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The relation between infrastructure and extractivism of non-timber forest products in the southwestern Amazon

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hereby declare on my honour that the present Master thesis has been independently prepared, solely with the support of the listed literature references, and that no information has been presented that has not been officially acknowledged.

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Thesis topic:	The relation between infrastructure and extractivism of non-timber forest products in the southwestern Amazon
Semester:	5

I declare, here within, that I have submitted the final digital text document to the examination office of the University of Hohenheim, and that the content and wording is entirely my own work. I am aware that the digital version of my document can and/or will be checked for plagiarism with the help of an analysis software program.

Landau, April 27, 2021

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Abstract

The expansion of infrastructure, especially roads, in the Amazon rainforest contributes to deforestation by facilitating detrimental practices such as logging and cattle ranching, leading to high risks of irreversible change and losses of ecosystem services. In contrast, extractivism of non-timber forest products (NTFPs) is an important alternative livelihood for rural households and can contribute to reduce deforestation, enabling the rural population to generate economic income from forests with a long-term perspective. Extractivism requires a certain level of infrastructure for transport, storage, processing, and market access. This study investigated whether and how infrastructure can contribute to forest conservation through targeted support for extractivism, while minimising detrimental side effects.

Three study areas were assessed, one in each country of the trinational border area of Brazil, Bolivia and Peru. Brazil nut (*Bertholletia excelsa*) and acai (*Euterpe* spp.) were analysed as two of the main local NTFPs. Remotely sensed data was analysed and trends in road construction, deforestation and NTFP volumes were identified with time series data from the period 2010 – 2020. Interviews with experts and stakeholders in each country were conducted (n=42) to identify the value chains, existing NTFP infrastructure and developments over time.

The results of this study show that lacking or precarious infrastructure can be limiting factors for extractivism, but also suggest that an increase in road infrastructure facilitates deforestation and decreasing NTFP volumes, so that an equilibrium should be sought. Few essential road connections of good quality can, besides many other preconditions, be considered as an optimal basis for sustainable extractivism. However, the results suggest that infrastructure alone is unlikely to sustain extractivism as a livelihood in view of more profitable, but more detrimental alternative livelihoods. The importance of appropriate institutional frameworks and economic incentives is highlighted. Further research involving a representative cross-section of the rural population is recommended.

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Abbreviations and acronyms

ABT	Autoridad de Fiscalización y Control Social de Bosques y Tierra (Authority for Social Control and Inspection of Forests and Land, Bolivia)
ACEAA	Asociación Boliviana para la investigación y conservación de ecosistemas Andino Amazonicós (Bolivian Association for Research and Conservation of Andean-Amazonian Ecosystems)
AFIMAD	Asociación Forestal Indígena Madre de Dios (Indigenous Forestry Association Madre de Dios, Peru)
AMOPREAB	Associação dos Moradores da Reserva Extrativista Chico Mendes (Association of Inhabitants of the Extractive Reserve Chico Mendes, Brazil)
ARFAPP	Asociación de Recolectores de Frutas Amazónicas Petronila Pando (Association of Amazonian Fruit Gatherers of Petronila Pando, Bolivia)
CIPCA	Centro de Investigación y Promoción del Campesinado (Centre for Research and Promotion of Peasantry, Bolivia)
Embrapa	Empresa Brasileira de Pesquisa Agropecuária (Brazilian Agricultural Research Corporation)
EUR	Erasmus University Rotterdam, Netherlands
GRFFS	Gerencia Regional Forestal y de Fauna Silvestre (Regional Forestry and Wildlife Management of Madre de Dios, Peru)
h	Hours
IBGE	Instituto Brasileiro de Geografia e Estatística (Brazilian Institute of Geographics and Statistics)
ICMBio	Chico Mendes Institute of Biodiversity Conservation
IIAP	Instituto de Investigaciones de la Amazonía Peruana (Peruvian Amazon Research Institute)
IOH	Interoceanic Highway
kg	Kilograms
km	Kilometres

m	Metres
m³	Cubic metres
MAP	Madre de Dios (Peru), Acre (Brazil), Pando (Bolivia)
NGO	Non-governmental organisation
NTFP	Non-timber forest product
RESEX	Reserva Extrativista (Extractive Reserve in Brazil)
RNTAMB	Reserva Nacional Tambopata (Tambopata National Reserve, Peru)
RNVSA	Reserva Nacional de Vida Silvestre Amazónica (Amazon National Wildlife Reserve)
RONAP	Recolectores Orgánicos de la Nuez Amazónica de Perú (Organic Amazonian Nut Gatherers of Peru)
SEFENBO	Sociedad de Exportadores de Familias Extractivistas Norte de Bolivia (Society of Exporters from Extractivist Families of Northern Bolivia)
SERNANP	Servicio Nacional de Áreas Protegidas por el Estado (National State Service of Protected Areas, Peru)
spp.	Species pluralis (referring to more than one species within a genus)
t	Tons
UAP	Universidad Amazónica de Pando (Amazonian University of Pando, Bolivia)
UFAC	Universidade Federal do Acre (Federal University of Acre, Brazil)
UKL	University of Koblenz-Landau, Germany
UNAMAD	Universidad Nacional Amazonica de Madre de Dios (National Amazonian University of Madre de Dios, Peru)

1 Introduction

Deforestation and degradation of tropical forests are among the world's major environmental problems, not only impacting local and global climate, but also causing a severe loss of ecosystem services that these forests provide (Brandon, 2014; Singh and Singh, 2017). Billions of people worldwide are estimated to depend on forest outputs to meet their livelihood requirements (Alvarez, 2018). But land use change through logging, cattle ranching, agribusiness and mining, among others, keep degrading tropical forest ecosystems and people's related livelihoods (Laurance and Bierregaard, 1997; Shanley et al., 2016), leading to high risks of irreversible change of the Amazon forests (Marengo et al., 2018).

To halt this, it is important to find sustainable resource management strategies, that reconcile forest conservation with development objectives (Duchelle, 2007; Nunes et al., 2012). Sustainable development relies on three pillars: environmental protection, social development, and economic development (United Nations, 2005). This prioritisation serves to dissect the major challenges faced by regions such as Amazonia: to integrate environmental and climate protection, ensuring the long-term provision of ecosystem services, and to provide economic opportunities for the population, enabling economic and social development and avoiding social conflicts.

1.1 PRODIGY project

This M.Sc. thesis forms part of and was supported by the project "**P**rocess-based and **R**esilience-**O**riented management of **Di**versity **G**enerates sustainabilit**Y**" (PRODIGY), financed by the German Federal Ministry of Education and Research (BMBF), and carried out by a consortium of six German universities as well as local Latin American universities and partner institutions. The aim of PRODIGY is to evaluate interrelationships related to biodiversity and social-ecological resilience and to identify tipping points in rural tropical systems of the southwestern Amazon (PRODIGY, 2021).

1.2 The MAP region

The study area of this work is located in the trinational border area of **M**adre de Dios (Peru), **A**cre (Brazil) and **P**ando (Bolivia) **-** also known as the MAP region. It is situated in the southwestern Amazon basin, which contains the largest remaining tracts of intact forest in the world and is considered a global biodiversity hotspot, as well as key provider of ecosystem services (Southworth et al., 2011). The region is also home to numerous different indigenous populations (Klarenberg et al., 2019).

In the MAP region, extractivism plays a key role as an economic income source for rural populations. Extractivism is the use of species thriving in natural or near-natural landscapes, without negatively affecting the naturally occurring species composition. This form of land use is comparatively environment-friendly and sustainable, as the resources are only selectively extracted (Hirschberg, 1999).

The post-Columbian history of the MAP region has been determined by two main characteristics: the relative remoteness from decision centres (state's capital cities) on the one hand, and its vast richness in natural resources of high economic value on the other hand, which caused successive waves of colonisation and migration (Callo-Concha et al., unpublished). Towards the end of the 19th century, the booming industrial revolution demanded high amounts of rubber for manufactured products. This raw material was extracted from wild-growing tree species like *Castilloa ulei* and *Hevea brasiliensis* and is regarded as the first economically important non-timber forest product (NTFP) of the region. Besides bloody conflicts, its extraction caused a flow of immigration and the emergence of several cities such as Rio Branco and Cobija (García, 1982; Rumrill et al., 1986). Due to the exportation and growing cultivation of rubber plants in Asia in the early 20th century, as well as the development of synthetic rubber in 1926, extractivism of rubber in Amazonia decayed in importance and is playing only a minor role nowadays (Orosco et al., 2013). In the decades following the decline of the rubber boom, the export of timber and Brazil nut (*Bertholletia excelsa*) gained importance as alternative livelihoods for the local population. Brazil nut, another NTFP, still remains economically important nowadays (Lindert and Verkoren, 2010).

Today, the MAP region is populated by about 1,2 million inhabitants and extends over approximately 310 000 km² (BCRP, 2018; IBGE, 2019; INE, 2020, 2013; INEI, 2017). The three regions share a similar biophysical environment, and thus a rich abundance of natural resources. But the historical, social and political processes that each of the three countries experienced, led to differences in their administrative regimes, social make-ups, as well as in their economic profiles and their respective infrastructure (Perz et al., 2015). In order to face alike challenges, e.g. deforestation and land-use change, and to safeguard the region’s environmental sustainability, the "MAP initiative" was formed in 1999 by a variety of institutions from Madre de Dios, Acre and Pando, seeking to set a politically neutral platform where stakeholders could interact and collaborate (Lindert and Verkoren, 2010). Thus, the MAP region became a geopolitical unit with high developmental potential, but confronting major challenges, many of which are yet unsolved.

1.3 Non-timber forest products in the MAP region

Forest logging, clear-cutting for cattle ranching and mining are commonly practiced by householders in the MAP region, with detrimental impacts on the biodiversity and ecosystem stability (Hellström, 2017). In contrast to these practices, extractivism of NTFPs depends on the conservation of forest ecosystems and is seen as a sustainable way of using the natural resources. It is documented that the gathering and selling of NTFPs such as resins, fruits, leaves, and oil seeds, which are common activities to supplement the livelihoods of rural populations in the MAP region and other tropical areas (Capurso, 2018; Hellström, 2017), are of major subsistence and socio-cultural relevance (Shanley et al., 2016). Furthermore, forests used for NTFPs extraction sustain a higher biodiversity and are more resilient than plantations or forests managed to produce industrial timber. They are also more capable to provide ecosystem services and act as a buffer against climatic fluctuations (Shanley et al., 2016).

Brazil nut (*Bertholletia excelsa*) and acai berry (*Euterpe* spp.) are two important NTFPs in the MAP region (Lopes et al., 2019). In 2018, 7 681 tons of Brazil nut and 4 549 tons of acai were produced in Acre alone, having generated revenues equivalent to more than 7,5 million US-dollars or roughly 6,5 million euros (IBGE, 2018). Also in the Manuripi National Reserve in Pando, Bolivia, the rural population generates up to 80 % of their income with Brazil nut (Orosco et al., 2013).

The Brazil nut tree reaches heights of 30 – 50 m. In November and December, the ripe fruits fall to the ground and can then be collected. The fruit usually weighs between 700 and 1500 g and contains 22 nuts on average, enclosed within a hard, woody shell (also referred to as "outer shell" or "*coco*"). Each nut in turn has its own shell and consists of about 50 % edible material and 50 % shell (CIAT, JICA, 1995; Loayza, 2018). Brazil nuts are primarily collected from wild Amazonian tree populations, since the species sensitively depends on intact forest ecosystem surroundings (Duchelle, 2007). Since the end of the rubber boom, Brazil nut has been the economically most important NTFP in the MAP region (Hellström, 2017; Terborgh and Peres, 2017). The Brazil nut tree and its fruit are shown in *Figure 1*.

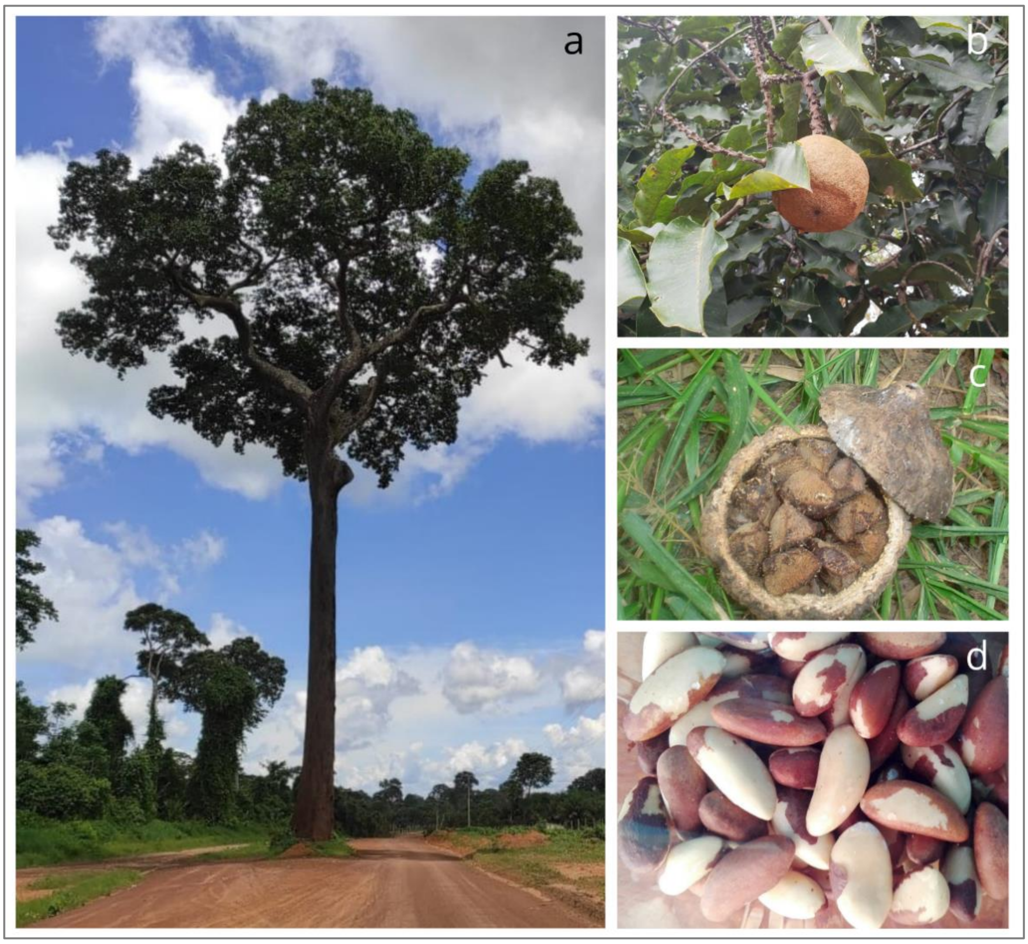

Figure 1: Brazil nut (*Betholletia excelsa*): (a) tree; (b) fruit on a tree; (c) opened ripe fruit; (d) shelled nuts. Pictures: A. Escobar, M. A. Albornoz, M. J. Villavicencio

Acai (*Euterpe* spp.) is a palm tree that frequently reaches 25 m of height or more. It grows abundantly in the Amazon rainforest. In the MAP region, two species of acai are of major importance: the Bolivian, single-stem acai (*Euterpe precatoria*) and the Brazilian, multi-stem acai (*Euterpe oleracea*). The acai palm was originally exploited to use the heart of the palm as a vegetable. Nowadays, such a use is not promoted anymore, because it requires to cut down the stem, which poses a severe damage to the plant, and in case of the single-stem acai (*E. precatoria*) kills the plant entirely. Today, the fruit, the acai berry, is the favoured NTFP, and is commercialised as juice, pulp and powder, which are used as ingredients for a variety of foods and beverages (Freitas et al., 2019; Lopes et al., 2019). The fruits are harvested manually by climbing the palm tree and cutting the ripe branches with a machete. The acai palm and the harvest of its fruits are shown in *Figure* 2.

Figure 2: Acai (*Euterpe precatoria*): (a) acai palm with fruit; (b) climbing the palm for harvest; (c) harvested acai raceme; (d) picking the berries from the panicles.
Pictures: A. Escobar, M. J. Villavicencio

The acai berry gained great popularity and economic importance from the 1990s on, continuing to be a growing market (Freitas et al., 2019; Ramos et al., 2018). This success is related to two main aspects that have been demanded increasingly by consumers worldwide in recent decades: healthy nutrition and sustainable production (Ramos et al., 2018). Demands are increasing in the USA, Europe, and Asia, as a consequence of marketing the acai berry as a "superfruit" with various health benefits (Freitas et al., 2019). Especially on the Bolivian side of the MAP region, the acai berry plays a considerable role as a product extracted from primary forests (Freitas et al., 2019).

Thus, although dozens of different NTFPs are produced in the MAP region (Perz et al., 2010a), this work will exemplarily focus on Brazil nut (*Bertholletia excelsa*) and acai berry (*Euterpe* spp.), as the two most important NTFPs at present.

1.3.1 Brazil nut value chain

The Brazil nut fruits are gathered from December to March (Orosco et al., 2013). The outer shell is directly removed with a machete and the seeds are transported manually or by motorbike to accumulation sites, called "*centros castañeros*", "*payoles*" or "*barracas*" in Spanish language. In these accumulation centres, the nuts are pre-selected and either air- / sun-dried for at least 3 - 4 days, or using a drying oven heated by fire. Afterwards, the nuts are packed in plastic bags of around 70 kg, and transported in motorised vehicles via rivers or roads to processing plants, where they are cleaned, shelled, disinfected, classified, further processed, packaged, marketed and prepared for export (Alvarez, 2018; Cronkleton and Albornoz, 2009; Elías, 2008; Poma et al., 2016; Soares-Filho et al., 2017). Brazil nuts are sold from the gatherers or landowners to intermediaries or directly to processing companies (Perz et al., 2010b). The main steps of the Brazil nut value chain are depicted in *Figure 3*.

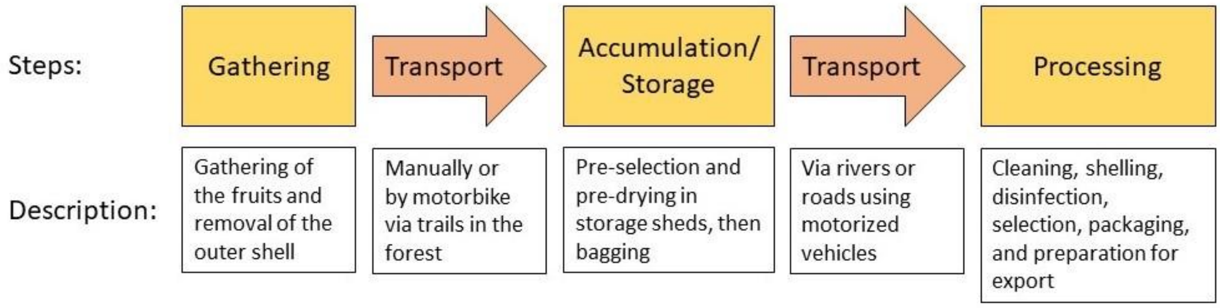

Figure 3: Main steps of the Brazil nut value chain. Own illustration based on Alvarez (2018).

If Brazil nuts are stored for longer periods of time without a prior drying process, there is a risk of fungal infestation and aflatoxin contamination. For this reason, infrastructure for the storage, transport and processing chain is key for a high quality and a marketable product (Schulz Blank, 2012).

1.3.2 Acai value chain

The harvest of the acai berry usually takes place between April and September, complementing the time during off-season of the Brazil nut. It is therefore well-appreciated by extractivists as an alternative forest resource (Ramos et al., 2018). After climbing the acai palm and harvesting the ripe branches, the acai berries are picked from the branches and pre-selected at the same time (*Figure 2* on page 5). The fruits are then packed in plastic bags and transported to a processing plant by motorbike, where they are weighed, selected, washed, disinfected, and exposed to a short thermal treatment to ensure food safety and quality. Subsequently, the fruit pulp is separated from the seeds and peel by centrifugation. The pulp is packed in plastic bags, either as such or diluted with water, to later be frozen for storage, commercialisation, and further transport (Freitas et al., 2019; Ramos et al., 2018). The main steps of the acai value chain are depicted in *Figure 4*.

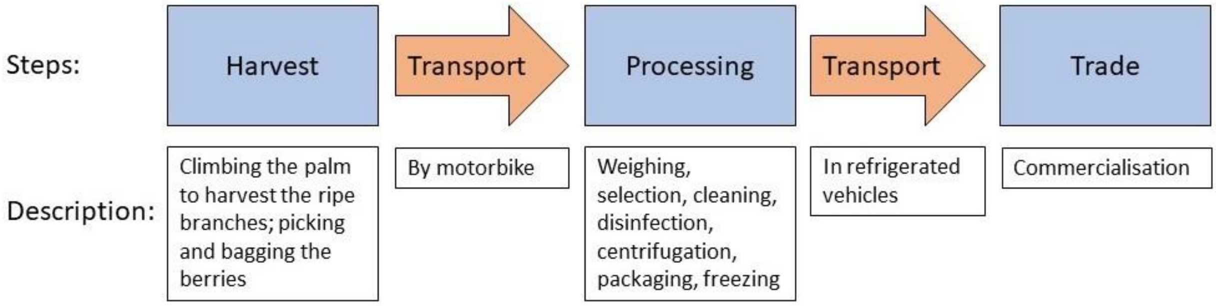

Figure 4: Main steps of the acai value chain. Own illustration based on Freitas et al. (2019) and Ramos et al. (2018).

Processing of the fresh fruits should take place within 24 hours after harvest, ideally within the first six hours after harvest, to avoid oxidation and quality loss (Freitas et al., 2019; Ramos et al., 2018). Thus, the commercialisation of acai is strongly dependent on the availability of infrastructure for transport and processing in the vicinity of the location of harvest, as well as for maintaining the cold chain after processing.

1.4 The infrastructure challenge

The road network in the area is increasingly being expanded. Since 2011, the Interoceanic Highway (IOH) connects ports on the Atlantic and the Pacific oceans, aiming to enhance economic integration and economic development of the region, and hence facilitate its competitiveness in global markets (Klarenberg et al., 2019; Mendoza et al., 2007; Roberts, 2011; Southworth et al., 2011). The highway crosses the MAP region longitudinally.

The three sides of the MAP frontier notably differ in the level of infrastructure and availability of paved and unpaved roads. Acre in Brazil has the most extensive network of primary and secondary roads, followed by Madre de Dios in Peru. Pando, on the Bolivian side, has the least extensive road network and the lowest percentage of paved roads (Southworth et al., 2011).

Infrastructure for transport generally increases the accessibility and the profitability of any production and trade activity by reducing the transportation costs (Nunes et al., 2012). As shown above, the gathering of NTFPs, if carried out at a commercial level, requires basic infrastructure for collection, transport, processing, storage, and trade, as well as a general market access. In many extractivist areas, roads are an essential means of transport for NTFPs. The sector depends on it to be able to transport the products from their origin to post-harvest infrastructures such as accumulation centres, processing plants, markets, and ports for overseas export. The availability of each of those infrastructure elements is key for the existence of extractivism and the financially rewarding trade of NTFPs on a supra-regional level (Arnold and Pérez, 2001; CSR, 2017).

However, there is a downside. There is evidence that road construction in forest areas often accelerates migration, land use change, deforestation as well as land and ecosystem degradation (Mendoza et al., 2007; Nunes et al., 2012). It is common in the Amazon basin that new roads are first introduced by loggers, who abandon them after removing hardwoods. These remaining networks provide access to lands and eventually attract settlers who set up farming fields and pastures (Walker et al., 2013). This expansion follows the "fishbone"-pattern, which emerges along primary roads by the construction of perpendicular secondary, and eventually tertiary roads, at the time that agriculturally used plots develop along them (Arima et al., 2005; de Filho and Metzger, 2006). An exemplary satellite view of the described forest fragmentation pattern is shown in *Figure 5*.

Figure 5: Forest fragmentation following the typical "fishbone"-pattern. Satellite image exemplarily showing a section of the state of Pará, Brazil. Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

A subsequent phenomenon is that land use is contingent on accessibility: lands closer to roads and markets are more valuable. Therefore, more profitable land use practices such as agricultural activities are more common in areas with good access, whereas less profitable practices, such as forest extractivism, are more common in remote areas (Perz et al., 2015).

All that contributes to increased deforestation in the vicinity of roads, decreases biodiversity and intensifies the loss of ecosystem services, which in turn affects rural households in the region, leading to limited rural livelihood options and conflicts in the use of natural resources (Börner et al., 2007; Ghazoul et al., 2015; Mendoza et al., 2007).

Thus, although infrastructure improvements can increase the profitability of NTFP production, they will also intensify competition for land and increase the profitability of other livelihoods such as livestock and agriculture, which are associated with deforestation and degradation of the ecosystems that NTFP production depends upon (Nunes et al., 2012). This interrelation between road construction and a loss of forest value components like NTFPs is a phenomenon that has been observed in the MAP region (Baraloto et al., 2015).

1.5 Objectives

It can be assumed that the extent of infrastructure availability and access is an important factor for sustainable NTFP extractivism in the MAP region. There are various factors that determine the setting of roads and other infrastructure elements for optimal household performance regarding economic, social, and environmental aspects. Particular factors may differ across the three sites, also depending on different governance and cultural-historical conditions in each country. It can also be assumed that some of these factors depend on the specific type of product and the respective supply chains and production techniques. Moreover, there may be effects in the development of infrastructure which may not be beneficial for the NTFP sector or may even restrict it. This could be the case, for example, if road network expansion were to exceedingly promote more intensive land-use practices, threatening the intact rainforest and thus the basis for the NTFP production, as mentioned in section 1.4.

To clarify the relation between road expansion, other infrastructure and NTFPs in the MAP region, the following research questions have been investigated:

1. How is each of the three sub-regions endowed in terms of roads and NTFP-related infrastructure? What are the respective logistic networks of Brazil nut and acai?
2. How have the road network, deforestation and the production volumes of Brazil nut and acai evolved in each of the three sub-regions between 2010 and 2020?
3. Which role does infrastructure play in NTFP extractivism? Is there a favourable infrastructure pattern for each of the sub-regions to support sustainable NTFP extractivism? And if yes, what are the key factors that determine it?
4. On the basis of the previous research questions, could the setting of road networks and other NTFP-related infrastructure possibly be improved to support sustainable NTFP-extractivism?

In that framework, the objective of this investigation is to contribute to a better understanding of how roads and post-harvest infrastructure are associated to sustainable NTFP-extractivism in the MAP region. The results are expected to contribute to the overall goal of the PRODIGY project, which is to understand the interrelationships related to the socio-ecological systems of the MAP region to prevent the overcoming of tipping points.

2 Material & Methods

Original plan and COVID-19-related limitations: Due to the COVID-19 pandemic during the entire research period of this thesis (2020), the planning and implementation of this work had to be changed and adapted fundamentally. This caused challenges and required the flexible restructuring of the methods to absolve them. Travelling to the study areas was not possible as originally planned. The implementation of a tri-national household survey within the framework of the PRODIGY project had to be postponed, which would have provided useful primary data also for this thesis. In this context, interviews with a larger number of rural householders were planned.

Implemented alternative approach: Instead of the original approach, this thesis has been implemented remotely and according to COVID-19-related safety measures in a multi-method approach, to address the objectives of this work.

Five local assistants in the MAP region were hired to support the on-site data collection in the period between October and December 2020. The assistants were based nearby the study areas and each of them had an academic background and scientific working experience. The assistants facilitated communication with key stakeholders, conducted interviews with locally based stakeholders, submitted data requests to local institutions, and performed geo-validations of infrastructure elements on-site. The assistants were coordinated remotely via video- and phone calls, e-mail, and messaging services.

As a first step, extensive literature and online research was conducted to determine the current state of research on the topic, and to identify local key stakeholders and potential informants. Secondly, and according to criteria elaborated by the PRODIGY project, three focal study areas were defined, one within each part of the MAP region. Their locations and spatial extents are depicted in section 2.1. Covering these study areas, time-series data was collected to have an overview of the developments during the period between 2010 and the present (2020), and to create a quantitative basis for subsequent stakeholder interviews. Thus, three datasets were built by geospatial analysis of remotely sensed data as well as based on secondary data:

- Forest cover and deforestation,
- Road network extent,
- Trends and changes in annual production quantities of Brazil nut and acai.

