Effects of land-use changes on ecosystem services and monetary values of tropical forest areas near Manaus and Coari, in the Brazilian Amazon

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M.Sc. Thesis

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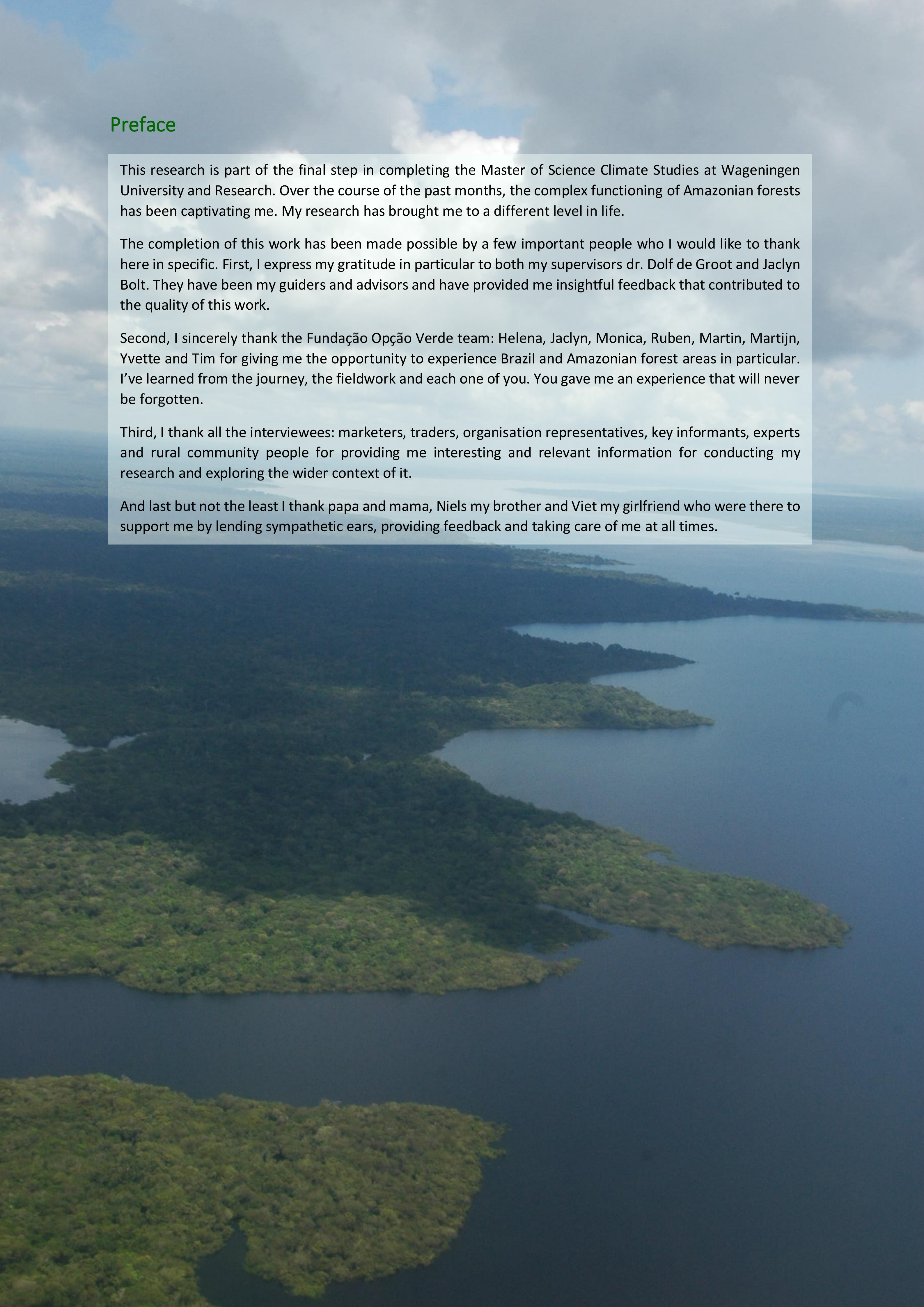
Cover picture (left) taken from *Global Forest Watch*, accessed online at: https://blog.globalforestwatch.org/data-and-research/technical-blog-comparing-gfws-2017-tree-cover-loss-data-to-official-estimates-in-brazil (2019).

Cover picture (right) taken from *World Wildlife*, accessed online at: https://www.worldwildlife.org/photos/deforestation-for-cattle-ranching-in-the-amazon (2019).

The quote at pp. 99 of this thesis report is taken from the book '*Spiegel van de natuur*' (2018) by Matthijs G.C. Schouten and translated by myself from Dutch into English.



Preface

This research is part of the final step in completing the Master of Science Climate Studies at Wageningen University and Research. Over the course of the past months, the complex functioning of Amazonian forests has been captivating me. My research has brought me to a different level in life.

The completion of this work has been made possible by a few important people who I would like to thank here in specific. First, I express my gratitude in particular to both my supervisors dr. Dolf de Groot and Jaclyn Bolt. They have been my guiders and advisors and have provided me insightful feedback that contributed to the quality of this work.

Second, I sincerely thank the Fundação Opção Verde team: Helena, Jaclyn, Monica, Ruben, Martin, Martijn, Yvette and Tim for giving me the opportunity to experience Brazil and Amazonian forest areas in particular. I've learned from the journey, the fieldwork and each one of you. You gave me an experience that will never be forgotten.

Third, I thank all the interviewees: marketers, traders, organisation representatives, key informants, experts and rural community people for providing me interesting and relevant information for conducting my research and exploring the wider context of it.

And last but not the least I thank papa and mama, Niels my brother and Viet my girlfriend who were there to support me by lending sympathetic ears, providing feedback and taking care of me at all times.

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Abstract

Amazonian tropical forests are important for the functioning of the Earth system. These forests are currently being disturbed and disrupted by land-use changes (i.e. the conversion from primary forest into shifting agricultural land or cattle pastures). This threatens the forest's stability and functioning. It is therefore important to conserve these forests. A way to conserve Brazilian forest areas is to purchase parcels of land and create a legally protected status as is done by the local foundation (fundação) Opção Verde. Opção Verde aims to protect and conserve primary forest areas and the local cultural heritage in the Brazilian Amazon. However, concern has risen that their forest areas could be subject to deforestation as a result of land-use changes because, for example, people in the Brazilian Amazon see forest conversion into agricultural land as a means to economically develop. But land-use changes affect the forest's functioning and consequently the services (goods and benefits) the forests provide.

I conducted fieldwork at local markets (in and near the cities Manaus and Coari) and rural community villages (alongside the Urucu River) to determine which land-use changes occur, what the deforestation rates are and what services are used from the forests. Stakeholders were identified, interviewed and mapped according to their relative influences on and interests in forest conversions and established land uses. In addition, a limited set of ecosystem services per land use were explored, analysed and valued. Different direct market-, indirect market-, and non-market valuation approaches were used.

By analysing the effects of land-use changes on ecosystem services and on the services' associated monetary values, the real welfare effects of the land-use changes are made explicit. The effects of land-use changes have been analysed on the following ecosystem services: food, water, raw materials, medicinal resources, climate regulation, pollination and seed dispersal, genepool protection and recreation and eco-tourism. These services have been valued in monetary terms (i.e. US$ per hectare per year). The total monetary annual value estimates per land use as a sum of the set of ecosystem services associated values resulted in the following: 1,437 US$ ha^{-1} $year^{-1}$ for primary forest, 1,607 US$ ha^{-1} $year^{-1}$ for shifting agriculture and 922 US$ ha^{-1} $year^{-1}$ for cattle pasture. The shifting agriculture thus has the highest gross monetary returns according to the sum of the monetary value estimates of the set of ecosystem services that were included.

Only limited sets of ecosystem services and the associated biophysical and monetary changes of these services could be analysed during my limited study. Also, uncertainties in the biophysical data that have been used to quantify the ecosystem services per land-use type, exist. For the monetary valuation, gaps in the absence of fieldwork data were bridged by making various assumptions and using reported literature findings. The total monetary value estimate of the primary forest land use type is likely underestimated since a limited set of ecosystem services has been considered.

In conclusion, intact primary forest areas from Opção Verde contain many provisioning services that are likely socio-economically important, especially to rural people and local vendors, traders and clients. Non-timber forest products that are derived from intact mature primary forest can potentially function as a substitute for cattle products in terms of monetary returns since the gross revenues from these products are substantially higher and more sustainably harvested than cattle products (i.e. meat). Because the total monetary value estimate of intact primary forest is higher than the total monetary value estimate of cattle pastures, my results can help to communicate the true welfare effects of the land-use changes and to counter-attack the primary indirect cause of deforestation (i.e. establishments of cattle pastures after forest clearances for timber harvest). As a substitution, the potential sustainable-based harvest and trade of timber and non-timber forest products can provide sufficient gross monetary returns while they simultaneously can contribute to the long-term conservation of forests.

1. Introduction

1.1 Background of the problem

The Amazon tropical ecosystems play important roles in the functioning of the Earth system. Tropical forests within these ecosystems, act as carbon pools in the global carbon cycle (Mitchard, 2018), influence global atmospheric circulation patterns (Nepstad et al., 2008) and harbour two-thirds of the terrestrial biodiversity (Slik et al., 2015). The Amazonian forests are home to many indigenous groups and rural communities (Blackman et al., 2017), ensure local and regional climate stability and provide key ecosystem services (Nobre and Borma, 2009) which are important for human wellbeing.

To date, the Amazonian forests are being disturbed and disrupted by land-use changes and other environmental alterations. This puts the stability and the functioning of the ecosystem at stake (Laurance et al., 2014; Nobre and Borma, 2009; Steffan-Dewenter, 2007). Changes that are primarily caused by the spatial enlargement of economic systems, in particular the expansion as well as intensification of agricultural land area. With regard to the Amazon tropical forest, two crucial reasons exist for expanding agricultural land. First, overall agricultural expansion is mainly driven by accelerating human production and consumption patterns (Vieira et al., 2008), which is fundamentally the result of global population and income growth (Laurance et al., 2014). Second, the national governments play a key role in allowing and encouraging conversions of natural ecosystems into agricultural land through policies (Mullan et al., 2018). State-sponsored agrarian settlement programs between the 1980s and 1990s were a major driver of tropical deforestation in Latin-America (Rudel et al., 2009). Concerning Brazil, its government still continues to encourage and settle communities in the Amazon region. By doing so, the government makes it pertinent to quantify economic benefits from agricultural settlements at the cost of the Amazon forest (Mullan et al., 2018, pp. 428).

Concerns and debate have risen about the substitution of natural capital with human-made capital (Pezzey 1992; Pearce et al., 1998; De Groot et al., 2010, pp. 6). Despite concerns and debate, and the growing understanding and awareness of the great importance and values of ecosystems and biodiversity, environmental change with regard to land degradation and biodiversity losses still persists to continue on a large scale (De Groot et al., 2010). To reduce human pressures on ecosystems and biodiversity, a critical amount of natural capital has to be conserved and protected (De Groot et al., 2010, pp.6).

In Brazil, a method to protect and conserve natural capital with Amazon forest in specific, is to purchase forest areas and to give it a legally recognised protected status (Reservas Particulares do Patrimônio Público, or RPPN) by Brazilian government agencies. This protected status ensures that the forest parcels become a private reserve, with the aim to conserve the area. A local foundation, Fundação Opção Verde (abbreviated with 'OV'), acquires forest areas by this means. Opção Verde aims to protect and conserve primary forest areas and the cultural heritage of Amazon regions into eternity (Forest Forever, 2018)[1]. Herewith contributing to the fight against deforestation, biodiversity losses, and global average temperature increases due to increased emissions from deforestation (Forest Forever, 2018). However, an issue of increasing concern arouse because of anthropogenic disturbances in the Brazilian Amazon as a result of land-use changes for agricultural purposes.

1.2 Study areas

Opção Verde has purchased forest areas near de cities of Coari and Manaus (Figure 1, 2), which have a total surface area of about 126,000 hectares (Face the Future, 2018)[2]. The current purchased areas are clustered at two different regions: southwest of Coari and north of Manaus, from here onward specified to with forest areas situated in the 'Coari-region' or 'county Coari', and the 'Manaus-region' (Figures 1, 2). The forest areas in the Coari-region are named: 'Araua', 'Urucu I', 'Urucu II', 'Urucu III', 'Coarizinho', 'Coarigrande', 'Mamia', 'Itanhaua', and 'Juma' (see Appendix VI). The forest areas in the Manaus-region are simultaneously named 'Urubu' (see Appendix VI). The exact geometric boundaries of the forest areas can be looked up in Appendix VI.

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[1] Forest forever (2019) from https://stichtingforestforever.nl/.

[2] Face the future (2018) maps taken from: face.maps.arcgis.com/apps/opsdashboard/index.html#/8e797dde5b3949beb35022ce005d3f49.

Figure 1: Northern Brazilian Amazon with indicated cities Coari, and Manaus (Google maps, 2019).

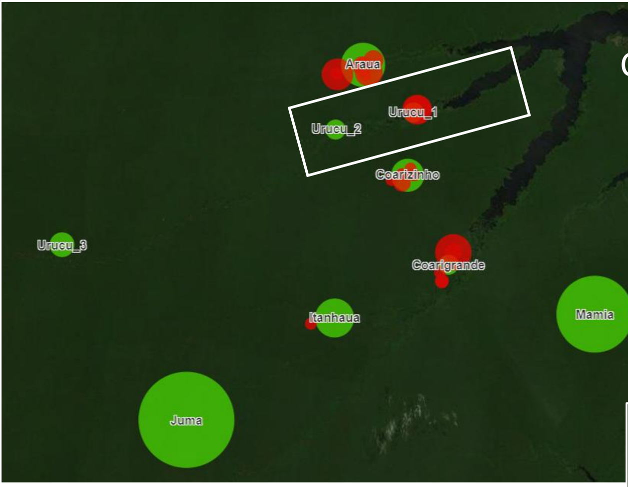

Figure 2: Coari-region with forest areas of Opção Verde in green and red spheres (red spheres indicate that at that the area has been subject to deforestation). Fieldwork was conducted at locations situated within the white rectangle (Face the Future, 2019).

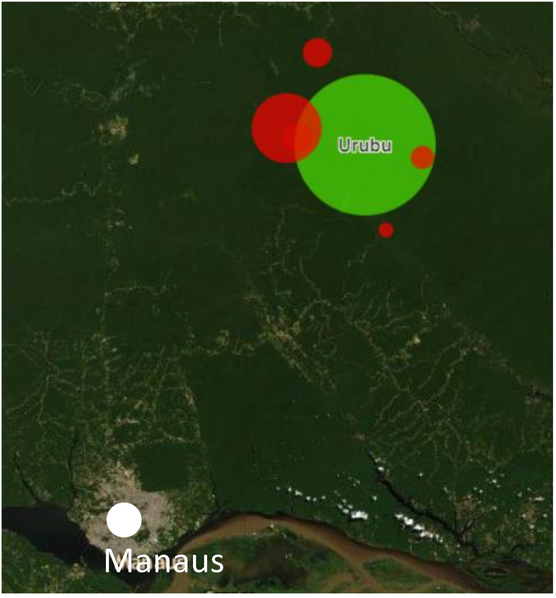

Figure 3: Manaus-region with forest areas of Opção Verde in green and red spheres (red spheres indicate that at that the area has been subject to deforestation) (Face the Future, 2019).

1.3 Problem statement

Opção Verde aims to conserve and protect primary forest areas and the cultural heritage in the Brazilian Amazon (Forest Forever, 2018). Concern has risen that their property areas could be subject to deforestation as a result of land-use changes. With the current politics in Brazil putting increased pressures on the Brazilian Amazon, the risk exists that deforestation rates increase. Another issue of concern is that people in the Brazilian Amazon see forest conversion (into land for agricultural purposes) as a means to achieve economic development (Rodrigues et al., 2009), which in definition means that both economic and social conditions improve (Cambridge, 2019)[3]. However, land-use changes have effects on the tropical forest's structures and processes, and consequently on the services these generate, which in turn can lead to value gains and losses that are not explicitly taken into account when such conversions are taking place. By analysing the effects of land-use changes on the ecosystem, the services it provides and the associated monetary values, it has been made explicit what the real welfare effects of such changes are.

1.4 Purpose of the study and research questions

My research aimed to provide an increased understanding of how land-use changes affect ecosystem services and associated monetary values of mature primary tropical forest areas in the northern Brazilian Amazon. The results of my research can eventually be used to explore the potential of the tropical forest's services to implement in socioecological-economic systems in which the monetary returns can substitute the returns from services of less sustainable land use practices. This in turn can contribute to maximise tropical forest and biodiversity conservation efforts of Opção Verde's forest areas.

The following main research question (RQ) was formulated:

What are the effects of land-use changes on ecosystem services and monetary values of tropical forest areas near Manaus and Coari, in the Brazilian Amazon?

To address this main research question, five research questions were formulated:

RQ1. Which land uses are relevant in analysing Opção Verde's forest areas and how are these land uses defined and characterised?

RQ2. Which relevant stakeholders are involved in or affected by the land uses from RQ1?

RQ3. Which ecosystem services are provided by the identified land uses of RQ1 and how can these be measured and quantified?

RQ4. What are the total monetary values and (social) present values of these land-use based ecosystem services?

RQ5. What are the planning and management implications for conserving Opção Verde's forest areas and what should be recommended for the sustainable use of their forests?

1.5 Outline of the report

My research first elaborates upon how the research questions are addressed. Chapter 2 provides insights in the methods and approaches that are used to explore, measure, quantify, and value relevant ecosystem services and the relative changes therein. RQ1 shows that the three land uses are important: primary forests, shifting agriculture and cattle pastures. The further research will focus on these three land-use types. The findings are presented in Chapter 3 to 7. This illustrates the effects of land-use changes on the ecosystem services and their estimated monetary values. Within these chapters, emphasis is put on the (cascading) effects that are brought about by the land-use changes with in particular forest conversions into shifting agriculture and forest conversions into cattle pastures. Implications of the main findings, conclusions and recommendations are presented in Chapters 8 to 10. Possibilities for further studies are also highlighted.

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[3] Cambridge (2019) from https://dictionary.cambridge.org/dictionary/english/economic-development.

2. Methodology

2.1 Methodological flow diagram

A methodological flow diagram (Figure 4) is developed to provide a clear and concise overview of the processes which my research entails. The different steps include: scoping phase, in which the thesis context and purpose is made clear, and which contributes to the identification of land uses; a stakeholder analysis, that identifies and priorities the most relevant stakeholders and stakeholder groups; stakeholder mapping in terms of relative influence and interest, and their relationships; an ecosystem-services analysis, that describes ecosystem services per land use and for which indicators are developed to measure them; an ecosystem-services valuation, that values each ecosystem service and allow to calculate the total monetary value (TMV) and the discounted future benefits to the present (i.e. the social present value (s-PV)) and, finally synthesise the result's implications and present recommendations for the sustainable use and conservation of Opção Verde's forest areas). The consecutive steps are mainly based on the *method for integrated ecosystem services assessment* proposed by De Groot et al. (2018). This approach should be seen as a procedure in which each step involves different analyses and methods that are explained in more detail in Section 2.2.

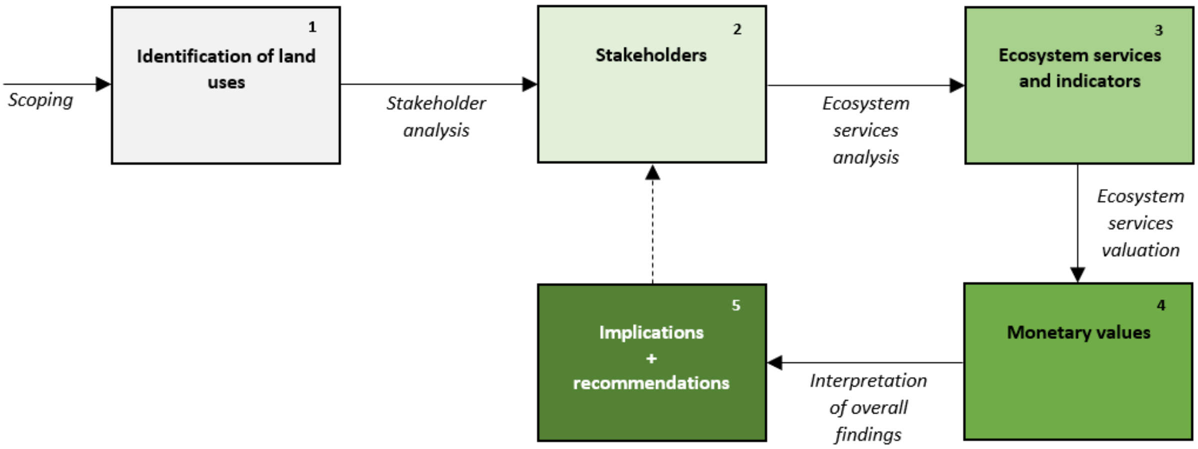

Figure 4: Methodological flow diagram for ecosystem services assessment to analyse the effects of land-use changes on ecosystem services and monetary values (based on De Groot et al., 2018, pp. 10).

In the framework for integrated ecosystem assessments of De Groot et al. (2018), three additional steps are included to capture the (economic, socio-cultural, or ecological) value, to communicate that value, and to ensure implementation of the study outcomes. Because of a limited amount of time for my research, these steps have not been included here. Note that it is important to capture and communicate research findings within the context of my research the effects of the land uses on ecosystem services and associated monetary values. Also implementation of results is important to give these practical significance.

2.2 Research methods

2.2.1 Scoping and land use identification

The context and purpose of the assessment was made clear during the scoping phase in which remotely sensed data and maps from Face the Future (2018) and literature findings were been used. In addition, fieldwork observations provided information on the shifting agriculture land use and the wider context of my research.

2.2.2 Stakeholder analysis

The stakeholder analysis was based on the schematic representation of Reed et al. (2009) which gives an overview of the rationale, typology, and methods for conducting stakeholder analyses. From this schematic representation, the stakeholder analysis for my research was conducted by the *descriptive* rationale and a typology involving three steps: 1) identifying stakeholders; and, 2) differentiating between and categorising stakeholders, for which the method of influence/interest-matrix mapping was used (Reed et al., 2009, pp. 1936).

A preliminary list of stakeholders was made before engagement during fieldwork took place. From this preliminary list, first contact was made with local and regional stakeholders in Manaus and Coari. During interviews with stakeholders, experts, and local people in Manaus and Coari more stakeholders were identified as the process advanced in the form of so called 'snowball-effect' or snowball sampling (Reed et al., 2009) even though this has not always been the intention during interviews that were conducted (e.g. sometimes snowball sampling was not undertaken, or it occurred that an interviewee recommended by itself persons/experts for continuation interviews). Prioritising the stakeholders was done according to their relative influence on or interest in any of the land uses. These relationships are mapped in an influence/interest-matrix (see Section 3.3).

2.2.3 Ecosystem-services analysis

This section explains the methods and frameworks that are used for the ecosystem-services. First, the background on the concept of ecosystem functions, services, and benefits is explained, and how this concept links with human wellbeing. Then, different classifications and typologies of the concept of ecosystem services are presented where is explained which classification and typology is used.

Most decisions about land-use changes that are made at decision-making tables across the globe to date, are based on incomplete information concerning the real effects associated with such changes (De Groot et al., 2018). These real effects concern the associated externalities (De Groot et al., 2018), and are often not incorporated in the process of decision-making. This has led, and still leads to, degraded landscapes and ecosystems which currently can be witnessed everywhere across the globe (e.g. far-stretching grasslands as cattle pastures in Brazil; deep excavated brown-coal mines in Germany; and monoculture oil-palm plantations in Indonesia). To incorporate the true effects of land-use changes in decision-making, the effects of such changes need to be well understood. A way to do so is by analysing the effects from a land-use change on the ecosystem and the services that system provides, which contribute to human wellbeing. Although it can be argued that such analyses are made from an anthropocentric viewpoint, it can be a way to minimise adverse impacts on (parts of) ecosystems and biodiversity.

Over the past decades, increasing attempts have taken place to systematically link the functioning of ecosystems with human wellbeing (De Groot et al., 2010, pp. 6). The Millennium Ecosystem Assessments (MA) and The Economic of Ecosystems and Biodiversity (TEEB) have provided concepts, frameworks, and methods to analyse, and assess the (changes in) ecosystems and biodiversity, and to what extent such changes have effect on different scales. The underpinned ecosystem functions provide ecosystem services, which in turn provide benefits to humans that contribute to human wellbeing. The TEEB framework links ecosystem functions to human wellbeing by this means (Figure 5) and has been used as a baseline for the ecosystem services analyses conducted in my research. To be clear about what is meant with ecosystem, ecosystem functions, and ecosystem services, these are defined as:

- An *ecosystem* is (defined by the MA) "a dynamic complex of plant, animal, and microorganism communities and the non-living environment, interacting as a functional unit." (MA, 2003, pp. 49). Humans and forests for example, are integral parts of ecosystems (MA, 2003, pp. 49);
- *Ecosystem functions* are underpinned by biophysical biotic and abiotic structures and processes (e.g. primary production). Ecosystem functions are defined by (De Groot et al., 2010, pp. 19) as: "a subset of the interactions between ecosystem structures and processes that underpin the capacity of an ecosystem to provide goods and services". Ecosystem functions represent the potential that ecosystems have to deliver certain services which depend upon the underpinned biophysical structures and processes (De Groot et al., 2010, pp. 11). An ecosystem function that is derived from the process of primary productivity, can be the accumulation of biomass;
- *Ecosystem (goods and) services,* from here onward referred to as 'ecosystem services' or later on as 'services' merely, are defined by Costanza et al. (1997, pp. 253) and TEEB (2010) as: ''the benefits people derive from ecosystem functions directly or indirectly, that contribute to human wellbeing.''

