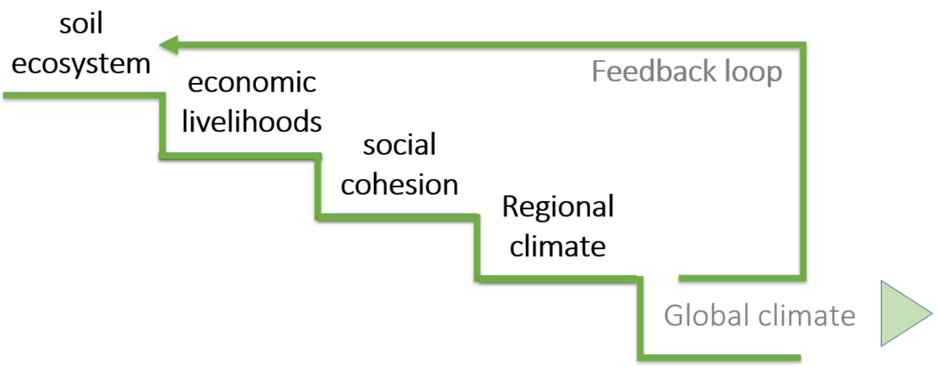


Figure 6: PRODIGY approach: hypothetical succession of tipping elements across the subsystems in the MAP region

Although the MAP region is ecologically homogeneous, the three departments, by their diverging political and institutional settings, and economic priorities, have developed complex social-ecological systems that differ among themselves. Hence, we contend that the MAP region inhabitants' livelihoods framed in those systems, and the disturbances they are confronted by, the loss of resilience and the eventual reaching of (a) tipping point(s), will necessarily relate to disruptions in these systems' features and functioning.

Therefore, our two research questions are: What are the features of rural households' complex social-ecological systems? What are the disturbances that could lead to the loss of resilience, and eventually the reaching of (a) tipping point(s)? To respond to them, we aimed at characterizing the socio-ecological systems, with a focus on the analysis of the structure, types and strengths of feedback loops between biodiversity and livelihoods aiming at identifying, describing and quantifying potential tipping points (PRODIGY Proposal, n.d.).

## 4.2 Research and analytical frameworks

We rely on complex systems and disruption and change approaches; and mixed methods and analyses to implement our research. The participation of local stakeholders, not only as providers of data, but also as active research contributors is an overarching premise (Stringer et al., 2006).

The unit of analysis is the rural household/householders' livelihoods. The sampling strategy follows a gradient of land use change/cover/intensity, from a heavily intervened area (generally a nearby road) to a conservation area (generally a national park) (PRODIGY Proposal, n.d.). Householders' livelihoods, spread across this gradient, are assumed to broadly range from various types of extractivism to off-farm activities, including extensive, intensive and subsistence farming and/or ranching (Figure 7).

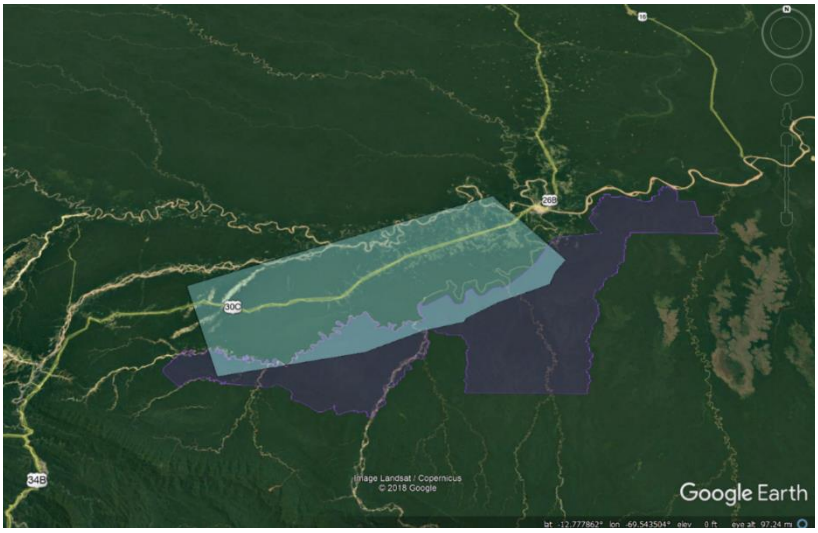


Figure 7: Sampling area in Madre de Dios, Peru. The sampling area stretches longitudinally along the Interoceanic Highway, involving the Tambopata national reserve and neighbouring areas; and transversally, to cover a gradient of land-use intensity (Source: Google Earth and demarcation by authors)

Our activities are divided into three successive and partially overlapping phases: (i) characterizing the countries' rural livelihood system(s), (ii) evaluating their functioning and resilience; and (iii) integrating the countries' evaluations into a larger assessment of the MAP region's tipping points.