Sources of raw data and the applied geoprocessing methods regarding each forest cover and road network extent are specified in section 2.2. For mapping, geoprocessing, and geospatial analysis, the Esri software ArcGIS 10.6 was used. The data sources and methods used for compiling the NTFP production volume datasets are described in section 2.3.

A core element of this work were the interviews with representatives of key stakeholder groups, based on which difficulties and possible solutions regarding NTFP production and the required infrastructure were depicted. A description of the interviewing methods and a list of the interviewed key stakeholders are shown in section 2.4. The interview results were contrasted against the outcomes of the time series analyses to cross-check the collected information and to assess and explain observed aspects.

Furthermore, the existing infrastructure networks for storage, transport and processing of Brazil nut and acai were investigated via interviews and complemented with literature research, data requests and on-site validations of infrastructure points. The materials and methods applied to elaborate each study area's logistic NTFP networks are specified in section 2.5.

Data requests to several local institutions were carried out, particularly for elaborating annual Brazil nut and acai production volumes, as well as for identifying existing NTFP-specific infrastructure elements.

Challenges: Its interdisciplinary and multi-factorial nature posed a major challenge of this study. The differences between the social, cultural, and institutional frameworks of the three regions and countries required to apply individual approaches according to each study area's characteristics. Another challenge was language. This study was carried out using four different languages for research and communication with assistants, experts, and stakeholders: English, Spanish, Portuguese, and German. Online-translators and -dictionaries were frequently used to facilitate communication.

2.1 Study areas

On each side of the trinational border areas of the MAP region, there exists at least one natural reserve as well as major roads. The core zones of the natural reserves can be considered as areas with land use intensities close to zero, whereas in the vicinity of major roads, there are often agricultural lands or settlements of high land use intensity. These characteristics make the MAP frontier an ideal study area for evaluating the interrelationships between infrastructure and land use. In the framework of the PRODIGY project, three areas within the MAP region were chosen, one on each side of the three bordering countries. In each study area, a gradient in land use intensity is represented, ranging from primary roads and agricultural lands to buffer zones and finally the core zone of a natural reserve. Based on that, three polygons were defined as the study areas specifically for this thesis, which in addition to showing the above-mentioned gradient in land-use intensity, should fulfil the following criteria: (1) Encompassing rural communities and areas used for NTFP-extractivism; and (2) being located in proximity of a larger city, where NTFPs are traded and processed.

An overview of the three study areas is shown in *Figure 6*.

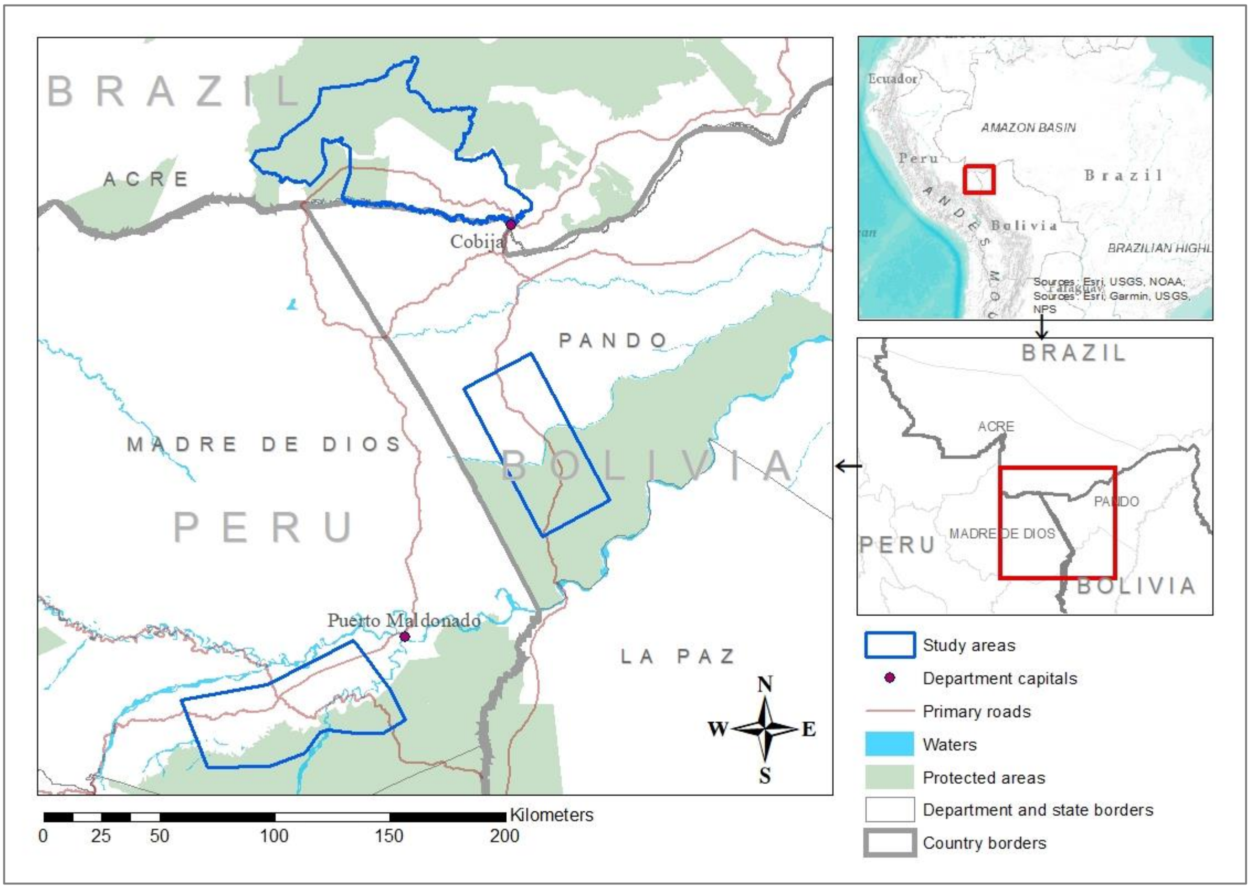

Figure 6: Locations of the three study areas. Map created with the Esri software ArcGIS 10.6. Sources: Esri, Garmin, OpenStreetMap, NOAA, NPS, RAISG, USGS.

On the Brazilian side, the municipality of Brasiléia fulfils all the criteria and was therefore chosen as the Brazilian study area. Brasiléia is one of 22 municipalities within the state of Acre and extends over an area of approximately 4 000 km². It is crossed by the BR-317, which is part of the interoceanic highway (IOH) and connects the two cities Assis Brasil in the west and Brasiléia in the east of the municipality. Brasiléia furthermore comprises a part of the Chico Mendes Extractive Reserve (RESEX). A map of the municipality of Brasiléia is shown in *Figure 7*.

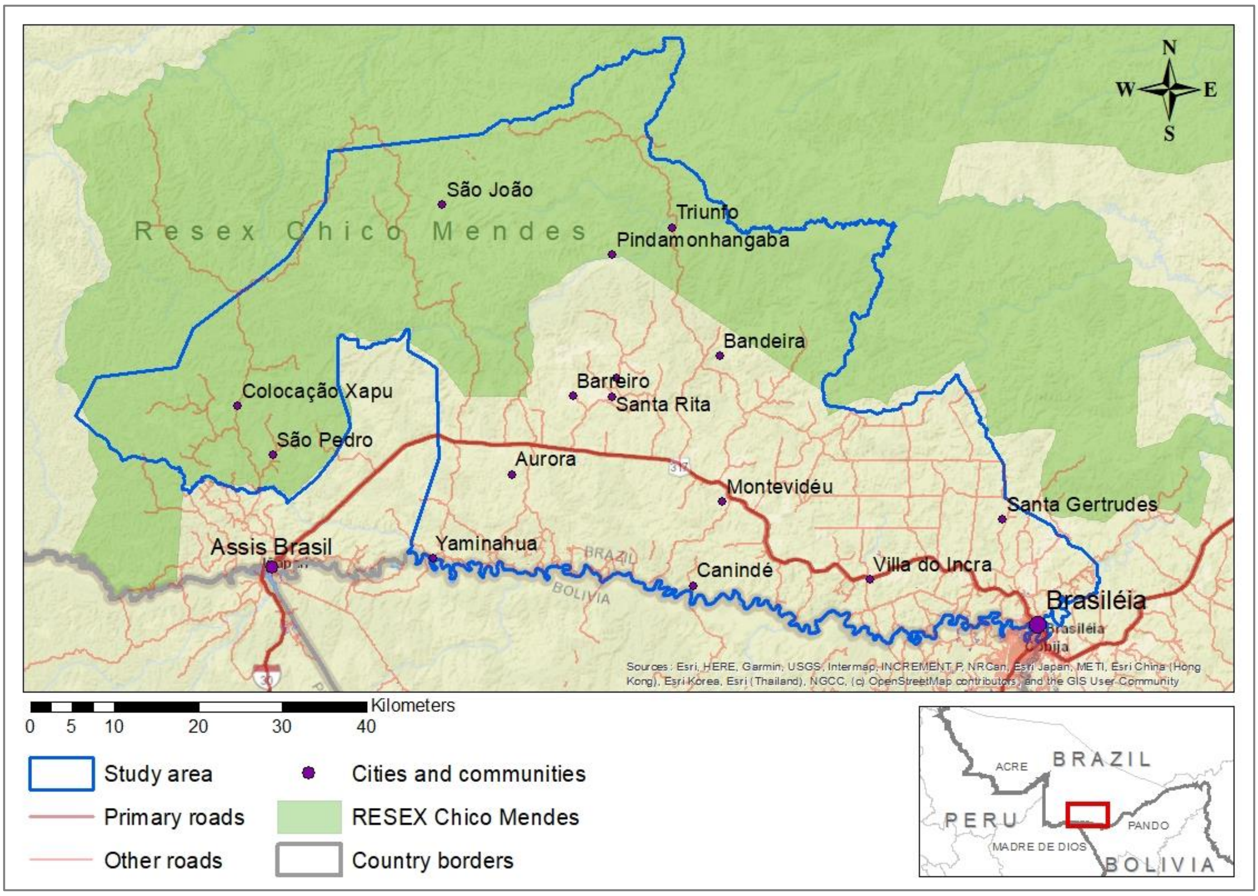

Figure 7: Map of the municipality of Brasiléia in the state of Acre, Brazil, being one of the study areas for this thesis. Map created with the Esri software ArcGIS 10.6.

The study area on the Bolivian side is located entirely within the municipality of Filadelfia, which is one of 15 municipalities of the department of Pando. The study area extends over approximately 2 400 km², covering roughly 20 % of the municipality's total area. It is crossed by the route 53, a national road which is an extension of the IOH and connects Chivé in the south with the city of Cobija as well as the IOH in the north. This study area furthermore comprises part of the Manuripi National Wildlife Reserve (RNVSA). A map of the study area in Bolivia is shown in *Figure 8*.

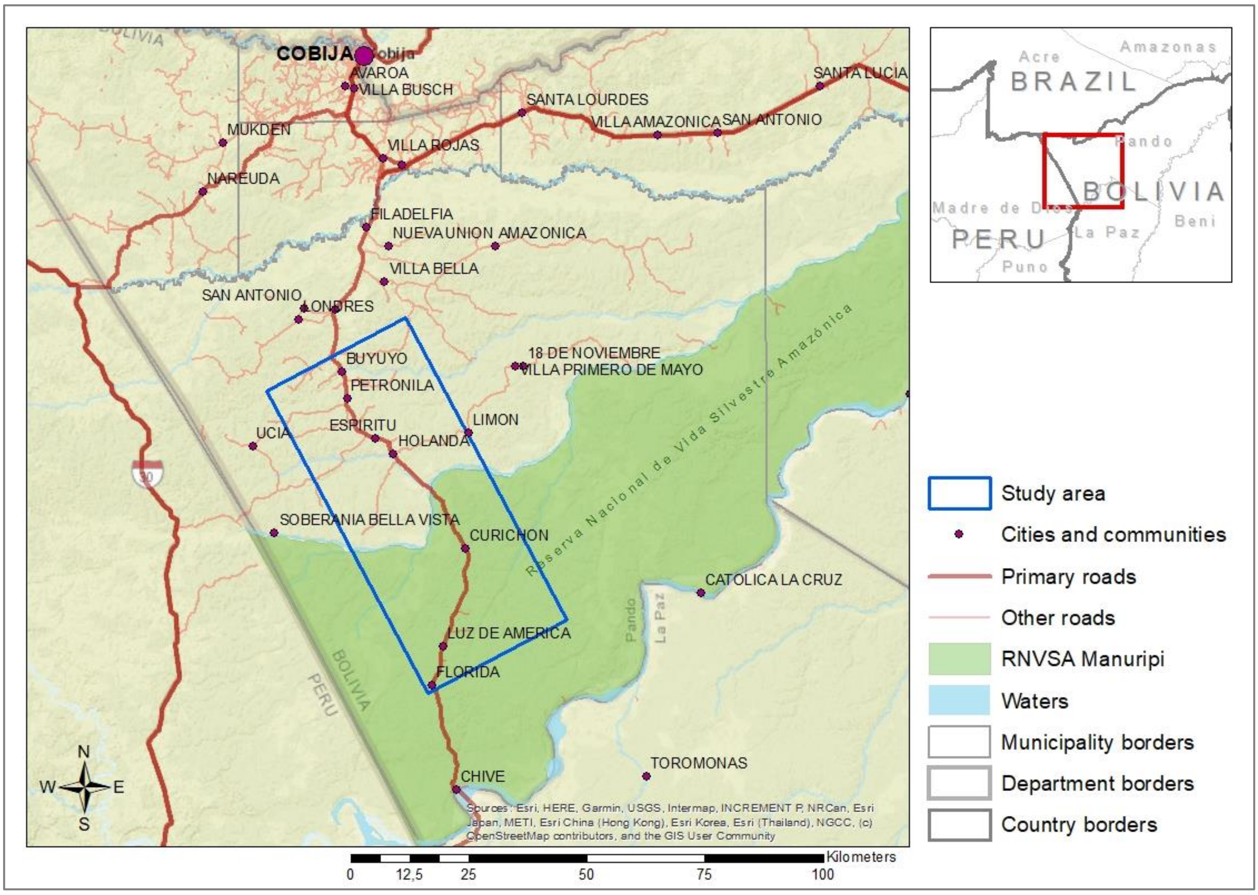

Figure 8: Map of the study area in the department of Pando, Bolivia. Map created with the Esri software ArcGIS 10.6.

On the Peruvian side, the study area is located in the south-east of the department of Madre de Dios and encompasses parts of the districts Inambari, Laberinto and Tambopata. This study area extends over approximately 2 900 km² and comprises part of the Tambopata National Reserve (RNTAMB), in the following referred to as Tambopata Reserve. The area is crossed by the national route PE-30, which is part of the IOH, leading to the city of Puerto Maldonado in the east and towards the interior of the country and the Pacific coast in the west. Puerto Maldonado is the main Brazil nut processing centre in Peru (Alvarez, 2018). A map of the study area in Peru is shown in *Figure* 9.

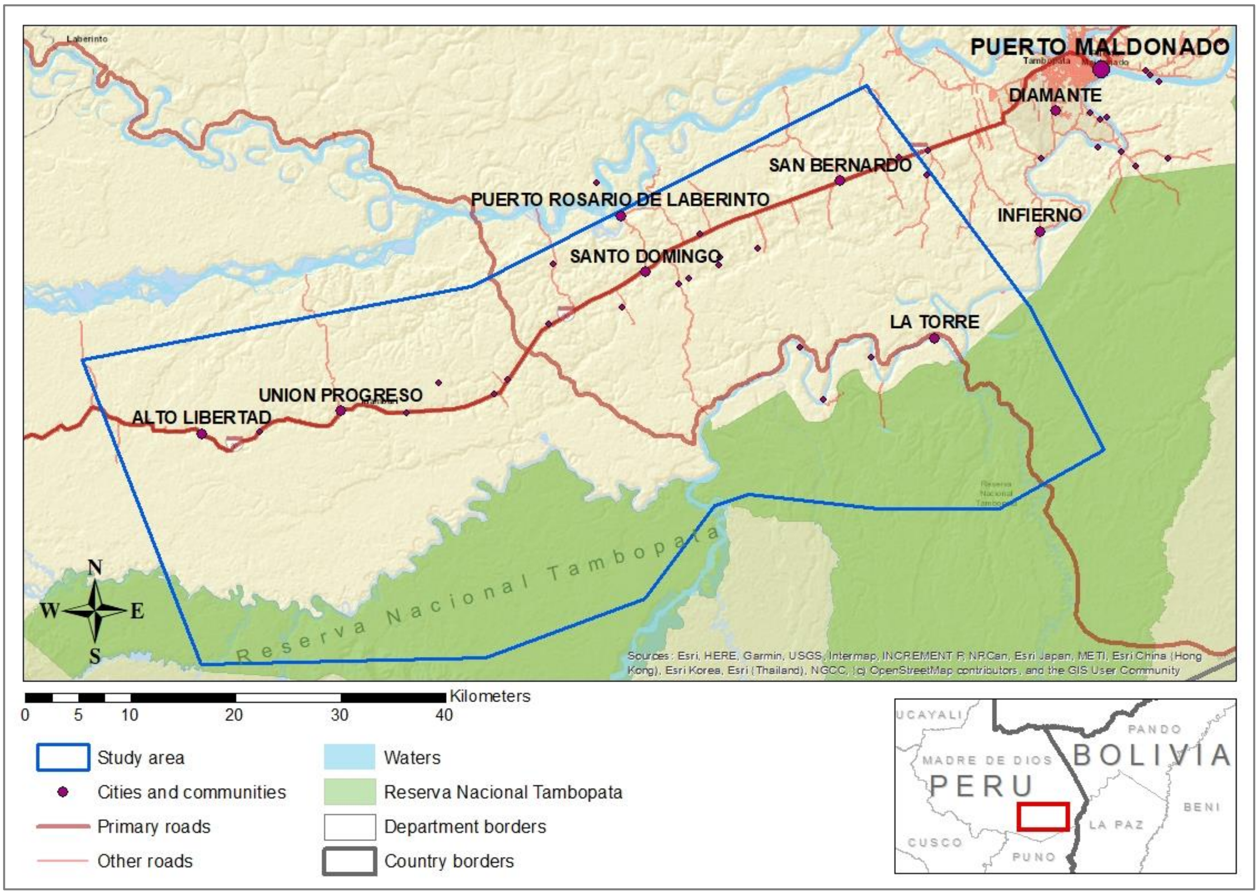

Figure 9: Map of the study area in the department of Madre de Dios, Peru. Map created with the Esri software ArcGIS 10.6.

NTFPs play an essential role in the socio-ecological householder systems of the three study areas and are used on a commercial level in each of them. All data collected in the course of this work was related as precisely as possible to the respective study areas.

2.2 Remotely sensed data

2.2.1 Forest cover

Tree cover and deforestation data was drawn from the "Global Forest Change" project of the University of Maryland, which compile worldwide tree cover and annual deforestation data based on Landsat imagery, available as gridded raster files online (Hansen et al., 2020). The following two raster datasets were downloaded:

- Tree cover 2000: A raster file representing the tree cover in the year 2000, defined as "*canopy closure for all vegetation taller than 5 m. Encoded as a percentage per output grid cell, in the range 0 – 100*" (Hansen et al., 2020);

- Yearly gross forest cover loss: "*Forest loss during the period 2000 – 2019 (…). Encoded as either 0 (no loss) or else a value in the range 1 – 19, representing loss detected primarily in the year 2001 – 2019, respectively*" (Hansen et al., 2020).

Based on these datasets, the deforested area within each study area was calculated, and the percentage of forest cover in reference to the total area for each year during the period 2010 – 2019. The datasets were clipped to the study area polygons using the ArcGIS tool "Clip (Data Management)". Hansen et al. (2013) define forest as a tree cover of more than 50 %. Therefore, this same definition was used in the analysis of the tree cover data by converting the tree cover 2000 dataset into a binary dataset distinguishing between tree cover of more than 50 %, encoded as 1, and tree cover of less than 50 %, encoded as 0.

The forest loss dataset was split into one dataset representing forest loss that occurred in the period between 2001 and 2009, and ten single datasets for each year as of 2010 and until 2019 using the ArcGIS tool "Raster Calculator". The analysed datasets have a spatial resolution of 28 m per pixel, resulting in an area of 784 m² or 0,000784 km² covered by each pixel. Based on the pixel count of each clipped raster file, the corresponding deforested area in km² was calculated by multiplying the respective pixel count with the factor 0,000784. The percentage of deforested area of each year was obtained by dividing the deforested area by the total area of each respective study area polygon. Inversely, the percentage of forest cover of each study area and year was obtained by subtracting the percentage of deforested area from 100 %.

This method allowed a detailed quantification of forest cover and its annual changes within each study area.

2.2.2 Road network extent and expansion

The respective road network extent and its development during the past decade were quantified for each of the three study areas by analysing and comparing satellite imagery from two different points in time.

Approach: Governmental institutions of all three investigated countries have annual registers of official roads, including quantifications of their extent (DNIT, 2020; INE, 2021; MTC, 2021). However, these data sets are not suitable to meet the requirements of this study for two reasons: (1) not all this data can be precisely related to the study areas of this work, as not all the study areas coincide with administrative divisions for which these numbers are available; (2) only official roads are recorded in the existing registers and it can be assumed that also unofficial roads play a role for NTFP transport. Therefore, a satellite image analysis is the most suitable method to record official as well as unofficial roads equally, and to precisely relate this information to each study area. In this respect, an image classification is an efficient method to detect and quantify different land cover types such as roads based on their different colour reflectance captured in multispectral satellite imagery. The land cover classification is one of the most common methods in remote sensing (Esri, 2021).

Sourcing of satellite imagery: In cooperation with the German Aerospace Center (DLR), the earth imaging company "Planet" provides access to up to 30 000 km² of satellite imagery free of charge for research projects (Planet, 2021). Imagery was requested specifically for this thesis project and Planet provided access to a quota of 30 000 km² of orthorectified 5-band RapidEye imagery with a spatial resolution of 5 m per pixel (Planet Team, 2020). RapidEye is a constellation of five satellites owned and operated by Planet. The constellation was active from 2009 until early 2020 (ESA, 2021; Planet, 2016).

Mosaicking: To quantify the road network extent and its development in each study area between 2010 and 2020, RapidEye imagery mosaics were created for the full extent of each study area with imagery from two different points in time. These mosaics were composed of a total of 136 single imagery tiles that were merged into coherent raster datasets using the Esri-software ArcMap 10.6 and the "Mosaic" – tool. Beforehand, the single imagery tiles were manually selected online from the Planet database as a basis for mostly cloud-free mosaics for each study area and each investigated point in time. According to the objective of evaluating road network expansion and developments between 2010 and 2020, imagery with a low cloud cover was searched from 2010 on, to create a reference mosaic for each study area. Due to limited availability of cloud-free RapidEye imagery, the reference mosaics are composites mainly of the year 2012, complemented with tiles of the year 2011. To assess the road network development as of 2012, a second mosaic was created with the most recent available imagery for each study area. Generally, the lowest cloud cover was found in imagery taken in dry season (between May and August). Since the RapidEye satellites were only active until March 2020 (ESA, 2021), the most recent available low-cloud imagery was of 2019. Thus, the results of this analysis represent an approximation of the road network extent and its development between 2012 and 2019. According to the performed image classification, the analysed final mosaics have cloud cover rates between 0,03 % and 1,3 % of the respective study areas.

Land cover classification: Based on each of the created imagery mosaics, an interactive supervised land cover classification was performed using manually defined training samples for each of the following five image classes:

- Roads
- Agricultural areas
- Forest
- Water bodies
- Clouds

An individual set of training samples was defined for each mosaic, based on which the land cover types were classified.

In *Figure 10*, an example of an output raster of the performed image classification is shown.

Figure 10: Example of the performed land cover classification, showing an extract of the study area in Pando, Bolivia: (a) RapidEye satellite image of 2012; (b) Land cover classification of the same extent. Source of satellite imagery: Planet Team (2020). Software used: ArcGIS 10.6 (Esri).

The ArcMap - tool "Extract by Mask" was used to fit the output raster of each image classification with the respective study area polygon. To calculate each class's geometry, the resulting raster data was converted to vector data and the attributes were dissolved based on their class name. When converting raster to polygon data, polygons were not simplified, to maintain the accuracy as derived from the raster image. In the resulting shapefile, the area of each image class was calculated in square kilometres using the "Calculate Geometry" - option. The resulting area covered by roads was then transformed into a percentage of the respective total study area, to allow a comparison of the relative road extents of each study area.

Limitations: This method detects roads and sections of roads which are not covered by canopy. Analysing roads in tropical forest areas by means of a land cover classification of satellite or aerial imagery is approximate and not fully accurate in detecting all existing roads, partly due to the mentioned limitation of only canopy-free roads being detected. A second possible cause of inaccuracy is that, especially when the satellite image was taken in a period of drought, some bare lands might appear free of detectable vegetation. Due to their similar appearance, such areas can hardly be discriminated of roads by colour reflectance, which can lead to two sorts of potential error in the resulting land cover classification: (1) some agricultural or bare lands being misclassified as roads; or reversely (2) some roads remaining undetected.

Nevertheless, even if roads cannot be analysed with perfect accuracy by this method, the results still provide a sufficient approximation of each study area's road network extent and its developments in the past decade, and thus served as a quantitative basis for the analysis conducted in this thesis.

2.3 Brazil nut & acai production volumes

Changes and trends in annual production volumes of Brazil nut and acai between 2010 and 2020 were investigated for each of the three study areas.

Acre, Brazil: The Brazilian Institute of Geography and Statistics (IBGE) provides the annual production volumes of different NTFPs on municipality level online (IBGE, 2020). Since the study area in Brazil is equivalent to the municipality of Brasiléia, the respectively published production data for Brazil nut and acai was used directly.

Pando, Bolivia: In Bolivia, information about the origin of locally produced commodities such as Brazil nut is administered by the Authority for Social Control and Inspection of Forests and Land (ABT), where the annual volumes of Brazil nut produced within the municipality of Filadelfia were requested. As the study area is located entirely within this municipality and covers roughly 20 % of its area, the reported volumes served as an approximation for Brazil nut production volumes in the study area. The data received from the ABT Pando consists of annual Brazil nut volumes extracted in the municipality of Filadelfia between 2013 and 2020 (ABT Pando, 2020). Data before 2013 was not available.

Interviews with experts and stakeholders revealed that acai is only commercially used in the study area since 2015. There are two processing plants for acai within the study area, which uptake all the acai harvested across the study area. The larger one is located in the community of Villa Florida, inside the Manuripi Reserve, and another smaller one is operated in the community of Petronila, outside the reserve. The annual quantities processed by these two facilities were summed up for each year, to most precisely approximate the annual amount of acai harvested for commercial use. Sources used are the business plan of the processing facility in Petronila (Lorini, 2017), the online repository of WWF Bolivia (WWF Bolivia, 2020) and records received from the Centre for Research and Promotion of Peasantry (CIPCA, 2020).