Different broadly recognised classifications and typologies for ecosystem services exist (e.g. Costanza et al., 1997; MA, 2005; TEEB, 2010; CICES, 2018; IPBES, 2018) (Table 1). For a systematic analysis of the ecosystem services that derive from the three distinct land-use changes in my research, the classification and typology of TEEB (2010) has been used. This ecosystem service classification and typology is created "to specify the relationships between, and transitions from ecosystem processes and components and their transition to goods and services" (De Groot et al., 2010, pp. 7). Within the typology of TEEB, four different service classes or categories are addressed, including: provisioning services; regulating services; habitat services; and cultural services. These categories together consist of a total of 22 ecosystem services, which have been developed by following the MA (2005) classification. De Groot et al. (2002, pp. 3) have defined these four service categories in the form of ecosystem functions as follows:

- **Provisioning services**: photosynthesis and nutrient uptake by autotrophs converts energy, carbon dioxide, water and nutrients into a wide variety of carbohydrate structures which are then used by secondary producers to create an even larger variety of living biomass. This broad diversity in carbohydrate structures provides many ecosystem services for human consumption, ranging from food and raw materials to energy resources and genetic material;

- **Regulating services**: ecosystems regulate essential ecological processes and life support systems through bio-geochemical cycles and other biospheric processes. These provide many services in addition to maintaining ecosystem and biosphere health such as climate regulation, and pollination;

- **Habitat services:** ecosystems provide refuge and reproduction habitats to wild plant and animal species, thereby contributing to (in-situ) conservation of biological and genetic diversity, and evolutionary processes;

- **Cultural services**: natural ecosystems have provided an undomesticated habitat for the most part of human evolution, and therefore may contribute to the maintenance of human health by providing opportunities for reflection, spiritual enrichment, cognitive development, recreation, and aesthetic experience.

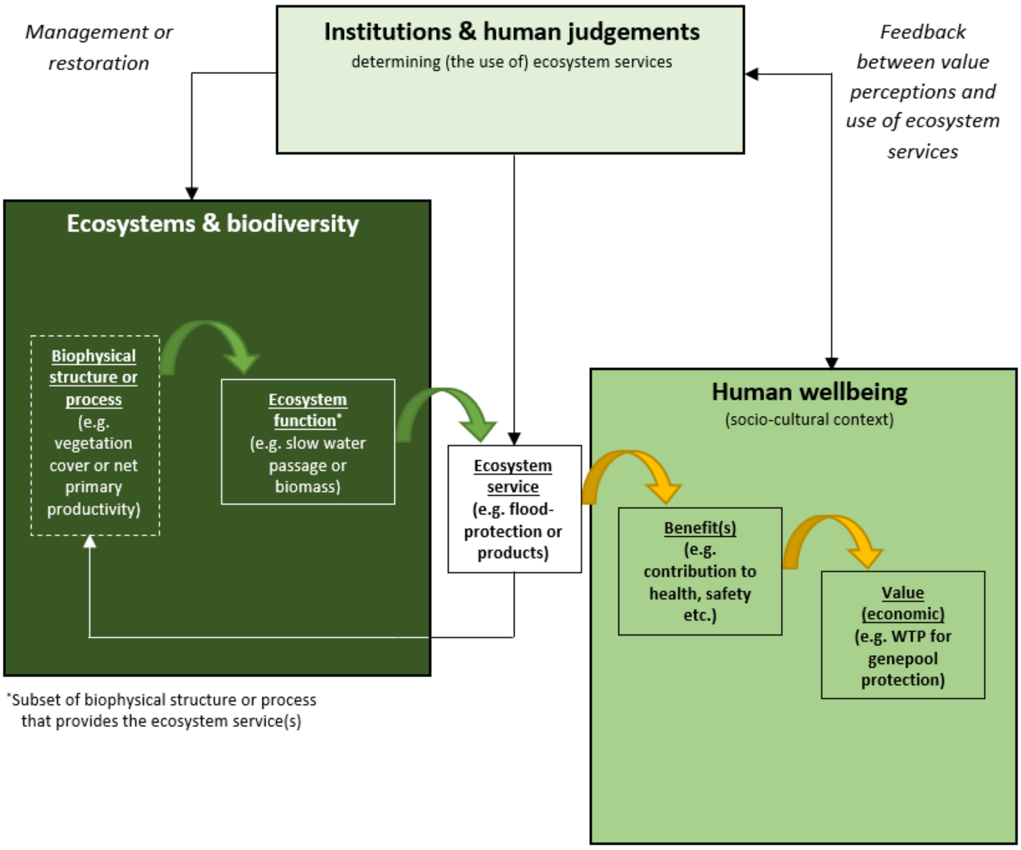

Figure 5: The TEEB framework for linking ecosystems and biodiversity to human wellbeing (adapted from De Groot et al. 2010 and Haines-Young and Potschin 2010).

A limited set of ecosystem services has been taken into account in my research which include:

- **Provisioning services:** *food; water; raw materials; medicinal resources;*
- **Regulating services**; *climate regulation; pollination (and seed dispersal);*
- **Habitat services:** *genepool protection;*
- **Cultural services:** *recreation and eco-tourism.*

Table 1: A comparison of the broadly recognised classifications and typologies of ecosystem services (adapted from De Groot et al., 2018). The TEEB classification and typology that is used for the ecosystem-services analysis is outlined with a green rectangle.

Costanza et al. (1997)	**Millennium Ecosystem Assessment (2005)**	**TEEB (2010)**	**CICES (v. 2017)**	**IPBES (May 2018)**
-	**Provisioning**	**Provisioning**	**Provisioning**	**-**
Food production	Food	Food	Biomass – nutrition	Food and feed
Water supply	Fresh water	Water	Water	
Raw materials	Fibre etc.	Raw materials	Biomass – Fibre & energy Mechanical energy	Energy
	Ornamental resources	Ornamental resources	-	Materials, (animal) labour & companionship
Genetic resources	Genetic resources	Genetic resources	-	Medicinal, bio-chemical & genetic resources
	Biochemicals	Medicinal resources	-	
-	**Regulating**	**Regulating**	**Regulating & habitat**	**-**
Gas regulation	Air quality regulation	Air purification	Mediation of gas- & air flows	Regulation of air quality
Climate regulation	Climate regulation	Climate regulation	Atmospheric composition & climate regulation	Regulation of climate
Disturbance regulation (storm protection & flood control)	Water regulation	Disturbance prevention or moderation	*Falls under 'mediation of other nuisances'* (see below)	Regulation of hazards and extreme events
Water regulation		Regulation of water flows	Mediation of liquid flows	Regulation of freshwater quantity, location and timing
Waste treatment		Waste treatment (esp. water purification)	Mediation of waste, toxics and other nuisances	Regulation of ocean acidification
Erosion control & sediment retention	Erosion regulation	Erosion prevention	Mediation of mass-flows	*Likely included in 'regulation of hazards and extreme events'* (see above)
Soil formation	Soil formation (supporting service)	Maintaining soil fertility	Maintenance of soil formation and composition	Formation, protection, and decontamination of soils and sediments
Pollination	Pollination	Pollination & seed dispersal	-	Pollination (and seed dispersal)
Biological control	Regulation of pests & human diseases	Biological control	Maintenance of pest- and disease control	Regulation of detrimental organisms and biological processes
-	**Supporting**	**Habitat**	**-**	**-**
Nutrient cycling	Nutrient cycling & photosynthesis, primary production	-	-	Maintenance of options *(similar to MA supporting services)*
Refugia (nursery, migration, habitat)	'Biodiversity'	Lifecycle maintenance (especially nursery)	Lifecycle maintenance, habitat and genepool protection	Habitat creation and maintenance
		Genepool protection		
-	**Cultural**	**Cultural (& amenity)**	**Cultural**	**-**
Recreation, including eco-tourism & outdoor activities	Recreation & eco-tourism	Recreation & eco-tourism	Physical and experiential interactions	Physical and psychological experience
Cultural (including aesthetic, artistic, spiritual, and education & science)	Aesthetic values	Aesthetic information, inspiration for culture, art & design		
	Cultural diversity			
	Spiritual & religious values	Spiritual experience	Spiritual and/or emblematic interactions	Supporting identities
	Knowledge systems, educational values	Information for cognitive development	Intellectual and representative interactions	Learning and inspiration

Note that also the services ‘genetic materials’, and ‘lifecycle maintenance (or ‘nursery’) were included in the selection for analysis but which due to the lack of sufficient data for the study areas of my research could not have been studied thoroughly. Table 1 shows the list of abovementioned services and their categorisation as proposed by TEEB (2010). The main reason for using the TEEB (2010) typology for ecosystem services and biodiversity valuation is because this one is most specific and inclusive in comparison with the typologies form Costanza (1997), MA (2005), CICES (v. 2017), and IPBES (2018).

Before ecosystem services could be valued in monetary terms, they were analysed and quantified in biophysical units. For the quantification in biophysical units, indicators were selected in which the units allow for measuring the effects of the land-use changes on that specific ecosystem service (De Groot et al., 2010). This was essential in order to be able to analyse the relative changes in the ecosystem’s associated monetary value estimates. The ecosystem services with the selected indicators are presented in Table 2. To obtain the necessary biophysical data for quantifying the chosen ecosystem services to the desired spatial scale (i.e. one hectare), primarily reported values from various literature findings were used (exact sources are referred to in-text). The indicators have been used to quantify the ecosystem services and the relative change, which in turn have been translated in monetary terms.

Table 2: Ecosystem services in the study area according to number and service category (TEEB, 2010), specification, and corresponding indicator in biophysical units.

Category Number	**Ecosystem service**	**Specification**	**Indicator**
Provisioning			
1	Food		
	Fruits	Açaí, bacuri, burití, guarana, jatobá, patauá, piquiá, tucumã, uxi/uchi	Net average productivity (fruit units/ha/year, or kg/ha/year)
	Nuts	Brazil nut	Net average productivity (kg/ha/year)
	Bush meat	Armadillos, deer, pigs, rodents	Total average biomass of game species (kg/ha)
	Cassava (Manihot esc. Cr.)	Cassava fresh roots	Net average productivity (cassava fresh roots calculated to cassava flour in kg/ha/year)
	Cattle)	Meat products	Cows per hectare multiplied by the potential consumption of meat in kg per cow
2	Water	Share of the annual precipitation that flows into forest streams (igarapes)	Average annual precipitation discharge into forest streams with deduction of the percent share that is lost due evapotranspiration (L/ha/year)
3	Raw materials		
	Timber	Harvest based on either the natural vegetation regeneration rate, or total stock of mature primary forest	Net average productivity based on the natural regeneration growth rate of mature tropical forest (m^3/ha/year), or the total stock (tonne/ha)
	Latex	Liquid (natural) latex	Net average productivity (L/ha/year)
4	Medicinal resources	Medicinal plants and vines	Bioprospecting as a function of the density of endemic species (number of species/ha/year)
Regulating			
8	Climate regulation	Carbon stock	Above and below-ground vegetation c stock (i.e. roots), and soil organic carbon (tonne/ha)
		Carbon flux (the net uptake/release of carbon from or into the atmosphere by vegetation)	Net average carbon uptake/release (tonne /ha/year)
14	Pollination	Effect of pollination by wild insect pollinator-species, analysis of the relative change is based on the change in floral and nesting resources (speculative)	Embedded in the monetary value estimates of other ecosystem services (e.g. fruits).
Habitat			
17	Genepool protection	Biodiversity maintenance	Stand vegetation biomass in percentage (primary forest = 100%)
Cultural			
18	Recreation and eco-tourism	On the basis how appealing a land use would be to international tourists (speculative)	Expenditures of tourists (per person/year)

2.2.4 Ecosystem-services valuation

The ecosystem-services valuation aimed at translating the analysed ecosystem services which each land use provides into a generally accepted value. The "value" of an ecosystem service can be analysed in various ways but generally falls within one of the following (value) domains: ecological, socio-cultural, and economic (MA, 2003; De Groot et al., 2010). For each domain, different indicators are needed in order to quantify ecosystem services into a measurable unit that represents the type of value being attached to them (Section 2.2.3). The ecosystem services addressed in my research have been valued within the economic (value) domain. In economics, the common metric for valuation is monetary[4] (Kumar, 2012). Each ecosystem service which is provided or derived from the three distinct land uses, is therefore valued in annual monetary terms and a spatial scale (i.e. US$ per ha per year, or in Brazilian Real (BRL) and then converted into US$). This means that the monetary unit associated with the ecosystem service captures the economic value domain merely (and thus excludes the ecological and socio-cultural values) (De Groot et al., 2010, pp. 262).

Because some rural communities in the Amazon tropical forest study areas do not possess money but trade products to meet their needs, the term 'monetary' is used in my research, instead of 'economic' to be more inclusive. Rural communities in fact do attach an economic value to the products they trade but do not necessarily do this by means of a currency. The monetary values are based on sustainable use levels where possible (e.g. the ecosystem services provided by primary forest are entirely based on sustainable use levels, but provisioning services provided by converted forest into cattle pasture are overall not considered to be sustainable because such conversions result in degraded landscapes partially or entirely). The sum or aggregate of all ecosystem service values or value types is the 'total monetary value' (TMV). The TMV is based on the total economic value (TEV) concept (Figure 6) (adapted from De Groot et al. 2018 and Ding et al. 2017).

In the TEV framework, a distinction is made between 'use values' and 'non-use values'. *Use values* are associated with private or semi-private goods which are often market priced (Pascual et al., 2010, pp. 15). *Non-use values* reflect the satisfaction of individuals which they derive from mere the knowledge that ecosystem services sustain or are maintained, and to which other people might have access to (Kolstad 2000; Pascual et al., 2010, pp. 15). The use values are further distinguished into 'direct use values' and 'indirect use values', and the non-use values are further distinguished into 'bequest values' and 'existence values'. A third value is assigned in the TEV framework which is considered to be both a use value as well as a non-use value: the 'option value'. The option value refers to the possibility to value the option that a given ecosystem service can be used in a future time period (Pascual et al., 2010, pp. 15). The value types presented in the TEV framework are listed and briefly described below by Pascual et al. (2010, pp. 14):

- The **direct use value** refers to direct human use of biodiversity (consumptive or non-consumptive). It is the value attributed to biodiversity in a utilitarian sense, which are generally provisioning services (consumptive) and cultural services (non-consumptive). Both service categories are often traded on actual markets and can therefore be valued through direct market valuation methods;
- The **indirect use value** refers primarily to the regulating services which due to the functioning of an ecosystem provide benefits to humans and therefore contribute to human wellbeing. These services generally support human production and consumption, which consequently can be valued through indirect market valuation methods;
- The **option value** refers to the importance that people give to the future availability of a given ecosystem service for the potential (private) benefit in a utilitarian sense either directly or indirectly;
- The **bequest value** refers to what individuals value from the knowledge that future generations will also have access to the benefits from ecosystems and biodiversity (intergenerational equity concerns);
- The **existence value** refers to the satisfaction that individuals derive from the mere knowledge that ecosystems and biodiversity continue to exist.

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[4] Important to note is that monetary valuation captures only a part of total value of an ecosystem service because using a monetary metric fails to incorporate numerous value types (i.e. socio-cultural, and ecological) that are essential in understanding human-environment interactions and relationships (De Groot et al., 2010; Kumar, 2012).

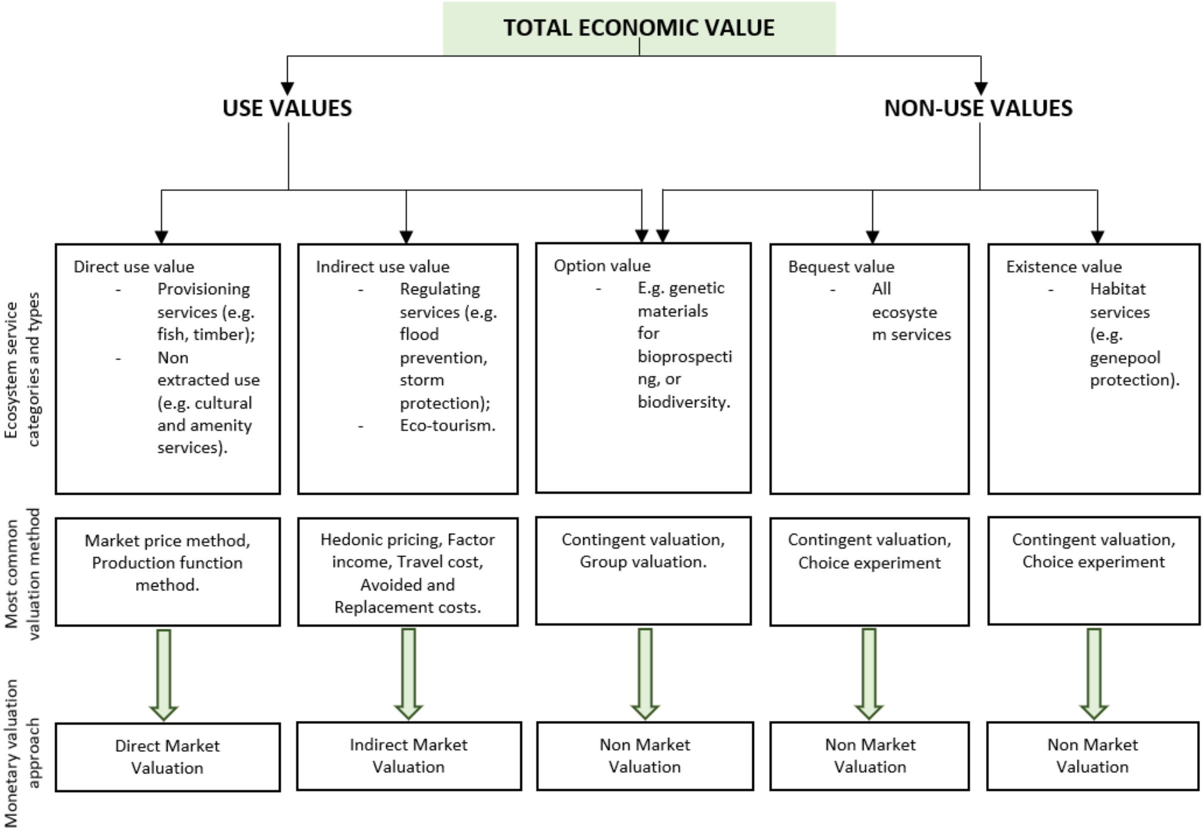

Figure 6: The TEV-framework with ecosystem service categories and types, most common valuation methods, and monetary valuation approaches (adapted from De Groot et al. 2018 and Ding et al. 2017).

Important to address is that there exist some limitations in 'valuation' or giving something a 'value'. A *value* can only be attributed to a given ecosystem service by human beings and is therefore merely perceived to be 'valuable' (to whatever extent) by human beings. This means that any (economic) value is anthropocentric. Yet, monetary values to date often do not reflect the truly how much worth something is. For example, provisioning services such as food are mostly traded on actual markets where demand and supply regulate the economic system. Still, this does not mean that it reflects an all-encompassing 'true' value of the given service. The primary reason for this is that in current economic systems the externalities are often not incorporated in the market value of a given provisioning service (e.g. the monetary value of a soybean, for which Amazon forest has been cleared to cultivate it, would be much higher when all externalities such as greenhouse gas emissions, biodiversity losses, and landscape degradation are taken up in its market value). Therefore, the (monetary) values that are attached to any given (provisioning) service addressed in my research, do not necessarily reflect the 'true' value of that specific service.

One can question why there is need to economically value ecosystems and biodiversity. Nearly everything we consume whether intended or not derives from underpinned ecosystem's biophysical structures and processes in one way or another. However, only a limited or partial amount of the consumed services provided by an ecosystem are incorporated in current markets in terms of (monetary) value. This means that current markets merely shed information of the values from a few thus limited amount of underpinned structures and processes (Brondízio et al., 2010). Ecosystem and biodiversity valuation can therefore provide a more complete and clearer picture of the importance of an ecosystem's functioning and the service(s) it provides by providing information which current markets lack. By doing so, it can be made explicit how human decisions (e.g. by making landscape changes) affect an ecosystem and the services it provides (Brondízio et al., 2010), and which when expressed in monetary terms allow for integration in decision-making processes (Mooney et al., 2005). Depending on the value type (i.e. use and non-use sub-types), the quantified ecosystem services according to the spatiotemporal scale in ha/year have been valued by using different valuation methods and approaches. These include: direct market valuation, indirect market valuation, and non-market valuation. In direct market valuation approaches data was used from explicit markets which reflect one's preferences or costs (Pascual et al., 2010, pp. 18). Indirect market valuation approaches were needed in the absence of explicit markets (e.g. to find the avoided costs in the presence/absence of a certain ecosystem service) (De Groot et al., 2002). Non-market valuation approaches involved the examination of “the importance, preferences, needs, or demands by people towards nature, and articulate plural values through qualitative and quantitative measures other than money” (Kelemen et al., 2014, pp. 1; Chan et al., 2012). Direct market valuation was used for the services: food; water; raw materials; and medicinal resources, indirect market valuation was used for the services: climate regulation, recreation and eco-tourism, and non-market valuation was used for the genepool protection service. The application of each valuation approach per ecosystem service has been described in more detail in Table 3. For the valuation estimates, uncertainty ranges have been given where possible.

Each monetary value estimate in USD/ha/year was discounted according to a (social) discount rate (SDR) to discount the benefits of future generations to the present. This discounted value is in economic literature referred to as the net present value (NPV). However, associated costs that come with the analysed goods and services have not explicitly been taken into account in the valuation analyses. Only the provisioning services have costs embedded in their monetary value estimates. For this reason, the term social present value (s-PV) is used rather than the *net* present value.

Table 3: Valuation methods and descriptive explanation per ecosystem service.

Category Number	**Ecosystem service**	**Valuation method**[a]	**Description**
Provisioning			
1	Food	DMV	
	Fruits	DMV	Fruits and nuts have been valued according to market values from markets and trading locations in Manaus (Feira da Banana; Feira da Moderna; Feira da ADS; Adolpho Lisboa) and Coari (Feira do Produtor Rural; Street market adjacent to the Feira do Produtor Rural; Mercado Municipal Clemente Vieira; Brazil nut trading location at Lake Coari). For the fruits from which market values could not be obtained, reported literature values were used. Each quantified fruit in terms of average productivity/ha/year was valued according to the fruit units or quantity that were/was sold on the local market and according to its market value. For the exact market value for each fruit, see Appendix II. The Brazil nut has been valued similarly, but the market value of this product was obtained at a trading platform in Lake Coari.
	Nuts	DMV	See the description *fruits* above.
	Bush meat	DMV	Valued according to the market value at the street market adjacent to the Feira Produtor Rural in Coari, which was 10 BRL/kg. Several different animal species were sold here as bush meat which were mainly unidentifiable. It was observed that armadillo was one of the animal species that was sold as bush meat.
	Cassava (*Manihot esc.)*	DMV	Valued by multiplying the average annual productivity with the average market value of various local markets in Manaus (6 BRL/kg farofa).
	Cattle (meat products)	DMV	Valued according to the density of 1.1 cows per hectare for smallholders and 10 BRL/kg meat market value.
2	Water	DMV	Valued according to the Manaus monthly water tariff (6 BRL/m^3) (Olivier, 2006)
3	Raw materials	DMV	
	Timber	DMV	Valued according to the net timber value of 708 USD/tonne (Torras, 2000)
	Latex	DMV	Valued according to the market value of dry rubber of 1.09 USD/kg, reported by Ribeiro et al. (2018)
4	Medicinal resources	DMV	Valued according to benefit transfer (Rausser and Small, 2000), who have used the production function approach for estimating the monetary value of medicinal plants in Amazon forest areas
Regulating			
8	Climate regulation	IMV	
14	Pollination	-	Value could not be estimated
Habitat			
17	Genepool protection	NMV	Valued according to the willingness to pay by residents from the UK and Italy in a situation when 5% of the biodiversity in Amazonia would be conserved (Horton et al., 2013)
Cultural			
18	Recreation and eco-tourism	IMV	Valued according to the average rent in forest areas in Brazil, reported by PROFOR (2015)

[a]DMV = direct market valuation; IMV = indirect market valuation; NMV = non-market valuation.

There exist no pure economic guidelines for choosing a legitimate discount rate as "responsibility to future generations is a matter of ethics, best guesses about the wellbeing of those in the future, and preserving life opportunities" (Gowdy et al., 2010, pp. 35). Because the direction of the discount rate for biodiversity and ecosystem benefits is uncertain (Sukhdev, 2008), two social discount rates have been used: 0% and 5%. These positive values are chosen because from the mere economic viewpoint, "a dollar received today is considered more valuable than that same dollar received in the future (NOAA, 2019)[5], as well as that a 5% is a common SDR for ecosystem services accounting. The social present values in USD/ha have been calculated by using a time horizon of 20 years and social discount rates of 0% and 5%, by using the Net Present Value equation (EQ):

$$NPV = \sum_{t=0}^{T} \frac{Ct}{(1+r)^t} \tag{EQ1}$$

With:

Ct is the net cash benefits minus costs (if applicable) for the given time period(s) *t*;
r is the (social) discount rate.