The first phase aimed at the **systems' participatory characterization.** It relied upon a combination of ethnography, stakeholder and network analyses, and a participatory systems analysis with the previously identified key stakeholders, to produce the so-called system zero (S0). In this phase we identified the most salient features of the country-systems (composition, organization and functioning), as well as the delineation of their boundaries (Table 1) (Ackermann & Eden, 2011; Bryson, 2004).

The second phase validates the identified **systems' components and their interactions** (feedback loops), substantiating the previous findings with qualitative and quantitative data to produce the system one (S1). For that, we implement specific MSc and PhD investigations on component-related subjects and will carry out a household survey to profile the stakeholders' livelihoods. Complementary, we will execute interviews with key informants and institutions, and group interviews.

The third phase will focus on the **systems' integration and modeling.** Building on the outcomes of the previous phases, we will identify important country-specific subsystems that will constitute the system two (S2). These systems will be dynamically modeled and analyzed, to foresee interventions on their operation over time. This should be our major contribution for policy-making.

Finally, the S2 insights will be shared with the PRODIGY team which should integrate biophysical, socioeconomic, and institutional drivers into a regional model of the resilience and tipping points in the Amazon MAP region (Figure 8).

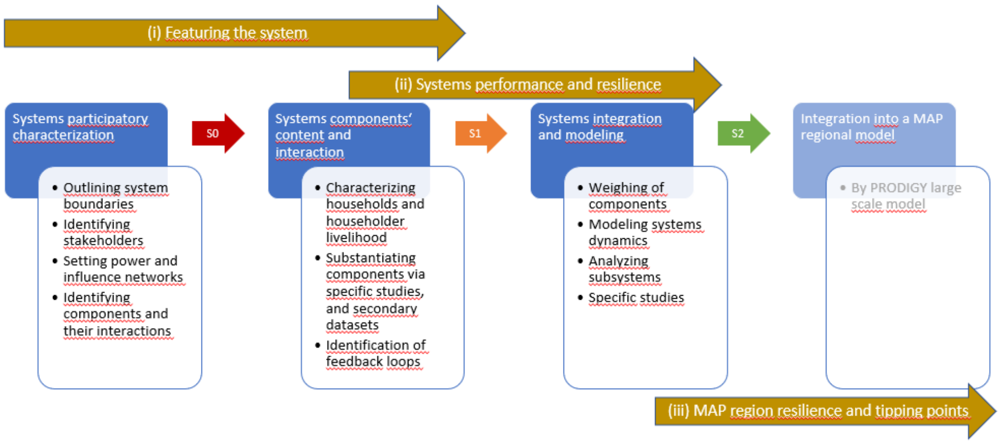


Figure 8: Research framework

## 4.3 Preliminary findings

The findings below correspond to our current advances (early 2022).

After categorizing the stakeholders in: government, non-government, grassroots organizations and the private sector, we applied network analysis to gauge their types and degree of interaction, and took that as a proxy of their degree of influence on the system (Prell, 2012). The identified key stakeholders participated in a systems analysis exercise to determine the system's components, the interactions among them, functions of the system and overall rationale. To achieve this we applied the specialized software Vester Sensitivity Model® (Vester, n.d.).

Fifteen components were identified per country. Four to six were specific to each of the sites, nine to eleven common in two, and six components were present in all three sites (Table 1).