Madre de Dios, Peru: In the case of Madre de Dios, the use of timber and non-timber forest resources is organised into concessions: areas awarded by the government for specific types of exploitation (Cossío-Solano et al., 2011). Many concessions are explicitly specified as Brazil nut concessions, defining their main use. Concessions within protected areas such as the Tambopata Reserve are managed by the National State Service of Protected Areas (SERNANP). Concessions outside protected areas are managed by the Regional Forestry and Wildlife Management office of Madre de Dios (GRFFS). A concession holder is registered for each concession and is obliged to report the annual produced quantities to SERNANP and GRFFS, respectively. In the course of this work and on behalf of the PRODIGY project, data requests were submitted to both SERNANP and GRFFS. Both institutions provided the relevant documentation of the extracted Brazil nut quantities reported by each concession holder (GRFFS, 2020a; SERNANP, 2020a), as well as digital maps and metadata of the concessions (GRFFS, 2020b; SERNANP, 2020b). With these data sets, trends and changes in annual Brazil nut production volumes were determined for the study area by evaluating those concessions located within it. The objective of this step was to investigate trends and changes in production quantities over time. Therefore, continuous annual data was required, which for some concessions inside the study area was not available for every year between 2010 and 2020. To avoid biasing the results with incomplete data, only those concessions for which continuous annual data was available were considered. Thus, the resulting numbers do not represent the total quantity produced within the study area. For six concessions inside the Tambopata Reserve as well as for nine concessions outside the reserve, continuous data was available. Therefore, these 15 concessions were considered in the quota sampling. The respective reported annual quantities of each of these concessions were summed up for each year between 2010 and 2020. The indicated volumes refer to Brazil nut with shell, but part of the raw data was indicated in volumes of shelled Brazil nut. In this case, the numbers were standardised back to the equivalent volumes of Brazil nut with shell. Since each Brazil nut consists of about 50 % shell (CIAT, JICA, 1995; Loayza, 2018), volumes indicated as shelled Brazil nut were multiplied by two.

In interviews with local experts, scientists, and stakeholders, it was found that the acai fruit is not used on a large commercial scale in Madre de Dios. The acai palm is partly used for local consumption and eventually sold on local fruit and vegetable markets, but not on a supra-regional level. Therefore, by the time of this research (2020), there were no harvested quantities of acai documented in Madre de Dios.

2.4 Interviews

Between October and December 2020, semi-structured interviews with 42 experts and stakeholders involved in the NTFP sector in the study areas have been conducted: 12 in Brazil, 18 in Peru and 12 in Bolivia. Four stakeholder groups were represented in each study area:

- NTFP extractivists and concession holders,
- Representatives of processing companies, associations and cooperatives who purchase or process NTFPs,
- Representatives of governmental institutions involved in NTFP and forest management,
- Researchers and representatives of non-governmental institutions involved in NTFP extractivism in the area.

An overview of the interviewees sorted by study area and stakeholder group is shown in *Table 1*.

Table 1: Overview of interviewees sorted by study area and stakeholder group. The respective number of interviewees of each stakeholder group and sub-group is indicated in brackets.

Study area	Stakeholder group	Role / Institution
Brazil	Extractivists (6)	Acai and Brazil nut extractivists, RESEX Chico Mendes (6)
	Cooperatives (1)	Cooperacre, Rio Branco (1)
	Governmental institutions (2)	ICMBio - Chico Mendes Institute of Biodiversity Conservation (1)
		Public Ministry of Acre, Rio Branco (1)
	Researchers (3)	Embrapa - Brazilian Agricultural Research Corporation (1)
		UFAC - Federal University of Acre, Rio Branco (2)
Peru	Extractivists and concession holders (6)	Extractivists and holders of Brazil nut concessions in the study area (6), two of which in the RNTAMB (2)
	Companies and associations (6)	AFIMAD - Indigenous Forestry Association Madre de Dios (1)
		Candela - Brazil nut processing & trading company (1)
		Natural Export & Services – Brazil nut trading company (1)
		Nueces SAC - Brazil nut processing & trading company (1)
		Rompeolas SAC - Brazil nut processing company (1)
		RONAP - Organic Amazonian Nut Gatherers of Peru (1)
	Governmental institutions (3)	GRFFS - Regional Forestry and Wildlife Management (1)
		IIAP - Peruvian Amazon Research Institute (1)
		SERNANP - National State Service of Protected Areas (1)
	Researchers (3)	Erasmus University Rotterdam (EUR), Netherlands (1)
		UNAMAD - National Amazonian University of Madre de Dios (1)
		University of Koblenz-Landau (UKL), Germany (1)
Bolivia	Extractivists (4)	Acai and Brazil nut extractivists in the study area (4)
	Companies and associations (3)	ARFAPP - Association of Amazonian Fruit Gatherers of Petronila Pando (1)
		SEFENBO - Society of Exporters from Extractivist Families of Northern Bolivia (1)
		Tahuamanu - Brazil nut processing company (1)
	Governmental institutions (1)	RNVSA Manuripi - Amazon National Wildlife Reserve Manuripi (1)
	Researchers and NGOs (4)	ACEAA - Association for Research and Conservation of Andean-Amazonian Ecosystems (1)
		UAP - Amazonian University of Pando (1)
		CIPCA - Centre for Research and Promotion of Peasantry (1)
		WWF Bolivia (1)

The interviews have been conducted personally via video- or phone calls and with the support of five local assistants. The assistants were trained beforehand via videoconferences, provided with questionnaires, and prepared to conduct the interviews, which consisted of four sections of questions on the following topics:

1. NTFPs in general,
2. The situation related to NTFP production in the area,
3. Infrastructure used for Brazil nut and acai extractivism,
4. The interviewee's opinion about the perspectives of NTFP extractivism in the future.

The questionnaire which served as a guideline for all the interviews was elaborated and pretested beforehand. The final questionnaire, consisting of open questions as well as of multiple-choice questions, is attached in appendix A. This questionnaire was adapted to each study area and translated into Spanish and Portuguese.

The objectives of the interviews were (1) to identify the value chains and existing infrastructure of Brazil nut and acai in each study area; (2) to assess the infrastructure developments as well as the status quo of NTFP-related infrastructure, especially with regard to major difficulties and possible improvements; (3) to assess trends and changes in Brazil nut and acai production volumes and production conditions over the investigated period of the past ten years; and (4) to better understand the socio-ecological context of the NTFP sector in the respective study areas.

2.5 Present NTFP infrastructure

The existing NTFP-related infrastructure of Brazil nut and acai was depicted in each of the three study areas. NTFP collection sites as well as transport ways, points of trade and locations of processing facilities were identified via literature and online research, data requests to governmental entities and research institutions, and the interviews with experts and stakeholders. Digitised road networks were drawn from OpenStreetMap and RAISG databases (OSM, 2020; RAISG, 2020).

Identified key infrastructure elements within the study areas have been partly validated and georeferenced with GPS coordinates and pictures by local assistants. The assistants have been coordinated and provided with information and maps via video- and phone calls, e-mail, and messaging services.

The materials used by the assistants for on-site validations were the following:

- Motorbike and fuel,
- Map of the respective study area showing the location of infrastructure elements to be validated,
- GPS device or GPS tracking application installed on a smartphone,
- Camera,
- Water and food,
- Written authorisation to enter a protected area (where required).

The objective of this step was to identify, localise and describe the main extractive areas, transport ways, and existing post-collection facilities of the Brazil nut and acai value chains in each study area to facilitate an assessment of the current state and possible improvements.

Due to logistic limitations as well as difficulties and travel restrictions related to the COVID-19 pandemic during the entire study period, the identified infrastructure elements could not or only incompletely be identified and validated.

3 Results

Structure of the chapter: The results are presented for each of the three study areas separately, followed by a cross-comparison of the time-series. For each study area, firstly, the results of the time series for forest- and road cover, and for Brazil nut and acai production volumes are presented. Secondly, the results of the stakeholder interviews are exposed. Finally, the NTFP infrastructure used in Brazil nut and acai production is depicted.

On the time series: In the sections 3.1.1, 3.2.1 and 3.3.1, the time series analyses are presented for each study area individually. The forest- and road cover analyses are presented in the same respective diagrams, since both factors represent percentages of land cover derived from satellite imagery. The Brazil nut and acai production volumes are also combined in the same diagrams. Linear trend functions allow the comparison of trends for the investigated period.

In section 3.4, the country-wise time series analyses are overlayed, showing one time series factor for all three study areas.

The time series must be interpreted with caution. Suggested causalities and correlations between the individual data series can only be assumed, not proven, as each of them is embedded in a complex network of different influencing factors.

On the Interview results: The interviews included open questions and multiple-choice questions. The outcomes of the former were summarised and complemented with the results of the latter, which are presented in bar charts indicating the percentage of interviewees who answered. Thus, the sum of responses can surpass 100 % if interviewees chose to respond to more than one answer. The numeric results of the multiple-choice questions are presented in *Table 5* in Appendix C.

Not every question was asked to every interviewee. The selection of questions was made according to the expertise of the interviewee and the situation during the interviews. For instance, specific questions about Brazil nut were only addressed to those interviewees involved with it. By that, some responses were coded with "no answer". The absence of an answer resulted also from precedent conditional questions, or the flat decision of the interviewee to not answer.

3.1 Acre, Brazil

3.1.1 Time series

The complete values on which the presented time series diagrams are based are summarised in *Table 2* of Appendix B.

Forest- and road cover: The time series of forest- and road cover percentages, analysed and calculated as described in section 2.2, are presented in *Figure* 11.

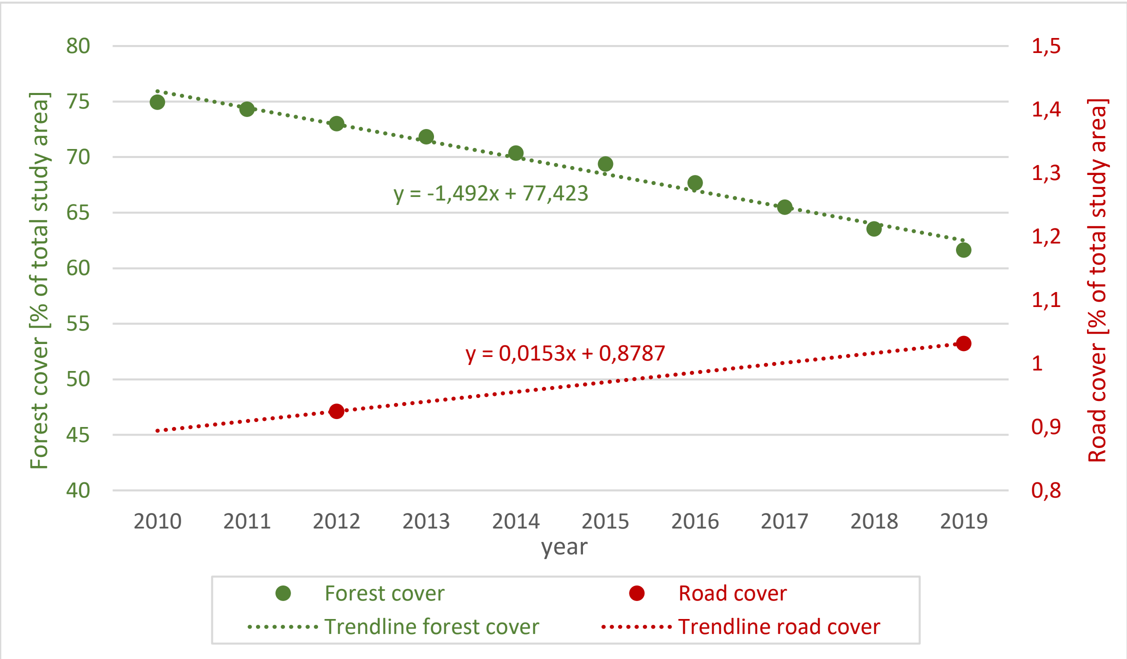

Figure 11: Time series of forest- and road cover percentages of the municipality of Brasiléia in Acre, Brazil. Sources: Own analysis based on data provided by Hansen/UMD/Google/USGS/ NASA (2020) and Planet (2020).

There is a continuous decline in forest cover, which decreased from 75 % in 2010 to roughly 62 % in 2019 with an increasing annual deforestation rate. Correspondingly, the road cover increased by 0,11 % from 0,92 % in 2012 to 1,03 % in 2019.

Brazil nut and acai volumes: The time series of Brazil nut and acai volumes produced within the municipality of Brasiléia between 2010 and 2019 are depicted in *Figure 12*.

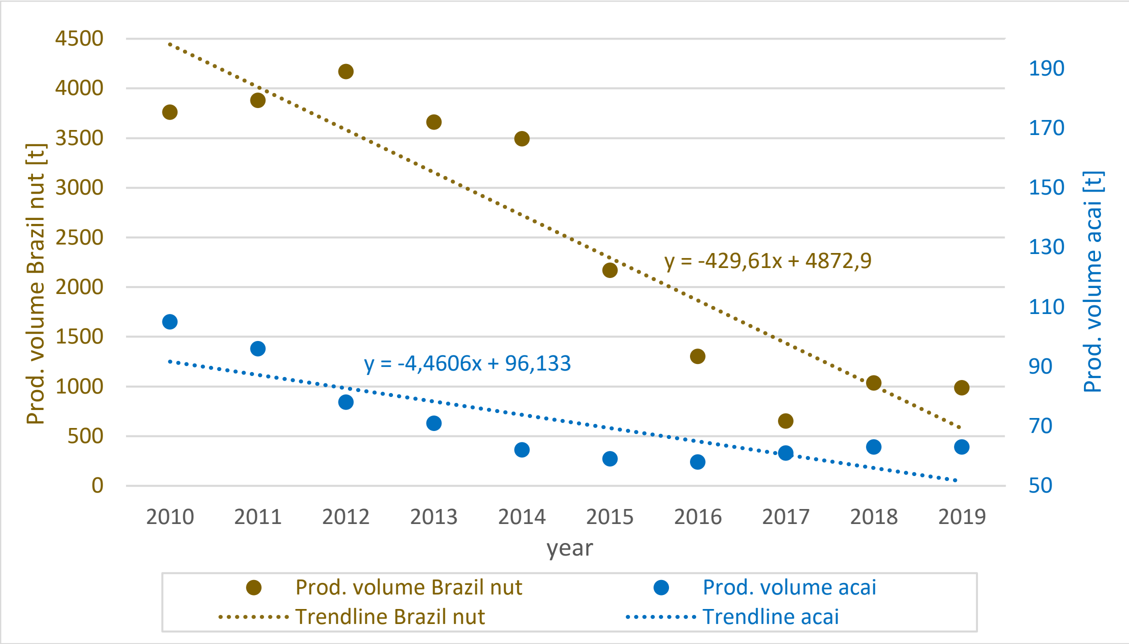

Figure 12: Time series of Brazil nut and acai volumes produced within the municipality of Brasiléia in Acre, Brazil. Data source: IBGE (2020).

The reported Brazil nut volumes show a clear downward trend over the investigated period between 2010 and 2019, with a maximum of 4 169 t in 2012 and a minimum of 650 t in 2017. The acai volumes have steadily decreased between 2010 and 2016 from 105 t in 2010 to 58 t in 2016. Between 2016 and 2018 the volumes slightly increased to a quantity of 63 t in 2018 and 2019 (IBGE, 2020). However, the overall trend between 2010 and 2019 is a decline.

3.1.2 Interviews

Value chains

In Acre, the main actor in NTFP processing and trade is the Central Cooperative of Extractive Commercialization of Acre (Cooperacre), which is based in Rio Branco. Their main target product is Brazil nut, but they also produce rubber, fruit pulp and copaiba oil. This cooperative owns various NTFP-related infrastructure facilities and participates in several supply chains (Cooperacre, 2015).

Brazil nut: The identified steps of the value chain were described to be (1) the collection of the Brazil nuts by extractivists, who (2) transport them either to their home or to other storage sites by cattle or motorbike. After storage, (3) either the extractivists bring the product by car, truck, or motorbike to cooperative-owned storage sheds, or a representative of the cooperative comes to pick up the nuts. Once accumulated, the nuts are (4) transported to the cooperative's processing factories for (5) sanding, classification, shelling, and vacuum packaging and are then (6) either sold on local markets or exported.

Acai: To avoid quality loss of the product, the acai fruit requires processing within a time window of only 48 h after harvest. This strongly determines the infrastructure requirements for the value chain, which consists of (1) the harvest and bagging of the fruit by extractivists for (2) transport to one of the cooperative-run processing plants, one of which is located in the city of Brasiléia and one in Rio Branco. Transport to the urban centres is usually done by the cooperative via roads, picking up the fresh fruit from the extractivist's communities. (3) In the cooperative's processing facility, the fruit is mashed, washed, heated, centrifuged and the pulp is filtered and packed. According to an interviewed Cooperacre-representative, the acai from Acre is not exported, as the local markets consume it entirely.

Production circumstances and volumes

The interviewees were asked if changes occurred in the production of Brazil nut and acai, and what they consider as influencing factors.

Brazil nut: The respective multiple-choice results are presented in *Figure 13*.

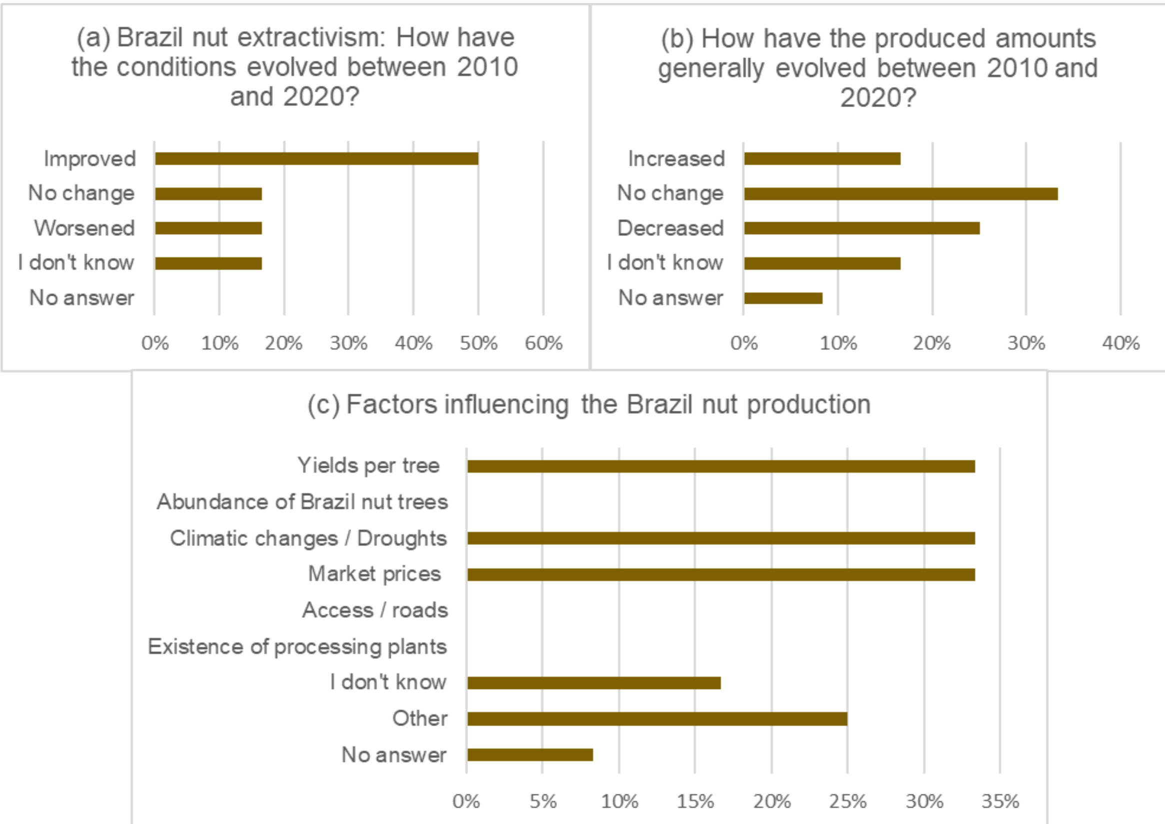

Figure 13: Results of the Brazil nut-specific multiple-choice questions of the interviews conducted with experts and stakeholders in Brazil.

As shown in chart (a) in *Figure 13*, 50 % of the interviewees stated that the conditions for Brazil nut extractivism improved in the past ten years, the remaining half consider the conditions had worsened, remained the same, or have no opinion. As the reasons for improvement, it was commented that nowadays, due to public investments, improved road access, advanced payment schemes and infrastructure of cooperatives, and performed training courses, more extractivists are involved in the production and trade of Brazil nut. Regarding reasons for worsening, the main commented aspects were low market prices, increased deforestation for cattle ranching, as well as a combination of biological and climate factors, such as pest infestations and droughts.

Chart (b) in *Figure 13* shows that one third of the interviewees observed no change in produced amounts of Brazil nut during the past decade. However, 25 % stated a decrease, while 17 % observed an increase in produced amounts, what suggests a split perspective without a clear trend. As presented in chart (c) in *Figure 13*, the most frequently alluded determining factors for the production of Brazil nut are the yields per tree, climatic changes / droughts, and market prices, with one third of the positions each. Access / roads, and the existence of processing plants were not chosen as influencing factors. Also, few interviewees mentioned deforestation, jointly with climatic changes / droughts. An interviewed UFAC professor mentioned a collapse in Brazil nut yields in 2017 due to drought, which is also documented in literature (Terazono, 2017), and a representative of the public ministry of Acre mentioned that the exploitation intensity of Brazil nut from the existing forests has increased, while the forest area itself is being reduced. Both statements align with the observed trends.

Acai: The results of the respective multiple-choice questions are presented in *Figure 14*.

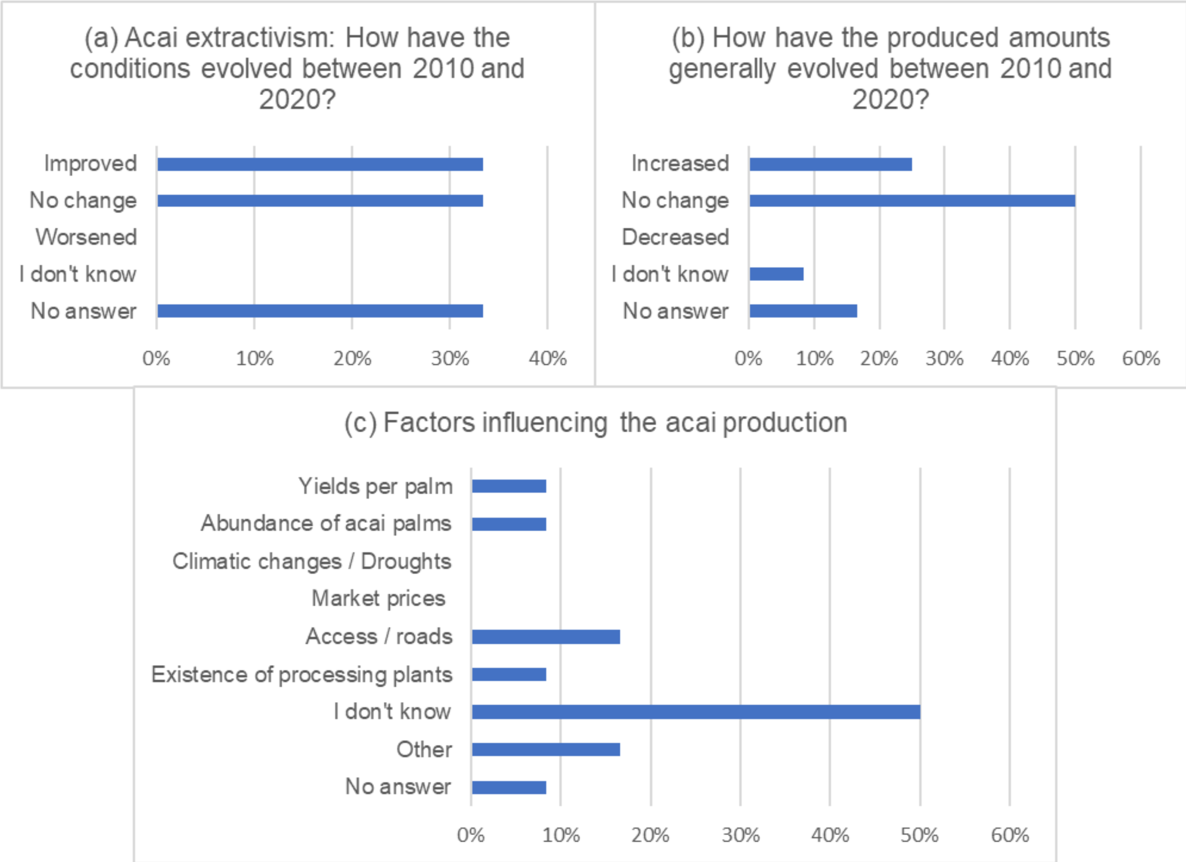

Figure 14: Results of the acai-specific multiple-choice questions of the interviews conducted with experts and stakeholders in Brazil.

Chart (a) in *Figure 14* shows that an improvement in the conditions of acai extractivism in the past decade was observed by the same percentage of interviewees that observed no change, both answer options being chosen by one third of all interviewees. None of the interviewees observed a worsening of the situation. Regarding improvements, it was mentioned that projects supported extractivists with technical training and harvesting equipment. The representative of ICMBio stated that there is still a lot of untapped potential in acai extractivism and indicated that its cultivation could be implemented to increase production in the area. Related to this, a local acai trader from Rio Branco explained that commercial acai cultivation in plantations, already practiced in other Brazilian states, is planned, but not yet implemented in the state of Acre, so that the state's acai production is entirely harvested from wild populations by traditional extractivism practices (A. Nascimento, personal communication, October 7 2020).

According to Cooperacre and extractivists from RESEX, the amount of commercially used acai inside the study area is maintained at a low level, due to a lack of adequate infrastructure required for the fast transport and processing. This issue was confirmed by some of the interviewed extractivists, who affirmed to extract acai, but only for private consumption, as the lack of infrastructure limits any commercial possibilities.

As can be seen in chart (b) in *Figure 14*, 50 % of the interviewees think that the produced amounts have not changed in the past ten years, whereas 25 % stated an increase. None of the interviewees observed a decrease in produced volumes. Chart (c) in *Figure 14* shows that, while half of the interviewees stated to not know what the influencing factors for acai volumes are, access / roads was indicated by 17 % of the interviewees, and one interviewee chose the existence of processing plants as an influencing factor.

Main challenges for extractivism

Ten out of the twelve interviewees, among which all the interviewed extractivists, see access and transport difficulties as a main challenge in terms of commercial extractivism in the study area. The poor conditions of unpaved roads were highlighted, conditioning market access in large parts of the study area, especially in the rainy season.

Regarding acai extractivism, both representatives of governmental institutions in Acre pointed to a lack of continuously available electricity to store the product as another main limiting factor.

Few interviewees also mentioned deforestation caused by cattle ranching as a challenge, posing a more attractive livelihood to rural householders than extractivism.

Infrastructure

The results of the multiple-choice questions related to infrastructure are presented in *Figure 15*.

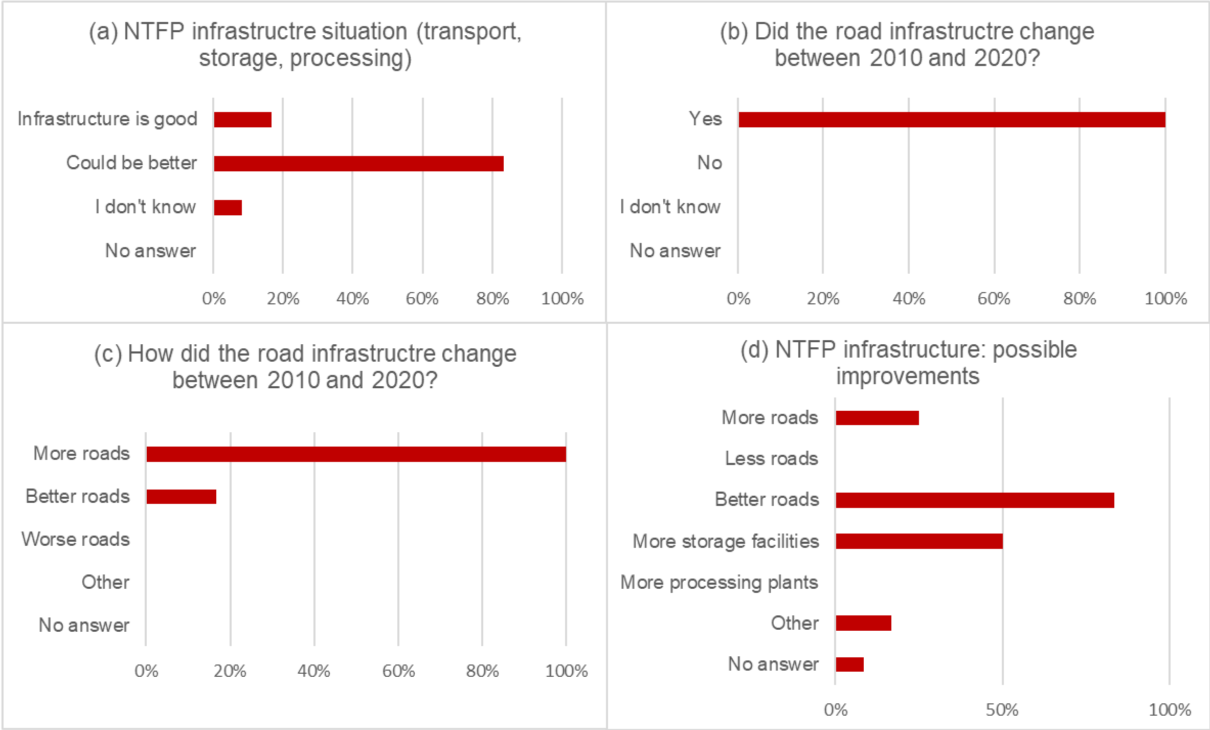

Figure 15: Results of the infrastructure-related multiple-choice questions of the interviews conducted with experts and stakeholders in Brazil.