2.3 Data collection

Data was collected by different means which included: on-site observations in and near the study areas to outline the background problems and explore which land uses were relevant to analyse on their services; carrying out 24 interviews (see Appendix III) for obtaining qualitative data; market research in Manaus and Coari for obtaining market values of forest, cassava, and cattle products; an inventory database (i.e. the ESVD from TEEB) for obtaining ecosystem service monetary value estimates; and, through explorative studies many reported literature findings have been used in order to conduct the ecosystem-services valuation.

2.4 Data analysis

Data has been analysed by various means. The stakeholders and stakeholder groups were preliminarily assessed through brainstorming sessions. Interviews then were carried out following, where possible, a snowball-sampling approach. During fieldwork and interviews it became clear which stakeholders were most relevant considering the influence on and interest of three distinct land uses and changes in ecosystem services accordingly. Stakeholders were categorised according to scale (local-global), and were mapped according to their relative interest in, and influence on either of, or a combination of the three land uses and associated ecosystem services. This resulted in a influence/interest-matrix with stakeholders were assigned a position in relation to other stakeholders. This resulted in a matrix with two axes: from low to high influence and from low to high interest (see Section 3.3).

The responses from interviews were analysed in a qualitative manner by categorising answers in themes, where as follows a mix of respondent's interviews were summarised and described in a story-line manner according to theme (see Appendix III).

Concerning the ecosystem-services analysis, these are analysed in a descriptive manner, and for which where suitable have been supported with illustrations. The associated monetary values have mainly been presented in tables to give a clear, concise, and quick overview of the estimates. Each synthesis of results in which the simultaneous monetary value estimates have been presented in tables, are when deemed to be important for highlighting specific data, also translated in graphical representations. A data management plan is presented in Appendix VII.

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[5] NOAA (2019) *The National Oceanic and Atmospheric Administration*. From http://www.sfu.ca/~heaps/483/discounting.html.

3. Land uses and stakeholders in and near the study areas

3.1 Land uses in and near the study areas

Three different land uses in and near the study areas are identified from which each the ecosystem services, and monetary values are analysed. The three identified land uses include: (I) primary forest, (II) shifting agriculture (of cassava *Manihot esculenta*), and (III) cattle pasture (in the form of smallholder farming). The first land use (primary forest) because natural mature primary forest dominates in the study areas. The second land use is identified through field observations at a riverine community alongside the Urucu River, who have cleared forest adjacent areas in their livelihood surroundings. The third land use (cattle pasture) is identified through an explorative study, in which was found that the development of cattle pastures is a predominant cause of deforestation in Brazil (Fearnside 2005; Fearnside, 2008; McAlpine et al., 2010). It should be kept in mind that the north region of Manaus is prone to forest conversion into cattle pasture, whereas the southwest region of Coari is prone to forest conversion into shifting agriculture. Any form of deforestation within the boundaries of OV's primary forest (property) areas is considered illegal. The sections below elaborate upon each land use in more detail.

3.2 Descriptions and characteristics of the identified land uses

3.2.1 Primary forest

The first identified land use in terms of land cover is 'primary forest' (LU1), which is intact mature dense-canopy moist tropical broadleaf forest that is habitually found in abundance in and near the study areas. It has a composition and structure that predominantly reflects natural processes (Kormos et al., 2018). This primary forest which in fact is for the most part not a 'land use' because human species do not use it, is however considered as a land use in my research as the ecosystem services provided by the forest are, where applicable, valued in utilitarian sense. This land use refers to the intact forest that is currently standing on main lowlands at the time that it is not flooded by the *várzea* seasonal floodplain since a large part of the study areas is subject to this natural phenomenon, which means that it's seasonally inundated by river water.

Various equivalent terms exist for 'primary' forests like this such as "frontier", "virgin", "pristine", and "old growth". Nevertheless, the term 'primary' is used for the forest type in thesis research as it is the term that is recognised at the intergovernmental level (Kormos et al., 2018). *Primary forest* is defined by the United Nations Food and Agriculture Organisation (FAO) as "a naturally regenerated forest of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed" (FAO, 2012). To clarify what the key characteristics are of primary forest, the FAO (2012, pp. 7) has described these as:

- Natural forest dynamics, such as natural tree species composition, occurrence of dead wood, natural age structure and natural regeneration processes;
- The area is large enough to maintain its natural characteristics;
- There has been no known significant human intervention, or the last significant human intervention was long enough ago to have allowed the natural species composition and processes to have become re-established.

Note that concerning the latter characteristic, a few forest sites within the study areas have been subject to some disturbances. The main disturbances here involve forest clearances due to the várzea floodplain, and forest clearances by human induced activities such as oil-drilling measurements (e.g. by oil company Petrobras) and settlements by rural communities.

Primary forest in the study areas is merely considered as a land use because rural communities use parts of this forest to sustain their lives. For the most part of the primary forest in the study areas, there are no humans present. When considering primary forest as utilitarian, the values associated with the ecosystem services can be compared with the values of ecosystem services provided by different land uses. In this way it can be made explicit that using the forest for sustaining human lives can be done in a manner in which all life can thrive, in contrast to land uses that are established through forest conversions. But when areas of a tropical forest are considered a land use, some degree of human disturbance must take place in order to gather or harvest products that are naturally provided by the ecosystem (De Groot et al., 2010). It should be stressed that such disturbances are perceived here as harmonised human-environment interactions, which have little impact on the ecosystem from a long-term perspective. The idea of primary forest as a land use puts emphasis on eliminating the 'distinction' between humans and nature.

3.2.2 Shifting agriculture: cassava

The second land use identified is 'shifting agriculture', also defined as 'shifting cultivation'. Shifting agriculture in and near the study areas of my research is primarily practiced by rural communities which cultivate cassava (*Manihot esculenta Crantz*). The cassava although a woody shrub which is propagated vegetatively, is grown as an annual crop (Ratanawahara et al., 2001). The cultivation of cassava or called *manioc* in Brazil, is practiced by rural communities from which in my research are identified mainly as riverine communities with livelihoods alongside the Urucu River. Manioc is a staple food for rural communities in Brazil who rely on it economically (Souza, 2010). To establish a plot for shifting agriculture, rural communities clear primary forest by the slash-and-burn principle. This principle is performed by clearing trees with axe or machete, followed by igniting the trunks and vegetation debris which is usually performed prior to the start of the wet season (Faminow, 1998). The extracted timber is used for construction purposes (e.g. houses, canoes) within the village (Interview 15). The function of burning the cleared plot is to give the soil a fertile pulse as a boost of nutrients for improved crop growth. Shifting agriculture in the Brazilian Amazon is explained in more detail in Box 2.

Box 2: Shifting agriculture in the Brazilian Amazon

Shifting agriculture (also defined by others as 'shifting agriculture' or 'swidden cultivation/agriculture') is for thousands of years being practiced in forests around the world and is the main land use that transforms forest landscapes in riverine Amazonia (Pedroso-Junior et al., 2009; Jakovac et al., 2017). Many forms of shifting agriculture exist, but all are characterised by the principle of 'slash-and-burn' which is defined by Peters and Neuenschwander (1998) as: "a continuous system of cultivation in which temporary fields are cleared, usually burned, and subsequently cropped for fewer years than they are fallowed." The shifting-fallow system in the tropics consists of cultivation periods and fallow periods at which the latter involves the regrowth of secondary vegetation which is cleared and burned again after a few years have passed by. The longer the fallow period, the more forest biomass will return which means increased nutrient returns to the soil, when the slash-and-burn principle is performed again results therefore in increased crop productivity (Alves-Pinto et al., 2018). Because nutrient cycles are short in Amazon forest and soil nutrient richness depends on biomass accumulation, long fallow periods are important for maintaining crop yields (Fraser et al., 2012).

Shifting agriculture has expanded under government policy between the 1960s and 1980s which have stimulated colonisation of agricultural frontiers in Latin America as well as in Asia (Rudel et al., 2009; Jakovac et al., 2017). In Brazil, shifting agriculture in the form of cassava cultivation is often practiced by rural (i.e. riverine) communities who use rivers as a medium for transportation. The cassava is for rural communities in Brazil a staple food, from which the tuberous roots are processed into a flour product called 'farinha' (Alves-Pinto et al., 2018). From the 1990s onward, shifting agriculture has intensified in the Brazilian Amazon because of increased population density and increased market demand for farinha (Alves-Pinto et al., 2018; Jakovac et al., 2017). This has led to reduced fallow periods over recent decades. With fallow periods from over 10-20 years and some reaching up to 60 years, being reduced to periods of 3-5 years (Ghazoul & Sheil, 2010; Jakovac, 2015; Jakovac et al., 2016). Because of the relatively little biomass accumulation and therefore little nutrient returns into the soil, shorter fallow periods can lead to increased deforestation as new plots for practicing shifting agriculture need to be cleared. Yet, shifting agriculture has been an appropriate and relative sustainable land use system for a very long time (Ghazoul & Sheil, 2010), which in comparison with other deforestation practices (e.g. for cattle ranching and soybean cultivation at the 'Arc of Deforestation' in Brazil) contributes to landscape degradation minorly in the absence of expansion and intensification.

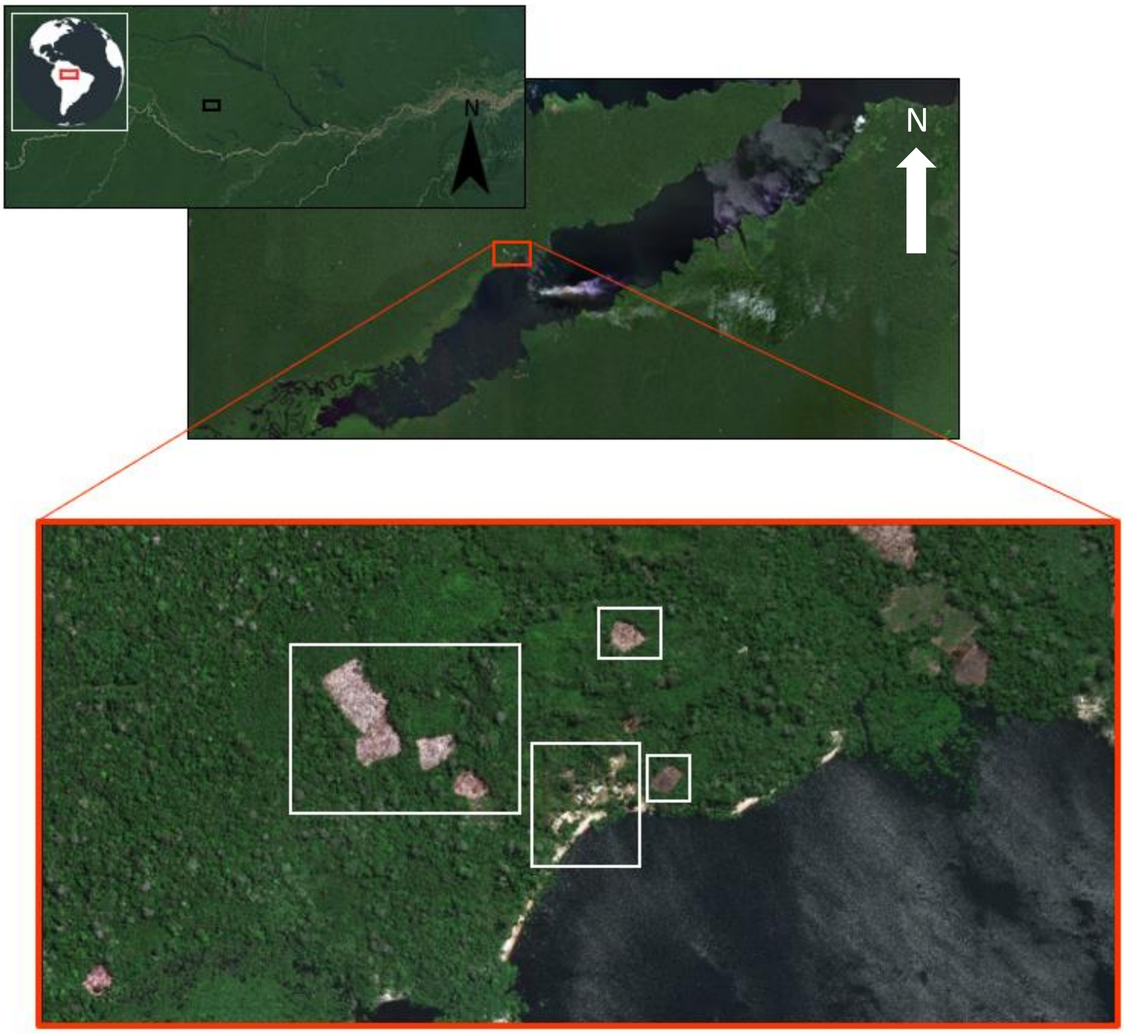

Figure 7: The Nossa Sénhora Nazare village alongside the Urucu River, with surrounding deforested patches in the northwest area. At least one of the deforested patches is currently used for a cassava culture (from Face the Future, 2018).

A rural people's plot to cultivate cassava crops often the size less than one hectare and is located in forest adjacent areas near community villages. One village (of approximately 20 – 25 people) typically has one to a few hectares for cultivation. However, after 2 to 5 years of cultivation (Silva et al., 2011), the soil is exhausted by the depletion of available nutrients. This drives the local people to shift to an adjacent forest area for creating a new plot for cassava to grow, using the same method over again. The local people leave the initial culture fallow i.e. for secondary vegetation to grow for restoring soil fertility. Site observations at one local community have exposed that what once was a cassava culture many years ago, now was used for cultivating banana crops. Here, a rotation of cultivation and a fallow period has been taking place in the same unit of land. This is considered as a form of shifting agriculture. It is however unclear whether shifting agriculture is being practiced among all rural communities that live in the region of Southwest Coari. If a community relies on the cassava as a food or income source, it is expected that expansion of the cassava culture through deforestation will take place. The fallow period in the Amazon region varies but is reported to be 5 years e.g. in Central Amazon regions while in certain traditional cassava cultivars the fallow period can be up to 10 years (Jakovac, 2015; Jakovac et al., 2016;). After a certain harvest and fallow cycle, the community at the Nossa Sénhora Nazare village uses the former cassava culture to cultivate banana crops. It is however unknown after how many cycles the cultivation of cassava crops changed into the cultivation of banana crops. Also, it cannot be stated that every cassava culture after left fallow will be used to cultivate bananas. Because the manioc is a staple and cash crop, it provides income to (riverine) communities. It is therefore expected that only certain cultures will be used for cultivating other crop types (e.g. banana), but that the cultivation of manioc will continuously be practiced as long as possible. Because it is unknown after how many harvest and fallow cycles the plot of land is used for cultivating banana crop instead of cassava crops, for the 20-year time period which is used for the ecosystem-services valuation in my research, it is assumed that during these 20 years merely cassava crops are cultivated. Note that the slash-and-burn agriculture is a long-standing tradition by forest and riverine communities (FAS, 2019)[6]. This type of agriculture is part of their culture and can from a socio-cultural viewpoint therefore be perceived as something that needs to be retained.

3.2.3 Cattle pasture

The third identified land use is 'cattle pasture' (LU3), because it is one that could possibly be a threat of deforestation to Opção Verde's primary forest areas in the future. The cattle in this land use is held by small farmers (referred to as 'small-scale farmers' or 'smallholders'), which clear forest areas of around 3 ha on average through the slash-and-burn principle (Muchagata & Brown, 2003). From the primary forest losses in Amazonia, the expansion of cattle pastures is the cause that predominates (Fearnside, 2005; Fearnside 2008) (Box 3). When interviews were carried out in Manaus, the local police emphasised that in the past deforestation for cattle pasture development was the primary cause of forest losses, but that to date deforestation for timber through (illegal) logging is the primary cause of deforestation in the Brazilian Amazon. Fearnside (2008) reported at the time that felling the forest indeed is the primary (direct) cause of forest loss in Brazil. The large majority of that cleared forest however, becomes cattle pasture (Fearnside, 2008; McAlpine et al., 2010). From this information can be stated that the direct cause of deforestation in Brazil is (illegal) logging, and the indirect cause of deforestation can be addressed to cattle pasture development. Therefore, the economic value of extracted timber by felling the trees in combination with the economic returns from the cattle pasture land use are both taken into account in the TMV.

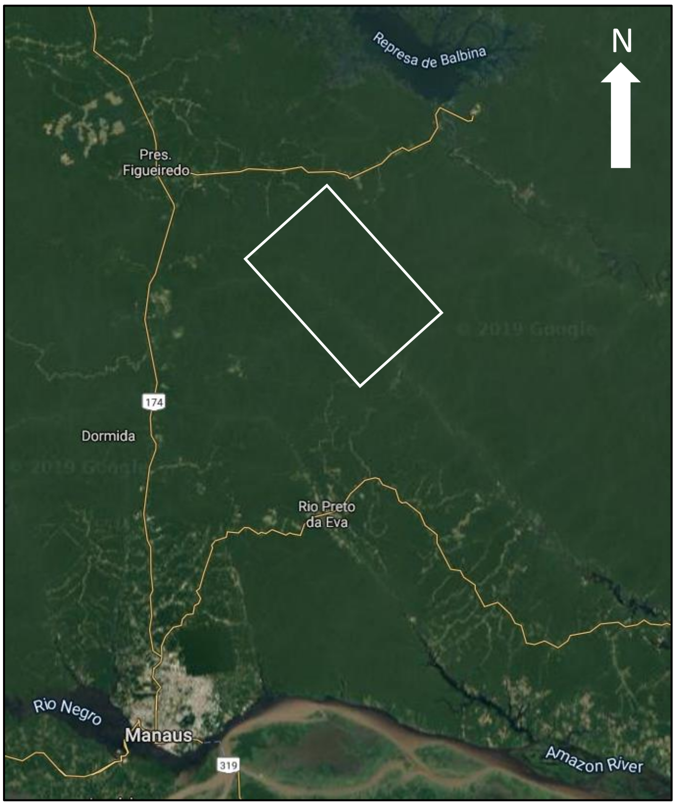

Figure 8: The BR-174 highway with a direct connectivity with Manaus (indicated with yellow line from Manaus vertical northward), with Opção Verde's forest areas located in east from the BR-174 highway within the white rectangle (satellite image from Google maps, 2019).

Small-scale cattle holders are responsible for some extensive deforestation at certain regions, while large-scale cattle holders are for the most parts of the deforested land in Brazil responsible (Laurance et al., 2002). Although

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[6] FAS Amazonas (2019) from http://fas-amazonas.org/.

in the southwest region of Coari no small-scale cattle ranching has been observed, a few cattle farms are located in the north region of Manaus (Figure 8). In specific for the region north of Manaus, the expansion of (small-scale) cattle pastures could be considered as a serious threat of deforestation at any point in time in the future. Two primary reasons explain this region could experience deforestation for cattle pastures. First, ranching is already taking place in the region which, due to possible rising global demands for cattle products (i.e. meat and dairy), could expand in terms of land area or intensify in terms of productivity. Second, the BR-174 federal highway is situated in the relative proximity of Opção Verde's forest areas which makes the region easier accessible for people to deforest nearby areas. Because the BR-174 is directly connected to Manaus (Figure 8), in and outflow of materials can be done in a rapid manner. On the other hand, because this highway functions as a transportation medium, it can also promote to transport other goods and materials such as non-timber forest products as it makes it relatively easy to get such products to markets. This however can also be an reason for cattle holders to increase their production. Either way, the highway can be seen as a stimulant to exploit forest nearby forest areas and as a possible threat that leads to increased deforestation in the future.

Box 3: Amazon forest conversion into cattle pastures as a threat of deforestation in north Brazil.

From the primary forest losses in Amazonia including deforestation for cattle pasture; croplands such as soy, cassava, maize, coffee, cacao; infrastructure development; and impacts from flooding from hydroelectric dams, and climate change, forest conversion for cattle pasture has predominated in the past (Fearnside 2005; Fearnside 2008). To date, land-use changes from forest to cattle pastures still contributes largest to deforestation in Brazil (Bowman, 2016). This major contribution to deforestation is reflected by the country's cattle herd, which is the largest on the global level (Charity et al., 2016). Fearnside (2008) reported that deforestation for cattle pasture has the tendency to increase in the future. Also, if increases in cattle pasture expansion will take place, it's worth mentioning that the Amazon is an attractive region for it (Barreto, 2006). The Amazon biome is attractive because in comparison to other regions in Brazil, the pastures in the Amazon have the highest productivity in terms of profit (Barreto et al., 2006). To keep cattle in the Amazon is so profitable because of the relative low land prices (Barreto et al., 2006). On the other hand, increased productivity of cattle ranching tends to be taking place in zones with suitable rainfall (which is between 1600 – 2200 mm/year) (Schneider et al., 2002). The Amazon forest is for 40 per cent of its total surface area subject to rainfall within this range (Schneider et al., 2002).

Furthermore, the Brazilian national law (under the 'Forest Code') stipulates that landowners are obliged to conserve 80% of the forest on their property in the Amazon region, and 20-35% in the Cerrado region (Soares-Filho et al., 2014). On one hand this law can contribute to the conservation of the majority of forest areas, while on the other hand it can also enable people to deforest their areas up to 20% in the Amazon region, and up to 65-70% in the Cerrado region. It is arguable whether these percentages as stipulated in the law, will not be exceeded. The Amazon forest region is vast with inland areas being difficult to access. This means that when deforestation activities are taking place, it makes it difficult to tackle these within a short term period.

3.3 Stakeholder analysis

A stakeholder analysis is carried out to identify which relevant stakeholders and stakeholder groups benefit from the ecosystem services provided by each distinct land use. Identifying relevant stakeholders in the context of ecosystem services assessments is important because it highlights which stakeholders could potentially be involved in decision-making and participatory processes, when Opção Verde's forest areas are being conserved or managed in a particular way (e.g. through a socio-ecological system). In the absence of a stakeholder analysis, there is a risk that (powerful) stakeholders can have a greater influence on decision-making and participatory processes than marginalised groups (e.g. rural communities without access to well-established social networks) (Reed et al., 2009, pp. 1935).

Following a systematic approach, stakeholders are classified from local to international stakeholders. In addition, the stakeholders are assessed and mapped on their relative influence on, and interest in primary forest (as a land use). This land use is explicitly chosen here because Opção Verde aims to conserve their primary forest areas. The stakeholders have been identified through interviews during fieldwork (for which some have been identified by the 'snowball effect'), through conversations with key informants, and members from Opção Verde. All stakeholders and beneficiaries are mapped in an interest-influence matrix (Figure 9). In this matrix the stakeholders are placed according to the degrees of how they benefit from, to what extent they are interested in, or how they can have influence on (changes in) ecosystem services that are provided by the Amazon primary forest in the study areas of my research. The colours indicate in what manner the stakeholder could be engaged when involvement is going to take place.

The stakeholders, their main benefits from and interest in specific ecosystem services, and relative influence on the conservation of primary forest areas are described below and are categorised from the local to global scale, including: rural communities; environmental non-governmental organisations (ENGOs); research institutions; timber companies; oil and mining companies; marketers and traders; smallholders (cattle); government agencies; the Brazilian central government; and the international community. There are also stakeholders and stakeholder groups who perform illegal activities (e.g. illegal harvest and trade of timber, bushmeat trade, drugs) which affect primary forest areas. Illegal activities can also have counter-effects on primary forest conservation and protection efforts. Because a mixture of distinct illegal activities is performed by a different set of stakeholders and stakeholder groups that are difficult to grasp in terms of their relative influence on and interest in primary forest. These have not explicitly been taken into account in the influence-interest matrix.

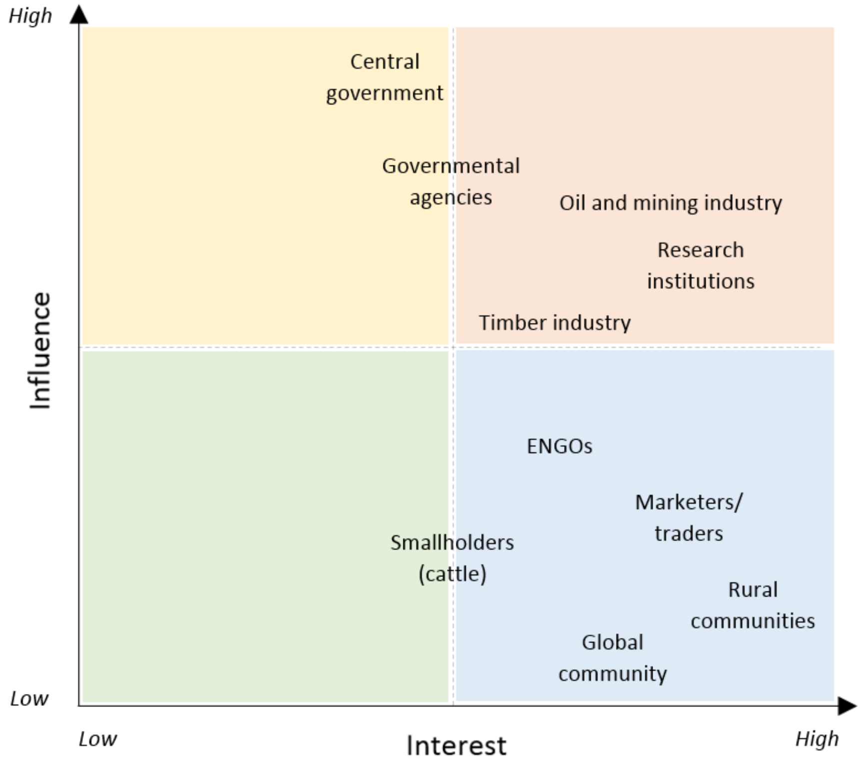

Figure 9: Influence-interest matrix of relevant stakeholders and stakeholder groups who benefit from, are interested in, or have influence on the ecosystem services provided by primary forest in the Brazilian Amazon. The colours represent possible engagement strategies, with green = 'monitor', yellow = 'keep satisfied', red = 'manage closely', blue = 'keep informed'.