Table 1: Systems' components by site

<table>
<tr><th>Brazil</th><th>Bolivia</th><th>Peru</th></tr>
<tr><td colspan="3">In all three sites</td></tr>
<tr><td colspan="3">• Extraction of NFTPs<br>• Impacts and risks due to changes in climate<br>• Extraction of timber<br>• Lobbying of local organizations<br>• Governance and laws in operation<br>• Market action and influence</td></tr>
<tr><td colspan="3">In two sites</td></tr>
<tr><td colspan="2">• Landscape/land use planning and implementation<br>• Influence of politicking and party bias<br>• Ecosystem services provision</td><td></td></tr>
<tr><td></td><td colspan="2">• Forest conservation/preservation<br>• Rural actors' agencies</td></tr>
<tr><td>• Expansion of road network</td><td></td><td>• Expansion of road network</td></tr>
<tr><td colspan="3">Exclusive to each site</td></tr>
<tr><td>• Forest land use conversion<br>• Livestock rearing expansion<br>• Strengthening of origin branding<br>• Devaluation of culture<br>• Cross-border traffic</td><td>• Sustainable management of natural resources<br>• Storage and transport infrastructure<br>• NTFP post-harvesting<br>• Financial injection</td><td>• Growth of productive activities<br>• Growth of small mining<br>• Development of ecotourism<br>• Indigenous communities' existence and agency<br>• Increase of illegal activities<br>• Increase of regional immigration</td></tr>
</table>

The determining features of all three systems relate to the main activities on which their economies depend, still all related to natural resources exploitation. The three major institutional actors were associated local land-users, political/government institutions and the market. The major challenge that the region faces is the creeping effects of ecological crises, exacerbated by the customary land-use interventions.

In Brazil and Bolivia land use planning is particularly relevant, as both governments have made it a key strategy to control deforestation and promote conservation, such as of NTFP species. Also important in the political agendas of these two countries are the provision of ecosystem services, although their implementation is so far very limited. On the downside it is observed recurrently in RESEX and more recently in Manuripi, that authorities and local organizations are engaged in strong politicking in favor of political allies to push their own agendas, which not always favor the majority.

Bolivia and Peru share the prioritization of forest conservation as a core goal. In Bolivia, this is fueled by its economic dependence on the Brazil nut. In Peru, forest conservation efforts have been accelerated with the emergence of new forest-dependent economic activities, such as ecotourism; still, mining appears as the core economic contributor but also the major disrupting factor. The broader acknowledgment and involvement of local actors of diverse profiles, as their relevance grows, is also important in both sites.

In Brazil and Peru, the road expansion network appears to be more relevant than in Bolivia. This is because the Interoceanic Highway does not pass as close to the Manuripi reserve as it does in the case of the other two conservation areas.

# 5 Conclusions and outlook

In this review, we have screened the historical and political/institutional settings of the three countries/sites that are part of the MAP region, and identified their distinctive characteristics and how they have determined the current social-ecological profile of rural households and their livelihoods.

Though each country exhibits specific features, they also share common characteristics and confront similar challenges, such as widespread ecological damage, economic volatility and high levels of immigration, recently exacerbated by the construction of the transoceanic highway. Such a scenario may become archetypical in the future, as Latin American governments are planning similar projects, i.e., highways crossing large portions of the continent, and a couple of them transversally, from the Pacific to the Atlantic Ocean. Such highways will very likely disrupt sensitive ecological areas and affect relatively isolated communities (Gudynas, 2007). Hence, the standpoint of our research: to disentangle the interventions in the MAP region and to investigate how local social-ecological systems may react to them in transboundary conditions, is well-justified.

Our preliminary findings have partially confirmed the precedent social-ecological profiling and challenges in the involved countries, but have also widened them by identifying emerging issues, such as the tradeoffs between exploitation and conservation by the different levels of road network expansion across countries, the risks of the mono-dependence of the Bolivian regional economy on Brazil nut, or how growing diverse economic activities, all natural-resources dependent, interplay in Peru.

Ongoing work focuses on extensive data collection (via a structured household survey), aiming at substantiating the system models in construction. Also, some of the identified key components are currently investigated via specific and disciplinary researches. We expect that the integration of these streams will provide a comprehensive view on the country-system models, and facilitate the detection of drivers that weaken their resilience and may led to tipping points.

Methodologically, the use of the transboundary premise and the selection of a participatory systems-based approach, seems adequate. The former allowed for the recognition of the peculiarities of each country-site despite their similitudes; and the latter, by helping to integrate the contribution of locals in the construction of plausible system models.

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