As presented in chart (a) in *Figure 15*, a majority of the interviewees think that the NTFP-related infrastructure could be better, and 17 % think that the existing infrastructure is good. However, some interviewees mentioned that it needs to be distinguished between the situation regarding Brazil nut and acai, by their different dynamics and infrastructure requirements, as Brazil nut can be stored for several months, while acai as a perishable product requires fast logistic flows within few days. Hence, the existing transport and storage infrastructure is considered as good for Brazil nut extractivism, despite the precarious access conditions; whereas for acai, an adequate transport and storage infrastructure is considered very limited or even non-existent. According to a UFAC professor, the access condition of the so-called "*Ramais*" (secondary unpaved roads) is one of the major limiting factors for the expansion of extractivism, pointing out that not the extent of the road network, but its precarious condition is the problem.

Importance of roads: The majority of interviewees affirmed that roads are fundamental for extractivism, being the only way, as no rivers exist, to transport NTFPs out of the study area. Also, road quality importance was underlined for acai, by the short time window for processing. However, the representatives of ICMBio and of the public ministry, consider that the necessary quantity of roads is exceeded, stating that even if more roads improve the flow of NTFP production, they support deforestation and thus the emergence of pastures more than the NTFP sector, being a land use competing with extractivism.

Infrastructure changes and effects: All the interviewees affirmed that there was a change in road infrastructure in the past ten years, as presented in chart (b) in *Figure 15*. As shown in chart (c), all the interviewees specified that more roads were opened, confirming the findings of the satellite imagery analysis; and 17 % stated that the road quality improved. The respondents specified that the overall road infrastructure increased, but especially the unpaved roads. Nevertheless, one third of the interviewees stated a lack of proper maintenance of the existing roads.

Regarding the effects for extractivism, the majority of interviewed extractivists explained to perceive the existing roads as good, despite their bad quality, as they enabled Brazil nut trade and transport to urban centres. The representative of ICMBio highlighted that transport was only facilitated in dry season, as seasonal rains severely hamper the transit.

Possible improvements: As presented in chart (d) in *Figure 15*, a majority of the interviewees think that better roads would improve the situation, and one fourth asserted that more roads would help. Half of the interviewees consider more storage facilities a potential improvement. The Cooperacre representative explained that the cooperative-owned storage sheds usually do not reach their capacities and therefore mentioned that more smaller storage sheds distributed across the area would reduce the extractivists' transportation efforts and costs. Regarding more storage facilities, the interviewed Embrapa-researcher pointed out that although important, building storage facilities also requires social organisation and enterprise management.

Finally, the representative of the public ministry mentioned besides road maintenance also the establishment of constant electric power as another important infrastructure element required especially for acai processing.

Sustainability

Almost all interviewees affirmed the question of whether extractivism is perceived as a sustainable activity. ICMBio pointed out that traditional extractivism is not only more sustainable but also more lucrative than livestock, and more appropriate to the profile of the region, especially regarding extractive reserves. Nonetheless, a regular identified pattern is that the money earned from extractivism is later invested in deforestation and the purchase of livestock.

Perspectives: All interviewed extractivists stated that NTFP trade would only increase on the conditions of better prices and improved access by road maintenance. The Cooperacre representative and a UFAC professor explained that logistics need to improve to reach the promising potential of acai, and that appropriate policies and government investments are needed. The Cooperacre representative stated land competition with the expanding agribusiness to cause decreasing Brazil nut volumes. Alarmingly, one fourth of the interviewees think that extractivism is threatened and might no longer be practiced in the study area in the future. The mentioned reasons were (1) the disinterest of future generations in extractivism as a livelihood and the support of deforestation, encouraged by the government; (2) the substitution of traditional extractivism by plantations; and (3) exploitative extractivism preventing forest recovery. Embrapa, on the other hand, expects advanced technology to improve productivity and working conditions for extractivism, so that commercial extractivism can have a future.

3.1.3 Present NTFP infrastructure

Brazil nut: As the biggest NTFP processor in Acre, Cooperacre, runs 26 storage sheds across the state for the accumulation of Brazil nuts, mainly from extractive reserves, such as RESEX Chico Mendes. The storage sheds have capacities between 100 and 300 m^3 of which a maximum of only 6 m^3 of Brazil nut is used, with annually varying turnovers. No storage shed could be identified in the study area. According to data researched by Soares-Filho et al. (2017), the nearest Brazil nut storage sheds to the study area are located in the cities of Assis Brasil, Epitaciolândia, and Xapuri. Another storage shed run by the Association of Inhabitants of the Extractive Reserve Chico Mendes (AMOPREAB) was identified by interviewees in the municipality of Assis Brasil. A picture of the validated AMOPREAB storage shed is shown in *Figure 16*.

Figure 16: Storage shed in RESEX Chico Mendes near the study area in Brazil. Picture: W. Silva de Araújo

Based on the dataset compiled by Soares-Filho et al. (2017), and confirmed by several interviewees, two Brazil nut processing factories in and near the study area were identified, one in each of the cities of Brasiléia and Xapuri.

Acai: According to data requested from ICMBio, acai extractivism is practiced in communities in the following sub-regions of the study area: Apodi, Guanabara, São Cristovão and Triunfo (ICMBio, 2020). In the conducted stakeholder interviews, it was stated that Cooperacre runs an acai processing plant in the city of Brasiléia.

The identified infrastructure elements and their locations are shown in *Figure 17*.

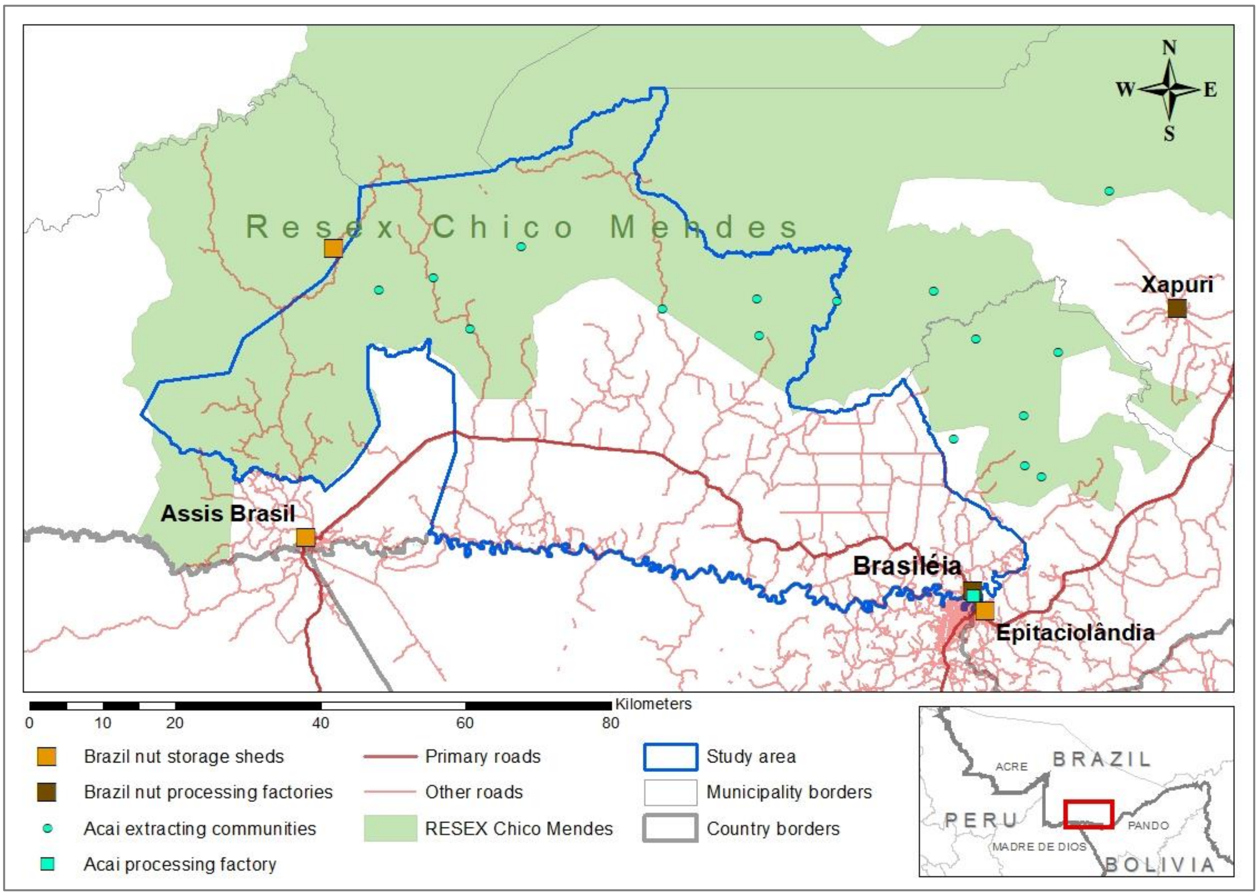

Figure 17: Identified key elements of the Brazil nut and acai value chains in and around the study area in Brazil. Map created with the Esri software ArcGIS 10.6. Sources: Esri, ICMBio, interviews, OSM, RAISG, Soares-Filho et al.

3.2 Pando, Bolivia

3.2.1 Time series

The complete values on which the presented time series diagrams are based are summarised in *Table 3* of Appendix B.

Forest- and road cover: The time series of forest- and road cover percentages, analysed and calculated as described in section 2.2, are shown in *Figure 18*.

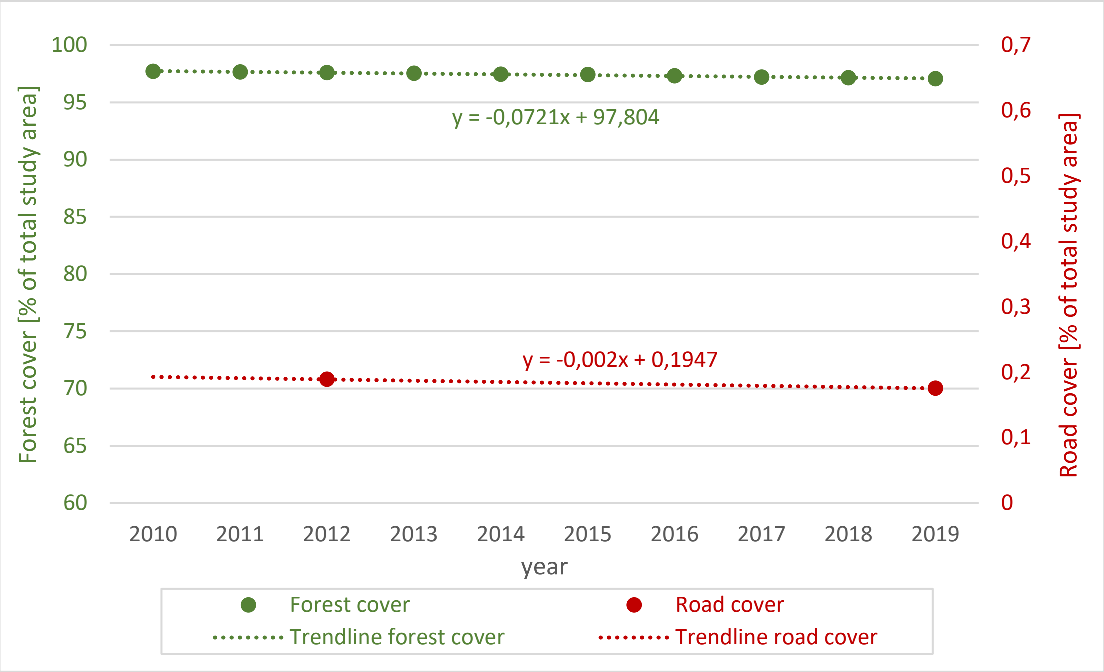

Figure 18: Time series of forest- and road cover percentages of the study area in Pando, Bolivia. Sources: Own analysis based on data provided by Hansen/UMD/Google/USGS/NASA (2020) and Planet (2020).

The forest cover remained on a high level during the investigated period, only declining from 97,70 % in 2010 to 97,05 % in 2019. Correspondingly, the road cover in 2012 was 0,19 % and slightly declined to 0,18 % in 2019. The detected decline can be explained by a methodical limitation which is further discussed in section 4.2.

Brazil nut and acai volumes: As described in section 2.3, due to a lack of specific data for the study area, the time series of Brazil nut extracted from the municipality of Filadelfia served as proxy statistics. Still, the available data only covered the period 2013 – 2020. These are presented in *Figure 19*, together with the acai volumes processed in the study area between 2010 and 2020.

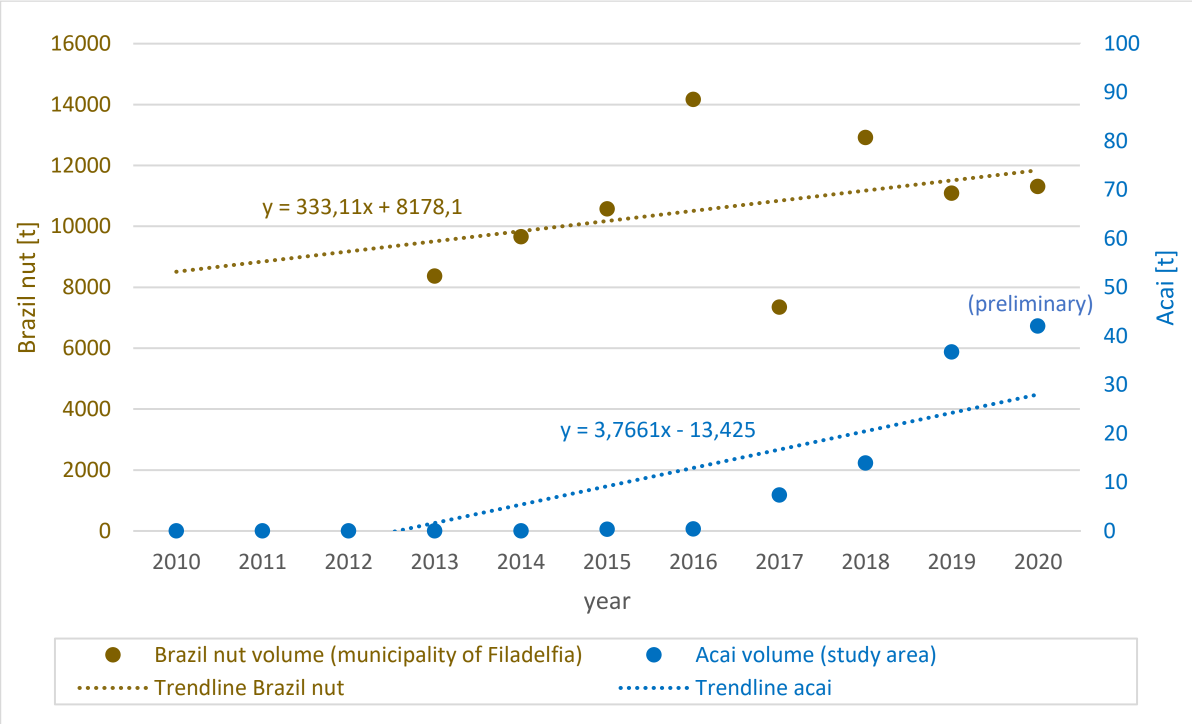

Figure 19: Time series of Brazil nut volumes extracted from the municipality of Filadelfia; and acai volumes processed within the study area in Pando, Bolivia. Acai volume Filadelfia 2020: preliminary. Data sources: ABT Pando (2020); CIPCA (2020); Lorini (2017); WWF Bolivia (2020).

The reported volumes of Brazil nut have considerably fluctuated, but anyhow stabilised in 2019. Despite that, a general trend of increase can be observed.

Acai volumes are characterised by a continuous increase since its commercial production started in the community of Petronila in 2015. The volume considerably increased by fifteen times when a second processing facility was established in the community of Villa Florida in 2017, and further increased to more than 40 t in 2020 (WWF Bolivia, 2020).

3.2.2 Interviews

Value chains

Brazil nut: Brazil nut extractivism in the study area was described to be organised either by families in the communities, or by the so-called "*barraqueros*", wealthier individuals managing forest areas for Brazil nut production ("*barracas*"). These hire external seasonal workers for Brazil nut collection and usually cooperate with processing companies. The basic steps of the Brazil nut value chain were described to be (1) the clearing of trails and maintenance of storage sheds as preparatory steps before the start of the collection season; (2) gathering of the nuts; (3) primary transport to a storage shed ("*payol*") by motorbike for (4) drying, pre-selection and (5) bagging in "b*arricas*" of about 66 kg each. (6) Further transport by truck or tractor either to a bigger accumulation shed, or to a community for storage in the extractivist's home or roadsides, or direct sale to intermediaries who pick the nuts up by car or truck for (7) further transport to either Cobija via road, or to El Sena or Riberalta via river for (8) the final processing. It was stated that around 95 % of the Brazil nut produced in Bolivia is (9) exported internationally.

Acai: As in Brazil, a time window of 48 h after harvest was reported, in which processing must take place due to the short shelf-life of the fruit. The basic steps of the value chain were described to be (1) the harvest in teams of between two and five extractivists, who (2) transport the fruit directly to a processing facility by motorbike. After (3) processing the fruit pulp is (4) stored in a freezer. Once the capacity is reached, (5) the pulp is transported in refrigerated vehicles by road to the city of Cobija to be (6) sold on local markets or to other departments of Bolivia. Acai from the study area was reported to be consumed on regional and national markets only, while export is mainly hampered by logistical difficulties.

Production circumstances and volumes

Brazil nut: The results of the respective multiple-choice questions are presented in *Figure 20*.

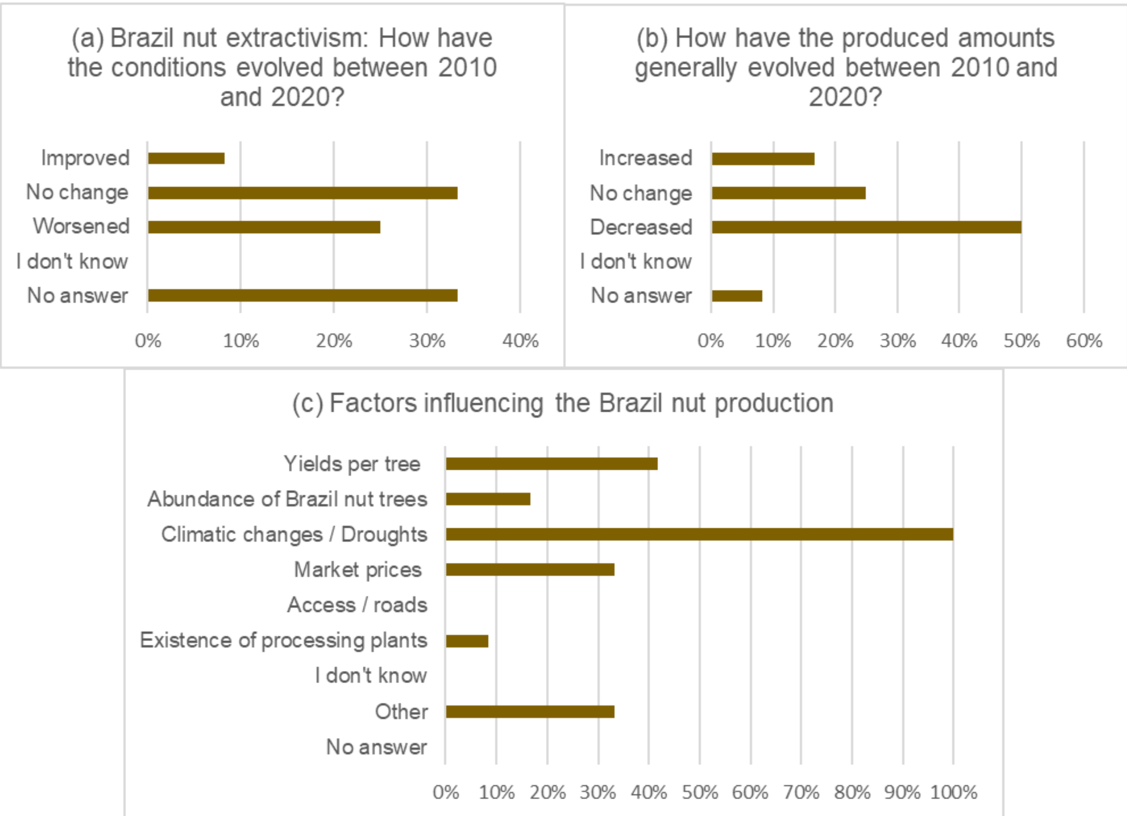

Figure 20: Results of the Brazil nut-specific multiple-choice questions of the interviews conducted with experts and stakeholders in Bolivia.

As shown in chart (a) in *Figure 20*, a third of all the interviewees stated that the conditions for Brazil nut extractivism have not changed in the past ten years, one fourth think that the conditions worsened, and a single interviewee thinks that the situation improved. Aside the technical advances in processing facilities, negative changes were more frequently mentioned, such as a higher exploitation pressure on the forest, and a decreasing demand, what resulted in a decreasing Brazil nut price.

Chart (b) in *Figure 20* shows that half of the interviewees reported a decrease in produced Brazil nut volumes, one fourth think there was no change and 17 % observed an increase. Still, two thirds of the interviewed experts and stakeholders underlined that Brazil nut yields are characterised by fluctuations from year to year. As presented in chart (c) in *Figure 20*, all the interviewees see climatic changes / droughts as the main influencing factor determining Brazil nut yields. In this context, as also mentioned by interviewees in Brazil, a prolonged period of drought was reported to have caused a decrease of 60-70 % in Brazil nut volumes in 2017 compared to the year before, which was stated to be a consequence of climate change. The described phenomenon is documented in literature (Terazono, 2017) and aligns with patterns observed in the time series.

A CIPCA representative pointed to the threatening of Brazil nut trees by deforestation and the setting of roads for timber extraction and agriculture. Relatedly, WWF Bolivia reported, referring to CIPCA investigations, that the annually produced Brazil nut volume did not change much, but that every year a larger forest area is accessed and tapped by extractivists to maintain this volume (Quiroz Claros et al., 2016).

As shown in chart (c) in *Figure 20* on page 39, access / roads was not chosen as a determining factor for the Brazil nut production. A representative of the Manuripi National Wildlife Reserve, in the following referred to as Manuripi Reserve, explained that rivers are the main transport means.

Several other influencing factors affecting Brazil nut volumes were mentioned, such as deforestation, political and economic crises, and the COVID-19 pandemic. ACEAA and WWF mentioned that price dynamics and the competition with substitutes on the market also play a role.

Acai: The results of the respective multiple-choice questions are presented in *Figure 21*.

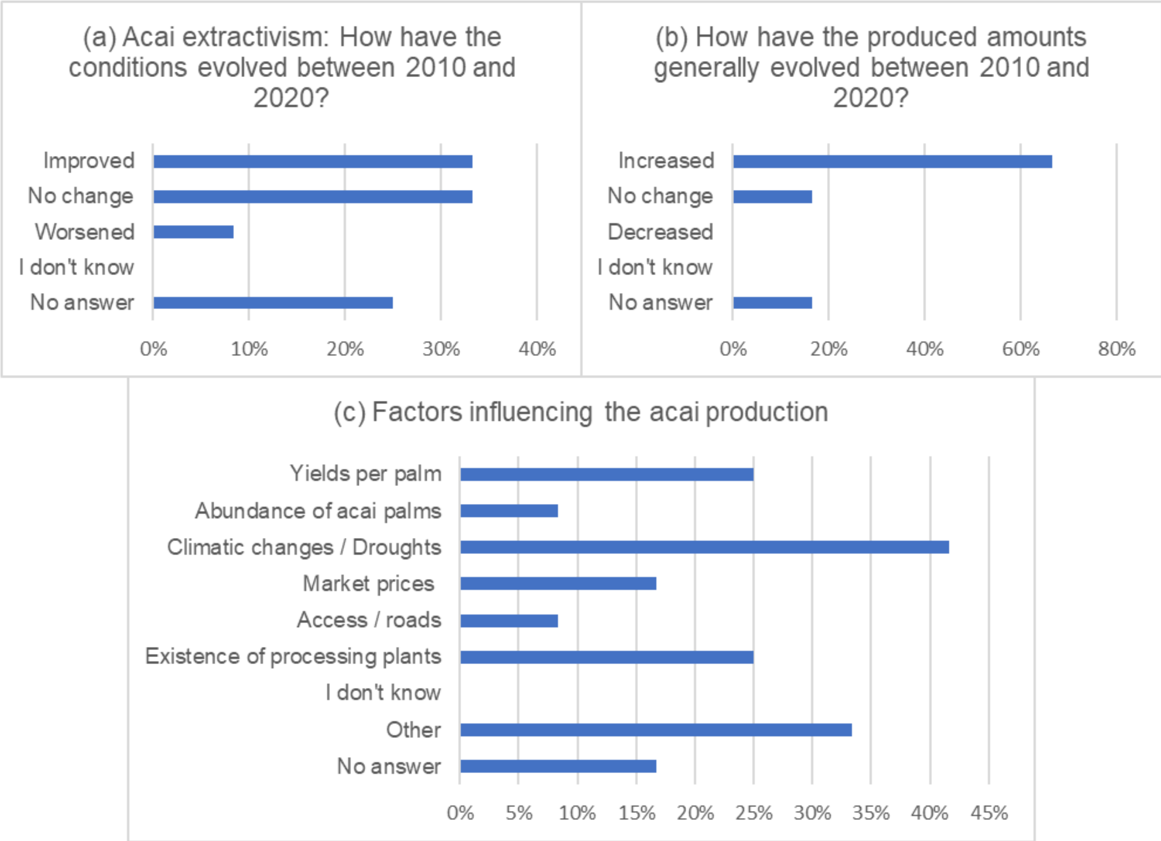

Figure 21: Results of the acai-specific multiple-choice questions of the interviews conducted with experts and stakeholders in Bolivia.

As shown in chart (a) in *Figure 21*, a third of the interviewees think that conditions for acai extractivism improved during the investigated period, while another third did not observe changes and one interviewee noted a worsening. Generally, acai was stated to be an emerging product with a great potential, yet an incipient transformation in Pando. The two existing processing facilities in the study area were described as too small to meet the potential and the high demand. Regarding improvements, the ACEAA representative mentioned that acai extractivism was strongly supported by several institutions with technologies, material, and knowledge. However, WWF explained that the conditions are still precarious and that standards are lacking, resulting in a fluctuating product quality.

Chart (b) in *Figure 21* depicts that a majority of the interviewees observed an increase in the collected acai volumes, confirming the quantitative findings of the present study. It was stated that trade of the acai fruit in the study area only started in 2015 and that it is yet far from its potential scale, as stated by CIPCA.