Local stakeholders

Rural communities (i.e. forest and riverine) benefit primarily from the ecosystem services provided by both the primary forest and the cassava cultivation land uses. This stakeholder group is dependent on the proper functioning of the Amazon tropical forest, because it provides them provisioning services in the form of food, water, raw materials, and medicinal resources. Rural communities also benefit from forest converted landscapes through the slash-and-burn principle, in order to practice shifting agriculture. This form of deforestation does have adverse effects on the services provided by small plots of primary forest, but in turn the shifting agriculture land use provides rural communities cash crops that are from economic importance. The principal adverse effect which a rural community will experience from such forest conversion is that all naturally occurring provisioning services are lost by the clear cut and burning of a plot of primary forest. It was observed at the Nossa Senhorá Nazaré community alongside the Urucu River however, that only a few patches were deforested of which each a few hectares maximum. This means the forest surroundings were cleared to such extent that the community will experience significant losses in provisioning services. This also demonstrates that rural communities often have one to a few plots of not more than 1 ha per plot cleared for shifting agricultural land (i.e. to cultivate cassava crops). Therefore, it is reasoned that in general, rural communities negatively impact the primary forest areas in their livelihood surroundings to a small extent in terms of forest conversion into shifting agricultural land. As a consequence, provisioning services will be lost to the temporal scale the changed land use is managed and secondary vegetation has not been regrown to a former mature biomass stand. It has also significant effects on other service categories, which will be explained in more detail in Chapter 4. There is also little known about what the consequences are from the game activities (or hunt for bushmeat) of rural communities on the tropical forest, and on biodiversity. Further research on this could provide new insights.

Environmental non-governmental organisations in the context of my research are considered those which aim at the protection and conservation of the Amazon tropical forest and its biodiversity. These organisations operate on the regional to local level. ENGOs benefit from the mere knowledge that given ecosystem services are provided by the proper functioning of the Amazon tropical forest. In economic terms, ENGOs benefit from ecosystem services which are considered as bequest and existence value (Section 2.2.4). The bequest value refers to all ecosystem services, and the existence value refers primarily to habitat services. Regarding the shifting agriculture land use, both forest clearances as forest conservation are brought about by rural communities. ENGOs could therefore be involved in projects together with rural communities who practice shifting agriculture. This to establish socio/cultural-economic projects for increased maintenance of the tropical forest and its biodiversity while simultaneously increasing the effectiveness and efficiency of their agricultural activities. Eventually, this could lead to reduced forest losses and increase protection of Amazon forest.

Research institutions are considered beneficiaries in terms of various ecosystem services because of their (potential) involvement in a wide variety of projects. It depends on the field of research and type of project, from which types of ecosystem services can be benefitted from by what sort of research institution. For example, the National Institute of Amazonian Research (INPA), benefits from the services provided by any type of landscape within the Amazon forest context, depending on the research that is being carried out. Other research institutes may benefit from ecosystem services that derive from a landscape within a social-ecological context (e.g. my research). From a different angle, stakeholders who are involved in pharmaceutical research projects can be interested in intact primary forest. For example, my research provides a list of various medicinal plant and tree species that can be found in intact primary Amazon forest (see Section 4.1.4 and Appendix IV), while it is expected that there are many plant and tree species with medicinal properties still undiscovered to date. This is likely also the case for animal species. The main interest of research institutions is therefore likely in projects which involve at least to some extent intact primary forest.

Timber companies are considered to be primarily interested in, and benefit from the timber stand in primary forest areas. Although it is illegal to extract timber from Opção Verde's forest areas, the timber industry in Brazil has a highly possible timber inflow for which illegal logging activities are taking place. Therefore, it should be kept in mind that mature primary forest is attractive for the timber industry (or at least a certain part of the chain i.e. for those who conduct illegal logging activities). Opção Verde's forest areas in the southwest region of Coari are however only accessible when the Urucu River is used as a medium for transportation, thus by boat. This means that it takes some time for illegal loggers to conduct their activities. This does not mean that there is no risk present, but it is expected that this region is less prone to illegal logging activities than Opção Verde's forest areas in the north region of Manaus (where a highway is situated in the west).

Oil and mining companies are interested in natural reserves (below-ground) which do not necessarily relate to a particular land use but do refer to provisioning services (i.e. raw materials). Both industries are rather interested in who factually is the landowner of those areas, where reserves are possibly present. For example, oil or mining drilling activities have taken place at several sites in Opção Verde's forest areas for which forest had been cleared. The foundation found out about the forest cleared 'patches' sometime later through satellite observations (Face the Future, 2018). Since any deforestation is considered illegal, the crux was that the former owner of the forest areas which are to date property of Opção Verde, had made certain agreements with an oil or mining company. These agreements (for which the landowner gets well paid) made happen that a company or multiple companies could (legally) deforest areas for drilling purposes. This means that there is an incentive for landowners to make agreements with oil or mining companies. Therefore, industrial companies do not directly benefit from an ecosystem service in the context of my research but do form a beneficiary and stakeholder when a particular land use is (partially) released to them. In addition, drilling and mining activities can have detrimental effects on the environment.

Marketers and traders are considered stakeholders because they benefit from the provisioning services provided all three land uses addressed in my research. Primary forest provides services that are traded on markets in Manaus and Coari in the form of, among others, fruits, nuts, latex, medicinal resources. From cassava (derived from shifting agriculture), farinha is made which is sold on markets in Manaus abundantly. From cattle pastures, smallholders transport cattle products to markets e.g. in Coari and Manaus (which in Coari is primarily meat). This means that it depends on what type of product the marketer sells or trader trades in order to perceive them as beneficiary to a related land use. However, the majority of the markets in Manaus and Coari offered fruits and nuts from which many derive from primary forest areas. Therefore, the main benefits for the marketers and traders as stakeholders from any land use are assumed to be associated with products which primary forest provides. Considering primary forest products, marketers and traders are dependent on the continuous supply of such. Therefore, they benefit from a stable functioning ecosystem which' benefits are related to regulating-, and habitat services. To this end, the majority of the marketers and traders in northern regions of the Brazilian Amazon primarily benefit from the conservation, maintenance, and use of primary forest areas. There is an upcoming market for 'honest', transparent, and sustainable forest products in Western countries, for which mainly intact and healthy functioning ecosystems are necessary for providing such products.

Smallholder cattle farmers are considered an economic beneficiary from the moment onward when forest is cleared, and the altered plot of land that is converted into cattle pasture is functioning. Smallholders primarily benefit from the provisioning services which are provided by the cattle pasture land use (i.e. cattle products such as meat, milk). One can also argue that smallholder cattle farmers are interested in primary forest areas because these can be converted into cattle pasture which in the same time could provide revenue from the extracted timber. From an ecological viewpoint, deforestation means that various ecosystem services are being affected (e.g. regulating-, and habitat services), and some are being lost on the local scale (e.g. habitat services). This can have adverse effects on the smallholder. For example, smallholders (like any other type of farmer) depend on regional climatic conditions as these affect their farmland. A certain amount of rainfall is considered suitable for maintaining cattle pasture vegetation in the Brazilian Amazon (Section 2.2.2). But deforestation contributes to increased atmospheric greenhouse gas concentrations, which in turn could lead to climate drying. Models have predicted that climate drying can lead to reductions in rainfall (Cox et al., 2000; Cox et al., 2004; Friedlingstein et al., 2006). As a consequence, reductions in rainfall could be causing difficulties for smallholders to maintain their cattle pastures in the future which consecutively could have adverse impacts on their productivity. There are more examples in which can be explained that forest conversions (in increasing amounts) could eventually have adverse effects on farmlands of any type. Therefore, smallholders are to some extent dependent on the functioning of the ecosystem which essentially regulates (regional) climatic conditions. Indeed, smallholders are considered beneficiaries (i.e. from their own established provisioning services) but perhaps for a limited time span. In addition, smallholders but also other stakeholders and stakeholder groups are also considered as losers here because various services are lost or degraded in ecological terms, when forest conversion into cattle pasture has taken place.

Government agencies in general do not necessarily directly benefit from ecosystem services (except for 'return' systems e.g. payments-for-ecosystem services or 'reducing emissions from deforestation and forest degradation' REDD+ payments) provided by any land use considered in my research. From a forest conservation viewpoint however, various government agencies in Brazil can be involved in cooperative projects to conserve and protect the Brazilian Amazon. Examples of government agencies which are considered for involvement can be: the Institute of Environmental Protection of the Amazon (IPAAM); Municipal Secretariat of Environment and

Sustainability (SEMMAS); the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA[7]), and also the Federal Police (Polícia Federal). These agencies have to some extent certain influence in the protection and conservation of primary forest, depending on their role in the wider context of 'conservation' and 'protection'. For example, the Federal Police can primarily be interested in putting a halt to illegal deforestation, while IPAAM can be interested in monitoring environmental impacts as a consequence of human activities.

National stakeholders

The Brazilian central government mainly benefits from intact primary forest, taking into account the various ecosystem services (see Section 2.2.3). The government also has a high influence on the protection of the forest (as it has the power to delegate). The government can also play an important role in supporting activities that can either be beneficial to some services and disadvantageous to other (e.g. financial aid for conservation efforts, or supporting agricultural activities through subsidies for which deforestation has to take place). The influence of the central government on how land is managed is considered to be relatively high. In the past months, the government has emphasised on increasing economic developments in the Amazon region. This can have consequences for the functioning of the tropical forest, and in turn can have effects on any other stakeholder or stakeholder group.

International stakeholders

The international community can be considered a beneficiary who primarily benefits from intact primary forest. The benefits are related to all services across the service categories provisioning, regulating, habitat, and cultural. The services that are benefitted from by the global community can mainly be assigned to the healthy functioning of the tropical forest which is especially true considering the increasing amount of degraded landscapes across the globe for which intact Amazon forest can provide still many goods and services (e.g. Europe has cleared the majority of its forests in the past). In terms of provisioning services, timber from the Brazilian Amazon can be seen as a major good that is being exported to areas across the globe. This however also puts pressures on the tropical forest because of the international timber demand. Concerning regulating services, climate regulation for example, is becoming increasingly valuable to the global community from a forest conservation viewpoint as the forest functions as a major climate regulator (i.e. as a carbon sink, which in turn can be seen as a way of climate change mitigation). Concerning cultural services (e.g. recreation, eco-tourism, spirituality and others), these are valuable to people which is exemplified in the quantities of tourists who visit the Brazilian Amazon forest in particular.

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[7] The influence of IBAMA as the environmental body of the Brazilian government should be considered with care when they are involved in projects in which is aimed at forest conservation and protection because in the past in 2005, the Brazilian magazine *Veja* reported that since the year 2003 over 60 employees from IBAMA were charged with corruption crimes (from Brito & Barreto, 2006, pp. 4; source *Veja*: Coutinho, L. As 7 pragas da Amazônia. Revista Veja. 12 December 2005, 102-112).

4. Ecosystem services and monetary values of primary forest

The Amazon moist tropical forest provides a wide range of services and benefits which contribute to human wellbeing on different scales. This means that there are services where for example primarily rural communities benefit from (e.g. fruits), and that there are services where the regional, national, or global community benefits from (e.g. Brazil nuts; uptake of atmospheric carbon by vegetation which in turn decreases atmospheric greenhouse gas concentrations). In this chapter, a variety of ecosystem services which one hectare of Amazon primary forest in the study areas provides, are analysed and valued monetarily. For the ecosystem-services analysis, the TEEB classification is followed, in which a distinction is made between provisioning services (Section 4.1), regulating services (Section 4.2), habitat services (Section 4.3), and cultural services (Section 4.4). The provisioning services include: fruits; nuts; game species; water (supply); raw materials; and medicinal resources. The regulating services include climate regulation, and pollination. The habitat services category includes merely the genepool protection service, and the cultural service ‘recreation and eco-tourism. Although each service is monetarily valued separately, it should be understood that in fact all services are interconnected which is especially true for the Amazon tropical forest services since these derive from the complex interlinkages and interactions of the ecosystem’s underpinned biophysical structures and processes. Therefore, the associated values are rough estimates in which part of the complexity of the ecosystem functioning are documented and translated in monetary terms.

4.1 Provisioning services

The Amazon tropical forest provides a diversity of products which can roughly be split in timber, and non-timber forest products (NTFP). For traditional livelihoods, NTFP are from great importance economically, socially, and culturally (Lopes et al., 2018). In this section, the following provisioning services are addressed: food (i.e. fruits, nuts, and game species); water (supply); raw materials (i.e. timber, and rubber from latex); and medicinal resources. In Table 4, the monetary values of the provisioning services from the primary forest land use are presented. The explanations for the calculations are given in the following subsections.

Table 4: Provisioning services provided by Amazon primary forest including: food (i.e. fruits, nuts, bush meat); water; raw materials (i.e. timber, latex); and, medicinal resources.

Number	Ecosystem service	Specification	Quantity (average harvest ha^{-1} year^{-1})	Monetary value average (US$ ha^{-1} year^{-1})^{a}
1	Food			
	Fruits	Açaí	672 kg	290
		Bacuri	155 fruits	10
		Burití	2,600 fruits	57
		Guarana	0.3 kg	1
		Jatobá	20 fruits	2.6
		Patauá	768 kg	15
		Piquiá	122	16
		Tucumã	1,125 fruits	122
		Uxi	450 fruits	101
	Nuts	Brazil nut	31 kg	53
	Bush meat (game species)	Armadillos, deer, pigs, rodents	0.7 kg	1.8
2	Water	Water supply from igarapés	41% of precipitation returns to igarapés	<0.00001
3	Raw materials			
	Timber	Harvest based on regeneration rate	0.5 m^3	307
	Latex	Latex (liquid)	4.5 L (1.5 kg dry rubber)	3
4	Medicinal resources	Bioprospecting as a function of endemic species’ density in Amazonia’s western uplands	0.001 endemic species	24

[a] The 2019 currency exchange rate of 1 BRL = 0.2602 USD (OANDA, July 3rd 2019) is used for converting Brazilian Real into United States Dollars, and is from here onward used as the currency exchange rate for all other monetary value conversions. From https://www1.oanda.com/fx-for-business/historical-rates?view=graph&base=BRL&quote=USD&duration=90.

4.1.1 Food

The Amazon forest provides an almost unlimited source of provisioning services which are still to date an important part of human diets (De Groot et al., 2002). It provides provisioning services in the form of a wide variety of fruits and seeds, nuts, palm hearts, and game species. The forest products that are addressed here in the economic valuation of the primary forest land use are from considerable importance to either marketers or traders at local markets in Manaus and Coari, or to forest and riverine communities with, in the context of my research, livelihoods alongside the Urucu River in in the southwest region of Coari. Note that there is a substantial amount of forest products not considered in the economic valuation here because of the lack of data (i.e. species distribution, density, and productivity) for many fruits, as well as due to time constraints for conducting comprehensive fieldwork analyses to obtain such findings. A comprehensive list with provisioning services i.e. fruits from Brazilian Amazon primary forest that have been considered for my research is presented in Appendix I. The provisioning services food (fruits, nuts), water, raw materials (timber, rubber), and medicinal resources are explained and valued in monetary terms below, respectively.

Figure 10: Inhabitant of the Nossa Senhorá village alongside the Urucu River, harvesting a clump of açaí fruits with a machete.

1. **Fruits**

Açaí (Euterpe oleracea Mart.)

There exists a wide diversity of açaí palm tree species, but three are considered to be from commercial importance which include the: *Euterpe oleracea, Euterpe precatoria,* and *Euterpe edulis* (Schauss, 2013). The Euterpe oleracea açaí palm is the most famous due to its ample availability and traditional use in the Amazon (Schauss, 2013). The açaí palm (*Euterpe oleracea*) can be found in abundance in the estuarine floodplain forest, and which' tree density varies from area to area depending on environmental and anthropogenic factors (Brondízio, 2002). At riverine communities some solitary açaí palms can be found at their livelihood surrounding environment, because the fruit can be made into a juice product that is from considerable economic importance. Açaí is mostly being sold in the form of (thick) juice, or for example used in deserts. To produce juice from the açaí, the fruit is (manually) sieved which results in the pulp to be pressed through. The seeds are rather large which therefore per fruit unit contains little amount of pulp. Açaí has a colorant that is comparable to a blackberry fruit, and when eaten fresh it leaves you with a dark-purple mouth for a little while. The açaí tastes rather 'healthy' than one would assume from a berry shaped tropical fruit. The seeds are often used to make handicrafts such as jewellery and sold on markets (e.g. the Adolpho Lisboa in Manaus).

It takes about 4 to 5 years before an adult açaí palm bears fruits. It is assumed that the açaí palm trees which grow in the primary forest land use for my research are all already mature and productive. One palm tree produces on average 4-8 fruiting stems per year, with each fruiting stem bearing a clump of 4 kg of fruit (Janick & Paull, 2008; Oliveira & Schwartz, 2018). This gives per tree an annual productivity range of 16-32 kg fruits. With on average 28 açaí *Euterpe oleracea* palm trees per hectare in unmanaged forests (Shanley, 2011) (meaning that human interference does not take place[8]), gives a productivity of 448-896 kg/ha/year açaí fruit. Thus on average results in 672 kg of açaí fruit/ha/year.

Valuation

Açaí fruit is sold on markets in various product types (e.g. fresh fruit, juice, pulp). To obtain the value according to the most sustainable-use level, the value of fresh fruit is used since it is sold in reusable baskets without any additional packaging material. Each basket full of fruits weighs about 14-15 kg (Shanley, 2011), thus on average about 14.5 kg. This results in a possible (average) yield of 46 baskets of açaí fruits/hectare/year. Market prices of açaí fruit vary, which mainly fluctuate due to seasonal changes (i.e. the start of the season (August), or the end of the season (January). The average value in 2007/2008 for one basket of açaí fruits was 6.25 USD (taken from 3.5 USD/basket in August, and 9.0 USD/basket in January) (Shanley, 2011, pp. 159). Using this data, the monetary value estimate for the açaí ranges from 193-386 USD/ha/year, with an average monetary value of 290 USD/ha/year.

Bacuri (Platonia insignis)

The bacuri tree is native to the Amazon (Jacomino et al., 2018). The bacuri tree density in unmanaged primary forest is estimated to be 0.05-1.5 trees/ha (Shanley, 2011). On average, a bacuri tree can produce 400 fruits in a per year, although bacuri trees rest from one year to the other with fruiting (Shanley, 2011). Using this data, it is estimated that the bacuri tree produces 10-300 fruits/hectare. To estimate the economic value of the bacuri tree per hectare of Amazon primary forest, the value of 2.0 BRL per 8 bacuripari fruits (sold on local markets in Manaus) is used from Rabelo (2012). This gives a monetary value range estimate of 2.5-75 BRL/ha/year or 0.7-20 USD/ha/year. This gives an average value estimate of 10 USD/ha/year.

Burití (Mauritia flexuosa)

A study by Peres (1994) has determined that a burití palm tree can be found in densities of 1 tree per 1.5 hectare in Brazilian lowlands (e.g. upper areas near the Urucu River). This comes down to 0.67 trees/hectare. Burití trees when mature, can produce on average 5-7 clusters per year, with 400-900 fruits per cluster (Bezerra et al., 2014). This means that one hectare of primary forest could produce on average 1600-3600 fruits per ha/year. With a market value of 2 BRL per 24 fruits (Rabelo, 2012), the monetary value of the burití palm tree is estimated at 133-300 BRL/ha/year or 35-78 USD/ha/year. This gives an average value estimate of 57 USD/ha/year.

Guarana (Paullinia cupana)

Guarana (Figure 11)[9] is a native species to the Brazilian Amazon, and is from significant importance from both an economic, and social viewpoint (Atroch & do Nascimento Filho, 2018). Indigenous people have used the guarana seeds to produce beverages for centuries long for its stimulant effects, as the seed contains caffeine (Blancke, 2016).

The guarana drink, which often offered in soda-like cans, is sold at many places in Brazil since it is a highly famous soft drink in the country. Because guarana is so popular in Brazil, the vine it is largely being cultivated (Ângelo et al., 2008). Although Brazil knows many plantations for growing guarana vines, it grows naturally in the Amazon lowlands (Blancke, 2016). Due to the lack of data on the natural growth density of the guarana vine in Amazon primary forest, the density of cat's claw (*Uncaria tomentosa*) is used instead because both are climbers. The density of cat's claw in terra firme forest is 1.7 vines/ha (Shanley et al., 2011). The yield of one guarana vine under breeding circumstances is reported to be 200 g (Rodrigues et al., 2018), which is assed to be an annual value. The 2011 market price of the seed was 7.45 BRL/kg (Schimpl et al., 2013). Using this data, the monetary value of the guarana vine is estimated at a monetary value of 2.5 BRL/ha/year (equal to 0.7 USD/ha/year).

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[8] Note that throughout the past, human influence e.g. manual seed dispersal could have been taken place at forest areas where people lived. Therefore, the values of the natural distribution and density of certain fruit bearing trees, vines, or plants that are used in my research for the economic valuation of the primary forest land use could have been influenced by human induced activities in the past.

[9] Guarana seeds photo taken from http://bosque-santa.blogspot.com/2012/01/guarana-blossoms.html.

Figure 11: Guarana fruits with and without peel (from bosque-santa, 2019)

Jatobá (Hymenaea courbaril)
The jatobá tree can rarely be found with a density of 0.05 trees per hectare. It is argued that this might be due to increased jatobá timber demands in the past (Shanley, 2011). Fruit production can vary largely per tree. With on average a productivity of 800 fruits/tree, and in favourable conditions one tree can reach up to 2000 fruits (Shanley, 2011). However, the jatobá tree does not produce fruits every year but usually rests and produces fruits from one year to another (Shanley, 2011). Therefore, it is estimated that the jatobá tree produces on average 400 fruits/tree/year. Calculating this to one hectare of primary forest, results in an estimate of 20 fruits/hectare/year. With a local market value in Manaus of 1.0 – 3.0 BRL per 12 jatobá seeds, gives a monetary value range estimate of 0.4-2.2 USD/ha/year. This gives an average value estimate of 2.6 USD/ha/year.

Patauá (Oenocarpus bataua)
Although sparsely found in upland areas, the patauá palm occurs in abundance in lower areas such as swamps or alongside streams (Shanley, 2011). In the dry forest areas from the Chico Mendes Extractive Reserve, a number of 16 palms/ha were reported (Shanley, 2011). This reported value is used for the primary forest areas of my research in the absence of other reported findings. It takes however 8-15 years for a patauá palm to bear fruit (Gomes-Silva, 2001). It is assumed that when a patauá tree will be found in the study areas of my research, it already bears fruits. Fruit productivity can reach up to 3 bunches/year with approximately 16 kg/bunch (Clay et al., 1999). Local markets in Manaus measure the patauá fruit per litre, with a value of 1 BRL/litre of patauá fruits (Rabelo, 2012). One litre is about 13 kg of fruit (Shanley, 2011). With 768 kg of fruit/ha/year (equal to 59 L/ha/year) and using the market value, gives a monetary value estimate of 59 BRL/ha/year or 15 USD/ha/year.

Piquiá (Caryocar villosum)
The density of the piquiá tree is 0.4-0.6 trees/ha although at some areas with presumably some indigenous management can occur in 2-7 trees/ha (Shanley, 2011). It seems difficult to estimate the annual productivity of piquiá fruits per tree since each tree produces a different amount, and most trees produce every other year (Shanley, 2011). Yet a fruit production was measured over a four-year time period by Shanley (2000) and reported an average annual productivity of 122 fruits. This gives a productivity range estimate of 50-73 fruits/ha/year. With a market price of 1.0 BRL per single fruit at the Rural Market in Coari, the monetary value of the Piquiá in primary forest is estimated between 50-73 BRL/ha/year or 13-19 USD/ha/year. This gives an average value estimate of 16 USD/ha/year.

Tucumã (Astrocaryum aculeatum; syn. *Astrocaryum tucuma)*
The tucumã (Figure 12)[10] is a palm fruit that is important to the Brazilian cuisine. It is a small round fruit from which the relative hard inside is usually sliced and eaten fresh in dishes such as tapioca, or sandwiches. At almost every market in Manaus and Coari the tucumã can be found. It has quite a 'creamy' or 'fatty' taste because of its oleic content. Various wild animals such as macaws, armadillos, monkeys, deer, peccaries, and agouti like the tucumã fruit and seed (Shanley, 2011). Agouti are the primary tucumã seed dispersers which they do so by

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[10] Photo from Pinimg (2019) at https://i.pinimg.com/640x/c6/77/21/c6772171cdece22b3d3562d6cf98f74c.jpg.

burying the seed for later consumption, which result in some of the seeds to sprout (Shanley, 2011, pp. 210). Because various animal species consume and disperse tucumã seeds, it can be that this has contributed to the relative high density of tucumã palm trees which can currently be found in Amazon primary forest.