As shown in chart (c) in *Figure 21*, several factors appear to influence the acai volumes, climatic changes / droughts being the most frequently chosen, and also important, the yields per palm. The limited existence and capacity of processing facilities was seen as a factor by a fourth of the interviewees. Especially the storage, i.e., the maintenance of the cold chain was stated to be a major bottleneck in the acai supply chain, which is also limiting the export of the product, as stated by a UAP lecturer and consultant.

Main challenges for extractivism

The main general challenge mentioned by extractivists was the low revenue for the dangerous and hard work that extractivism implies. Furthermore, the WWF representative mentioned the impact of the COVID-19 pandemic on the demand for NTFPs due to difficulties in transport and logistics.

Regarding Brazil nut, five out of the twelve interviewees stated the fluctuating and decreasing prices to be the major challenge, especially for families whose livelihoods strongly depend on Brazil nut extractivism, as added by the WWF representative.

Regarding acai, the refrigeration of the product was mentioned by a fourth of the interviewees as the major challenge. The CIPCA officer explained that the geographical remoteness of Pando from the main markets in La Paz and Santa Cruz, poses difficulties in transport as well as price competition with producers in the department of Santa Cruz.

Infrastructure

The multiple-choice results related to infrastructure are presented in *Figure 22*.

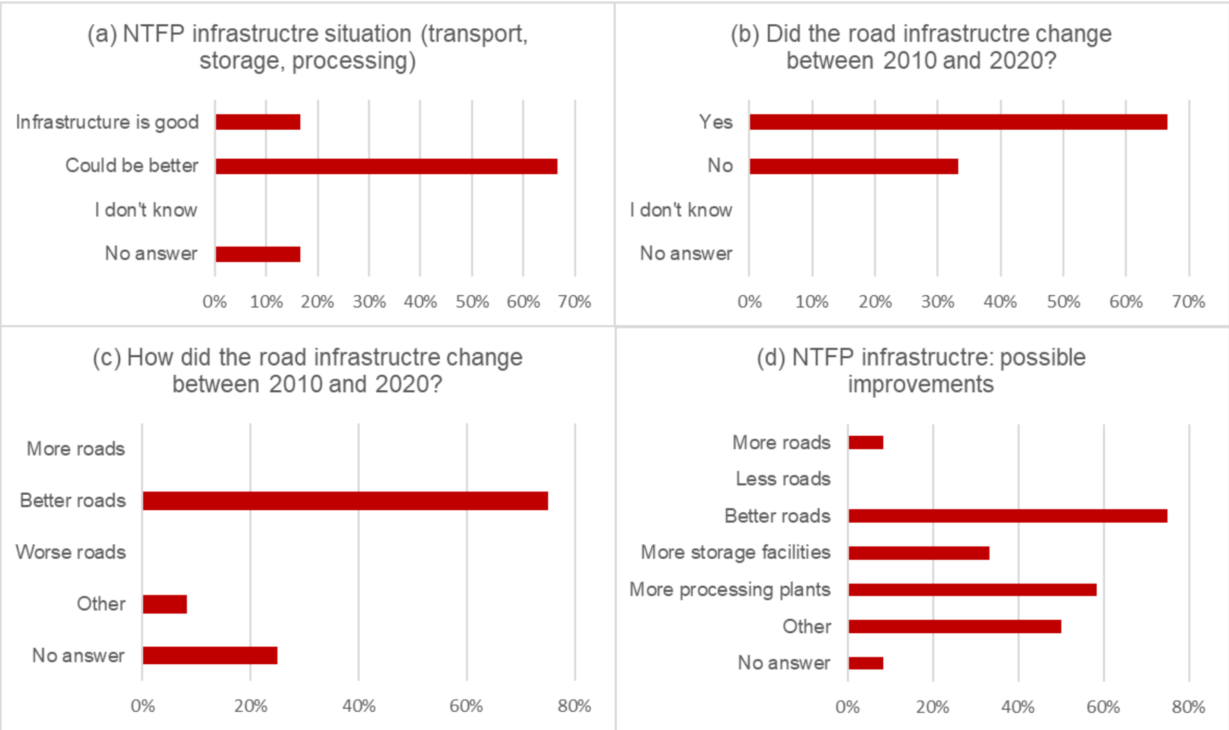

Figure 22: Results of the infrastructure-related multiple-choice questions of the interviews conducted with experts and stakeholders in Bolivia.

As presented in chart (a) in *Figure 22*, two thirds of the interviewees think that the NTFP-related infrastructure could be better, and one sixth perceive the existing infrastructure as good. Among them, WWF described the Brazil nut infrastructure as very good, especially due to technical progress in processing. Both, the representative of CIPCA and of the Manuripi Reserve highlighted that Brazil nut collection takes place only in the rainy season, so their transport on unpaved roads is only possible using heavy machines, like tractors, which cause higher impacts on the ecosystem in terms of emissions and soil consolidation, compared to other motorised vehicles. The representative of the Manuripi Reserve mentioned also cases when the climate affected NTFP transport during the dry season by drying up rivers, being the major transport ways towards Riberalta, Bolivia's main Brazil nut processing centre. The existing roads in the study area were stated to be maintained, but according to CIPCA, ongoing construction for paving is hindering transport. The acai-related infrastructure was described as growing, but still limited in means to preserve the product by maintenance of the cold chain or by freeze-drying.

Importance of roads: Almost half of the interviewees affirmed that roads are important for extractivism. It was stated that they are key especially for acai, by the fast flow required to prevent its spoilage. Regarding Brazil nut, the representative of the Manuripi Reserve pointed out that roads and trails are important to transport the product from the forest to storage facilities, and for some also for transport to Cobija, although most of the production is transported by river to Riberalta. ACEAA stated that the essential roads already exist and only need to be maintained and improved.

Infrastructure changes and effects: As can be seen in chart (b) in *Figure 22*, two thirds of the interviewees perceived changes in the infrastructure in the investigated period. As presented in chart (c) in the same figure, 75 % of the interviewees related this change to the improvement of the roads, whereas none of the interviewees stated that more roads were built, confirming the findings of the satellite imagery analysis. The representative of the Manuripi Reserve explained that the opening of new roads is prohibited in the reserve and mentioned that despite the road benefits, i.e., access to national and international NTFP markets, road network improvements also caused problems such as land invasion, illegal hunting, and detrimental effects on the ecosystem. Finally, the WWF representative pointed out that access to electricity made acai processing possible in the study area.

Possible improvements: Chart (d) in *Figure 22* shows that 75 % of the interviewees consider further improvements of the existing roads as important, and more NTFP storage- and processing facilities were also strongly demanded. ACEAA and CIPCA stated that the paving of the route 53, which is already in construction, would benefit extractivism, and that more Brazil nut processing facilities should be installed in the department of Pando, where 70-80 % of Bolivia's Brazil nut is collected, whereas most processing factories are located in Riberalta. However, the representatives of CIPCA and WWF indicated that there is more specialised workforce available in Riberalta. Still, two interviewees observed that more value could be added to locally produced Brazil nuts, by installing post-processing facilities to obtain products such as Brazil nut oil and -milk.

Regarding acai, one fourth of the interviewees stated that more acai processing facilities are needed, and the representative of the Manuripi Reserve suggested the community of Luz de America as a prospective strategic location in terms of distance and efficiency, but also mentioned a lack of available workforce there. Moreover, a general position was that investments in transport logistics and appropriate equipment and materials are needed to maintain quality standards in processing. Two interviewees pointed out the need to set up either infrastructure for maintaining the cold chain in Cobija, or a freeze-drying facility to preserve the product, which would also enable its export.

Sustainability

Ten out of the twelve interviewees affirmed the question of whether extractivism is perceived as sustainable, three of which commented that extractivism helps to conserve the forest. On that, the representative of the Manuripi Reserve pointed out that seasonal Brazil nut gatherers are only allowed to stay in the reserve for up to three months, to prevent overexploitation and to ensure natural regeneration. However, ACEAA stated that incentives are needed to support extractivism as a livelihood and to prevent the shift towards livestock rearing and agribusiness, which trigger deforestation.

Perspectives: Infrastructure improvements, such as the pavement of the main road crossing the study area and the construction of a bridge crossing the Manuripi river in the community of San Silvestre, were reported to be planned and are expected to improve NTFP transport, but to also affect the environment.

Neither the interviewed extractivists, nor the WWF representative expect changes regarding the Brazil nut value chain, being already consolidated. CIPCA stated that Brazil nut can only be remained as a commodity on condition of a reasonable price in the future. The expected additional value generation by transformation could contribute to that.

Regarding acai, a majority of the interviewees expect the market to keep growing, and higher quality standards to be introduced to meet the growing national and international demand. Advances in conservation of the product are also expected, presumably by the installation of a freeze-dryer or other conservation technologies. Moreover, more acai-processing companies are expected to settle in the area, and ACEAA expects the formation of new NTFP-related associations and cooperatives.

3.2.3 Present NTFP infrastructure

The roads in the study area were described to be gravel- and dirt roads, but partly being in construction to be paved. Besides roads, rivers were pointed out as important transport ways especially for Brazil nut.

Brazil nut: Brazil nut was reported to be collected in the entire department of Pando, but with the Brazil nut trees being unevenly distributed in patches. 15 % of Bolivia's total exported Brazil nut volume is collected within the reserve, where 40 "*barracas*" exist, and 50 hectares of land are assigned to each community inhabitant for Brazil nut collection.

It was found that there are various storage and accumulation sheds of different sizes distributed across the study area, which are either private, community-owned, or company-owned. Only few of them could be identified and validated in the context of this work. The locations of the community-owned accumulation sheds in the Manuripi Reserve were drawn from each community's Integrated Management Plan of Forests and Land (PGIBT), managed by the ABT (ABT, 2014). Three of these sheds, located in the communities of Curichón, Luz de America and Villa Florida, were validated with GPS coordinates and pictures in November 2020 with the help of a local assistant.

No Brazil nut processing facilities exist inside the study area. Processing of Brazil nut collected inside the study area was reported to take place in the cities of Riberalta and El Sena in the east, and Cobija in the north of the study area. Transport to Riberalta and El Sena takes place via the rivers "Rio Madre de Dios" and "Rio Manuripi", transport to Cobija is done via roads. Five processing plants were reported to be located in Cobija, the company "Tahuamanu S.A." running the biggest one with an annual processing capacity of 10 500 t. Besides Tahuamanu, the "Beneficiadora Tatiana" and the "Empresa Boliviana de Almendra y Derivados" (EBA) are companies in and around Cobija, which were found to process Brazil nut from the study area. The locations of their Brazil nut processing plants were drawn from ACEAA documentations (ACEAA, 2017). Riberalta was reported to be Bolivia's main Brazil nut processing centre with about 25 Brazil nut processing factories located there. It was reported that 95 % of the Brazil nut produced in Pando is exported internationally.

Acai: Commercial acai harvest takes place in proximity to the existing processing facilities. Two were identified inside the study area, one in the community of Villa Florida in the Manuripi Reserve, and another in Petronila, outside the reserve. Both processing facilities were validated with GPS coordinates and pictures in November 2020, with the help of a local assistant. According to a representative of the Association of Amazonian Fruit Gatherers of Petronila (ARFAPP), the acai processing facility in Petronila has the capacity to process 2 - 3 t of acai pulp per year, which CIPCA records confirm (CIPCA, 2020), and a storage capacity of 1500 litres of frozen acai pulp. Villa Florida's processing facility has a cooling chamber with a storage capacity of 10 t. It was furthermore reported in interviews that another acai processing facility is run in the community of Trinchera in proximity to the study area.

The locations of the identified NTFP-related infrastructure elements are presented in *Figure 23*.

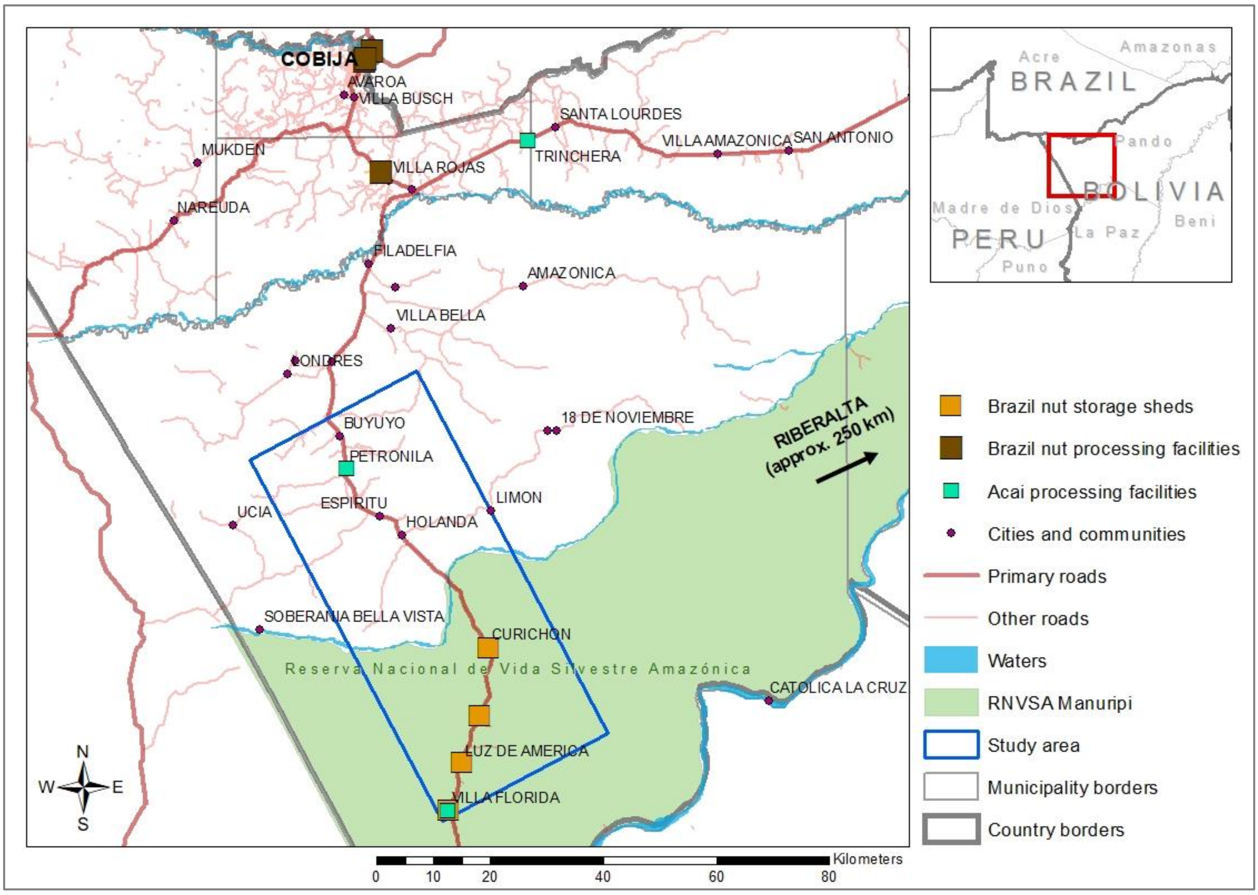

Figure 23: Identified key elements of the Brazil nut and acai value chains in and around the study area in Bolivia. Map created with the Esri software ArcGIS 10.6. Sources: ABT, ACEAA, Esri, interviews, OSM, RAISG.

3.3 Madre de Dios, Peru

As described in section 2.3, it was found that by the time of this study, acai has not reached a commercial scale in Madre de Dios. Therefore, no data was available regarding acai in the study area in Peru.

3.3.1 Time series

The complete values on which the presented time series diagrams are based are summarised in *Table 4* of Appendix B.

Forest- and road cover: The time series of forest- and road cover percentages, analysed and calculated as described in section 2.2 are shown in *Figure 24*.

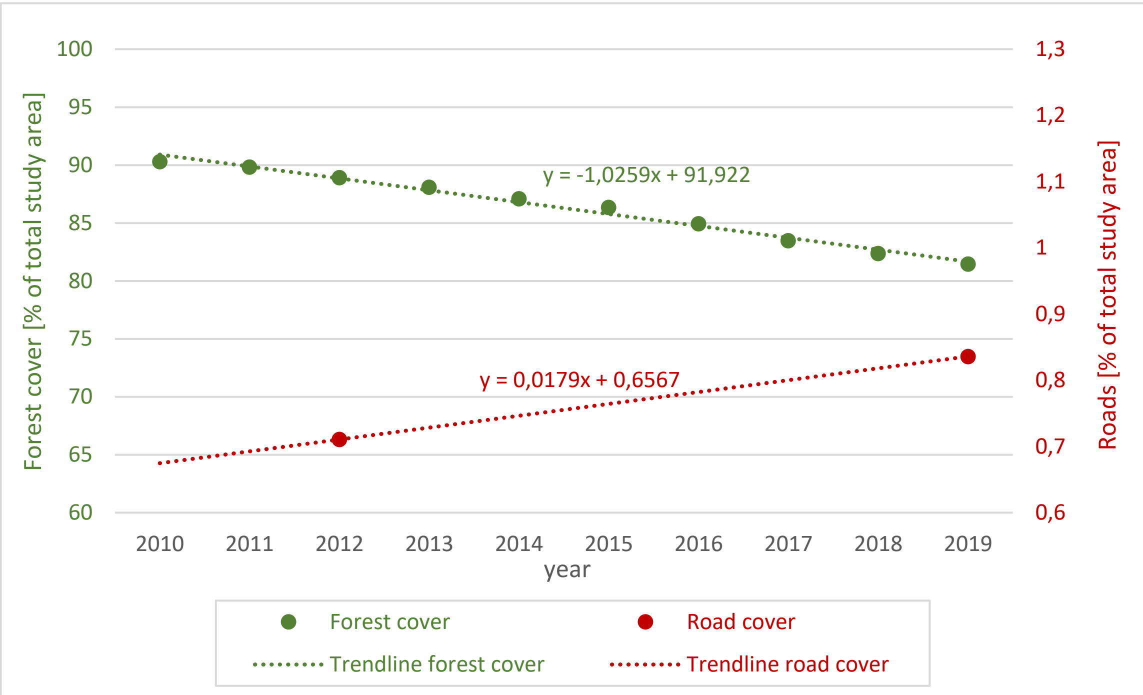

Figure 24: Time series of forest- and road cover percentages of the study area in Madre de Dios, Peru. Sources: Own analysis based on data provided by Hansen/UMD/Google/USGS/NASA (2020) and Planet (2020).

The results show a continuous decline in forest cover, ranging from 90 % in 2010 to roughly 81 % in 2019; whereas the road cover increased from 0,71 % in 2012 to 0,84 % in 2019.

Brazil nut volumes: Trends and changes in Brazil nut volumes produced in concessions in the study area in Peru are shown in *Figure 25*. The indicated volumes do not represent the total amount produced within the study area, instead, they represent a quota sampling of the available continuous data from the indicated registers, as described in section 2.3, aiming to portray the trends and changes in Brazil nut volumes over time.

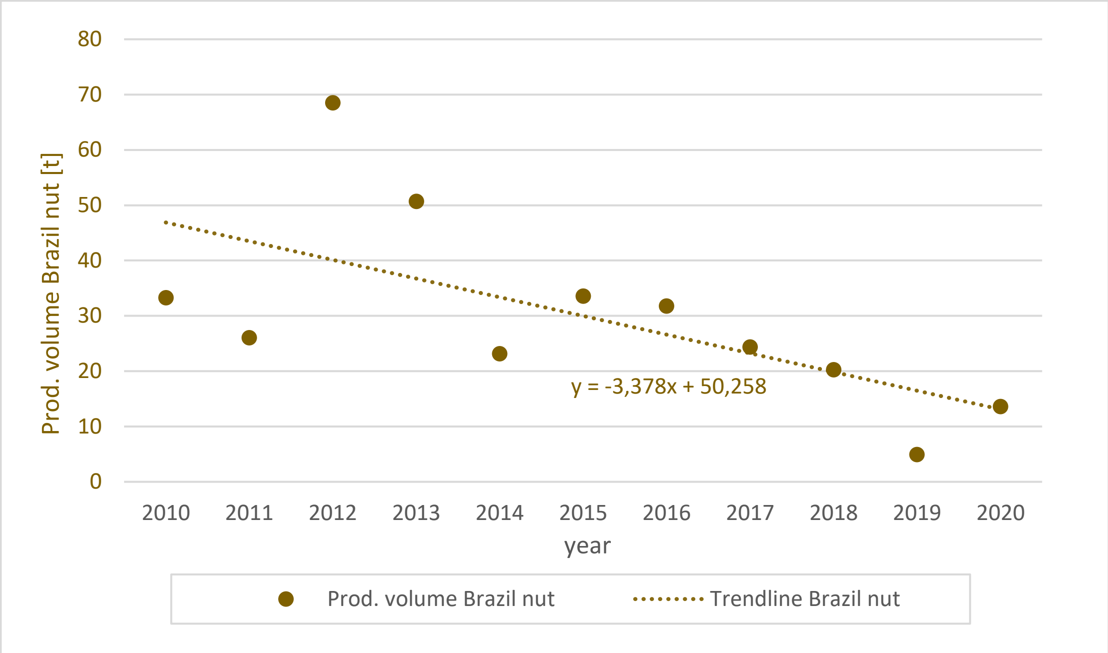

Figure 25: Time series representing trends and changes in Brazil nut volumes gathered in concessions within the study area in Peru, for which continuous annual data were available. Data sources: GRFFS (2020); SERNANP (2020).

The annual Brazil nut volumes are characterised by fluctuations and a clear downward trend over the investigated period.

3.3.2 Interviews

Brazil nut value chain

After the clearing of trails, the fruits are gathered and opened in the forest, to take out the nuts only. The subsequent steps depend on the location of collection and the respective accessibility. In the Tambopata Reserve, the nuts are carried to storage sheds called "*payoles*" by foot, since the use of motorised vehicles is prohibited. Outside the reserve, this transport step is done either by foot or by motorbike, if storage sheds are used. After accumulation and a pre-drying step in the "*payoles*", the nuts are bagged in "*barricas*" of approximately 70 kg, before being brought to riversides or roads for further transport to points of trade where they are sold to either intermediaries, associations, or processing companies. From these points of trade, the nuts are further transported to accumulation centres or processing facilities in Puerto Maldonado. In general, transport preferably takes place via roads, if available, but in many cases by boat via rivers.

It was reported that many extractivists inside the study area, especially concessions near the IOH, do not use post-harvest infrastructure such as "*payoles*", and instead transport the nuts to their homes, or to the roadsides of the IOH, from where they are sold to intermediaries or processing companies without prior storage or drying; or the extractivist directly brings the nuts to a processing facility in Puerto Maldonado. Part of the processed Brazil nut is transported to Lima for export.

Production circumstances and volumes

The results of the multiple-choice questions regarding Brazil nut production are presented in *Figure 26*.

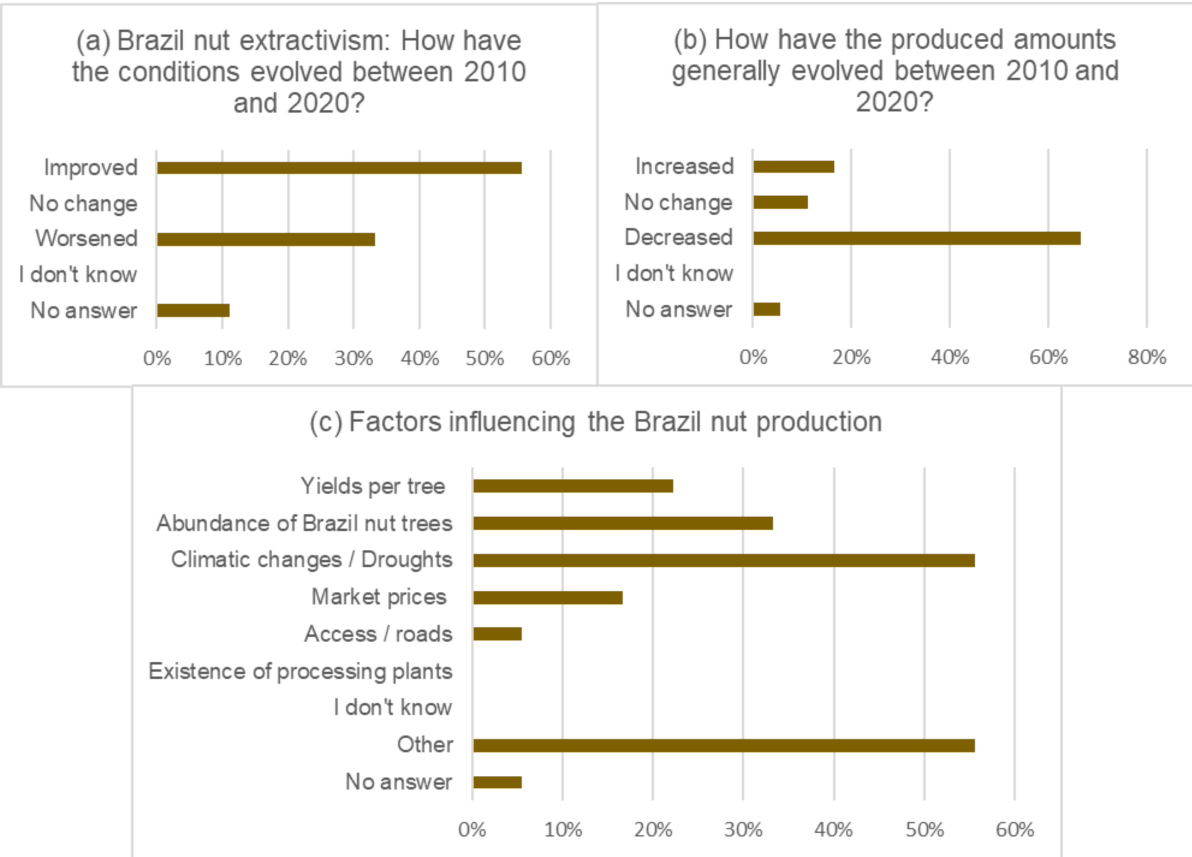

Figure 26: Results of the Brazil nut-specific multiple-choice questions of the interviews conducted with experts and stakeholders in Peru.

As presented in chart (a) in *Figure 26*, a majority of 56 % of the interviewees stated that the conditions for Brazil nut extractivism generally improved throughout the investigated period, whereas one third stated the conditions have worsened. Improvements were described in terms of better access and improved post-harvest management and quality standards, which altogether resulted in a better price. Two processing companies stated that the increased price was an incentive for extractivists to access previously unused forest areas. Among the reasons for a worsening of the situation were mentioned: decreasing volumes and, especially in areas near roads, immigration, which resulted in increasing social problems like invasions and Brazil nut robbery. Moreover, a representative of the processing company "Candela" underlined that the use of "*payoles*" for pre-drying is nowadays less common than before, what results in a lower nut quality.

It was recurrently stated that the Brazil nut production in the study area is relatively low compared to the main Brazil nut areas in Madre de Dios, which are located in the north of Puerto Maldonado. As shown in chart (b) in *Figure 26*, a majority of the interviewees observed a decrease in the Brazil nut volumes collected for the investigated period, which confirms the findings of the time series analysis. Still, few of the interviewees stated that the produced amounts have increased, and only two interviewees observed no change. The yields were described as fluctuating, and one local trader stated a variation in cycles of 4-5 years, which coincides with the statement of an interviewee in Bolivia.

Several factors were mentioned to influence Brazil nut volumes. Chart (c) in *Figure 26* shows that out of the given answer possibilities, "climatic changes / droughts" and "other" were the options chosen by most of the interviewees. Only one interviewee considered "access / roads", correlating access to the Brazil nut price, since facilitated transport increases rentability. Nevertheless, the existence of processing plants was not chosen as an influencing factor.

Other factors mentioned were deforestation and forest degradation due to illegal timber extraction and clearing for agriculture, as well as forest fires, increasing population and urbanisation, all resulting in a reduction in the number of Brazil nut trees in the area.

Main challenges for extractivism

Invasive immigration and illegal mining were stated to be major challenges for extractivists, as they cause environmental and social problems such as deforestation and forest degradation, contamination, land tenure insecurity, violence, corruption, and Brazil nut robbery. An area called "*La Pampa*" in the west of the study area was reported to be the centre of illegal mining in the region.

Furthermore, an underrepresentation of local extractivists in political decisions and a lack of appropriate support for extractivism in the study area was reported.

Three interviewees also mentioned the disinterest of future generations in extractivism as a livelihood. The EUR researcher stated the Brazil nut price to be disproportionately low compared to cultivated nuts and explained that Brazil nut is an easily replaceable product, which prevents it from being valued appropriately.

Several interviewees stated that the poor accessibility to Brazil nut concessions causes difficulties in transporting the nuts out of the forest; and three interviewees reported a lack of appropriate post-harvest infrastructure such as "*payoles*", as determining the product quality. A general lack of quality standards, control, and traceability of Brazil nut were also seen as deficiencies.

Infrastructure

The results of the multiple-choice questions related to infrastructure are presented in *Figure 27*.

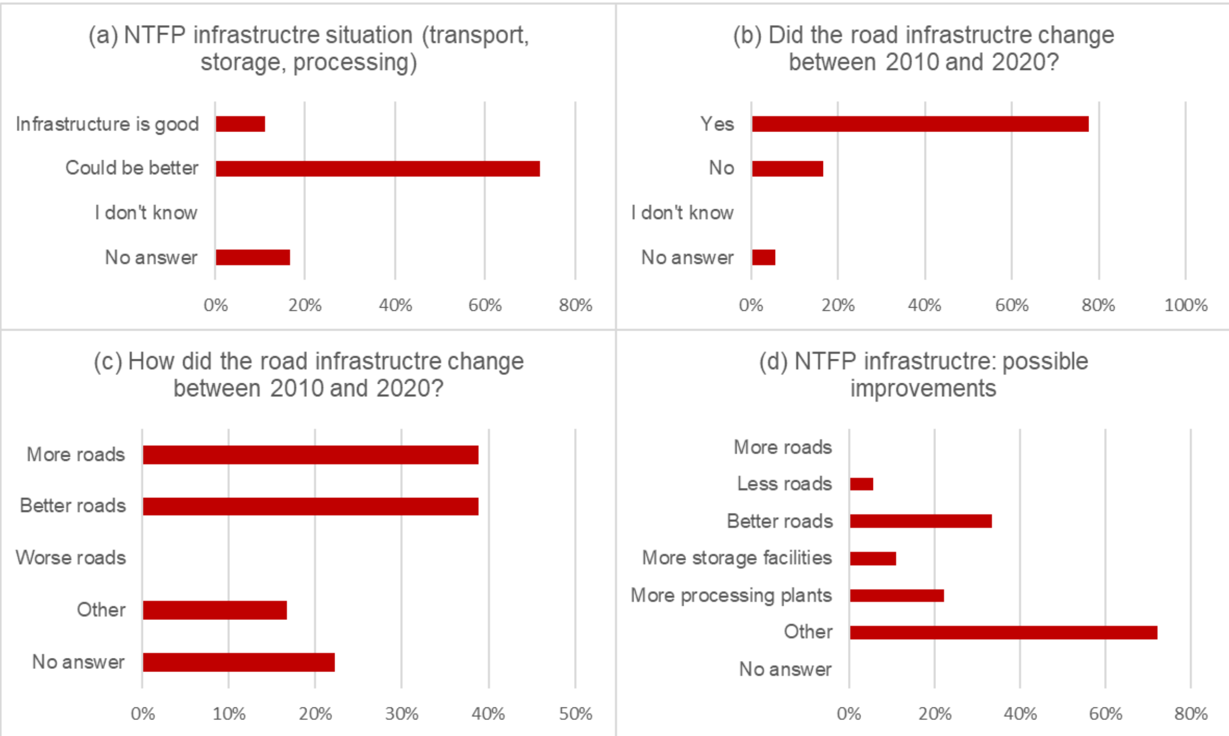

Figure 27: Results of the infrastructure-related multiple-choice questions of the interviews conducted with experts and stakeholders in Peru.

As presented in chart (a) in *Figure 27*, a majority of the interviewees finds that the NTFP-related infrastructure situation in the study area could be better, and only two interviewees consider the existing infrastructure as good. The two interviewed holders of concessions inside the Tambopata Reserve indicated that there are no motorways in the reserve, footpaths and rivers being the main means of transport there. The interviewed IIAP representative described a lack of appropriate storage facilities to maintain quality standards, but assesses the existing processing infrastructure as good. The trade-off between efficiency and ecological sustainability was pointed out by the interviewed UKL researcher, mentioning the example of the road network extent.

Importance of roads: Five interviewees described roads as essential for extractivism. One of them explained that road transport is considerably cheaper and thus more profitable than transport by boat. However, other five stated that roads indeed facilitate transport, but that their negative effects, such as supporting illegal logging and causing invasions and social conflicts, overweigh the positive ones.

Infrastructure changes and effects: As can be seen in chart (b) in *Figure 27*, the majority of the interviewees perceived changes in the study area's infrastructure in the investigated period. These were equally characterised as "more roads" and "better roads", as shown in chart (c) in *Figure 27*. Relatedly, the paving of the IOH and the construction of bridges were also mentioned.

The observed improvement of access and transport conditions had positive and negative effects. One third of the interviewees mentioned positive effects such as facilitated transport as well as increased efficiency and product quality, and one researcher indicated these to be reasons for a generally high acceptance and positive perception of roads among rural householders. However, half of the interviewees pointed out to the negative effects of the observed infrastructure developments, having facilitated illegal logging and mining, and having caused social conflicts such as invasions of Brazil nut concessions, land tenure conflicts and robbery. In this context, the GRFFS representative stated that more roads caused changes in the ecosystem and thus assumed an impairment of the Brazil nut production as a result. Two researchers mentioned that, as a consequence of the infrastructure transformation, part of the study area's landscape is today characterised by the fishbone-pattern.

Possible improvements: As presented in chart (d) in *Figure 27*, better roads were chosen as a potential improvement by a third of the interviewees, 22 % think that more processing plants would improve the situation, 11 % chose more storage facilities, and one interviewee stated that less roads would be an improvement.

However, a majority of the interviewees indicated complementary responses: Two holders of concessions in the Tambopata Reserve stated that the installation of a Brazil nut processing plant in the community of Infierno would reduce transport costs and support the local population; and one of them also stated that boats with higher capacities could make transport by rivers more competitive with transport via roads.

Moreover, four interviewees indicated that aggregated value could be added locally by setting facilities to produce Brazil nut oil, -flour and -soap, instead of only exporting the primary product. However, it was also put into perspective that the implementation of facilities for transformation processes is associated with challenges such as the availability of a stable electricity supply, political stability, sufficient workforce, knowledge, and a long-term perspective.

Four interviewees stated that the construction and use of storage sheds and accumulation centres could improve the product quality and reduce losses by avoiding critical points of contamination by inappropriate storage. The interviewed IIAP representative pointed out to the general necessity of introducing quality standards, as well as of responsibly organising and managing land tenure.

Moreover, four interviewees underlined the need for reforestation, also with Brazil nut trees.

Sustainability

The question of whether extractivism is perceived as sustainable was affirmed by 17 out of 18 interviewees and was sustained by its contribution to forest conservation. The representatives of both, IIAP and SERNANP, indicated that the Tambopata Reserve is a good example of sustainable extractivism and forest management. The EUR researcher underlined the existing concession system in Peru as another good instrument for forest management. One concession holder stated that sustainability depends on the implemented extractivism practices, for example if motorised vehicles are used in the forest or not. Contrarily, the AFIMAD representative described the use of motorbikes in the forest as a compromise minimising both physical efforts and environmental impacts.

Nevertheless, the importance of certain preconditions for sustainable extractivism, such as education and conscientiousness in terms of good management practices along the value chain, and the resolution of legal issues, was pointed out by several interviewees.

Perspectives: Almost one third of the interviewees expect changes in the future regarding extractivism, whereas two interviewees do not expect changes.

Several interviewees expressed concern that the local Brazil nut production might further decline and possibly disappear due to low profitability and more attractive land use options such as agriculture and logging. As Brazil nut being an emblematic product of Madre de Dios, the GRFFS representative stated that the government will invest more in its conservation and the recuperation of degraded areas via projects, while pointing out the necessity of good coordination between the local, regional, and national governments.

The IIAP representative expects more aggregated value to be added to Brazil nut, and Candela expects to have a greater market and a fair price in the future. Another local Brazil nut trader raised hopes that extractivism could become a main source of livelihood instead of being a complementing activity; and expects, as well as two researchers, further formations of extractivist associations in the future. To this end, a concession holder from the community of Infierno reported that the community is considering to install its own processing plant.

3.3.3 Present NTFP infrastructure

Geospatial data regarding Brazil nut concessions was provided by GRFFS for concessions outside the Tambopata Reserve and from SERNANP for concessions within the Tambopata Reserve (GRFFS, 2020b; SERNANP, 2020b). SERNANP also provided the locations of Brazil nut storage sheds in the reserve (SERNANP, 2020b).

For transport within the Tambopata Reserve, it was found in the conducted interviews that due to the prohibition of motorised vehicles, only footpaths and rivers are used.

The locations of trading points where Brazil nut from the study area is sold from extractivists to intermediaries and processors were also identified in the conducted stakeholder interviews. Puerto Rosario de Laberinto was reported to be a major one for concessions outside the Tambopata Reserve, and Puerto Infierno another for Brazil nut collected within the reserve. Brazil nut is transported to both locations by the extractivists mainly via rivers. The company "Nueces SAC" reported to also purchase Brazil nut at km 55 of the IOH, at the intersection with the road to Boca Union.

It was found that there are neither major accumulation centres nor processing facilities within the study area, besides the ones in the city of Puerto Maldonado. Based on the conducted interviews and literature (Quaedvlieg and Santelices, 2018), Brazil nuts were found to be processed in Puerto Maldonado by the following associations and companies (list may be incomplete):

- ASCART
- Candela
- El Bosque
- El Califa

- La Nuez SRL
- Manutata SAC
- Nueces SAC
- Rompeolas SAC

The Indigenous Forestry Association of the Tambopata Reserve (AFIMAD) does not run its own processing facility, but reported to have an accumulation centre in Puerto Maldonado, from which the nuts are transported to ASCART's processing plant. Of the above-mentioned processors, Candela, El Califa, Nueces SAC and Rompeolas SAC were reported to also process Brazil nut collected inside the study area. Nueces SAC estimated to buy approximately 140 t of Brazil nut per year from the study area.

The locations of the identified Brazil nut-related infrastructure elements are presented in *Figure 28*.

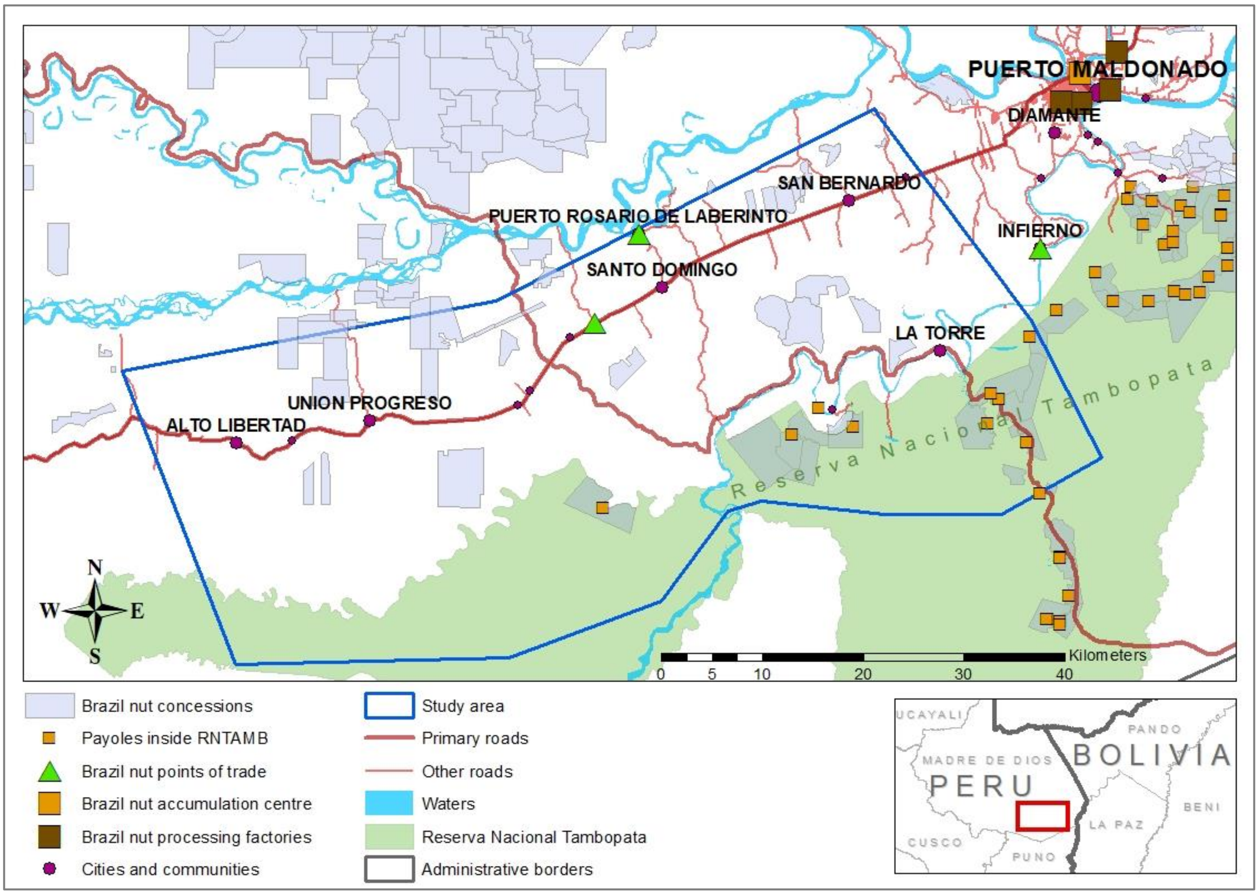

Figure 28: Identified key elements of the Brazil nut value chain in and around the study area in Peru. Map created with the Esri software ArcGIS 10.6. Sources: Esri, GRFFS, interviews, OSM, RAISG, SERNANP.

3.4 Cross-comparison of the time series

In the following chapter, the time series are presented for each investigated factor as a cross-comparison of the three study areas. The complete values on which these time series are based are summarised in *Table* 2 – *Table 4* of Appendix B.

3.4.1 Forest cover

The forest cover percentages of each study area are presented in *Figure 29*.

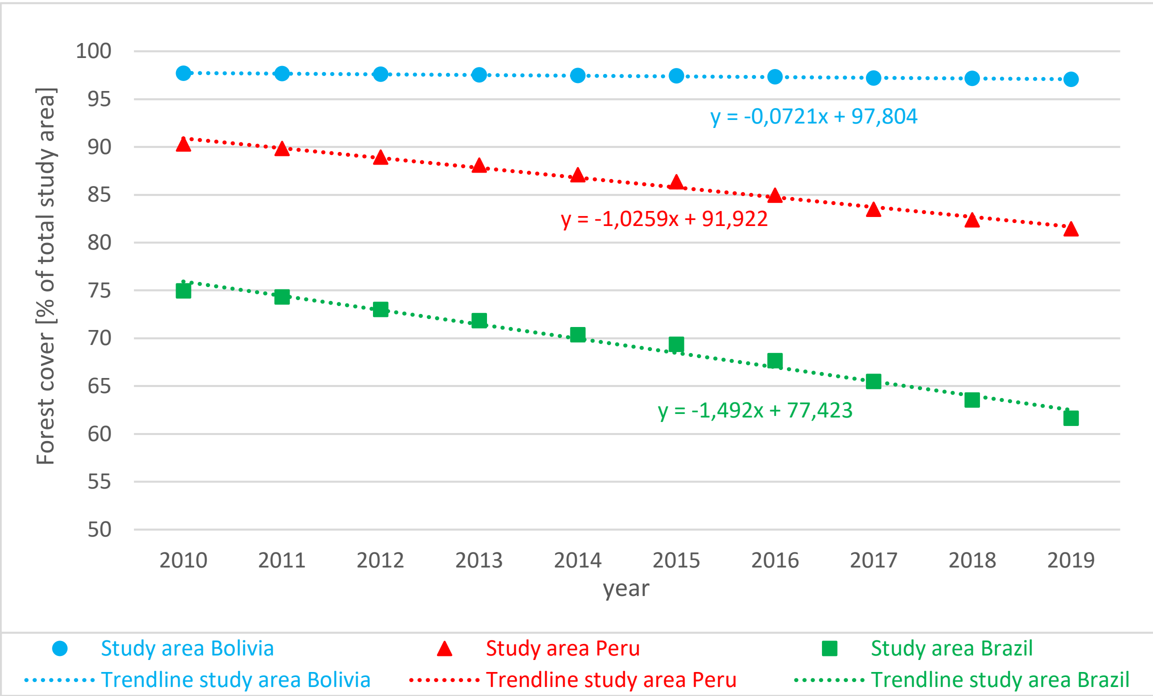

Figure 29: Time series of forest cover percentages of the three study areas. Source: Own analysis based on data provided by Hansen/UMD/Google/USGS/NASA (2020).

The percentages of forest cover notably differ among the three study areas. In Bolivia the forest cover is the highest with a small decrease from 98 % in 2010 to 97 % in 2019. Peru ranks the second in forest coverage among the three sites, having decreased from 90 % to 81 % during the investigated period; and in Brazil, the lowest forest cover was found, having decreased from 75 % to 62 % between 2010 and 2020.

Consistently, the Bolivian area shows the lowest deforestation rate and Brazil the highest, while the study area in Peru takes a position in between.

3.4.2 Road cover

The road cover percentages of each study area are depicted in *Figure 30*.

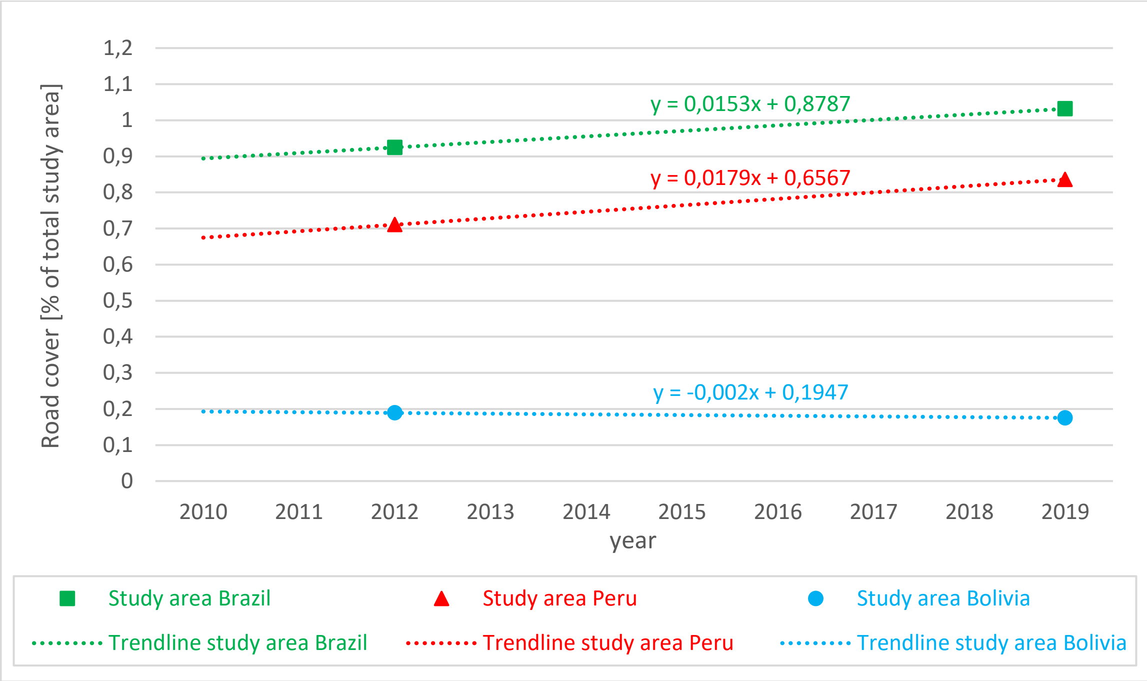

Figure 30: Time series of road cover percentages of the three study areas. Source: Own analysis based on RapidEye satellite imagery provided by Planet (2020).

Consistent with the forest cover results, the study areas also considerably differ in road cover. In Brazil there was the highest percentage of road cover detected in both 2012 and 2019, passing the one-percent-mark during this period; while in the Peruvian study area it was roughly 0,2 % lower at both investigated points in time. In Bolivia, the relative road cover remained below 0,2 % and was thus about five times lower than in Brazil and almost four times lower than in Peru, without any detectable increase between 2012 and 2019. Rather was a decrease detected, which can be explained by a methodical limitation and is further discussed in section 4.2.

3.4.3 Brazil nut volumes

The time series of Brazil nut volumes investigated for each of the three study areas are presented in *Figure 31*.

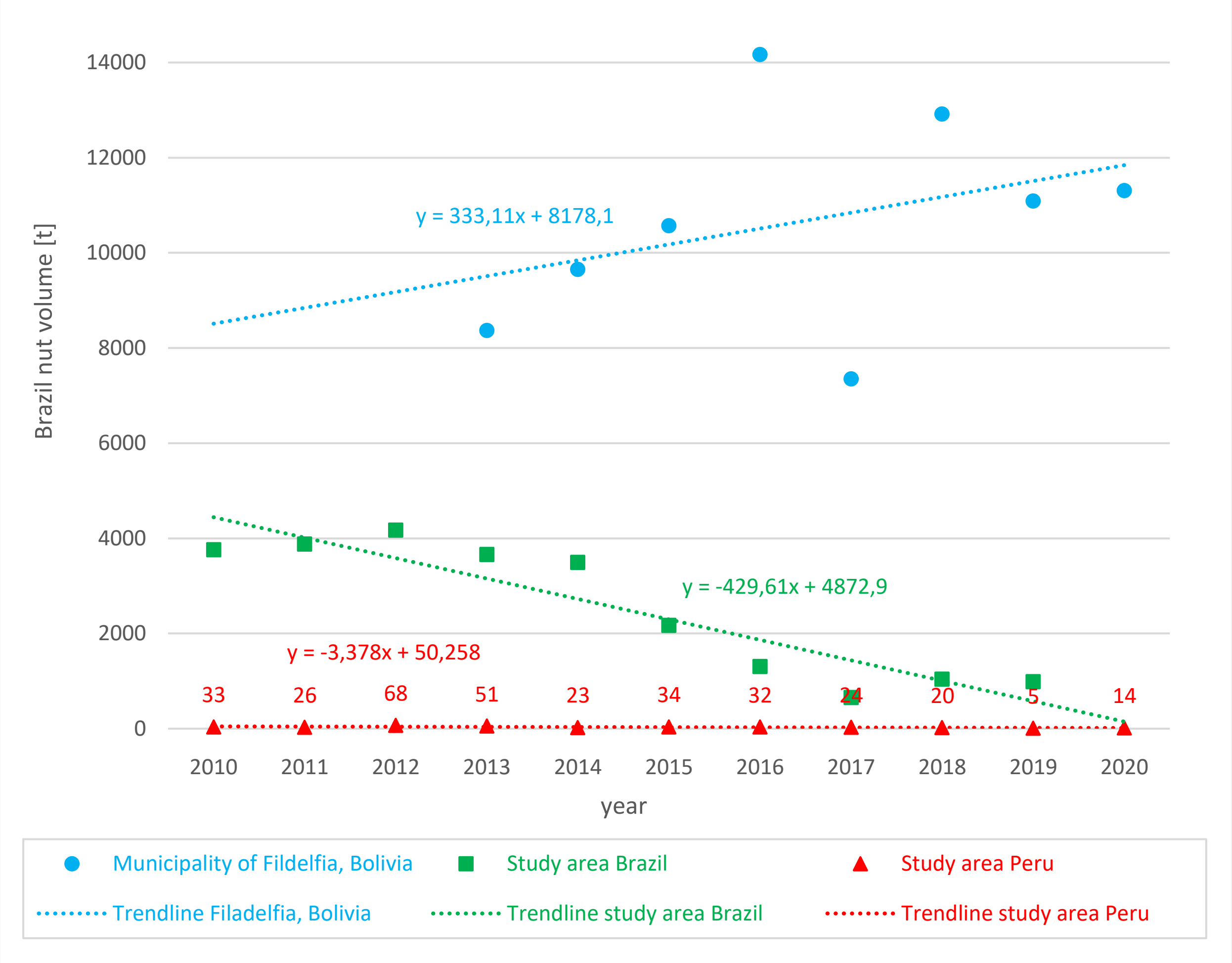

Figure 31: Time series showing the Brazil nut volumes and trends elaborated for each of the three study areas. Data sources: ABT Pando (2020); GRFFS (2020); IBGE (2020); SERNANP (2020).

As described in section 2.3, the time series of Brazil nut volumes extracted from the municipality of Filadelfia served as an approximation for the study area in Bolivia and, in this regard, no data was available before 2013. Besides that, the values for Peru do not represent the total volume produced in the study area, but are the result of a quota sampling that only includes concessions for which continuous data was available. Therefore, it should be noted that the presented time series do not allow a comparison between the magnitudes of each study area's Brazil nut production, as these are absolute values and each of the presented time series represents a different size of area. Thus, the time series shown serve to estimate trends and not to compare absolute scales, which is important to bear in mind when interpreting the data.

The trends and changes in annual Brazil nut volumes produced in the investigated period show different patterns in all three study areas. The municipality of Filadelfia experienced an overall increasing trend, whereas the other two study areas both experienced a trend of decreasing annual Brazil nut volumes. However, the lack of data for Brazil nut volumes in Bolivia between 2010 and 2012 reduces the comparability of the respective trends. Nevertheless, some similarities can be detected. For both the study areas in Brazil and in Peru, a maximum was registered in the year 2012, for which no data was available regarding the study area in Bolivia. Similarly, the volumes in the municipality of Filadelfia in Bolivia and in the study area in Brazil both experienced a minimum in 2017, which is not evident in the data elaborated for the study area in Peru.

3.4.4 Acai volumes

The time series of Acai volumes investigated for the study areas in Brazil and Bolivia between 2010 and 2020 are presented in *Figure 32*. As described in section 2.3, it was found that the acai fruit is not used on a considerable commercial scale in Madre de Dios in Peru, wherefore regarding the study area in Peru, no documentations of produced acai volumes were available.

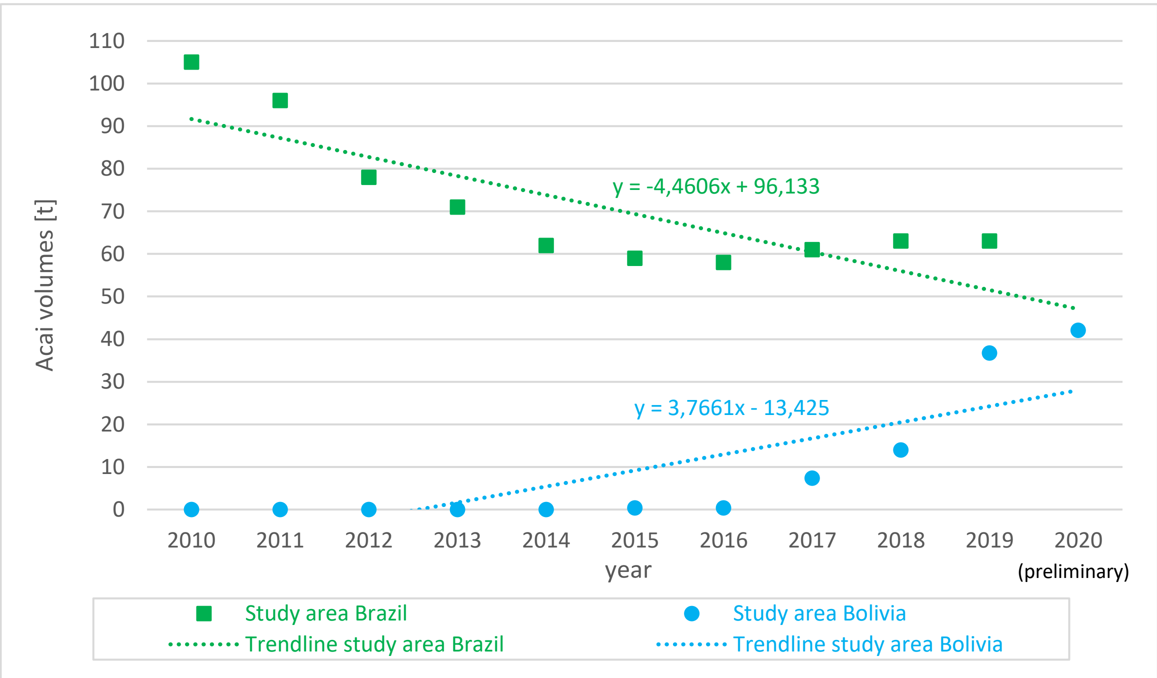

Figure 32: Time series showing the acai volumes and trends investigated for the study areas in Brazil and Bolivia. 2020: preliminary. Data sources: CIPCA (2020); IBGE (2020); WWF Bolivia (2020).