Figure 12: Tucuma fruits in peal and unpealed (from Pinimg 2019).

In primary forest areas, the tucumã palm tree is solitary and can be found in quantities up to 10 adults/hectare (Costa et al., 2002). On average, a palm produces 2 to 3 bunches fruit per year with each bunch containing an average of 200-400 fruit units (although bunches can contain as low and high as 35 to 700 fruit units) (Shanley, 2011; Lira et al., 2013). Costa and Duarte (2002) reported that in primary forest areas the tucumã tee can reach up to 10 individuals per hectare, whereas Schroth et al. (2006) state that in disturbed areas the tree density can be very high (which can likely be owed to seed dispersal by rodents and that germination occurs by fire e.g. because of slash-and-burn agriculture), while the tree density in primary forest is rather low. In order to not overestimate the tree density here a density of 1-2 trees per hectare is used; based on “the very low” statement of Schroth et al. (2006), and the reported value of 10 trees/hectare that could be found in primary forest by Costa and Duarte (2002). This gives a productivity of 750-1500 tucumã fruit units/ha/year. The market price of tucumã (Manaus Modern Fair) is 5 BRL/12 fruit units. This gives a monetary value range estimate of 313-625 BRL/ha/year or 81-163 USD/ha/year. This gives an average monetary value estimate for the tucumã of 122 USD/ha/year.

Uxi/Uchi (Endopleura uchi)
The uxi tree can be found in a density of 0.03-3.0 trees per hectare in forests gives an average tree density of 1.5 per hectare (Shanley, 2011). The majority of the trees produce fruits annually of approximately 1000 fruits per tree, yet some can take a year of rest (Shanley, 2011). When a tree takes a year rest in producing fruits, its productivity of that year falls to between 400-500 fruits (Shanley, 2011). It is assumed that a rest year takes place once every five years (Shanley, 2011). This means that on average over a time period or 5 years, a tree produces 1290 fruits/ha/year. With a local market value in Manaus of 3.0 BRL (the average of 2.0 – 4.0 BRL) per 10 fruits (Rabelo, 2012), the uxi/uchi tree in forests is estimated at a monetary value range of 258-516 BRL/ha/year or 67-134 USD/ha/year. This gives an average value estimate for the uxi/uchi tree of 101 USD/ha/year.

There are some fruit trees that have been included in the ecosystem services valuation-analysis but have been disregarded eventually. Because for many fruit species reported data i.e. on density and productivity was lacking, monetary valuation analyses could not be conducted. A list of all fruits that were considered is presented in Appendix I. A few fruit species (i.e. acerola, rambutan, and titica) which are from considerable socio-economic importance in Brazil and therefore worth mentioning, are described below. These are however not valued in monetary terms and thus not taken into account in the TMV of the primary forest land use.

Acerola (Malpighia glabra)
The acerola tree can be found in natural areas in Brazil, while the tree is likely to be native to the Caribbean and the Antilles (Moura et al., 2018). Brazil is the largest producer and exporter, as well as the largest consumer of acerola fruit on the global level (Sazan et al., 2014). One of the primary reasons that Brazil is such an important player on the ‘acerola-market’ is that the country kept expanding its acerola cultivated area from 1988 onward (Moura et al., 2018). Because the acerola tree is not native to the Amazon forest, and because it is difficult to

trace whether the acerola fruits that are being sold on markets in e.g. Manaus come from cultivated areas or not (which is assumed to be likely the case for the majority of the acerola fruits that are being offered), the acerola fruit is not taken into account in the economic valuation of the primary forest land use.

Rambutan (Nephelium lappaceum)

The rambutan (Figure 13), a lychee-like fruit, is being sold on various markets and by street vendors in Manaus. However, the fruit originates from western Malaysia and Singapore (Blancke, 2016). This fruit is therefore not native to the Amazon in Brazil. Consequently, it is assumed that the rambutan fruits that are being sold on local markets e.g. in Manaus, are not gathered from forested areas but possibly coming from cultivated areas. The rambutan is therefore not taken into account in the valuation of the primary forest land use in my research.

Figure 13: Rambutan fruits sold at municipal markets in Manaus Brazil (author's photo).

Titica (Heteropsis spp.)

Titica fruit is not taken into account in the economic valuation of primary forest here because a study by Plowden et al. (2003) found that with experimental cutting of mature titica roots, the vine only showed regrowth at 16% of 115 potential harvesting roots on host trees. Because harvesting titica roots could have severe impact on its growth or regrowth, this species is not considered as a fruit to be utilitarian in my research.

1. Nuts[11]

Brazil nut (Bertholletia excelsa)

Brazil nuts (Figure 14)[12] are almost primarily sourced from trees situated in natural areas (Ghazoul & Sheil, 2010). A Brazilian law ratified in 1965 forbids to cut down Brazil nut trees (Sthapit et al., 2016), which therefore many trees to date still stand their ground. Sometimes the force of the law can be observed for example when roads are built around Brazil nut tree. The Brazil nut can be an important protein source for rural communities. When it is difficult to get protein from fish and terrestrial animal species, the Brazil nut can function as a substitute for the animal protein. In general, the Brazil nut is mainly used as a forest product which is traded on markets e.g. in Manaus and Coari, because of its cultural and economic importance. The productivity of the Brazil nut tree highly depends per tree and at which location the tree grows. Some trees don't even produce any nuts at all or could rest from one year to another with nut production (Interview 8). The quantity of Brazil nuts also depends on climatic factors, e.g. on the local temperature (Interview 11). Both Brazil nuts and açaí berries are products that give favourable profits when sold on markets in Coari (Interview 11). Aniude, a villager from the local community at Esperanza stated that "there is a large amount of Brazil nut trees in the forest." However, he also stated that "there are no Brazil nuts this year" (Interview 16), meaning that there is zero nut productivity. Interviewee 10 stated that: "the Brazil nut is, together with açaí, cacao, guarana, and coffee, the most valuable product to sell on a market in the country." Because the Brazil nut is a valuable product both culturally and economically, one can question why the Brazil nut tree is not domesticated. The answer to this question is twofold. On one hand, the tree grows so slow that it takes a long time before the tree could possibly bear fruits. On the other hand, the Brazil nut productivity is dependent on large-bodied solitary wild bee pollinators, which

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[11] The Brazil nut is a forest product from considerable economic and social importance. Other nut species (e.g. cashew) that are sold on local markets could possibly come from cultivated areas (Dendena & Corsi, 2014). Therefore, merely the Brazil nut is taken into account in the economic valuation of primary forest as a land use in my research.

[12] Todavida (2019) photo (left) from https://todavida.de/brazilnutstree/.

mainly exist in areas with (intact) natural forest, and which are relatively difficult to manage in the absence of its natural habitat (Ghazoul & Sheil, 2010, pp. 336).

Figure 14: The brazil nut. Left: intersect with brazil nuts in their shells and in the coconut-like capsule (from Todavida, 2019). Right: brazil nuts in their shells and cut open from their shells in plastic bags, ready to be sold at the Manaus Moderna market (author's photo).

Valuation

The density of the Brazil nut tree in primary forest varies widely, which can be 0.1 trees/hectare or up to 29 trees/hectare (Smith et al., 1992). A study by Shanley et al. (2011) has reported the Brazil nut tree density in unmanaged forest to be between 0.1-4.0 trees/hectare. To reduce the uncertainty of the Brazil nut tree density (by taking into account all 120,000 hectares of primary forest areas from OV), the average of 0.1-4.0 trees/hectare is taken, which results in 2.05 trees/hectare unmanaged forest. The Brazil nut tree produces coconut-like capsules which each contains 10-25 hard-shelled woody fruits (Shanley, 2011). It is however difficult to estimate the annual fruit and nut production or yield per tree or per hectare since the production varies from year to year, is temperature dependent, and is related to the size of the tree (Shanley, 2011; Smith et al., 1992). In addition, not every Brazil nut tree produces capsules (Smith et al., 1992). Nevertheless, a study by Miller (1990) has used data from the region in Eastern Amazonia and has assessed a production of 63-216 fruits per tree. To calculate this into nuts (including shells) with taking the range of 10-25 nuts per fruit, results in an estimated value range of 630-2,160 nuts/tree (with a minimum of 10 nuts incl. shells per capsule) to 1,575-5,400 nuts/tree (with a maximum of 25 nuts incl. shells per capsule), per year (assuming exact same fruit productivity each year). For estimating the monetary value of both minimum and maximum ranges of the annual fruit production of the Brazil nut tree, the average unitary mass of 6.17 grams of a nut including shell is used (Nogueira et al., 2014). Multiplying this with the nut production per tree, results in a minimum (min.) of 3.9-13.3 kg of annual nut production and a maximum (max.) of 9.7 – 33.3 kg of annual nut production. When taking the value of 350 BRL/53 kg (equal to 1.72 USD/kg) (price paid to extractivists at a floating trading location in the Coari Lake), the monetary value per Brazil nut tree is estimated to be 25.8-87.8 BRL/year (min.), and 64-220 BRL/year (max.). Multiplying the annual productivity with the tree density in unmanaged (primary) forest of 2.05 trees/hectare, gives that the monetary value of the Brazil nut tree is estimated to be 53-180 BRL/ha/year (minimum range), and 131-451 BRL/ha/year (maximum range). This gives a value range estimate of 30-76 USD/ha/year and an average value estimate of 53 USD/ha/year.

2. Palm hearts

From the various useful products that can be extracted from palms i.e. fruits, seeds, palm hearts, leaves, trunks, young roots, stems (Shanley, 2011, pp. 161), palm hearts (also known in Brazil as 'palmito') (Figure 15)[13] are a forest product from arguable importance. Many of the palm heart extraction in the past, have led to the mortality of the extracted stem, with currently still illegal palm heart extraction activities taking place (Angelo et al., 2018). When palm tree stems die, it can have profound effects on certain animal species which depend on the gathering

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[13] Photo left from Vancouver Observer https://www.vancouverobserver.com/blogs/sophisticatedvegetarian/2010/05/12/discover-palm-hearts and photo right from Portal Macauba http://www.portalmacauba.com.br/2018/06/desenvolvimento-de-cultivares-de.html.

of fruits from that specific palm tree (Guimarães et al., 2018). Because my research addresses economic values from forest products that are primarily based on sustainable-use levels, any form of forest usage needs to be considered carefully i.e. those without interference with the ecosystem's functioning. Concerning the açaí palm tree, the extraction of palm heart is a sustainable option because its harvest can be from the same stem in a continuous manner (Shanley, 2011).

Shanley (2011, pp. 160) reported that over 99 per cent of the palm hearts sold on markets in Brazil are derived from açaí tree stems. Riverine or forest communities could extract palm hearts for consumptive purposes or to trade them on markets, but this would mean that the stem cannot bear açaí fruits anymore. Although for multi-stemmed palm tree species (e.g. açaí) the tree can survive, since the beginning of the 1980s there have been various indications that palm heart extraction occurs in an unsustainable manner (Pollak et al., 1995). To date, palm heart extraction has decreased largely (Shanley, 2011) because communities rather focus on the gathering of açaí fruits for either consumptive purposes or for trade due to the high market demand. Because most açaí trees are extracted for its fruits by e.g. (riverine) communities, and because almost all palm hearts that are being extracted come from açaí stems, the choice is made to incorporate the value of açaí fruits in the TMV of the primary forest as a land use rather than açaí palm hearts. For the other palm trees which account for less than 1% of the total palm hearts extracted in Brazil, it is expected that the monetary value of this product over an average species distribution and density in one hectare of primary forest is on the low hand and therefore considered as negligible.

Figure 15: Palm hearts. Left: whole harvested palm hearts stacked (from Vancouver observer). Right: palm hearts sliced (from Portal Macauba).

3. Bush meat

The meat of wild animals i.e. mammals, or bush meat (hereafter referred to as 'game species'), are an important part of diets of people from rural communities in tropical regions around the globe (Barboza et al., 2016). Although for Ribereinhos (riverine community people e.g. people who live in villages that are located alongside the Urucu River) fish are one of the main dietary protein sources, for the analysis of the services that are provided by primary forest, fish are in my research not taken into account.

zIn the forest surrounding areas of the Nossa Senhorá Nazare village there are currently not many game species to hunt (Interview 15). Interviewee 15 stated that "if the water level is high, not much game can be found because the animals go to back to the inlands". The amount of game species which can be hunted, depend on the level of the local water levels which relate to the changes in the seasonal várzea floodplain. "When the water level is low, we can hunt again" (Interview 15). However, in the Barro Alto village a school teacher said "that animals go away from the village because people deforest areas on the small-scale in order to sustain themselves" (Interview 13). It is assumed that the clear-cut of small patches of forest is done to cultivate crops (e.g. cassava) or to create home gardens with fruits and nuts such as mango, lime, and cashew. Yet, villagers do not necessarily focus on hunting game species for their daily diet. People do kill game for consumptive purposes, but merely when specific species cross their paths coincidently (Interview 15). Specific species for game are often small, such as armadillos, pigs, deer, and rodents (Interview 15; Interview 13).

Valuation

In a street adjacent to the Clemente Vieira market in Coari, a marketer sold bush meat (or meat from game species for forest and riverine communities) which he took from nearby forest areas (Interview 19). Because it is considered an illegal activity to sell bush meat, the interviewee (seller of the wild meat) wanted to stay anonymous. Yet, a market value of a certain product represents the actual value of it. Therefore, the acquired market value from a stand in Coari is used in my research to value game species. The marketer sold the bush meat for 10 BRL/kg, which included species such as tapir, armadillo, deer, and pig (i.e. peccary) (Interview 19). More specific, major game species for forest or riverine communities include: marsh deer *Blastocerus dichotomus*; pampas deer *Ozotoceros bezoarticus*; red brocket deer *Mazama americana*; grey brocket deer *Mazama gouazoubira*; tapir *Tapirus terrestris*; white-lipped peccary *Tayassu pecari*; collared peccary *Tayassu tajacu*; lowland paca *Cuniculus paca*; tamandua *Tamandua tetradactyla*; giant armadillo *Priodontes giganteus*; and six-banded armadillo *Euphractes sexcintus* (Leeuwenberg & Robinson, 2000, pp. 383). Figure 16 shows an armadillo paw that is sold as bush meat at a street corner adjacent to the Clemente Vieira market in Coari.

Figure 16: Armadillo paw sold as bush meat at a street corner adjacent to the Clemente Vieira market in Coari, Brazil.

Because of the lack on harvest data, a study by Peres (2000) is used for the quantification of game species for the study areas of my research. Peres (2000) surveyed the game biomass for various forest sites in the Brazilian Amazon. For the Urucu region (which also is part of the study areas of my research), a game biomass of 693 kg/km^2 is reported (Peres, 2000). This means a game biomass of nearly 7.0 kg/ha. Using the market value of 10 BRL/kg, gives a bushmeat stock value of 70 BRL/ha. Data on the amount of bushmeat consumption per year has not been obtained for the study areas of my research. Just to illustrate, Pinedo-Vasquez (2014, pp. 6) has reported a value estimate of 63 ± 25 kg/person/year for bushmeat consumption by rural communities in the Amazon. This value estimate however seems to be on the higher end for the rural communities in the study areas of my research since they have stated that there are (currently) not many species for game (Interview 15). Also, they do not seem to overhunt species as bushmeat is merely obtained when species crosses paths coincidently (Interview 15). For this reason, the assumption is made that not more than 10% of the stock value is consumed which means that 0.7 kg/ha is consumed annually (which gives a monetary value estimate of 7 BRL/ha/year, equal to 1.8 USD/ha/year), in order to minimise the possibility that bushmeat consumption leads to defaunation, and in turn to other cascading effects (e.g. decreased seed dispersal). Note however that there are many other factors than bushmeat consumption by rural communities, which could lead to defaunation (e.g. regional climatic changes which alters the food supply upon which certain animal species depend).

4.1.2 Water

It is difficult to treat water as an isolated provisioning service which is provided by intact Amazon forest because water in terms of supply is in this ecosystem influenced by many hydrological processes (Vörösmarty et al., 2005). The study areas of my research primarily consist of primary forest vegetation in which water as a provisioning service could be present in the form of forest streams and wells since mature primary moist tropical forests provide watershed services which are maintained naturally even during dry periods (Edwards et al., 2014). Riverine communities use water mainly from rivers (interview 15) but could also use water from the forest. It was mentioned that these forest water sources are either small streams or so called *igarapés*, which are streams of water that are connected to larger streams, or rivers. How much water in volume is present and taken from igarapés in the study areas is unknown. The water extracted from the rivers and streams are used primarily for consumptive purposes in the form of drinking, cooking, washing, and waste removal (McClain et al., 2001). Interviews with people from riverine communities with livelihoods alongside the Urucu River did not clarify if they use water from igarapés, and if so, to what extent and (percentage) share they do. It was mentioned however that they mainly use water from the Urucu River. Therefore, it is assumed that not more than 0-20% of their total water use is derived from forest water sources.

Due to the lack of data on the volume of water sources used from the forest i.e. igarapés and other streams that are present in the study areas, the potential total water yield is calculated by using the volume of annual precipitation and water flux values. A study by Kunert et al. (2017) reported the annual rainfall of a central Amazon region to be 2302 L/m^2 from which 59% is returned to the atmosphere through evapotranspiration. Just to illustrate, if the other 41% (equal to 944 L/m^2) of the precipitation would all infiltrate the soil and reach streams and springs before merging into larger water bodies (disregarding any other water losses) that are merely situated in primary forest areas, and value that volume of water according to the Manaus monthly water tariff[14] of 6 BRL/m^3 (equal to 1,000 L) (Olivier, 2006), gives an economic value estimate of <0.0001 BRL/ha/year. This value estimate is rather low compared to the value estimates of other services addressed in my research. Water supply is from great essence for riverine or forest communities, but because its rather low monetary value here it is not taken into account in the total monetary value of the primary forest land use.

4.1.3 Raw materials

Under raw materials from Amazon primary forest for my research are considered: timber, and latex for rubber production, because of their (natural) regenerative characteristic. This section first addresses (sustainable) timber, and then rubber from latex.

Timber
To extract timber from Amazon forest areas, the operation needs a medium of transportation. For the study areas of my research, the region north of Manaus is close to the BR-174 highway which can increase the risk that timber extraction will occur. For the county Coari, the only medium of transportation are rivers (with the main thoroughfare being the Urucu River). This means that it would take relatively long for timber extraction to take place in comparison with a region where built infrastructure is present. However this does not mean that less timber extractive activities would take place. Also, in the case that logging occurs, it could offset a chain of similar logging events by encouraging others. Note, that the aim of Opção Verde is to conserve their forest areas for the very long term (i.e. eternity). Therefore, timber extraction could be seen as an activity which possibly does not meet that aim.

Valuation
Torras (2000) has reported a sustainable tropical timber harvest value from the Brazilian Amazon forest. The value of Torras (2000) is based on the annual natural regeneration rate of 0.51 m^3/ha, and a net timber price of 708 USD/t (Torras, 2000, pp. 287). With a conversion ratio value of 0.85 to calculate from volume to mass in tonnes, Torras (2000) has estimated the timber value to be 307 USD/ha/year. Because the value estimate of Torras (2000) is based on sustainable use levels due to the natural vegetation regeneration rate, this in theory

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[14] Based on the 2004 water tariff structure of Manaus, with a consumption of >60L/month corresponds with a value of 6 BRL/m^3 (Olivier, 2006).

means that the monetary value here can be considered annually and infinite. Note however that any external factors that can influence the vegetation growth rate (e.g. climatic conditions) are not taken into account.

I argue whether timber extraction should be included in the valuation analysis since harvest activities likely have adverse effects to the surrounding areas to some extent. Timber extraction in the form of logging can lead to forest degradation (Verweij et al., 2009). Some ways of effect-reducing logging exist e.g. selective logging or reduced impact logging but even these can result in (widespread) collateral forest damage (e.g. a decline in vegetation regrowth; canopy openings which results in drier understories and providing fuel loads, increasing fire risk; and soil disturbances (Foley et al., 2007; Putz et al., 2008).

Latex
Latex is derived from the rubber tree *(Hevea brasiliensis).* The latex is collected from the tree by diagonal cuts or small trenches in the bark (Figure 17). The rubber tree is native to the Amazon, which can be found in primary forest in a range of 0.07-3.0 individual trees per hectare (Shanley, 2011). Each tree produces on average 4.5 litres of latex per year, which is equal to 1.5 kg of dry rubber (Shanley, 2011). Rubber tappers can reach up to This results in an average latex production of almost 7.0 L/ha/year (equal to 2.3 kg dry rubber). The market value (price paid to extractivists) used for of one kg of dry rubber was 1.09 USD/kg (Ribeiro et al., 2018). Using this market value, the monetary value of rubber as raw material per hectare of the primary forest land use ranges between 0.1-5.0 USD/ha/year, which gives an average value estimate of 2.6 USD/ha/year.

Figure 17: Collecting liquid latex from the *Hevea Brasiliensis,* by making diagonal cuts in the tree bark (left: from world wildlife, 2019; right: from wild rubber, 2019).

4.1.4 Medicinal resources

Forests are sources of biochemicals which contribute to human health in the form of drugs and pharmaceuticals (Elmqvist et al., 2010; De Groot et al., 2002). There are many plant and tree species used as medicinal resources that are known to be native to the Amazon forest in Brazil[15] (Berg, 1991; Coelho-Ferreira, 1996; Silva et al., 2007; De Melo et al., 2009; Pedrollo et al., 2016). In Brazil, these plants and trees are harvested for their roots, barks, leaves, oils, and resins (Shanley, 2011, pp. 85). At the Clemente Vieira market in Coari, one marketer sold barks from trees as medicinal products (Figure 18). It was said that these products were harvested from nearby primary forest areas. It was not possible to gather quantitative data to assess how much of the medicinal products were taken from nearby forest areas by the marketers. There is however a relative high demand for medicinal products from the Amazon forest such as tree bark and plant species in Brazil. Because of the popularity of such products, it came up during market research that certain people could pretend to sell plant and tree species' roots, barks, and leaves as 'medicinal products' even though these products do not contain medicinal properties at all. For a detailed overview of which medicinal plants can be found in Brazil[16], Pedrollo et al. (2016) have reported various

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[15] Worth mentioning is that from the 211 medicinal plants sold in local markets in Belém, 95 were found to be native to Amazonia (Shanley, 2011). In the period from the year 1994 to 2000 there were 12 medicinal plants that were sold, considered to be highly popular from which there were 7 native to terra firme forest, including: andiroba (*Carapa guianensis*); barbatimão (*Stryphnodendron barbatiman*); copaíba (*Copaifera spp*.); pau d'arco (*Tabebuia impetiginosa*); marapuama (*Ptychopetalum olacoides*); sucuúba (*Himatanthus sucuuba*); and veronica (*Dalbergia subcymosa*) (Shanley, 2011, pp. 86).

[16] Currently there are various medicinal plant and tree species available at markets in Brazil, however a significant amount of medicinal plant and tree species is still undiscovered to date (Elmqvist et al., 2010).

medicinal plant and tree species through an assessment of five riverine communities at the Jauaperi River. Appendix B provides a comprehensive list of the medicinal plants found during the study by Pedrollo et al. (2016).

Figure 18: Different parts of plants and vines with being said to have medicinal purposes. Sold at the Clemence Vieira market in Coari, Brazil (author's photo).

Valuation

Due to the lack of data on the primary forest species' density that are considered as medicinal resources, the ecosystem-services valuation database (ESVD) from TEEB was accessed to retrieve a value estimate for medicinal plant and tree species in Brazil. In the ESVD, a value estimate of 24.27 USD/ha/year from a study by Rausser and Small (2000) is reported. Rausser and Small (2000), have assessed the medicinal resources of Amazonia's uplands through 'biodiversity prospecting'. With biodiversity prospecting, or in short, bioprospecting, is meant "the search for plant and animal species from which medicinal drugs and other commercially valuable compounds can be obtained" (Oxford, 2019)[17]. Rausser and Small (2000) based their value on the density of endemic species in Amazonia's western uplands, calculated by using the production function approach. Because the study areas of my research are located in Brazil's northern lowlands, the value estimate of Rausser and Small (2000) from Amazonia's western uplands is used for the valuation of the medicinal resources of the primary forest land use here in the form of benefit transfer.

4.2 Regulating services

Tropical forests plays key roles in regulating the Earth's system on the local, regional, and global scale. Various regulating services exist, from climate regulation and pollination have been analysed in my research. In Table 5 the monetary values of these regulating services from the primary forest land use are presented.

Table 5: Regulating services 'climate regulation' and 'pollination' provided by amazon primary forest including the specification of the service, the quantity, and monetary value estimate in USD/ha/year.

Number	Ecosystem service	Specification	Quantity	Monetary value (US$ ha^{-1} year^{-1})
8	Climate regulation	Carbon stock[a]	13 t C/ha/year	351[b]
		Carbon flux[c]	0.7 t C/ha/year	20
14	Pollination	Pollination by insect pollinator species with intact mature primary forest as their habitat	unknown	-[d]

[a] For this value estimate a social discount rate of 0% is applied because the present value of this service will be computed later on in my research (see Chapter 7).

[b] Embedded in the monetary value estimates of all other primary tropical forest services.

[c] The carbon stock is considered to be a potential (capital) value which is (based on the social cost of carbon) an avoided damage cost if one leaves the forest intact (i.e. no forest clearances take place).

[d] The carbon flux is considered to be an active or added value as it is continuously reducing the amount of atmospheric carbon, and therefore decreasing the amount of radiative forcing (which mitigates global climate change through decreasing global average temperatures).

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[17] Oxford (2019) from https://en.oxforddictionaries.com/definition/bioprospecting.

4.2.1 Climate regulation

Tropical forests regulate the climate through many processes. One of these processes is the direct absorption of CO_2 by vegetation through photosynthesis. The absorption of CO_2 by vegetation leads to terrestrial carbon storage in five distinct pools: above and below ground live biomass, deadwood, litter, and soil (Brockerhoff et al., 2017, pp. 3022). This stored carbon in a standing forest is defined in my research as the 'carbon stock'. It should be noted that the carbon stock increases over time as forests grow, not considering any losses due deforestation. Also, CH_4 and N_2O have a significant effect on the climate as greenhouse gases, which are mediated by soil microbes (i.e. methanogens, methanotrophs, and nitrifying and denitrifying bacteria) (Oertel et al., 2016). Moreover, forests absorb solar radiation which increases the Earth's surface temperature, however on the other hand forests also contribute to the cooling of the Earth's surface due aerosol particle formation by trees (Elmqvist et al., 2010) (Box 4).

Box 4: Forests as actors in warming and cooling the Earth's surface

Trees help cooling the Earth's surface, even though evergreen forests (e.g. tropical forests) have relatively dark surfaces which absorb more solar radiation than lighter surfaces, this surface warming is offset by evaporative cooling (Krieger, 2001; Bonan, 2008). The evaporative cooling by forests is a result of the sustainment of the hydrological cycle, which leads to feedbacks with cloud formation and precipitation patterns (Bonan, 2008). In addition, forests emit biogenic volatile organic compounds, which can form into aerosol particles (Elmqvist et al., 2010, pp. 32). Aerosols have a substantial effect on the climate as they intercept and scatter solar radiation, and because aerosols act as nuclei for cloud condensation (Elmqvist et al., 2010, pp. 32). Increased cloud condensation leads therefore to an increase in the albedo, which because of its white surface increasingly reflects incoming solar radiation. The interception and scattering of solar radiation, and the increase in albedo through cloud condensation, reduces the amount of solar radiation that reaches the Earth's surface (Elmqvist et al., 2010). Therefore, forests are actors in cooling the global climate (Kulmala et al., 2004).

Valuation

For my research, the valuation of the climate regulation service is conducted by finding both the carbon stock and the carbon flux of one hectare of primary forest. Both the stock and flux are estimated and valued according to the social cost of carbon (SSC). Due to lack of information on regulating services of OV's forest areas, secondary data (that is from reported literature findings) is used for the valuation of the climate regulation service in my research. Carbon stock information of the Baixo Juruá extractive reserve was used (Figure 19)[18]. The Baixo Juruá extractive reserve contains primary forest vegetation that is comparable to the vegetation of the study areas. The Baixo Juruá extractive reserve is a 'state sustainable-use conservation unit' (SSU). Such extractive reserves are protected areas, established by the government, from which natural resources are used in a sustainable way for preserving its biodiversity (Mattar et al., 2018). Fearnside et al. (2018) has estimated the carbon stock of this reserve, based on the biomass of each vegetation type (Nogueira et al., 2015). The calculated carbon stock includes the vegetation which consists of the biomass above, and below ground (i.e. roots, not soils) (Fearnside et al., 2018), and the soil C stock. The carbon stock of the vegetation in the Baixo Juruá reserve is estimated to be 181.65 t C/ha for the year 2014 (Fearnside et al., 2018). The soil organic carbon (SOC, hereafter referred to as C) stock (measured over a soil depth of 100 cm) in the Urucu river basin is reported at a mean value of 7.32 kg C/m^2 (Ceddia et al., 2015, pp. 63), which equals 73.2 t C/ha. This gives a total C stock value estimate for the study areas of 255 t C/ha (or 12.8 t C/ha/year with a time *t* horizon of 20 years), which represents the C content of the vegetation above and below ground, and the soil carbon.

Various approaches exist for valuing carbon stock. However, from a societal perspective there are two major approaches for valuing carbon stock which are: (i) the marginal abatement cost of carbon (MACC), and (ii) the 'social cost of carbon' or SCC (Valatin, 2011; Abson et al., 2011). The MACC approach is based on the marginal cost of reducing carbon emissions per t C, thus reflecting the cost of reducing emissions rather than the damage imposed by creating them (Abson et al., 2011; Price et al., 2007, pp. 2). Whereas SSC estimates show the price the world has to pay for each t of gas emitted, if no action is taken (Stern, 2007). However, both approaches are criticised due to the uncertainties of climate change impacts and estimates that are based on future projections (Abson et al., 2011). Nevertheless, SCC estimates demonstrate the price of carbon that society should be willing

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[18] Figure (right) taken from Protected Planet at https://www.protectedplanet.net/reserva-extrativista-baixo-jurua-extractive-reserve.

to pay now, in order to avoid future costs resulting from increased carbon emissions (Abson et al., 2011). Therefore, value estimates following the SCC approach are used to value the carbon stock of one hectare of primary forest for my research.

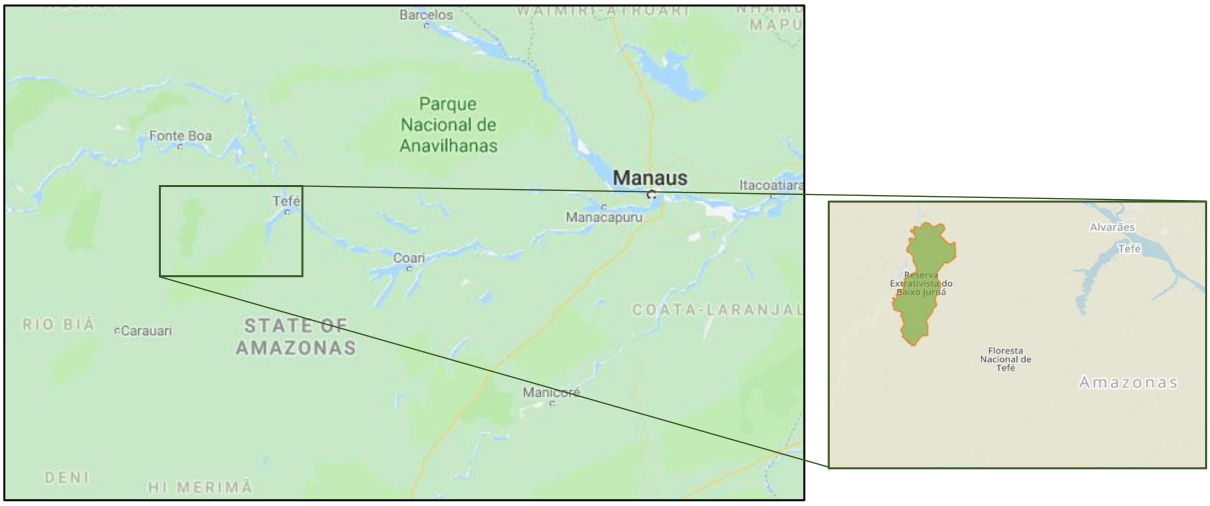

Figure 19: (left) the Baixo Juruá extractive reserve in the State of Amazonas (Google maps, 2019) and (right) the Baixo Juruá extractive reserve at a lower spatial scale (Protected planet, 2019).

The SCC varies depending on the atmospheric concentration (the stock of greenhouse gases) and on which emission trajectory the world is on (Stern, 2007; Price et al., 2007, pp. 4). Hence, there is a different SCC for each different pathway of future emissions and stocks (Stern, 2007, pp. 29). Stern (2007) suggests that the optimum stabilisation goal of the global atmospheric concentration of greenhouse gases ranges between 450 – 550 ppm CO_2-eq for the year 2050. If the target set is between 450 – 550 ppm CO_2-eq, then the SSC is estimated to start in the range of 25–30 USD per t of CO_2-eq (Stern, 2007, pp. xvii). Using this value for the carbon stock of one hectare of mature primary forest (255 t C/ha) gives an average monetary value of 7013 USD/ha. This value estimate represents the *potential* SCC that is avoided if one conserves the forest area. However, because it represents the carbon stock of primary forest, it is considered to be a capital value and thus not an annual value. To use this value estimate in accordance with the economic values of all other ecosystem services that are analysed in my research, the capital value needs to be translated into an annual value. To do so, a time period of 20 years is used to represent the annual flow, which results in a carbon stock value range of 319-383 USD/ha/year. This gives an average monetary value estimate of 351 USD/ha/year. For this value estimate a SDR of 0% is used (in Chapter 7 also a positive SDR is used to discount the benefits of the climate regulation service on future generations to the present).

To take the *'active'* or *'added'* value of the climate regulation service provided by primary forest, the carbon (C) flux (or flow) by vegetation is valued which is the continuous uptake of atmospheric carbon. The C flux is considered as an actual reduction in the SCC, as the mature forest vegetation continuously takes up carbon, thus acts as a carbon sink. Few tropical forests have bene reported to act as carbon sources rather than sinks, although which arguably could be related to emission causing activities, severe drought or disturbance recovery (Wolf et al., 2011, pp. 2764; Saleska et al., 2003; Hutyra et al., 2007). When examining the global carbon budged, it is clear that there is a carbon sink in the terrestrial biosphere (Malhi, 2010). Worth mentioning however, is that climate models predict reductions in rainfall over Amazonia because of climate drying (Cox et al., 2000, 2004; Friedlingstein et al., 2006). This can lead to forest dieback, which result in the Amazon forest to become a carbon source instead of a sink, emitting large amounts of CO_2 emissions (Fisher et al., 2007, pp. 2361). In my research, mature primary forest in the study areas are treated as a carbon sink. The main reason for this is because for various decades to the current day, mature tropical forest vegetation has in general acted naturally as carbon sinks, absorbing more carbon than it emits (Laurance et al., 2014; Edwards et al., 2014; Pandey et al., 2019). In addition, if a shift from carbon sink to source would be taking place to date, then that would possibly mean that currently, this shift is at an early stage which will not likely result in the Amazon forest to act as a carbon source overall. Pan et al. (2011) have reported the carbon flux of tropical intact forest[19] the global level at 1.02 ± 0.47 Pg C year^{-1} for the yearly period between 2000-2007 over an area of 1392 Mha. Their average value estimate is based on the tropical forests in Africa, South America, and Southeast Asia and contains a 10-20% uncertainty (Pan et al., 2011, 990-992). When calculating their value estimate to one hectare gives 0.73 tonne C/ha/year. With a SCC of 25–30 USD per t of CO_2-eq (Stern, 2007), the average monetary value of the carbon flux of intact primary tropical forest is estimated to be 20.1 USD/ha/year.

4.2.2 Pollination

Pollination is from crucial importance for the persistence of natural ecosystems (Sapir et al., 2015, pp. 106). Pollination as a service can be brought about by insects, but also through other forms such as by wind or water. Concerning pollinator species, a wide variety exist e.g. insects, mammals, birds, and bats which ensure that reproduction processes of plants and trees are being maintained (De Groot et al., 2002). From insect pollinator species in many ecosystems, bees are the predominant and economically most important of all at most geographical regions across the globe (Kremen et al., 2007). For this reason, the persistence and survival of the vast amount of biodiversity across the globe (including the human species) depends on such species in the context of pollination. The pollination service at the local scale is brought about by pollinator species that forage within or between habitats (Kremen et al., 2007), which can ultimately have significant effects on forest areas in a larger spatial scale. It is estimated that 80% of the wild plant species directly depend on insect pollination (Potts et al., 2010), which for crop plants on the global scale account for over 75% that rely on pollination by species (the other 25% is brought about by other forms of pollination e.g. wind) (Nabhan and Buchman, 1997). Increased anthropogenic disturbances threatens wild pollinator species through habitat fragmentation and destruction (Sapir et al., 2015). From a global perspective, bee pollinators are perceived to be one of the most significant insect pollinators, although it is reported that habitat fragmentation and habitat loss is the predominant disturbance factor affecting the abundance and diversity of these pollinator species (Winfree et al., 2009; Sapir et al., 2015). To date, habitat fragmentation and loss because of agricultural expansion and intensification has resulted in alarming (regional) declines of insect pollinator species on the global scale (Botsch et al., 2017; IPBES, 2019). Wild pollinator species could therefore become increasingly important to farmers (Lonsdorf et al., 2009).

In Amazonian tropical forests plant and tree species reproduction does not only take place through the pollination by animal species but is also brought about through seed dispersal by e.g. mammals and fish (see Box 5). Although the importance of the pollination service for the persistence of entire ecosystems is widely recognised, the (monetary) value of the service for tropical forest areas is poorly understood. Only a few studies have shed light on a certain share of the monetary value of the pollination service that pollinator species in tropical forest areas provide (e.g. Ricketts et al., 2004). Ricketts et al. (2004) have estimated the value of the pollination service from an economic viewpoint which reflects the producer surplus of agricultural crop yields. Because most types of crop cultivation would be impossible in the absence of pollinator species (De Groot et al., 2002), it is a reasonable proxy for addressing a monetary value to the service. However, for the primary forest as a land use here, it seems difficult to quantify and monetarily value the pollination service as a function of agricultural productivity because the total amount of agricultural land in and near the study areas is <0.05%[20].

Because the 'object' of valuation here is primary forest, the mere way for analysing the monetary value of the pollination service (when considering it a separate service) would be to deduct shares of monetary values from all other valued services that together form the total monetary value of the forest. In other words, because the pollination service contributes to all other ecosystem services and is therefore in fact embedded in other services, and thus as well in the monetary values of these services, there is no need for a separate monetary valuation. Mburu et al. (2006, pp. 14) have explained this as follows: the maintenance of most other services provided by the forest (e.g. fruits, timber, climate regulation), when the pollination service does not on itself directly benefits people, means that "there is no need to include the value of the pollination service in the total monetary value estimate of the forest as this would lead to double counting." Yet, since the Brazil nut is from considerable social-economic importance especially to the local, regional, and national scale in Brazil, it can be stated that the pollination service (which is mainly brought about by large-bodied solitary wild bee pollinators)

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[19] Tropical intact forest: tropical forests that have not been substantially affected by direct human activities; flux accounts for the dynamics of natural disturbance-recovery processes (comprehensive C pools including dead wood, harvested wood products, living biomass, litter, and soil) (Pan et al., 2011, pp. 989).

[20] Calculated by taking the 50 ha of shifting agricultural land (Face the Future, 2018) over a total surface/study are of 126,000 ha.

is from great importance and thus holds a significant value, even though that value is not expressed here in monetary terms. Another way to estimate the monetary value of the pollination service of tropical forest is to estimate the agricultural producer surplus in the presence of pollinator species. However, because the object of valuation here is forest, it would make the value estimate irrelevant when agricultural land would be used as the object of valuation as a proxy for the pollination service.

Box 5: Seed dispersal by mammals and fish in the Amazon

Many animals are important seed dispersers in the Amazon. Monkeys for example, swarm over the forest in search for fruits and other edible forest products. When fruits are consumed, the leftovers (which often include the fruit seeds) are dropped on the forest floor, giving chance for new life to thrive. Also, other mammals e.g. the agouti (*Dasyprocta spp.*) disperse seeds through consumption. In the case of the Brazil nut (*B. excelsa*), the agouti is good for almost all of the nut's seed dispersal (de Oliveira Wadt et al., 2018). Another form of seed dispersal is brought about by fish. During the várzea floodplain, forest areas including are getting accessible for fish which can then are able to consume the available fruits and seeds in the areas they roam. Although the ecosystem services that can be derived from and are provided by the várzea seasonal floodplain are not taken into account in the valuation of the primary forest land use in my research, it is worth mentioning that there is certain value attached to seed dispersal by Amazon fish, which in turn ensures that certain fruit tree species continue to thrive. The tambaqui for example, is a fruit-eating fish which disperses seeds through excretion (which unlike many other fish swallows the seed rather than destroying it during consumption) (Correa et al., 2007; Gottsberger, 1978). The tambaqui is a fish of relative high economic value (i.e. for its meat) which could be considered of even higher economic value because of it disperses seeds (which therefore contributes to increased reproduction rates of fruit plant and tree species). Many other species disperse seeds in the Amazon forest, and some other forms of dispersal are important for species to reproduce (e.g. by wind, or ballistic dispersion) (Hawes and Peres, 2016). Deforestation e.g. of one hectare would likely not affect seed dispersal by wind when seeds are light enough for wind blows to carry, but any effect on this service should be considered when large areas are being deforested.

Because of this reasoning, the pollination service from primary forest is considered to be one that cannot be seen separate or isolated from other services that are provided by intact primary forest. To illustrate, animal pollination in Amazon forest areas contributes to enhanced fruit productivity, which benefits fruit and seed-eating insects, birds, mammals, and fish (Kremen et al., 2007, pp. 306). This can lead to increased seed dispersal which contributes to the maintenance of, and leads to increased plant diversity and abundance, and thus to primary productivity, which provides vegetation that contributes to disturbances prevention, erosion control, soil fertility, water purification, climate regulation and more (Kremen et al., 2007, pp. 306), from Memmott et al., 2004; Tilman et al., 2001; and Daily, 1997). Another example is that wild pollinators are supported by their natural intact habitat in the form of forage and nesting resources, which can be considered to be part of the biodiversity maintenance service (Veldtman, 2018, pp. 2). The pollination service also supports the 'biological control' service, since native insect species can supress populations of potentially pestiferous native herbivorous insects (Losey & Vaughan, 2006, pp. 314). Therefore, the monetary value of the pollination service here is embedded in all other monetary values of the services provided by the primary forest and will therefore not be separately valued to avoid double counting. The limitation then however is that because not all ecosystem services (as proposed by TEEB, 2010) are taken into account in my research, means that the pollination service is only represented by the monetary values of those services that are analysed.

4.3 Habitat service: genepool protection

The Amazon tropical forest is home to a vast amount and a wide range of biological diversity of wild plants and animal species on Earth (De Groot et al., 2002). Biological diversity, or 'biodiversity', is extremely valuable from an ecological, socioecological, or anthropogenic perspective as it contributes to the functioning of entire ecosystems which in turn, play significant roles in the functioning of the Earth's system. The term 'biodiversity' is presented here as defined by the Convention on Biological Diversity (CBD, 2019)[21]:

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[21] CBD (2019) from https://www.cbd.int/convention/articles/default.shtml?a=cbd-02.

"The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems."

The Amazon forest species' survival depends on a healthy habitat because it provides them food, water, and shelter (TEEB, 2019). Therefore, it is from crucial importance to maintain the biodiversity the Amazon tropical forest is home to. Maintaining biodiversity is defined by TEEB (2010) as the 'genepool protection' service or in other words 'the biodiversity protection service'. This service is one that provides benefits not only on local and regional scales, but also to the global scale because it is contributes to the functioning of ecosystems, for which therefore the world at large might be willing to pay (Fearnside, 1997).

The Amazon is home to a vast amount of biodiversity and although still unmeasured to its full extent, accounts already for up to a tenth of the total global plant and animal species (Torras, 2000, pp. 286). Current human activities are causing unprecedented rates of biodiversity losses and continue to take place, with the rate of species extinction on the global level being ten to hundreds of times higher than the average rate over the past 10 million years (IPBES, 2019, pp. 8), threatening the stability and persistence of entire ecosystems and in turn the services these provide. It is therefore from great importance to value the biodiversity protection service of the Amazon forest. The economic valuation of the biodiversity conservation service is empirically difficult to conduct regarding its measurability, because the economic benefits deriving from biological diversity cannot be seen as isolated benefits due to the interconnectedness with many other services (e.g. the provisioning of goods, or services deriving from the stable functioning of an ecosystem) (Hanley et al., 1995). Nevertheless, various studies (e.g. Pearce, 1996; Kramer & Mercer, 1997; Siikamäki & Layton, 2007) have analysed the value of biodiversity of various ecosystems and hotspots across the globe.

Valuation

The economic value of the biodiversity protection service of the primary forest land use is derived from the Ecosystem-services valuation Database or ESVD from The Economics of Ecosystems and Biodiversity. The ESVD has included three studies (Horton et al., 2003; Torras, 2000; Verweij et al., 2009) who have reported value estimates, for biodiversity protection in Brazil, of 48, 194, and 18 USD/ha/year., respectively. Both Torras (2000) and Verweij et al. (2009) used benefit transfer for their value estimate, where Horton et al. (2003) used contingent valuation to estimate their values. For the valuation of the biodiversity maintenance service, the value estimate of Horton et al. (2003) is used because their study involved a non-users' willingness to pay (WTP) which reflects to what extent we as humans value the vast amount of biodiversity the Amazon is home to. Horton et al. (2013) evaluated the non-users' WTP from residents of the United Kingdom and Italy, for a programme implementation to protect the ecosystem services that are provided by the wealth of biodiversity of protected areas in Brazilian Amazonia (Horton et al., 2013, pp. 139). It can be argued whether an individual's (or household's) WTP reflects the actual value of the biodiversity protection service. Also, worth mentioning is that regulating services can hardly be seen as isolated services, while the value derived from contingent valuation methods in general (i.e. WTP) is purely addressed to that single ecosystem service in specific. Note that the WTP greatly depends on the socio-economic context in which the valuation takes or has taken place (Pascual et al., 2010, pp. 7). Horton et al. (2013) conducted surveys non-randomly which were related to a range of socio-economic characteristics. The WTP for the implementation of the programme to conserve 5% of Amazonia's biodiversity wealth according to the study by Horton et al. (2013, pp. 143), which derived via the ESVD, was reported at 48 USD/ha/year. It is expected that this value is rather low since protecting the primary forest's biodiversity promotes the conservation of other services as well. These services are not separately considered in the valuation of the biodiversity maintenance service, which would hypothetically be speaking result in an added value per service considered.

This value of 48 USD/ha/year represents the biodiversity in terms of stand biomass of mature primary forest which expressed in percentage accounts for the full 100%. This percentage value will be used later on in my research report to calculate the relative change in the stand biomass in percentage which in turn is calculated over intact mature primary forest (which thus equals here 48 USD/ha/year).

4.4 Cultural services: eco-tourism and recreation

Amazon tropical forest can provide cultural services, which are defined here following the definition by Tallis and Ricketts (2011, pp. 206), which is: "*ecosystem's contribution to the nonmaterial benefits (e.g. capabilities and experiences) that arise from human-ecosystem relationships.*" With the 'potential' provision of cultural services is meant that these services are only valuable to humans when these are utilised, thus when human-environment interactions take place. Based on the TEEB typology, ecosystems can provide the following cultural services: recreation and eco-tourism; aesthetic information; information for culture, art, and design; spiritual experience; and, information for cognitive development). For my research, merely the recreation and eco-tourism service is addressed.

In the southwest of Coari alongside the Urucu River, a former lodge is situated in the forest areas of Opção Verde, called 'the Flamboyant'. During on-site fieldwork it was observed that the carrying (primary) structure of the Flamboyant (made of wood) was mainly intact. Therefore, when renovated, the lodge could provide overnight stays to tourists (i.e. eco-tourism) and/or can be transformed e.g. into a scientific research centre (for cognitive development). Because formerly, the lodge was used for tourism, it is considered for my research to hold a potential recreational value which can be projected to the primary forest land use due to the intact mature primary forest surroundings. For the valuation of the recreation and eco-tourism service, a value estimate (Ribeiro et al., 2018, pp. 525) is used. Their approach used a meta-analysis and spatially explicit regression, which together estimate that the tourism average rent in forest areas in Brazil is 14 USD/ha/year[22] (PROFOR, 2015).

4.5 Synthesis

In this section an overview is given of the monetary value aggregates per ecosystem service category (i.e. provisioning, regulating, habitat, and cultural) (Figure 20). For the provisioning services and habitat services, the minimum and maximum value estimates are included which indicates the uncertainty range of these service categories.

The total monetary value estimate of the primary forest land use is 1,437 USD/ha/year with a minimum monetary value estimate of 1,168 USD/ha/year and a maximum monetary value estimate of 1,699 USD/ha/year. The TMV consists of the four service categories provisioning services (1,002 USD/ha/year with a minimum value of 769 USD/ha/year and a maximum value of 1,232 USD/ha/year); regulating services (371 USD/ha/year with a minimum value of 337 USD/ha/year and a maximum value of 405 USD/ha/year); habitat services (48 USD/ha/year); and cultural services (14 USD/ha/year).

The provisioning services consist of fruits (açaí, bacuri, burití, guarana, jatobá, patauá, piquiá, tucumã, uxi/uchi), the Brazil nut, bush meat (armadillos, deer, forest pigs, rodents), water in terms of supply, raw materials (timber and liquid latex from the rubber tree) and medicinal resources.

From the non-timber forest products, the açaí fruit has the highest monetary value (290 USD/ha/year) which accounts for 29% of the monetary value aggregate estimate for provisioning services. Also the tucumã (122 USD/ha/year), uxi (101 USD/ha/year), burití (57 USD/ha/year) and the Brazil nut (53 USD/ha/year) have potentially relatively high monetary returns when these are harvested from Opção Verde's forest areas and retailed at markets. Also timber has a relatively high monetary value estimate (307 USD/ha/year) which accounts for 31% of the monetary value aggregate estimate for provisioning services. The monetary value for water (in terms of supply) is rather low because there was no data available on the quantity of water streams (i.e. igarapés) in volume per hectare. Medicinal resources are considered a valuable service because of its relative high associated monetary value estimate of 24 US/ha/year which corresponds with a quantity of 0.001 endemic species per hectare.