The overall linear trends of both time series are diverging. In the study area in Brazil it is a clear downward trend, due to the continuous decrease of produced acai volumes between 2010 and 2016, dominantly outweighing the subsequent steady increase until 2020. For Bolivia, a clear increasing trend was found, due to the continuous increases in produced volumes since the start of commercial production in 2015, reaching more than 40 t in 2020.

4 Discussion

4.1 Acre, Brazil

Due to the absence of major rivers, roads are the most essential transport ways in the study area. Roads originally made commercial Brazil nut extractivism possible, but have also disproportionately facilitated deforestation. A vast road network extension and concurrent deforestation have occurred in the study area during the period 2010 – 2020, while the collected volumes of Brazil nut and acai show decreasing trends.

Declining Brazil nut volumes

Apart from climate-induced fluctuations, the competition for land with agribusiness seems to be another key factor in the decrease of the Brazil nut production. It can therefore be assumed that the decline is closely linked to the increasing deforestation, which was facilitated by the road network expansion. Changes in regional climate are proven to be consequences of deforestation (Marengo et al., 2018), and might increasingly affect Brazil nut yields in the future.

The acai challenge

After a continuous decline in acai production between 2010 and 2016, the produced volumes started to slightly increase in 2017. Besides the market-driven factor of the increasing demand and price (Ramos et al., 2018), this trend reversal might also be linked to the collapse in Brazil nut volumes induced by a drought in 2016 (Terazono, 2017). As a consequence, some extractivists involved in acai trade, might have increased their acai production to compensate the losses from the low Brazil nut yield, and possibly maintained a stable acai production since then, as a backup against further fluctuations in Brazil nut yields. In any case, a diversified NTFP sector should be encouraged to reduce the dependency on one single resource (Khan and Martinez, 2013), which is, particularly in the case of Brazil nut, subject to natural fluctuations. However, the acai production in the study area is generally low due to logistic limitations, especially due to precarious road conditions, prohibiting processing within the required time window of 48 h after harvest.

Generally, acai produced in the state of Acre was found to be exclusively extracted from wild-growing populations, whereas in other Brazilian states, acai is already cultivated. This confirms the IBGE statistics, which indicate that acai is produced in Acre as a forest product, but not as an agricultural product (IBGE, 2020). Hence, it is necessary to distinguish between acai cultivation and acai extractivism in terms of sustainable forest use, since cultivated crops affect ecosystems more than traditional extractivism (Belcher et al., 2005). In Acre, the cultivation of acai and other NTFPs could compete with traditional extractivism in the future and replace it in the long term. However, as the Brazil nut example shows, this is not yet possible with all NTFP species, and targeted marketing strategies could enhance traditional extractivism as a sustainable production, to increase the consumers' willingness to pay for the more labour-intensive gathering of wild-growing products. Nonetheless, in terms of sustainable land use, the transformation of agricultural areas such as pastures into integrated managed forestry-systems, including acai, is suggested as a good alternative to cattle ranching (Belcher et al., 2005), which is, as mentioned above, the major driver of deforestation and severe environmental impact (Marengo et al., 2018), which the present work has confirmed.

Interestingly, none of the interviewees reported decreasing acai quantities. Instead, a majority pointed to either an increase or no change in acai production between 2010 and 2020, whereas IBGE statistics show a downward trend over this period (IBGE, 2020), as shown in the time series. This divergence could be due to the limited number of interviewees, which does not allow for a precise representation of the entire study area, to which the time series data refers. Strong regional differences could therefore have led to discrepancies.

The infrastructure paradox

Interestingly, the road conditions in the municipality of Brasiléia fail to appropriately support a diversified NTFP sector including perishable NTFPs like acai, but at the same time, the road network exceeds what can be considered necessary to enable sustainable extractivism, as it has caused vast deforestation and the emergence of pastures nearby roads. Furthermore, the road network is not designed for extractivism; as the profit prospects are limited, the investments in road maintenance are correspondingly poor. In general, remote roads were opened by loggers for their immediate requirements and received no further maintenance (Walker et al., 2013).

A crucial factor for the development of such an extensive road network, is the lack of rivers as a natural means of transport in the municipality of Brasiléia. NTFPs could only be commercially used when a road network was already established. But as the roads were created with the objective of deforestation, detrimental land use practices preempted extractivism before it could develop as a major economic sector. The exploitation of the region in terms of logging, cattle ranching and NTFPs was parallel, but logging and agriculture were dominant, which can be attributed, at least in part, to the initial situation of the transport infrastructure. An increasing extent of unpaved roads led to continuous deforestation and more consumptive land use, continuously degrading the ecosystem that NTFP production depends upon (Nunes et al., 2012), without having provided the conditions to efficiently use NTFPs as sustainable forest resources. Government policies contributed significantly to the expansion of logging and large-scale cattle ranching, increasingly promoted by the Brazilian president Jair Bolsonaro (de Area Leão Pereira et al., 2020).

Although the conducted interviews confirm that lacking infrastructure can be considered as the main inhibiting factor for NTFP productivity (CSR, 2017), the example of Brasiléia shows that more transport infrastructure does not necessarily benefit extractivism. Fewer roads of better quality might have supported a more diversified and prospering NTFP sector, but would have also required targeted, strict policies, which are hard to implement in remote areas of bad access. Nevertheless, there is still an untapped potential for sustainable extractivism in the study area, which with the appropriate measures, could be implemented.

Potential improvements

The improvement and maintenance of strategic roads could contribute to the establishment of a sustainable and diversified NTFP sector in Brasiléia, through the simultaneous application of incentives for traditional extractivism to compete with other land uses, such as cattle ranching. However, to maintain forests as the basis of extractivism, policies preventing deforestation, as well as reforestation and the transformation of deforested areas into managed forests and agroforestry systems, are urgently needed.

The establishment of a stable electricity supply in strategic locations could support the storage, transport, and processing of perishable NTFPs such as acai. Moreover, the installation and use of more Brazil nut storage sheds, strategically distributed across the area, would reduce transport efforts and make extractivism more efficient.

However, to specifically support traditional extractivism in the long term, and at the same time, prevent further ecosystem degradation as a consequence of general infrastructure establishment and conversion to other land uses, a framework of policies and institutional supporting measures is necessary. In this context, it is key to create incentives for the local population by promoting traditional extractivism as a lucrative livelihood, for example with educational programmes and projects, subsidies for NTFPs, or even setting environmental taxes for cattle ranching.

Nevertheless, the findings of the present work confirm earlier studies, according to which, with improved access and increasing opportunities for alternative livelihoods, rural householders might prefer other activities than extractivism (Belcher et al., 2005). People cannot be forced to stick to extractivism if that hinders their development. But incentives, aligned with the objectives of sustainable development, could make traditional extractivism more attractive as a livelihood. It might also be worth promoting a combination of extractivism and integrated agroforestry systems, which would also contribute to more sustainable land use, compared to logging and livestock, and might be more profitable than extractivism alone.

4.2 Pando, Bolivia

An increasing trend in the production of both Brazil nut and acai was observed during the investigated period. Especially the acai production increasingly prospered from 2015 on, confirming the high potential in Pando and the high demand (Ramos et al., 2018). Although rivers are an essential transport route for Brazil nut, roads are also essential for the NTFP sector, especially regarding the transport of acai. However, the road network did not expand during the investigated period and correspondingly, the high forest cover remained.

The road network

The slight decline in road cover between 2012 and 2019 can be explained by a methodical limitation in the land cover classification from satellite imagery. When visually comparing the two composite images, it becomes clear that the road network in fact did not change much, rather did the tree canopy grow over some parts of the roads, as shown exemplarily in *Figure* 33. Concurrent to this observation is, that the road construction and the previous clear-cutting had been more recent in 2012, and that the gap in the canopy was therefore even larger. This observation sustains the finding that no new roads were opened in the study area during the investigated period.

Figure 33: RapidEye satellite imagery exemplifying the increased canopy cover over a secondary road in the Bolivian study area in 2019, compared to 2012. Source of satellite imagery: Planet Team (2020). Software used: ArcGIS 10.6 (Esri).

Logistically, the study area has a good point of departure for Brazil nut extractivism. Rivers pose a natural means of transport towards the east and are complemented by the national road 53 as a connection from north to south. Together, these enable transport to different urban centres, without counting with an extensive secondary road network. It can also be assumed that the importance of Brazil nut extractivism as a main livelihood (Orosco et al., 2013), and the favourable transport infrastructure, contributed to prevent deforestation of the extent that has occurred in neighbouring countries such as Brazil.

Correspondingly, most interviewed experts and stakeholders perceive the existing roads as sufficient to support extractivism, only criticising their quality. The already planned upgrading, such as the pavement of the major road and the construction of bridges, will help to deal with the remoteness of the area and the accessibility to marketplaces; and facilitate the commercialisation of other emerging NTFPs such as acai. The improved infrastructure efficiency might also increase mobility, and thus the availability of additional workforce from the surrounding areas, as one precondition (among others) for the establishment of further NTFP processing facilities in proximity to the collection grounds.

However, roads are proven to also cause social and environmental problems (Mendoza et al., 2007; Nunes et al., 2012) and an excessive commercialisation of NTFPs can lead to resource degradation (Arnold and Pérez, 2001). Therefore, integrated policy planning and a strong institutional framework are necessary to prevent negative effects, such as deforestation and detrimental land-use changes as observed in Brazil, to maintain NTFPs as a profitable economic activity.

The acai boom and its limitations

The access to electricity made acai processing possible. Since then, the continuous increase in acai production observed in the time series analysis and confirmed by interviews, verifies the growth of acai trade and markets asserted by earlier studies (Freitas et al., 2019; Ramos et al., 2018).

Aside the limiting factors for acai production, like the maintenance of the cold chain, low capacities of storage and preservation, and the limited available work force and technical knowledge, the two existing acai processing plants in the study area were stated to be too small to meet the existing demand. More processing plants could contribute to increase the productive capacity of the region and to optimise the storage and processing of acai harvested in the proximate surroundings. For instance, the five communities in the Manuripi Reserve transport acai to Villa Florida for processing. Considering that the fruit pulp is subsequently transported to Cobija, this implies an inefficient back-and-forth transport of acai from the communities of Curichon, San Antonio and Luz de America, which could be avoided by the establishment of more processing plants between Villa Florida and Cobija. Consequently, efficiency could be increased and negative impacts, in economic and environmental terms, could be reduced. Furthermore, the implementation of preservation techniques, such as freeze drying, have the potential to facilitate the acai supply chain. However, it must be kept in mind that acai powder is a different final product with different properties and a different demand than acai pulp (Ramos et al., 2018).

Nevertheless, many interviewees, especially representatives of NGOs who supported the implementation of acai processing plants, strongly affirm that building more processing plants is not a silver bullet. A successful implementation also requires, besides sufficient available labour power, medium- to long-term support, to create and sustain the knowledge and skills to operate and maintain the facility.

General challenges and the future of extractivism

It is striking that a majority of the interviewees stated the occurrence of a decrease in Brazil nut production between 2010 and 2020, whereas the ABT statistics show an increasing trend (ABT Pando, 2020). In this context it must be mentioned that numbers were only available from 2013 onwards. Nevertheless, two hypotheses could explain this divergence regarding Brazil nut volumes: (1) The strong natural fluctuations make it difficult to estimate general long-term trends, and recent events such as the drought-induced collapse of rare magnitude in 2017 (Terazono, 2017), might have influenced the perception towards an overall decline. (2) In addition, as mentioned with regard to results in Brazil, the limited number of interviewees could have contributed to the discrepancy, as it was not representative for the entire municipality of Fildeflia, to which the time series data refer. Thus, strong regional differences in production volumes and trends could have led to interview results that deviated from the overall trend in the municipality.

Climate-induced yield fluctuations and an increasing exploitation pressure on the forest were stated in interviews to be general challenges for extractivism. Besides, referring to Brazil nut, the decreasing prices were pointed out; and regarding acai, the above-mentioned logistic challenges and transport limitations were mentioned. These and other difficulties are also described in literature (Quiroz Claros et al., 2016) and suggest the need of further targeted policies and institutional support for the NTFP sector, which will certainly evolve and adapt to the demands and opportunities in the future.

The Brazil nut value chain was generally described as consolidated with a good infrastructure for collection, transport, and processing. Yet, the implementation of a stabilising mechanism for its price was suggested as one big potential improvement in the future. It is also expected and promoted that adding value to Brazil nut would further support the local economy and strengthen the NTFP sector. Regarding acai, its production is expected to increase, and preservation technologies are to be implemented, to enable international export. Furthermore, wild cacao was mentioned as a promising NTFP.

In terms of sustainability, the Manuripi Reserve applies conservation measures such as the prohibition to open new roads, and a limited stay of three months for seasonal Brazil nut gatherers, to prevent overexploitation of the resource. In view of the consolidated high Brazil nut productivity of the reserve, and the increasing acai productivity, these measures can be considered as effective in terms of forest conservation and sustainable management.

The general infrastructure situation in the study area can be considered close to optimal to support the Brazil nut production, yet insufficient regarding acai and other NTFPs. The use and commercialisation of acai and a further diversification of the NTFP sector could be promoted and sustained with targeted infrastructure improvements and complementing governmental and institutional frameworks and investments. The accomplishment of sustainable development goals should be the objective to maintain and support the good NTFP situation.

4.3 Madre de Dios, Peru

In Peru, the road network was expanded, and considerable deforestation occurred simultaneously between 2010 and 2020. In the same period, the produced volumes of Brazil nut followed a decreasing trend, and acai has not reached a commercial level of production. Roads and especially the IOH, as well as rivers are important and abundantly used for the transport of Brazil nut.

Status quo

Interviews as well as satellite imagery revealed that mining is, besides logging and agriculture, a major contributor to deforestation. Mainly illegal gold mining is causing tremendous environmental and also social problems, especially towards the west of the study area in a region referred to as "*La Pampa*", where vast areas were deforested, silted up and contaminated with mercury. The main mining area is indicated in *Figure 34*.

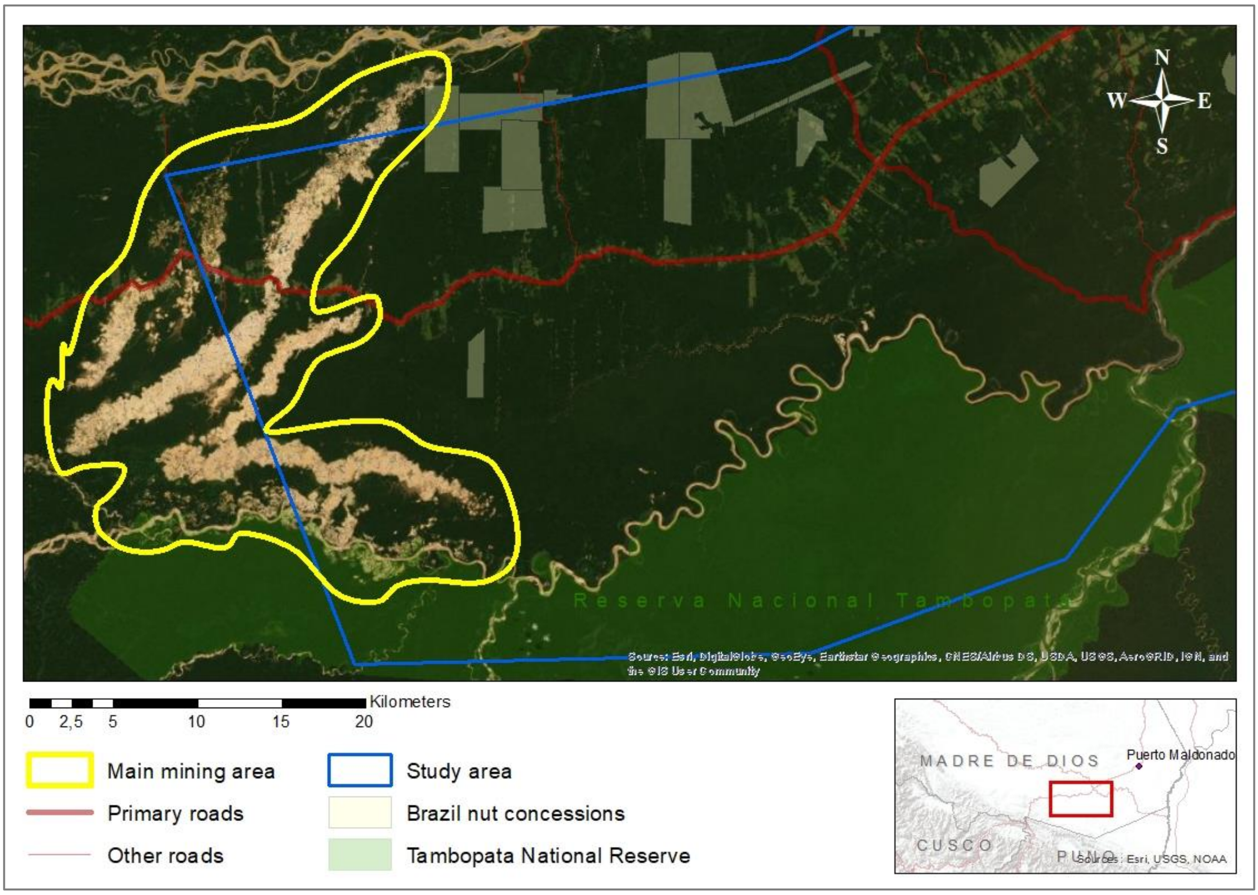

Figure 34: Main mining zone in the west of the study area in Madre de Dios, Peru. Sources: Esri, GRFFS, OSM, RAISG, SERNANP.

Due to the direct IOH connection, combined with the boom of gold mining, as well as other valuable resources, the region has experienced strong immigration, which, in addition to the clearing of land and urbanisation, is causing various social conflicts.

All these also affect the Brazil nut sector. However, although the Brazil nut volumes were proven to have decreased, the majority of interviewees stated that the conditions for its production have improved, due to better access and processing standards, which both contributed to a better price. The price, in turn, is an incentive for extractivists to further access forest areas for Brazil nut gathering.

Another factor that may relate to the decrease in production volumes, is that the improved access and immigration augmented Brazil nut robbery from concessions. Yet, it remains unclear if that could significantly contribute to the decreasing trends reported by concession holders.

Also, it was found that due to the proximity to the city of Puerto Maldonado, combined with good access and transport conditions, many concessionaires do not use storage facilities in the forest anymore. Instead, the collected nuts are now directly brought to the extractivist's homes near the IOH, from where they are either sold to intermediaries, or brought directly to the processing facilities in Puerto Maldonado by the extractivists themselves. Another reason for that, is the prevention of robbery. But this has a downside: as a consequence of the lack of storage and pre-drying, processing companies reported lower nut quality, which increases losses in the selection step of processing. The non-use of storage facilities is especially acute in concessions nearby the IOH. Concessions inside the Tambopata Reserve, which are more remote and less accessible, still use in-situ storage and pre-drying facilities, also because no motorised vehicles are permitted within the reserve. Thus, transport of Brazil nuts out of the reserve to processing plants happens mostly via rivers, which is ecologically favourable, but implies higher transport costs and less flexibility than transport via roads.

Boon and bane of roads

In terms of road construction and the use of motorised vehicles in the forest, the study area is facing a trade-off between the efficiency of Brazil nut production and its ecological sustainability. Extended and maintained road networks improve accessibility and thus make transport substantially faster and cheaper, which increases the overall profitability. However, negative side effects are evident and may even overweigh the positive effects of roads. Invasive immigration as well as illegal logging and mining, all facilitated by improved road access, were found to be major challenges for extractivism, causing a variety of severe environmental and social problems, and thus affecting the Brazil nut production.

From an ecological point of view, it can therefore be concluded that, where rivers are available, these should be the main transportation means, complemented by paths and trails. Regarding economic and social aspects, a reasonable trade-off in road construction must be found. Investments in increased boat capacities and subsidies for river transport could be options to support the competitiveness of transport via rivers, with the less sustainable but more efficient road transport, and reduce the incentives for further road construction.

Generally, in terms of access by road and the resulting environmental effects, it must be distinguished between access to Brazil nut grounds, which are mostly trails or paths in the forest with relatively low environmental impacts; and the access by larger roads, which are usually not primarily built for extractivism (Walker et al., 2013) and cause higher ecosystem impacts and social problems (Mendoza et al., 2007; Nunes et al., 2012), what was confirmed by stakeholders. However, large roads also considerably facilitate NTFP transport to urban centres.

Perspectives and potential improvements

Despite the improvements carried out, the existing infrastructure was described as suboptimal for the NTFP productivity. Improved access to the Brazil nut concessions, as well as the establishment of higher quality standards, including systems for control and traceability are matters of potential improvement. The installation of more storage facilities needs to be assessed in terms of rentability and benefits for quality standards.

Another potential improvement lies in the value that can be added to the Brazil nut by transforming it into a variety of processed products, which might open new markets and trade channels. Peru is an exporter of mainly primary products; thus, the mentioned value generation is a hitherto unused economic opportunity.

Regarding acai, it can be assumed that the fruit will be commercially extracted in the future, as it is present in Madre de Dios and is considered to have a great potential as an NTFP (Ramos et al., 2018).

Reforestation, as already promoted and partly practiced, is another promising measure to sustain forest extractivism, especially considering the drastically decreasing Brazil nut volumes, for which deforestation is one major cause.

Additionally, the associativity of extractivists should be promoted and supported, to enable a strong representation of their interests, also in political decisions. This could be crucial especially in the study area, as it is not considered one of the main Brazil nut centres of the country and thus lacks an appropriate representation of extractivists and their interests.

In ecological terms, the Tambopata Reserve is a prime example of sustainable forest management and the support of traditional extractivism. The infrastructure of the reserve, which is based on rivers and footpaths, provides the necessary access to extract Brazil nut, while minimising impacts on the ecosystem. In this view, restrictive measures regarding road construction and the use of motorised vehicles should be maintained and could be expanded also to other extractivist areas.

However, traditional extractivism is fighting for economic competitiveness with alternative sources of livelihood, which are more profitable and more attractive to future generations. Therefore, integrated conceptual solutions are required to prevent further forest degradation and losses of valuable ecosystem services. Education and the resolution of legal and social issues with governmental support are key for the achievement of sustainable development goals and an optimal use of NTFPs as an integrated measure of forest management.

4.4 Cross-comparison of the study areas

Access and deforestation

The results confirm on a smaller scale the findings of earlier studies, according to which Acre has the most extensive road network among the three sides of the MAP region, and Pando the least extensive, Madre de Dios being situated in between (Southworth et al., 2011). Moreover, the results of the present study show that the ranking of the study areas in terms of road cover extent inversely coincides with the ranking of forest cover rates in all three study areas, which confirms that roads are favouring deforestation, as stated in literature (Mendoza et al., 2007; Nunes et al., 2012). In addition, it could be shown that these trends have intensified between 2010 and 2020. In contrast to Brazil and Peru, the NTFP volumes in Bolivia increased during the investigated period, which suggests that the extracted volumes of NTFPs are related to the road network extent and forest cover in each region. Furthermore, stakeholders from both Peru and Bolivia, reported that the total forest area accessed for Brazil nut collection is increasing, which confirms earlier findings (Quiroz Claros et al., 2016).

Climate influences

Besides the direct anthropogenic effects, climatic conditions were found to be major influencing factors on Brazil nut productivity, as stated by the majority of the interviewees. A collapse of produced Brazil nut volumes occurred in 2017, caused by a severe drought in and around the MAP region in 2016 (Terazono, 2017), which was related to the climate phenomenon "*El Niño*" (Marengo et al., 2018). The resulting decline in Brazil nut volumes can be seen in the time series elaborated for Brazil and Bolivia and was also mentioned by interviewees in all three countries. Surprisingly, the drop is not that clear in the time series of Peru, which might be due to storage of Brazil nut by extractivists, retained to level out price fluctuations. Moreover, interviewees from Bolivia and Peru mentioned that Brazil nut yields are oscillating in cycles of 4-5 years, which again suggests a coherence with the occurrence of "*El Niño*".

Regarding the overall decline in Brazil nut production found in the time series of Brazil and Peru, it can be assumed that these are also partly influenced by climate change. Previous studies revealed a general trend of increasing temperatures and prolonged dry seasons in the Amazon region (Marengo et al., 2018).

The role of infrastructure

To extract NTFPs, the forest must first be accessed by trails and paths either by foot or with small vehicles such as motorbikes. Further transport of Brazil nuts is ecologically more sustainable via rivers, but economically more efficient via roads. In contrast to that, the production of acai in most cases requires roads for fast transport due to its perishableness. While in literature, a time window of 24 h between harvesting and processing the acai fruit is mentioned (Freitas et al., 2019; Ramos et al., 2018), interviewees in Brazil and Bolivia reported a time window of 48 h. This allows for further transport or intermediate storage of the fruit, but it can be assumed that the faster processing takes place, the higher will be the resulting product quality. Acai processing facilities equally serve to process other fruits such as "*Majo*" (*Oenocarpus* spp.), another local NTFP (Miranda et al., 2008). This advantage could contribute to a diversification of the NTFP sector and thus to a stabilised income for extractivists.

In interviews, the low price of Brazil nut and its strong fluctuations, were abundantly named as major challenges for extractivists. Storage infrastructure can help to level out price fluctuations, yet only in the short to medium term, and it is mainly used for Brazil nut, as the products stability allows a storage for several months. With appropriate cooling- or drying technologies, storage would also be possible for perishable products like acai. However, a stable electricity infrastructure is a general precondition for mechanised NTFP processing with modern technologies and quality standards.

Moreover, there is no initiative to add value to the locally produced Brazil nut. Stakeholders report that this would have the potential to stabilise and strengthen the local NTFP economies by increasing revenues. In this context, appropriate processing infrastructure could facilitate the transformation of Brazil nut into products such as Brazil nut milk, -oil, -flour, -soap and -butter.

Existence of rivers: It can be assumed that the availability of rivers as transportation routes has an influence on the overall infrastructure network of the region. Where good waterway connections are available, less road infrastructure is required than in locations without access to waterways. Rivers can serve to transport NTFPs and other goods from remote areas of extraction to urban centres for trade and processing, which enables commercial extractivism. Thus, the absence of rivers crossing the area could be a factor that contributed to Brasiléia having developed the most extensive road network and correspondingly, holding the highest deforestation rate among the three study areas. In the other two sites, rivers are for some extractivists the main ways of Brazil nut transport.

The use of waterways for NTFP transport depends on several factors, such as the availability of alternative transport options, the distance to the destinations, the volumes to be transported, and the time window that the stability of the product allows. Rivers are more suited for transportation of storable goods such as dried Brazil nut, whereas fresh and perishable products, such as acai, require fast flows and more demanding infrastructural and logistic arrangements. In this case, the in-situ lyophilisation of fruits could not only decrease losses and risks of contamination, but also help to overcome the main challenge of cooling and storage, and furthermore, reduce transport costs due to weight reduction, and even enable its export. Correspondingly, rivers could also be used to transport the preserved NTFP, which may end up in a more sustainable transport network. However, the marketability of freeze-dried acai needs to be assessed, as the fruit is generally consumed fresh at the national level. The lyophilisation could therefore rather open up possibilities for international trade, but not replace the use of fresh acai.

The infrastructure optimum

The Bolivian study area not only shows the lowest deforestation and road cover rates, but it is also the only one, where an increase in Brazil nut and acai volumes was documented in the investigated period. As infrastructure is considered a major factor in NTFP production (Arnold and Pérez, 2001; CSR, 2017), the present study suggests that the infrastructural situation in Bolivia is closer to optimal, in terms of supporting extractivism, than in Peru and Brazil. Few roads, maintained in a fair quality, could be more sustainable than an extensive road network of bad quality, as it is the case in Brazil. As a conclusion, regarding the sustainable use of NTFPs, generally essential roads should be maintained in good quality, and the road network should not be extended more than what is necessary to transport the extracted NTFPs to processing and trade centres. This would ensure a smooth product flow and enable the population to profit of the extracted NTFPs in the long term, while maintaining a balance of roads and forest cover.

Roads - opportunities and downsides: Roads are usually favoured by rural populations, as they promise better access, contribute to development, reduce efforts and costs, and generate a variety of alternative livelihood opportunities, though some of which may compete with extractivism.

An interesting observation from the conducted interviews is, that extractivists settled in remote areas with difficult access conditions, tended to underline the positive effects of roads; whereas extractivists established in areas of good road access, for example in proximity of the IOH, tended to highlight the negative effects of roads, and complained that their construction had worsened the situation and caused environmental and social problems. This observation suggests that the perception of the roads benefits shifts once the road is built. Even if roads indeed improve economic livelihood options and development, their medium- to long-term side effects and prospective negative impacts tend to be disregarded or underweighted, as long as they do not or only sparsely exist. This positive bias in the assessment of roads may in the medium- and long-term lead to an expansion of the road network which could exceed the sustainable optimum. This phenomenon could be related to the economic theory of time preference, according to which short-term benefits are valued more than long-term benefits (Wohltmann, 2018).

The necessary framework: However, it is important to note that infrastructure alone will never have the effect of exclusively supporting the use of NTFPs. Traditional extractivism needs protective and supportive measures and economic incentives to sustain itself in the face of other, competing land use options. Therefore, to reach a long-term success and consolidation, the NTFP sector requires appropriate political and institutional frameworks with targeted supporting measures. Such interventions, policies and infrastructure changes must be adapted to each region and each situation accordingly, since each has its own optimal balance and the different potentials and limitations cannot be generalised (Pérez and Byron, 1999). In this context, the rural householders and extractivists themselves, being those stakeholders who are often disregarded despite being main actors at the front line, must be not only considered but also included in the shaping of the future (Lagneaux, 2018). Contributing to this, social infrastructure such as the associativity of extractivists should also be promoted and supported, to enable the representation of their interests and needs, also in the political arena. Moreover, the work of NGOs also plays a vital role in development support, as they are already active in promoting the NTFP sector, especially in the initiation of commercial acai extractivism.

Protected areas, if well managed and controlled, are great and important instruments to achieve forest conservation while safeguarding the economic productivity of the forest. For instance, in the Manuripi Reserve in Bolivia, no new roads are allowed to be built, and in the Tambopata Reserve in Peru, the use of motorised vehicles is generally prohibited. Both regions are major Brazil nut producers and maintain extractivism as a livelihood, where the transport of NTFPs happens mainly on trails and paths in the forest, and via rivers, which minimises the impact and can be seen as ecologically sustainable. However, a diversification of the used NTFPs is limited under these circumstances, since the use of perishable NTFPs might require fast transport and a more invasive infrastructure, which underlines the trade-off between roads and forest conservation. Relatedly, the success of protected areas also requires the willingness of the rural population to keep applying these traditional methods, which should remain profitable over other alternatives.

Extractivism - incentives and discouragement: Thinking about economic and social sustainability, it is unclear whether transporting the products via rivers will keep extractivists commercially competitive and whether the effort will pay off in the future, or whether the following generations might rather be increasingly disinterested in extractivism as a livelihood, as already reported by stakeholders in Brazil and Peru. It is also essential "*to distinguish between those who can improve their livelihoods through NTFP activities, and those who have no other option but to continue to gather NTFPs in order to survive*" (Arnold and Pérez, 2001). If extractivism in its traditional form is to be maintained, incentives are needed for the rural population to continue doing this labour-intensive and dangerous work in the future, despite other attractive livelihood alternatives. Targeted infrastructure and access improvements could facilitate the work, but legal and institutional frameworks are required to create specific incentives and to minimise negative side effects. For instance, a stable price, good international marketing and creating consciousness in consumers to support sustainable production, could help to increase the price paid and thus the profitability of extractivism.

Limitations of access for extractivism: Beyond that, it is generally questionable if more and more of the Amazon ecoregion should be made accessible, even for extractivism, by extension of the road networks. The objective of this work was to find suggestions for a balance between the different dimensions of sustainability and how infrastructure patterns can possibly contribute to it. In this context, it must be recognised that the assessment of sustainability generally depends on the relative context. For instance, regarding the ecological dimension of sustainability, it is without question that the impact of extractivism on ecosystem stability and biodiversity is considerably lower than those of logging and cattle ranching. However, even extractivism causes an ecological impact on primary forest. Earlier studies found that NTFP production is not *per se* sustainable, but that the commercialisation of NTFPs can also result in degradation of the resource and in poorer stakeholders being disadvantaged (Arnold and Pérez, 2001). Large conservation areas without any infrastructure are essential to conserve untouched primary rainforest ecosystems as well as territories of indigenous peoples. It is therefore important to find a reasonable limit of access, to prevent a complete commercialization of the Amazon rainforest. Protected areas and extractive reserves are a good approach; however, the effectiveness and the level of conservation depends on the respective implementation.

Extractivism can substantially contribute to limit deforestation, but it is essential to keep it sustainable and compatible with the needs and rights of the least powerful stakeholders: the rural populations and the indigenous peoples. Thus, it can be concluded that extractivism is not always sustainable, but in view of competing, more detrimental land use practices, extractivism is to be favoured in areas where access is already established or inevitable, and where sustainable livelihood alternatives are needed.

Implications for the sustainability agenda

Pando seems on a good way to match the sustainability objectives, since extractivism is maintained and diversified, generating economic income with a perspective of growth, while road construction and deforestation are maintained at a low level.

Contrarily, in Acre, high road cover and deforestation rates as well as decreasing NTFP volumes, create doubts in reaching ecological sustainability. Deforestation is profitable in the short term, but prevents the achievement of sustainable development goals in the long term.

In the forest concession system, Madre de Dios has found an important and efficient measure for sustainable management. However, high deforestation and road cover rates, and challenges such as land tenure issues, illegal mining, and social conflicts, are complicating the long-term perspectives of extractivism.

The overall MAP region remains an area rich in resources and with great potential, that can be used in a sustainable way, but is endangered by a variety of detrimental practices that compete with extractivism in terms of land and profitability.

4.5 Further considerations

Well-practiced extractivism is a sustainable form of land use in tropical forest areas, and should therefore be promoted and supported by governments, NGOs, and other stakeholders. Yet, to prevent the overcoming of tipping points in large-scale socio-ecological systems, it will be necessary to tackle the causes of deforestation and ecosystem degradation, especially in the largest rainforest of the world. Therefore, the causes of resource depletion and destructive land-use practices should be addressed on a global level by questioning the immense world-wide demand for goods that are produced at the expense of natural ecosystems.

5 Conclusion

This work aimed to evaluate how infrastructural circumstances can optimally support sustainable forest management by favouring extractivism, taking as examples Brazil nut (*Bertholletia excelsa*) and acai (*Euterpe* spp.), in the three countries of the MAP region: Brazil, Peru and Bolivia. To achieve this, the logistics of these products' value chains were depicted providing a wider analytical context, by analysing the developments in road networks, deforestation, and produced volumes of the mentioned NTFPs between 2010 and 2020. Furthermore, this work attempted to explore the idea of an "infrastructure optimum", which could support the sustainable use of NTFPs in the MAP region.

The three regions clearly differ in their respective infrastructure conditions, development trends, and NTFP production, what allows to identify some potential interrelationships. For instance, the results confirm that lacking or precarious infrastructure can be major limiting factors for extractivism, but also, that an increase in road infrastructure facilitates deforestation and social conflicts, as well as contributes to the decrease of NTFP volumes. Besides the direct effect on the abundance of NTFPs, the caused deforestation also affects the remaining forest's homeostasis and thus contributes to a further decrease in biological NTFP production. It was therefore found that optimal infrastructure conditions to support sustainable extractivism include a minimal road extent, but the existence of essential roads of good quality to enable a smooth transport of the produced goods, which applies particularly to perishable products such as acai. The optimal extent and expansion pattern of roads also depends on the existence of rivers used as transport means. The availability of appropriate storage and processing facilities within reach of the areas of collection is another prerequisite for successful NTFP use, but is conditioned by factors such as the availability of sufficient labour and technical knowledge, as well as a stable political and institutional framework providing an economic long-term perspective.

The findings of this study demonstrate the fragile equilibrium to be confronted in the quest for sustainable development, and shows the disadvantaged position of extractivism. Therefore, institutional support is needed if traditional extractivism is to be maintained as an economic practice in line with sustainable forest use. Social infrastructure such as extractivist associations are also crucial to represent and target the rights and requirements of extractivists, to give them a voice and to keep extractivism competitive.

This work focused on two different NTFPs: Brazil nut as a storable, and acai as a perishable product, which thus have different infrastructural requirements. That facilitates an extrapolation of the findings to other NTFPs. In any case, transport infrastructure as well as some processing facilities can serve for more than one specific product. Moreover, general findings regarding infrastructure effects on forests and extractivism, could also be considered in other forest areas.

The totality of factors influencing the complex network of socio-economic interrelationships, some of which were depicted in this work, must be considered in an overall assessment. In this context, clear objectives must be set, to pave the way for sustainable development, considering all its dimensions and complexity.

Limitations and future research

Due to the broad nature of this study, covering two products and their infrastructure networks in three different countries over a period of ten years, it can only render an overview of the general situation of each study area; and part of its findings can cautiously be extrapolated to other products and areas. Hence, there is potential for future research to investigate various issues more in detail.

Among the limiting factors confronted, was that complete NTFP volumes between 2010 and 2020 were not available for each of the study areas in the desired extent and detail, so approximations and estimations were made. This lowers the comparability of the results of the three study areas among each other. Moreover, the identification, as well as the ground-truthing of existing infrastructure elements and road cover, was very limited, due to pandemic-related constraints. Therefore, the road cover results can only be regarded as an estimation and not as true data.

To further disclose the rural population's perception of infrastructure developments and of NTFPs as a livelihood, a larger number of interviewees per country is recommended and would provide more representative results. In this respect, it would also be interesting to survey a representative cross-section of the local population, also including those not directly involved in the production of NTFPs.

Also, more detailed maps of the existing NTFP-related infrastructure should be created. This could be achieved with more extensive on-site research and by contacting a larger number of stakeholders involved in the NTFP supply chains. It is also advised to assess the effectiveness of the recommendations provided in this work, such as the creation of economic incentives, the combination of extractivism and agroforestry systems, and the initiatives for the transformation of NTFPs.

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Appendices

A Interview questionnaire

Semi-structured interview – M.Sc. thesis Paul Mathaess – PRODIGY project

The relation between infrastructure and extractivism of non-timber forest products in the southwestern Amazon

Instructions:

The order of questions can be modified during the interview. Not every question and sub-question necessarily has to be asked to every interviewee. The questions will be preselected according to the expertise of the interviewee and can be further adapted during the interview. The questions about Brazil nut are only addressed to those interviewees who are involved with the subject of the Brazil nut, the same applies to the questions about acai. Different actor groups are planned to be interviewed. Questions that are only to be directed to one of the actor groups are indicated as such.

Presentation:

Hi, we are a team of researchers from the University of Hohenheim and the University of Koblenz-Landau in Germany. This is an interview about the relation between infrastructure and extractivism of Brazil nut and acai. Our work is part of the PRODIGY research project. The information from this interview will be used confidentially and only for the realization of this scientific work with research objectives, maintaining the anonymity of the interviewee. Participation in this interview is voluntary, the interviewee is not obliged to answer all the questions and the interview can be stopped at any time if the interviewee so wishes. The interview will take approximately 60 minutes. Thank you very much for contributing to our research!

Declaration of agreement:

- Do you agree this interview to be recorded (if possible)? The record will not be published, it just helps us to not miss any information.
  ☐ Yes, I agree ☐ No
- Do you agree that we use the results of this Interview in our research?
  ☐ Yes, I agree ☐ No

Name of the interviewed:	
Institution/position:	
Place of work:	
Interviewer:	**Medium of interview ((video-)call, physical):**
Date:	**Location / GPS point:**

General questions:

1. **Do you work with non-timber forest products?**
   ☐ Brazil nut ☐ Acai fruit
2. **Are you active in the study area? (map of study area shown)**
   ☐ Yes ☐ No
3. **In which area(s) are you active?**

The situation in the study area:

4. **What are the main difficulties/challenges that extractivists are facing in the area?**

5. **a) Brazil nut:**
Have the conditions for producing Brazil nut improved or worsened in the past 10 years?
☐ improved ☐ stayed the same ☐ worsened ☐ I don't know
   - **Why?**
   - **Apart from yearly fluctuations, have the produced amounts generally increased/decreased in the past 10 years?**

     ☐ increased ☐ decreased ☐ no change ☐ I don't know

     - **Why do you think that is the case? What do you think are the influencing factors? (several answers possible)**

     ☐ Yields per tree ☐ Abundance of Brazil nut trees
     ☐ Climatic changes / Droughts ☐ Market prices
     ☐ Access / roads ☐ Existence of processing plants
     ☐ I don't know ☐ Other reasons: _______________

b) Acai:

Have the conditions for producing acai improved or worsened in the past 10 years?
☐ improved ☐ stayed the same ☐ worsened ☐ I don't know
   - **Why?**
   - **Apart from yearly fluctuations, have the produced amounts generally increased/decreased in the past 10 years?**
     ☐ increased ☐ decreased ☐ no change ☐ I don't know
     - **Why do you think that is the case? What do you think are the influencing factors? (several answers possible)**

     ☐ Yields per palm ☐ Abundance of acai palms
     ☐ Climatic changes / Droughts ☐ Market prices
     ☐ Access / roads ☐ Existence of processing plants
     ☐ I don't know ☐ Other reasons: _______________

Brazil nut, acai and infrastructure (storage sites, roads, processing plants):

6. **We are interested in the value chain in the area:**
a) Brazil nut:
   - **What are the steps that the Brazil nut passes between harvest and export? Who is involved in each step? And how is the Brazil nut transported in each step (paths, roads, rivers; carried, motorcycle, tractor, car, boat, others)?**
   - **<u>Question to extractivists, associations/cooperatives, companies:</u>**
     Please show us in the map your area of production. Mark with "P"
     (map of study area shown)
   - **Can you tell us where are the locations of (please also mark in the map):**
     - Areas where Brazil nut is collected (Bcol)
     - Points of trade (Bt)
     - Storage points (Bst)
     - Processing plants (Bpr)
     - the transport ways of the product (please indicate with arrows)
       → **Does this information (or part of it) exist as a digitized map?**
   - **Do you have further information about the processing plants?**
     - When were they built / since when are they used?
     - Where do the products processed there come from?
     - What is the capacity of the plant / what is the annual product turnover?

b) Acai:

- **What are the steps that the acai berry passes between harvest and export? Who is involved in each step? And how are the acai berries transported in each step (paths, roads, rivers; carried, motorcycle, tractor, car, boat, others)?**

- **<u>Question to extractivists, associations/cooperatives, companies:</u>**
  Please show us in the map your area of production. Mark with "P"
  (map of study area shown)

- **Can you tell us where are the locations of (Please also mark in the map):**
  - Areas where acai is collected (Acol)
  - Locations of cooperatives/associations (Acop)
  - Points of trade (At)
  - Storage points (Ast)
  - Processing plants (Apr)
  - the transport ways of the product (please indicate with arrows)
    → **Does this information (or part of it) exist as a digitized map?**

- **Do you have further information about the processing plants?**
  - When were they built / since when are they used?
  - Where do the products processed there come from?
  - What is the capacity of the plant / what is the annual product turnover?

7. **What do you think about the infrastructure situation in the area with regard to Brazil nut and acai extractivism?**
   - **Does the existing infrastructure (transport ways, storage and processing facilities) support well the production of Brazil nut/acai? Or could the situation be better?**

   ☐ infrastructure is good ☐ could be better ☐ I don't know

   - **What could be improved to support extractivism of Brazil nut and acai?**
     ☐ More roads ☐ Less roads
     ☐ Better roads ☐ More storage facilities
     ☐ More processing plants
     ☐ Other: ____

8. **Which role do roads play for extractivism? Are roads essential for the production of Brazil nut / acai?**
   - **Did the road infrastructure change within the last 10 years?**
     ☐ Yes ☐ No ☐ I don't know

     → **If yes, how did it change? Are there today:**
   ☐ more roads ☐ better roads ☐ worse roads
   ☐ Other: ____________________________________
   - **What was the effect for Brazil nut / acai producers?**

Extractivism Perspectives:

9. **What do you think will be the future of Brazil nut and acai extractivism in the area? Do you expect changes? If yes, of which type?**

10. **Do you think Brazil nut/acai extractivism is generally sustainable/beneficial for the environment and the forest?**

11. **Can you recommend us further contacts that we could talk to about the topic?**

B Time series data

The numeric time series values are presented for each study area individually in *Table* 2 – *Table* 4.

Table 2: Time series data collected with regard to the municipality of Brasiléia in Acre, Brazil.

	Study area Acre, Brazil (Municipality of Brasiléia)					
year	**deforested area [% of total area]**	**forest cover [% of total area]**	**roads [km²]**	**roads [% of total area]**	**prod. volume Brazil nut [t]**	**prod. volume acai [t]**
2010	25,05	74,95			3.760,0	105,0
2011	25,70	74,30			3.880,0	96,0
2012	26,98	73,02	36,21	0,92	4.169,0	78,0
2013	28,18	71,82			3.660,0	71,0
2014	29,63	70,37			3.492,0	62,0
2015	30,63	69,37			2.168,0	59,0
2016	32,33	67,67			1.301,0	58,0
2017	34,51	65,49			650,0	61,0
2018	36,46	63,54			1.035,0	63,0
2019	38,36	61,64	40,4	1,03	985,0	63,0
2020						
Data source:	Own analysis based on Global Forest Change data (Hansen et al. 2020)	Own analysis based on Global Forest Change data (Hansen et al. 2020)	Own analysis using the Esri software ArcMap 10.6 and RapidEye satellite imagery provided by Planet Labs.	Own analysis using the Esri software ArcMap 10.6 and RapidEye satellite imagery provided by Planet Labs.	IBGE Brasil https://cidades.ibge.gov.br/brasil/ac/brasileia/pesquisa/16/12705?indicador=12715	IBGE Brasil https://cidades.ibge.gov.br/brasil/ac/brasileia/pesquisa/16/12705?indicador=12715

Table 3: Time series data collected with regard to the study area in Pando, Bolivia.

	Study area Pando, Bolivia					
year	**deforested area [% of total area]**	**forest cover [% of total area]**	**roads [km²]**	**roads [% of total area]**	**prod. volume Brazil nut [t]**	**prod. volume acai [t]**
2010	2,30	97,70				0,00
2011	2,34	97,66				0,00
2012	2,41	97,59	4,56	0,19		0,00
2013	2,47	97,53			8.366,53	0,00
2014	2,54	97,46			9.652,87	0,00
2015	2,59	97,41			10.569,77	0,36
2016	2,68	97,32			14.164,35	0,41
2017	2,79	97,21			7.348,63	7,37
2018	2,85	97,15			12.912,84	13,96
2019	2,95	97,05	4,23	0,18	11.088,65	36,73
2020					11.307,78	42,07
Data source:	Own analysis based on Global Forest Change data (Hansen et al. 2020)	Own analysis based on Global Forest Change data (Hansen et al. 2020)	Own analysis using the Esri software ArcMap 10.6 and RapidEye satellite imagery provided by Planet Labs.	Own analysis using the Esri software ArcMap 10.6 and RapidEye satellite imagery provided by Planet Labs.	Data refers to Municipio of Filadelfia. 2010 - 2012: no data. Source: ABT Pando, 2020. Sources indicated by ABT: TOBOROCHI, SICOB	Processed volumes of Villa Florida and Petronila accumulated. Amounts refer to acai pulp produced. 2020: projected. Sources: CIPCA 2020, Lorini 2017, WWF Bolivia 2020

Table 4: Time series data collected with regard to the study area in Madre de Dios, Peru.

	Study area Madre de Dios, Peru					
year	deforested area [% of total area]	forest cover [% of total area]	roads [km²]	roads [% of total area]	prod. volume Brazil nut [t]	prod. volume acai [t]
2010	9,71	90,29			33,25	
2011	10,17	89,83			26,00	
2012	11,08	88,92	19,6	0,71	68,50	
2013	11,92	88,08			50,66	
2014	12,91	87,09			23,11	
2015	13,65	86,35			33,56	
2016	15,05	84,95			31,78	
2017	16,53	83,47			24,35	
2018	17,64	82,36			20,22	
2019	18,55	81,45	23,06	0,84	4,89	
2020					13,58	
Data source:	Own analysis based on Global Forest Change data (Hansen et al. 2020)	Own analysis based on Global Forest Change data (Hansen et al. 2020)	Own analysis using the Esri software ArcMap 10.6 and RapidEye satellite imagery provided by Planet Labs.	Own analysis using the Esri software ArcMap 10.6 and RapidEye satellite imagery provided by Planet Labs.	Own investigation based on data provided by GRFFS and SERNANP	Not used on supra-regional commercial scale according to expert and stakeholder interviews.

C Interview answers to multiple-choice questions

Table 5: Results of the interview answers to multiple choice questions.

Brazil

Total number of interviewees: 12

1 **Brazil nut extractivism: How have the conditions evolved between 2010 and 2020?**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
Improved	6	50%
No change	2	17%
Worsened	2	17%
I don't know	2	17%
No answer	0	0%

2 **Brazil nut: How have the produced amounts generally evolved between 2010 and 2020?**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
Increased	2	17%
No change	4	33%
Decreased	3	25%
I don't know	2	17%
No answer	1	8%

3 **Factors influencing the Brazil nut production**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
Yields per tree	4	33%
Abundance of Brazil nut trees	0	0%
Climatic changes / Droughts	4	33%
Market prices	4	33%
Access / roads	0	0%
Existence of processing plants	0	0%
I don't know	2	17%
Other	3	25%
No answer	1	8%

4 **Acai extractivism: How have the conditions evolved between 2010 and 2020?**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
Improved	4	33%
No change	4	33%
Worsened	0	0%
I don't know	0	0%
No answer	4	33%

5 **Acai: How have the produced amounts generally evolved between 2010 and 2020?**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
Increased	3	25%
No change	6	50%
Decreased	0	0%
I don't know	1	8%
No answer	2	17%

6 **Factors influencing the acai production**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
Yields per palm	1	8%
Abundance of acai palms	1	8%
Climatic changes / Droughts	0	0%
Market prices	0	0%
Access / roads	2	17%
Existence of processing plants	1	8%
I don't know	6	50%
Other	2	17%
No answer	1	8%

7 **NTFP infrastructre situation (transport, storage, processing)**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
Infrastructure is good	2	17%
Could be better	10	83%
I don't know	1	8%
No answer	0	0%

8 **NTFP infrastructre: possible improvements**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
More roads	3	25%
Less roads	0	0%
Better roads	10	83%
More storage facilities	6	50%
More processing plants	0	0%
Other	2	17%
No answer	1	8%

9 **Did the road infrastructre change between 2010 and 2020?**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
Yes	12	100%
No	0	0%
I don't know	0	0%
No answer	0	0%

10 **How did the road infrastructre change between 2010 and 2020?**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
More roads	12	100%
Better roads	2	17%
Worse roads	0	0%
Other	0	0%
No answer	0	0%

Bolivia

Total number of interviewees: 12

1 **Brazil nut extractivism: How have the conditions evolved between 2010 and 2020?**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
Improved	1	8%
No change	4	33%
Worsened	3	25%
I don't know	0	0%
No answer	4	33%

2 **Brazil nut: How have the produced amounts generally evolved between 2010 and 2020?**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
Increased	2	17%
No change	3	25%
Decreased	6	50%
I don't know	0	0%
No answer	1	8%

3 **Factors influencing the Brazil nut production**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
Yields per tree	5	42%
Abundance of Brazil nut trees	2	17%
Climatic changes / Droughts	12	100%
Market prices	4	33%
Access / roads	0	0%
Existence of processing plants	1	8%
I don't know	0	0%
Other	4	33%
No answer	0	0%

4 **Acai extractivism: How have the conditions evolved between 2010 and 2020?**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
Improved	4	33%
No change	4	33%
Worsened	1	8%
I don't know	0	0%
No answer	3	25%

5 **Acai: How have the produced amounts generally evolved between 2010 and 2020?**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
Increased	8	67%
No change	2	17%
Decreased	0	0%
I don't know	0	0%
No answer	2	17%

6 **Factors influencing the acai production**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
Yields per palm	3	25%
Abundance of acai palms	1	8%
Climatic changes / Droughts	5	42%
Market prices	2	17%
Access / roads	1	8%
Existence of processing plants	3	25%
I don't know	0	0%
Other	4	33%
No answer	2	17%

7 **NTFP infrastructre situation (transport, storage, processing)**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
Infrastructure is good	2	17%
Could be better	8	67%
I don't know	0	0%
No answer	2	17%

8 **NTFP infrastructre: possible improvements**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
More roads	1	8%
Less roads	0	0%
Better roads	9	75%
More storage facilities	4	33%
More processing plants	7	58%
Other	6	50%
No answer	1	8%

9 **Did the road infrastructre change between 2010 and 2020?**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
Yes	8	67%
No	4	33%
I don't know	0	0%
No answer	0	0%

10 **How did the road infrastructre change between 2010 and 2020?**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
More roads	0	0%
Better roads	9	75%
Worse roads	0	0%
Other	1	8%
No answer	3	25%

Peru

Total number of interviewees: 18

1 **Brazil nut extractivism: How have the conditions evolved between 2010 and 2020?**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
Improved	10	56%
No change	0	0%
Worsened	6	33%
I don't know	0	0%
No answer	2	11%

2 **Brazil nut: How have the produced amounts generally evolved between 2010 and 2020?**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
Increased	3	17%
No change	2	11%
Decreased	12	67%
I don't know	0	0%
No answer	1	6%

3 **Factors influencing the Brazil nut production**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
Yields per tree	4	22%
Abundance of Brazil nut trees	6	33%
Climatic changes / Droughts	10	56%
Market prices	3	17%
Access / roads	1	6%
Existence of processing plants	0	0%
I don't know	0	0%
Other	10	56%
No answer	1	6%

7 **NTFP infrastructre situation (transport, storage, processing)**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
Infrastructure is good	2	11%
Could be better	13	72%
I don't know	0	0%
No answer	3	17%

8 **NTFP infrastructre: possible improvements**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
More roads	0	0%
Less roads	1	6%
Better roads	6	33%
More storage facilities	2	11%
More processing plants	4	22%
Other	13	72%
No answer	0	0%

9 **Did the road infrastructre change between 2010 and 2020?**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
Yes	14	78%
No	3	17%
I don't know	0	0%
No answer	1	6%

10 **How did the road infrastructre change between 2010 and 2020?**

Answer options:	Number of interviewees who chose the answer:	Percent of interviewees who chose the answer:
More roads	7	39%
Better roads	7	39%
Worse roads	0	0%
Other	3	17%
No answer	4	22%