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[22] Value estimate is based on the assumption that 10% of the total surface area of Brazilian forests are used for recreational purposes.

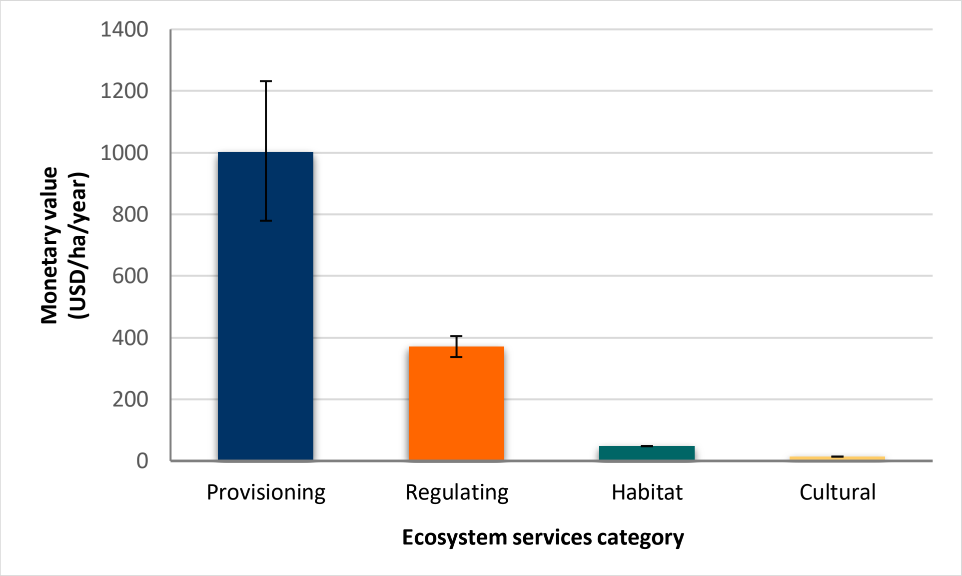

Figure 20: Estimated monetary value aggregates in USD/ha/year per ecosystem service category (i.e. provisioning, regulating, habitat, and cultural) for primary forest.

The regulating services consist of climate regulation and pollination for which merely the climate regulation service could be valued in monetary terms. The monetary value estimate of the climate regulation service is 371 USD/ha/year with a minimum value of 337 USD/ha/year and a maximum value of 405 USD/ha/year. This uncertainty range is related to the range of the SCC (25-30 USD tonne C) which correlates with an atmospheric greenhouse gas concentration of 450 – 550 ppm CO_2-eq. The habitat service genepool protection is estimated at a monetary value of 48 USD/ha/year. This service has no uncertainty range because it represents the WTP of European citizens (i.e. from the U.K. and Italy) for conserving parts of Amazonian forests. The monetary value estimate of the cultural service eco-tourism and recreation is 14 USD/ha/year.

5. Ecosystem services and monetary values of shifting agriculture

5.1 Provisioning services

The shifting cultivation of cassava (*Manihot esculenta* Crantz) provides primarily cassava fresh roots which are sold in the form of *farinha,* cassava flour. Prior to the annual yield of cassava roots, forest must be cleared to transform the landscape to make it readily available for cultivation purposes. Many of the former provisioning services will be lost, except for the water supplied by forest streams. The main yield from this conversion is the timber stock, assigned to the ecosystem service 'raw materials'. This section addresses these provisioning services, for which monetary value estimates are given. In Table 6 the monetary values of the provisioning services from the shifting agriculture land use are presented.

Table 6: Provisioning provided by shifting agriculture (i.e. the cultivation of cassava crops), including the specification of the service, the quantity, and monetary value estimate in USD/ha/year.

Number	Ecosystem service	Specification	Quantity	Monetary value (US$ ha^{-1} year^{-1})
1	Food	Cassava fresh roots	3,300 kg/ha/year	934
2	Water	Water supply from igarapés	41% of precipitation discharged to igarapés	<0.00001
3	Raw materials			
	Timber	Extracted timber from slash-and-burn	32.3 t/ha	508

5.1.1 Food

There are various cassava plant species, but in the Brazilian Amazon two types are generally grown. These are a sweet and a bitter cassava. The sweet cassava can be cooked and consumed without the need to process it. The bitter cassava (*Manihot esculenta* Crantz) (Figure 21) is generally cultivated by rural communities, and needs to be processed because of its cyanogenic content (McMahon et al., 1995), which has a poisonous effect on the human body. The cassava is a staple food and is from considerable socio-economic importance for rural communities in Brazil (Sousa et al., 2018). Processing the bitter cassava can be done in various ways to create a variety of products such as farinha and farofa. The riverine community at the Nossa Senhora village processes cassava roots into farinha (also called farofa) (Interview 15) which is fried coarse cassava flour. Farinha can be made with other ingredients e.g. onions or meat, but for the valuation of the bitter cassava, the market value of the natural farinha is used because this product needs the least amount of additional ingredients. It could be that for frying the course cassava flour, oil or butter is used. The processing of the bitter cassava goes as follows: the cassava root is pealed; the pealed root is crushed into pulp by using a petrol-driven engine; the pulp is pressed to remove the moist content (this juice can be sold on markets); then the drier pulp is sieved; and finally, the sieved pulp is fried in an enormous paella-like pan on fire using fuelwood. From the rest product (the fibres that are left when the cassava root is crushed into a coarse flour), a sort of starchy porridge is made which is consumed by the community themselves (Interview 15).

Valuation

The economic value of the cassava (*Manihot esculenta* Crantz) fresh roots involves a 21-year time scale including 3 shifting-fallow cycles (which each cycle consisting of a 2 year shifting-, or cropping period with 1 harvest, and a 5 years fallow period). This results in 3 harvests with 3 fallow periods in between. After each shifting-fallow cycle (which per cycle is equal to 7 years), Jakovac et al. (2016, pp. 122) reported that the cassava yield decreases with 0.72 t/ha. The mean cassava fresh root yield at the first cycle was reported to be 23.8 t/ha, with an average yield decrease of 0.72 t/ha gives for the second and third cycles yields of 23.08 t/ha and 22.36 t/ha, respectively. The total yield of fresh cassava roots in a 21 year time period based on the reported values by Jakovac et al. (2016) is therefore estimated to be 69.24 t/ha. Translating this data to an annual yield estimate gives 3,300 kg/ha/year. The peal of a cassava root results in an average of 25-30% of weight loss per root. This means that that annual fresh root yield without peal gives a value estimate of 2392.5 kg/ha/year. With an average moisture content of 75% (FAO, 1983)[23] which will be lost during the processing of the cassava into pulp for farinha, gives a value estimate of 598 kg/ha/year of fresh/raw cassava (pulp). This weight is hereafter used for the calculation of the monetary value of the pulp as farinha product (without taking into account any added or lost value losses).

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[23] FAO (1983) from http://www.fao.org/3/x5415e/x5415e01.html.

a 2019 market value of farinha (observed at the various markets in Manaus, see Appendix III) of 5-7 BRL/kg, gives a monetary value range estimate for the cassava crop yield (as a function of farinha production) of 2990-4186 BRL/ha/year or 778-1089 USD/ha/year. This gives an average monetary value estimate of 943 USD/ha/year.

Figure 21: Cassava *Manihot esculenta* is being processed in a farinha production plant at the Nossa Senhora village, located alongside the Urucu River in Brazil.

5.1.2 Water

Hypothetically speaking, when primary forest is converted into a plot for cultivating cassava, any former (small) water stream i.e. igarapés, that could be found in the forest can be considered here to disappear together with forest clearing activities. However, because riverine communities are partly dependent on these water sources, it is expected that any form of water supplied by the forest will be protected. Therefore, any forest conversion activity will likely take place at sites where no water sources are present. For this reason, the monetary value of water as a provisioning service will be equal to the value for the primary forest land use (see Section 4.1.2), which is <0.00001 USD/ha/year.

5.1.3 Raw materials

Merely timber from primary forest is considered as a raw material for this land use. Timber is extracted through clear cutting trees (and other types of vegetation) by using machetes (Interview 17). From what has been observed at the shifting agricultural plot with cassava crops near the Nazareda Dailingh village, it is assumed that the majority of the plot was harvested for its timber. Therefore, a high intensity timber harvest is considered here. The extracted timber is generally being used for construction purposes within the village (e.g. for canoes, houses) (Interview 15).

Valuation

Due to the lack of quantitative data on timber extraction from the primary forest study areas, a typical harvest intensity value estimate of 38 m^{3} ha^{-1} is used (Barni et al., 2015, pp. 274). Using the volume to mass conversion rate of 0.85 and the net timber price of 708 USD/t from Torras (2000), gives a monetary value of 22,868 USD/ha for the timber stock. To translate this timber stock value to an annual value, the time scale considered is when the aboveground biomass is fully regrown. Various studies report a range of aboveground biomass recovery rates and different time scales for tropical forests to have fully regrown (e.g. Fearnside and Guimaraes (1996) who have reported aboveground vegetation accumulation rates of an average 6.1 Mg/ha/year at shifting agricultural land, and an average 6.8 Mg/ha/year at cattle pasture; Steininger (2000) found values of 9.1 Mg/ha/year for crops, and 5.0 Mg/ha/year for pastures; while Gehring et al. (2005) reported an average approximate time scale of 175 years at which 75% of the original biomass has been regrown, and Edwards et al. (2014, pp. 515) state that in the southern Amazon, conventionally logged forests recover 77% of their original biomass in 16 years). In my research, an average value of 25 years for the aboveground biomass to have entirely regrown is used, as reported by d'Oliveira et al. (2011) which is based on Saldarriaga et al. (1988), for the first 40 years that accumulation takes place. This temporal value of 25 years in my research does not distinguish between varying land use types, and does not involve any further aspects that could influence the regrowth of aboveground biomass, such as the management intensity of the former land use, vegetation competition for light and nutrients (d'Oliveira et al., 2011), and impacts from natural destructive processes.

When the 25 year time scale is added to the 20 year time horizon of the shifting agriculture land use (since during the time period agricultural activities are taking place, biomass will not regrow and accumulate), gives that it takes an approximate average 45 years for the aboveground biomass to regrow and accumulate to a level that is comparable to that existed in the forest originally (in terms of volume or mass, not in species richness and abundance). Therefore, this (total) time horizon of 45 years is used here to translate the timber stock value estimate of 22,868 USD/ha into an annual monetary value, which results in 508 USD/ha/year[24]. Note that this value estimate does not involve a social discount rate because discounting future benefits will be conducted later on in this chapter (see Section 5.5).

5.2 Regulating services

Forest conversions alters biophysical structures and processes. This brings about effects on regulating services, for example changes in carbon stock in soils, and alters the carbon flux. Also wild pollinator species will be affected, in terms of habitat loss, and decreases in floral and nesting resources, upon which pollinators depend. In this section, the climate regulation service and the pollination service are addressed and for which the effects of land-use change (i.e. from primary forest to shifting agriculture) are described. In addition, the change in the associated monetary values have been analysed. In Table 7 the monetary values of these regulating services from the shifting agriculture land use are presented.

Table 7: Regulating services 'climate regulation' and 'pollination' provided by the shifting agriculture land use, including the specification of the service, the quantity, and monetary value estimate in USD/ha/year.

Number	Ecosystem service	Specification	Quantity (tonne C ha^{-1} year^{-1})	Monetary value (US$ ha^{-1} year^{-1})
8	Climate regulation	Emissions from biomass burning	-0.7	-18.7
		Carbon stock after land-use change	6.4	176[a]
		Carbon stock gain from secondary growth	0.1	2.5
		Carbon flux	0	0
14	Pollination	-	-	-

[a]For this value estimate a social discount rate of 0% is applied because the (social) present value of the service will be computed later on in this chapter (see Section 5.5 and Chapter 7).

5.2.1 Climate regulation

Converting primary forest into a plot to cultivate cassava (Manihot esculenta) crops by using the slash-and-burn principle alters the vegetation and soil carbon stocks. Also as a direct result of biomass burning, emissions of CO_2 and other trace gases are released into the atmosphere (Ramankutty et al., 2007), which has effects on both the regional and the global scale (Ometto et al., 2011). Clearing the forest by burning causes openings in the forest canopy, alters the temperature and humidity balance, and which eventually could lead to differences in regional rainfall (Ometto et al., 2011). The burning of biomass however also provides carbon returns to the soil because of the now dead litter (Foley et al., 2007), which is why riverine communities practice this principle so to give the soil a fertile pulse for improving crop growth and productivity. For the valuation of the climate regulation service provided by the shifting agricultural land use as a result of forest conversion, the (changes in) carbon stock and the carbon flux are taken into account. Any other factors affecting the climate regulation service are not taken into account in order to be consistent with the valuation of the service for the primary forest land use (see Section 4.2.1) e.g. variations in surface energy budgets that are mediated by albedo, evapotranspiration, and biophysical effects (Perugini et al., 2017, pp. 2).; or any changes in precipitation quantities and patterns, and temperatures (Llopart et al., 2018).

Valuation

Silva et al. (2011) have reported a yearly average greenhouse gas emission value from the burning phases of shifting agriculture in Brazil at 0.68 Mg (or tonne) CO_2-eq/ha/year[25]. This reported value includes CO_2, CH_4 and N_2O. To translate the 0.68 tonne CO_2 into a monetary value, the SSC of 25–30 USD per tonne of CO_2-eq (Stern,

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[24] Note that the costs of the timber harvest, processing, and construction in terms of labour hours are not taken up in the estimated monetary value.

[25] This value estimate is based on author's calculations from reported values for Brazil from Silva et al. (2011, pp. 12), which involve the following assumption: a biomass combustion completeness of 40.6%; and, reported annual emissions from Silva et al. (2011) are based on cropping periods of 2 years, and fallow periods of 2 years. The CH_4 and N_2O trace gases are calculated to CO_2-eq with GWPs of 28 and 265, respectively (IPCC, 2014).

2007, pp. xvii) is used. This results in an average monetary value estimate of -18.7 USD/ha/year from biomass burning (the negative indicates that carbon is emitted into the atmosphere).

The carbon stock changes significantly with the conversion of primary forest into a plot for shifting agricultural land. The extraction of timber results in 24% of the total amount of carbon stored (here equal to 44 t carbon) to be released into the atmosphere (Edwards et al., 2014). That timber extraction results in such relatively high percentage of C loss can be owed to the fact that in tropical forests, 56% of the carbon is stored in the biomass (Pan et al., 2011, pp. 989). The carbon that is in total being 'lost' from the stock in mature primary forest's soil and vegetation (in which the C loss from timber extraction is embedded), accounts for 25% and 60%, respectively (Moutinho, 2005). Calculating these percentages over the 73.2 t C/ha (soil) and 182 t C/ha (vegetation) gives C stock losses of 18.3 t/ha and 109 t/ha, respectively. This means that deforestation for establishing a plot for shifting agriculture (to cultivate cassava crops) results in a total C stock (vegetation above and below ground, and SOC) reduction of approximately 50%, which is equal to 127.7 t C/ha which, over calculated over a time period of 20 years gives an annual value of 6.4 t C/ha.

To value this carbon stock loss in monetary terms (by using the SSC of 25-30 USD per t of CO_2-eq (Stern, 2007, pp. xvii), results in a 'monetary value loss' relative to primary forest of 160-192 USD/ha/year. This means that the monetary value of the carbon stock of forest converted shifting agricultural land is estimated at 159-191 USD/ha/year (with a SDR of 0%). This gives an average annual monetary value of 176 USD/ha/year.

In addition, considering the soil carbon recovery during the fallow period, a value of 0.2 t C/ha/year is reported by Lal et a. (2000), from which 10% released again when the secondary growth is cleared for a new cycle of cultivation. Over a time period of 20 years, it would mean that 10 years can be attributed to cultivation periods, and 10 years can be attributed to fallow periods. Calculating the soil C recovery including the 10% release, gives an increase of 1.8 soil C stock over a period of 20 years. This results in a monetary value estimate of 50 USD/ha or 2.5 USD/ha/year with a SDR of 0%. In conclusion, the climate regulation service provided by the shifting agriculture land use is estimated at a total annual value range of 145-174 USD/ha. This gives an average monetary value estimate of 160 USD/ha/year.

Due to the lack of data on the carbon flux from cassava cultivation in the form of shifting agriculture, it is assumed that the majority, if not all of the carbon that is taken up by the cassava crops during the growth period, will be released into the atmosphere again when harvest takes place. For this reason, the carbon flux for the shifting agriculture land use is set equal to 0 t C/ha/year. Consequently, a monetary value of 0 USD/ha/year is attributed to the flux here.

5.2.2 Pollination

Land-use change for establishing agricultural landscapes has might effect on pollinator communities and crop pollination services (Steffan-Dewenter & Westphal, 2008). At least it will have effects to certain extents on pollinator species because the two basic essential resources required for pollinators to persist on a landscape are affected, which include floral and nesting resources (Lonsdorf et al., 2009). Deforestation by clear-cutting large vegetation and burning the debris to give the soil a fertile pulse goes hand in hand with the destruction of the natural habitats of wild pollinator species. When looking at the temporal scale of 20 years, the clear cut and burning of primary forest, which then is converted into shifting agricultural cropland could at some point provide nesting resources and sites e.g. underside branches or other vegetation debris which is not cleared entirely, in parts of large tree chunks (da Silva Carvalho-Filho & Oliveira, 2017), or at parts from secondary vegetation growth in between cassava crops.

The effects of forest conversion here on the pollination service is highly dependent on the spatial scale of the change one considers. Deforestation for establishing one or a few plots (of not more than 1 hectare per plot) for converting it into shifting agricultural land likely has little effect on the pollination service since most of the pollinator habitat remains to exist intact. The main reason that little effect would take place is because the agricultural land is then still surrounded by the vast Amazon forest landscape which because of its carrying capacity will not significantly be affected because of minor forest conversions. Note however that one hectare of intact forest should not be considered identical to the one next to it terms of ecological factors (e.g. floral and nesting resources upon which pollinator species depend). This suggests that the pollination service by pollinator species which have intact forest as their habitat, can be increasingly affected at places with sparse or concentrated resources. In addition, some species (e.g. wild bumble bees) prefer uncultivated areas much more for nesting sites than cultivated areas (Morandin et al., 2007). Considering a spatial scale of 1 hectare of forest conversion into land for shifting agriculture (which is the spatial scale used for analysing the effects of the land-use change in my research), it is assumed that there will not be any significant effects on wild pollinator species communities in terms of abundance and richness. When considering the current situation at the forest areas of Opção Verde in which 50 ha is deforested for shifting agricultural land (over the course of the past 18 years) (Face the Future, 2018), this total surface area of land-use change did likely not have significant impact on the overall pollination service when merely considering the vast forested surrounding areas. However, when the spatial scale of land-use change is 1 isolated hectare (so when there is only 1 hectare of forest that is converted into agricultural land without any surrounding landscape, hypothetically speaking), then one could argue that the entire pollination service would be lost because of the pollinator species' habitat loss.

For estimating the effect of the land-use change from forest to shifting agricultural land on the monetary value of the pollination service, the service should be analysed separately. Because for the pollination service from the primary forest land use there has not been estimated a monetary value separately for the primary forest land use to avoid double counting (see Section 4.2.2), it should be recalculated here. For the primary forest land use the pollination service is embedded in the monetary value estimates of all other services which together form the total monetary value of the primary forest land use. To deduct the shares of the values of those services that can purely be addressed to 'pollination' in order to estimate a monetary value that is associated with pollination as a separate service, it would need a longer time span than that of current research (my research). If such a study will be carried out, one needs to know to what extent the pollination service contributes to the value of each ecosystem service separately, that is provided by intact primary forest. For fruits for example, this could be done by estimating the productivity surplus as a function of pollination by wild pollinator species. Just to illustrate, Klein et al. (2006) reported a minimum of 10% increased production for 63 crops because of animal pollination. if the fruits that are considered as provisioning services in my research, would indeed have at least a 10% increased productivity because of animal pollination, as reported by Klein et al. (2006), then this could mean that pollination as a separate service for these fruits alone would have an approximate value of around 30 USD/ha/year.

Another way for calculating the effect of land-use change on a monetary value estimate of the pollination service can be by estimating change in agricultural productivity in the absence/presence of the service. Since the land use here is shifting agriculture in which cassava *Manihot esculenta* crops are cultivated, the straightforward way to estimate the change in generated economic value is the result of a change in the producer surplus (Hein, 2009, pp. 2009). But this means that the pollination service is valued from an economic agricultural perspective while the object of the value is the change in land use (from forest to shifting agriculture). Therefore, it seems the monetary value change here can merely be estimated when conducting time consuming research which essentially would involve something in the direction of analysing the effects of the land-use changes on important pollinator species and communities (e.g. through niche modelling; or analysing and quantifying the effects on population increases/declines as a function of changes in floral and nesting resources) in and near the study areas of my research or another representative tropical forest area.

It has been considered here to monetarily value the pollination service according to the generated monetary change as a result of a change in the producer surplus in the annual cassava yield. The cassava *Manihot esculenta* does flower, but is a plant that reproduces vegetatively (also known as 'vegetative propagation', which simply means that it naturally reproduces itself) for which Klein et al. (2006) have reported that pollinators increase the seed production, but does not result in increased crop productivity. For this reason, the production function approach for estimating the monetary value of the pollination service for the cassava crop could not be used. It seems that a more suitable approach exists for estimating the value of the pollination service in this case, which is one that is reported by Kremen et al. (2007, pp. 306), who have stated that the value "may be estimated by measuring change in seed or fruit set of open-pollinated flowers exposed to natural levels of pollinators against exclusion treatments in which only self or wind pollination occurs." Data on the change in seed set for the cassava crop because of wild-pollinator species within the context of my research have not been reported in current literature which, in combination with a limited time period conducting such an analysis, resulted neither in a monetary value estimate for the pollination service for the shifting agriculture land use from intact primary forest surroundings.

To illustrate, when the monetary value of the pollination service of the shifting agriculture land use here could be estimated as a function of the increased (annual) productivity by taking the 10% yield increase of Klein et al. (2006) and based on the value estimate of the annual cassava productivity as reported in Section 5.1.1, then a monetary value of the pollination service for the shifting agricultural land use with intact surrounding forest would be 101 USD/ha/year (but this value estimate is then already embedded in the monetary value of the total annual cassava production). Note that through the monetary valuation of the pollination service of an agricultural (or other intensively utilised) landscape, interest could be raised among agricultural practitioners and decision-makers to increase efforts for conducting activities which aim at increased protection and conservation of wild pollinator species (Hein, 2009).

5.3 Habitat service: genepool protection

Forest conversion into a plot for practicing shifting agriculture affects the genepool protection service (i.e. biodiversity maintenance). Deforestation through any practice causes biodiversity losses on the local scale (Ometto et al., 2016). When mature primary forest is clear cut for creating a plot to practice shifting agriculture, the initial stand biomass will be lost. From the moment onward when the plot is abandoned, and climatic and biophysical factors are favourable, stand biomass returns (in volume) through regrowth. The stand biomass is used as a proxy to estimate the monetary value change when primary forest is converted into a plot for shifting agriculture.

Valuation

The estimated monetary value of the genepool protection service from mature primary forest is reported at 48 USD/ha/year (Section 4.3.1). Because the majority of a plot is cleared and burned following the slash-and-burn principle, most of the former vegetation will be lost. However, it is assumed that plant and tree species which are from socio-economic importance to riverine communities will be conserved for utilitarian purposes (e.g. medicinal plants, fruit trees), although it can be argued that in general, riverine communities will not clear plots of land where such plant and tree species are present. This assumption can be translated into a percentage share of biomass stand that will be conserved when land-use change takes place, which is assumed to be in the range of 0 – 20%. Taking the average of this range, gives that 10% of mature primary forest stand biomass is maintained. When coupling the reported value of 48 USD/ha/year to the stand biomass of primary forest (representing 100%), and calculating the 10% biomass stand to remain when land-use change has taken place, results in a monetary value for the genepool protection service of 4.8 USD/ha/year for the shifting agricultural land use.

5.4 Cultural services: eco-tourism and recreation

The recreation and eco-tourism service which former primary forest provided is considered to be lost for the most part when a plot of forest has been converted into a cassava cultivar when merely looking at the spatial scale of one hectare. From a wider viewpoint, it can be argued that deforestation for a transformed shifting agriculture land use by riverine communities would affect the former monetary value of the recreation and eco-tourism only partially. A reason for this is that riverine communities have generally not more than a few hectares of their livelihood surroundings cleared, which, because they are also dependent on the forest, ensures that most of the forest surrounding area remains intact. Consequently, tourists would still be satisfied from an ecological viewpoint since they generally come to Amazonia to experience the (intact) tropical forest or basin and all biological diversity and richness the region holds. It can also be argued that riverine communities and their livelihood surroundings are attractive for tourists, at least for some of them. Riverine communities and the practice of shifting agriculture is for centuries a long standing tradition, which can therefore be seen as cultural identity and thus may be appealing to tourists across the globe. So to some tourists a land-use change from forest to shifting agriculture would be less attractive, while to other tourists it would be increasingly attractive to experience. This could therefore lead to either a decrease or increase in the value estimate of the recreation and eco-tourism service, by taking the value of primary forest as a baseline. Also, the combination intact forest with rural communities that have cassava cultivars can be interesting for tourists. Because the value change is described here only in a speculative manner, the change has not been quantified and measured in monetary terms due to time constraints.

5.5 Synthesis

In this section an overview is given of the monetary value aggregates per ecosystem service category (i.e. provisioning, regulating, habitat, and cultural) (Figure 22). For the provisioning services and habitat services, the minimum and maximum value estimates are included which indicates the uncertainty range of these service categories.

The total monetary value estimate of the shifting agriculture land use is 1,608 USD/ha/year with a minimum monetary value estimate of 1,436 USD/ha/year and a maximum monetary value estimate of 1,776 USD/ha/year. The TMV consists of the four service categories provisioning services (1,443 USD/ha/year with a minimum value of 1,286 USD/ha/year and a maximum value of 1,597 USD/ha/year); regulating services (160 USD/ha/year with a minimum value of 145 USD/ha/year and a maximum value of 174 USD/ha/year); habitat services (5 USD/ha/year); and cultural services for which the monetary value could not be estimated because of the lack of data.

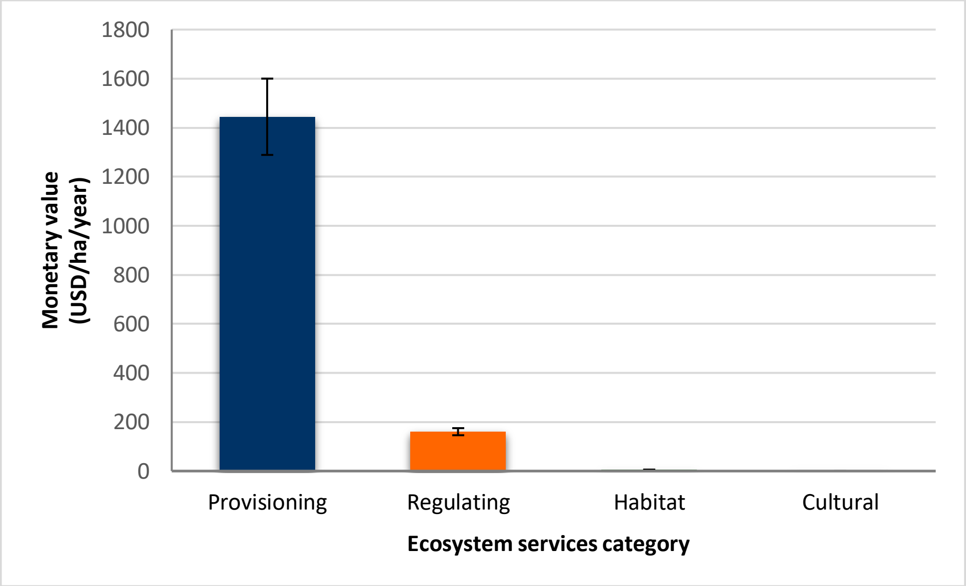

Figure 22: Estimated monetary value aggregates in USD/ha/year per ecosystem service category (i.e. provisioning, regulating, habitat, and cultural) for shifting agriculture.

The provisioning services consist fresh cassava roots, water in terms of supply and the raw material timber. Fresh cassava roots have the highest monetary value estimate (934 USD/ha/year) which accounts for 58% of the TMV of shifting agriculture. This annual value estimate is based on a productivity at locations with intact primary forest surroundings. Also timber has a relatively high monetary value estimate (508 USD/ha/year) which is the total timber stock that is obtained as a result of deforestation through the slash-and-burn principle. This monetary value estimate accounts for 32% of the TMV.

The regulating services consist of climate regulation and pollination for which merely the climate regulation service could be valued in monetary terms. The monetary value estimate of the climate regulation service is 160 USD/ha/year with a minimum value of 145 USD/ha/year and a maximum value of 174 USD/ha/year. This uncertainty range is related to the range of the SCC (25-30 USD tonne C) which correlates with an atmospheric greenhouse gas concentration of 450 – 550 ppm CO_2-eq. Forest conversion into shifting agricultural land has substantial effects on the climate regulation service (i.e. on the carbon stock and carbon flux). The carbon stock in tonne per hectare decreases with 55% when primary forest is converted into shifting agricultural land to cultivate cassava crops. The carbon flux in tonne per hectare decreases with nearly 100% because of the continuous cropping and harvest of cassava, which means that the initial carbon stored with increased crop growth is being released into the atmosphere at the time that harvest takes place.

The habitat service genepool protection is estimated at a monetary value of 4.8 USD/ha/year (equal to 10% of the value estimate for primary forest). This service has no uncertainty range because it is based on the WTP of European citizens (i.e. from the U.K. and Italy) for conserving parts of Amazonian forests. The monetary value estimate of the cultural service eco-tourism and recreation could not be estimated, but it is speculated that although deforestation would decrease the interest of tourists so some extent, rural communities can also attract tourists because of their cultural identity and long historical livelihoods in ways which can still be witnessed today.

6. Ecosystem services and monetary values of cattle pasture

6.1 Provisioning services

The monetary value estimates of the provisioning services from the cattle pasture land use are presented in Table 8 below, which include food in the form of cattle products (i.e. meat) and raw materials (i.e. timber).

Table 8: Provisioning services provided by cattle pasture, including the specification of the service, the quantity, and monetary value estimate in USD/ha/year.

Number	Ecosystem service	Specification	Quantity	Monetary value (US$ ha^{-1} $year^{-1}$)
1	Food	Cattle products (i.e. meat)	1.1 cows/ha	286
2	Raw materials			
	Timber	Extracted timber from slash-and-burn	32.3 t/ha	508

6.1.1 Food

In the Brazilian Amazon, smallholders deem to find it economically viable to convert forest and former cropland areas into cattle pastures (Pereira et al., 2016, pp. 2). Forest conversions into cattle pastures have been encouraged from the 1990s onward in the form of so called agrarian reform 'settlement projects' to support family farming through government credit exclusively for investments in cattle (Pereira et al., 2016). Smallholders of these settlement projects have been mainly focussed on animal husbandry i.e. cattle since, possessing a mixed herd dual cows for dairy and beef production since such cows are less expensive and provide better calving (Pereira et al., 2016, pp. 8). Pastures are often planted with the forage grass *Brachiaria humidicola* (e.g. Hohnwald et al., 2006; Siegmund-Schultze et al., 2007) and are generally maintained by smallholders performing the slash-and-burn principle (Siegmund-Schultze et al., 2007) and are in my research considered to possess <100 hectares.

Valuation

The average stocking density of cows per hectare in the Brazilian Amazon varies across literature but all are in the proximity of 1 animal/ha, depending on the site studied. Walker et al. (2000) reported a stocking density of 0.9 animals/ha, Pacheco (2009) reported a stocking density of an average 1.2 animals/ha, and Pereira et al. (2016) reported a stocking density of 1.3 animals/ha in 2006, and 0.95 animals/ha in 2011. All reported values combined gives an average stocking density of 1.1 animals/ha (over a stocking density range of 0.9-1.3 animals/ha).

Oliveira et al. (2019) have reported that family farming in Brazil can generate up to a gross revenue of 378 USD/ha/year (which is an average value calculated over the farming of annual crops, perennial crops, livestock, and NTFPs), and reported that smallholders in Brazil can generate up to a net income of 104 USD/ha/year. When using the stocking density of 1.1 animals/ha, reported values of 500 kg meat per animal and a 20% rate of utilisation[26] (Oliveira et al., 2019, pp. 173) gives a meat production range of 90-130 kg/ha. With a market value of 10 BRL/kg meat (Interviews 18, 20, 21), results in a monetary value estimate of 900-1300 BRL/ha/year or 234-338 USD/ha/year. This gives an average monetary value estimate of 286 USD/ha/year for smallholder cattle pastures. However, this value only represents meat and does not involve dairy products. Accurate data on dual cows/dairy is missing for the study areas of my research, but dairy products should be included if one aims to increase the relevance of the estimated monetary value for cattle products in the Brazilian Amazon since many smallholders in this region have dual cows.

6.1.2 Water

It is speculated that forest conversions into cattle pasture generally leads to the loss of small possible water sources. However, as was stated that the water sources considered in my research are from igarapés, these are forest streams which cannot simply be turned into land for any purpose. In theory, deforestation would mean loss of water sources in terms of supply, it is however questionable whether smallholders will alter such landscape characteristics. It is therefore assumed that water provided by igarapés are not affected by smallholder cattle farmers.

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[26] Reported values from Oliveira et al. (2019) are from a study area in Madre de Dios, Peru.

6.1.3 Raw materials

Merely timber is considered as a raw materials which will be affected when forest is converted into cattle pasture. Timber is often extracted by felling trees before pasture is planted. The monetary value estimate for timber is considered to be similar to that of the shifting agriculture land use since the total amount of timber stock is extracted as part of the landscape transformation. Note however that the type of extraction can be different for smallholders than for riverine communities (who use machetes and axes for clear cutting trees and other vegetation). The monetary value for the timber stock was for the shifting agriculture land use estimated at 508 USD/ha/year (see Section 5.1.3), which is likewise used for the timber value here.

6.2 Regulating services

In Table 9 the monetary values of the regulating services from the cattle pasture land use are presented, including the carbon stock after forest conversion, the net carbon flux, and the pollination service according to the losses of floral and nesting resources.

Table 9: Regulating services 'climate regulation' and 'pollination' provided by the cattle pasture, including the specification of the service, the quantity, and monetary value estimate in USD/ha/year.

Number	Ecosystem service	Specification	Quantity (tonne C ha^{-1} $year^{-1}$)	Monetary value (US$ ha^{-1} $year^{-1}$)
8	Climate regulation	Carbon stock after forest conversion	3.7	102[a]
		Carbon flux	1.0	28
14	Pollination	Significant habitat loss of wild insect pollinators in terms of floral and nesting resources	-	-

[a]Calculated by using a social discount rate of 0%.

6.2.1 Climate regulation

In comparison with other land uses, grasslands from cattle pastures seems in theory easily be manageable. A cattle holder does not specifically need to cultivate the grassland (Dale et al., 1993), but reality proves differently as can be seen in tropical regions such as the Brazilian Amazon. Tropical forest soils can be little productive without the input of external additives (e.g. fertilisers). This can result in many cattle holders to abandon their pastures and continue to clear other forest sites (Dale et al., 1993). Similar to the conversion of mature primary forest into a plot for shifting agriculture, forest conversions into cattle pasture results in significant carbon losses from the soil and vegetation C stock.

Valuation

Forest conversion into pasture results in a 90-100% carbon loss from the vegetation C stock (Moutinho, 2005). This value is equal to an average 173 t C/ha lost to the atmosphere. Concerning the soil C, deforestation into pastures emit less than shifting agricultural land because the grassland of pastures are not cultivated (Dale et al., 1993). The majority of the literature findings report soil C losses up to 40% (Dale et al., 1993; Fearnside and Barbosa 1998; Fearnside & Barbosa, 1998). But to not overestimate the soil C loss here, a reported soil C loss of 12% is used (Moutinho, 2005) which is equal to 8.8 t C/ha. This value estimate approaches but does not closely meet the one reported by Fearnside and Barbosa (1998) of the loss of 13.1 tonne C/ha from the top 0-100 cm layer of the soil when forest to pasture conversion has taken place. From author's calculations, the C stock that is left in the vegetation after forest conversion is 9.1 t C/ha, and the stock that is left in the soil after forest conversion is 64.4 t C/ha. This means that deforestation for cattle pasture results in a total C stock loss of approximately 71% (from the vegetation above and below ground, and SOC), which is equal to 182 t C/ha.

To value these C stock losses in monetary terms (with regard to the SSC of 25-30 USD per t of CO_2-eq (Stern, 2007, pp. xvii), results in average monetary value losses of 4550-5460 USD/ha. This gives an average monetary value loss estimate of 4755 USD/ha or 242 USD/ha (soil C stock). Forest conversion into cattle pasture with a time horizon of 20 years and a discount rate of 0% gives a altered soil stock monetary value range of 93-111 USD/ha/year. This gives an average value estimate of 102 USD/ha/year.

For the carbon flux, a study by von Randow et al. (2004, pp. 22-23) have compared fluxes from forest and pasture in southwest Amazonia and concluded that because the "reduction in nocturnal respiration is higher than the reduction in the daytime uptake, the combined effect is a 19-67% higher daily uptake of CO_2 in the pasture, compared to the forest. This high uptake in the pasture site is not surprising, since the growth of the vegetation is constantly renewed, while the cattle remove the biomass." Taking the average value (43%) of this higher daily uptake of CO_2, and calculating that over the 0.73 t C/ha/year, gives that pasture takes up 1.0 tonne C/ha/year. With a SCC of 25–30 USD per t of CO_2-eq (Stern, 2007) gives an estimated value range of 25-30 USD/ha/year, or an average monetary value of 27.5 USD/ha/year.

6.2.2 Pollination

Deforestation into cattle pasture has likely detrimental effects on the floral and nesting resources upon which pollinator species depend. This can be explained by the fact that nesting sites for important bee species (the most important wild insect pollinator species; e.g. the orchid bee *Euglossini*) in Amazon tropical forest areas are destroyed with forest clearing activities. Orchid bees generally use hollow trees and wooden cavities such as tree trunks for creating nests, build these 'aerial' e.g. under leaves, and inside termite nests (Ramírez et al., 2002). Continuous flat landscapes likely decreases nesting opportunities for wild bee pollinators. Moreover, cleared areas of 'even' 100 meters wide can act as a barrier to bee species (e.g. *Euglossa*), which constrains their foraging range and can result in pollinators not to be able to cross the landscape and thus cannot pollinate certain areas if there are no forest corridors that link other areas (Jaeger, 2013). Also, any floral resources present in the former forest area are also mainly lost when cattle pasture has come in place. For any floral resources left or newly thrive in the managed grassland, it can be that the cattle grazes these floral resources. Both these effects can result in alterations in pollinator community compositions (Kremen et al., 2007), which in turn can result in lower plant reproduction rates, affecting various other ecosystem services through cascading effects (e.g. decreased vegetation growth, which can lead to a decrease in gross carbon uptake, which can lead into a decreased climate change mitigation potential, and so forth). Moreover, the loss of natural habitat in terms of degradation or destruction and habitat fragmentation caused by land-use changes, could reduce the gene flow and re-colonisation rate of the affected pollinators (Kremen et al., 2007, pp. 302). Forest conversions can therefore make the altered landscape from little interest for insect pollinator species. To what extent the effects of land-use change i.e. deforestation for cattle pasture are on wild insect pollinator communities is however poorly understood. Likewise as argued in Section 4.2.2, it is unclear to what extent the land-use change here has effect on the monetary value of the pollination service. However, it is assumed that the effect on the monetary value of the pollination service that is associated with the land-use change from forest to pasture is from such great proportion that value of the service for pasture reaches (near) zero USD/ha/year (or could result in a negative value even when the value change is measured in terms of pollinator population or community changes). Although it remains a speculation here because of the lack of reported data, it is expected that the pollination service has lost its (monetary) value almost entirely.

6.3 Habitat service: genepool protection

When mature primary forest is converted into cattle pasture nearly all biodiversity in terms of biomass stand is assumed to be lost. Because the cattle pastures are managed for a certain time period, during this period secondary vegetation cannot grow. Mature primary rainforest is characterised by its complex structures, dark understorey, and relative stable humidity and temperature (Edwards et al., 2014). Forest interior species are therefore rapidly affected when deforestation takes place, since this lead to narrower environmental niches, light-sensitivity, and increases thermal stress (Edwards et al., 2014, pp. 513). Deforestation for cattle pasture therefore has significant effects on animal species. Besides effects on species' habitats, forest clearances brings about cascading effects (e.g. clearing a fruit tree can lead to decreased local fruit availability, which can lead to decreased seed dispersal activities, which in turn, can lead to decreased distribution and abundance of that specific fruit tree. This in turn can lead to decreased fruit availability in a specific region, which as a consequence can have other cascading effects).

Valuation

The estimated monetary value of the biodiversity for mature primary forest is 48 USD/ha/year (see Section 4.3.1). Using the forest stand biomass as a proxy for the biodiversity maintenance service, it is expected that due to forest conversion into, and maintenance of cattle pasture (grassland) the monetary value attached to the biodiversity here is lost entirely (associated with a 100% decrease in stand biomass). Therefore, a monetary value of 0 USD/ha/year is attached to the biodiversity maintenance service provided by the cattle pasture land use when assuming that in a 20-year time period the cattle pasture will remain feasible to operate.

6.4 Cultural services: eco-tourism and recreation

The recreation and eco-tourism service which primary forest provides, is expected to be lost when deforestation has taken place and cattle pasture is established. This can be explained by the simple fact that grassland as pastures does not likely attract tourists who visit Amazon regions. It can even mean that increased pasture development at the cost of primary forest, leads to decreased attractiveness which in turn can have adverse effects on the amount of tourists visiting nearby areas. Hence, a monetary value of 0 USD/ha/year is addressed to the recreation and eco-tourism service.

6.5 Synthesis

In this section an overview is given of the monetary value aggregates per ecosystem service category (i.e. provisioning, regulating, habitat, and cultural) (Figure 23). For the provisioning services and habitat services, the minimum and maximum value estimates are included which indicates the uncertainty range of these service categories.

The total monetary value estimate of the cattle pasture land use is 923 USD/ha/year with a minimum monetary value estimate of 860 USD/ha/year and a maximum monetary value estimate of 987 USD/ha/year. The TMV consists of the four service categories provisioning services (795 USD/ha/year with a minimum value of 742 USD/ha/year and a maximum value of 846 USD/ha/year); regulating services (128 USD/ha/year with a minimum value of 118 USD/ha/year and a maximum value of 141 USD/ha/year); habitat services (0 USD/ha/year); and cultural services (0 USD/ha/year).

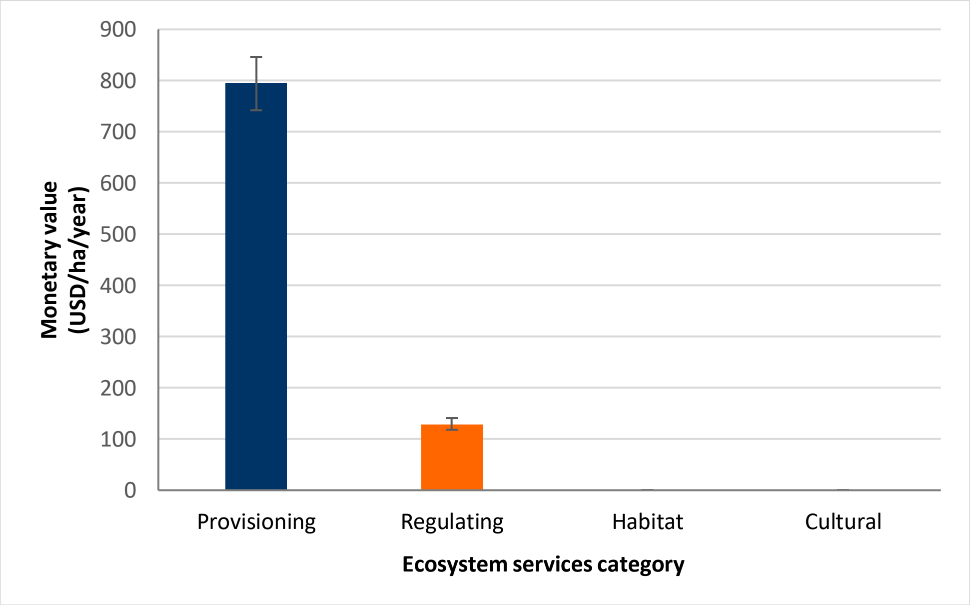

Figure 23: Estimated monetary value aggregates in USD/ha/year per ecosystem service category (i.e. provisioning, regulating, habitat, and cultural) for cattle pasture.

The provisioning services consist cattle products (i.e. meat) and the raw material timber. Cattle products are estimated at a monetary value of 286 USD/ha/year which accounts for 31% of the TMV of cattle pasture. Timber is estimated at a monetary value of 508 USD/ha/year (which is the same value estimate as for the shifting agriculture land use), which is the total timber stock that is obtained as a result of deforestation through the slash-and-burn principle. This monetary value estimate accounts for 55% of the TMV.

The regulating services consist of climate regulation and pollination for which merely the climate regulation service could be valued in monetary terms. The monetary value estimate of the climate regulation service is 128 USD/ha/year with a minimum value of 118 USD/ha/year and a maximum value of 141 USD/ha/year. This uncertainty range is related to the range of the SCC (25-30 USD tonne C) which correlates with an atmospheric greenhouse gas concentration of 450 – 550 ppm CO_2-eq. Forest conversion into cattle pasture has substantial effects on the climate regulation service (i.e. on the carbon stock and carbon flux). The carbon stock in tonne per hectare decreases with 72% when primary forest is converted into cattle pasture. The carbon flux in tonne per hectare however increases with 43% in comparison with the carbon flux from primary forest because of the constant regrowth of grass since the cattle remove this biomass.

The habitat service genepool protection is estimated at a monetary value of 0 USD/ha/year because the assumption that nearly all of the vegetation stand biomass that was present in the primary forest now has been lost because of deforestation through the slash-and-burn principle. The monetary value estimate of the cultural service eco-tourism and recreation is estimated at a monetary value of 0 USD/ha/year as it is assumed that cattle pastures are from little to no interest to tourists.

7. Comparative analysis of the three land uses

In this chapter, the monetary value estimates of the ecosystem services for each distinct land use (primary forest, shifting agriculture, and cattle pasture) are presented and compared with each other. In Table 10 an overview is given of the ecosystem services with associated monetary value estimates per land use. The monetary value aggregates per service category per land use are presented in Figure 24.

Table 10: Monetary value estimates per ecosystem service and category, per land use (in USD/ha/year). Also the TMV and s-PV is presented per land use.

Land use	→	*Primary forest*	*Shifting agriculture*	*Cattle pasture*
Number	**Ecosystem service**	**Monetary value (US\$ ha^{-1} year^{-1})**	**Monetary value (US\$ ha^{-1} year^{-1})**	**Monetary value (US\$ ha^{-1} year^{-1})**
	Provisioning	**1,004**	**1,442**	**794**
1	Food	670	934	286
2	Water	<0.00001	<0.00001	0
3	Raw materials	310	508	508
4	Medicinal resources	24	-[a]	-[a]
	Regulating	**371**	**160**	**128**
8	Climate regulation	371	160	128
14	Pollination	-[b]	-[c]	0
	Habitat	**48**	**5**	**0**
17	Genepool protection	48	5	0
	Cultural	**14**	**-[c]**	**0**
18	Recreation and eco-tourism	14	-[c]	0
TMV[d]		**1,437**	**1,607**	**922**
Discounted value				
s-PV[e] (SDR[f] = 0%)		**28,740**	**32,140**	**18,440**
s-PV[e] (SDR[f] = 5%)		**17,908**	**20,027**	**11,490**

[a] Not applicable.

[b] Embedded in the monetary value estimates of all other primary tropical forest services.

[c] Could not be estimated.

[d] TMV = total monetary value (USD/ha/year).

[e] Social present value (USD/ha)

[f] SDR = social discount rate; over a period of 20 years.

Food, water, raw materials, and medicinal resources

From my valuation analysis with regard to the ecosystem services food, water, raw materials, medicinal resources, climate regulation, pollination, genepool protection, and recreation and eco-tourism, the shifting agriculture land use has the highest total monetary value estimate (1,607 USD/ha/year), followed by primary forest (1,437 USD/ha/year), and cattle pasture (922 USD/ha/year). That the SA land use has the highest TMV can be owed to the value estimate of 934 USD/ha/year for food (i.e. farinha from fresh cassava roots), which accounts for 58% of the TMV. For the primary forest land use, the monetary value estimate for food is somewhat lower: 677 USD/ha/year, which accounts for 47% of the TMV. For cattle pasture, food was estimated at 287 USD/ha/year, which accounts for 25% of the TMV. Note that at the time of land-use change, forest products such as fruits and nuts can be extracted, thus holding certain value that are not taken into account in the analyses of my research. This means that (depending on the time of the year e.g. some fruit trees have seasonal fruit productivity) a onetime value from the provisioning services in terms of non-timber forest products (i.e. fruits, nuts, latex, and medicinal resources), should be added to the TMV of the changed land use, which then when spread over the time horizon of in this case 20 years, can be added to the annual total monetary value estimate of the forest converted land use. For timber, this has been done.

For raw materials, the shifting agriculture and cattle pasture land uses have the highest monetary value estimate (508 USD/ha/year) which represents merely the potential revenue from timber harvest. When only looking at cattle pasture, the timber yield is relatively high in comparison with the other services' value estimates. When looking across the three land uses, it is more profitable to extract forest products in a sustainable manner as this incurs a gross revenue of 1,004 USD/ha/year. It should be kept in mind that the timber value estimate for both the SA and CP land uses is highly dependent on the temporal scale one considers if annual extraction takes place. Looking from an eternal temporal scale, it is simply impossible to have each year an equal or higher timber yield in the same plot of land in terms of volume and quality if timber is extracted at a higher rate than the ecosystem's natural vegetation growth rate.

For cattle pasture, the value of the extracted timber accounts for 60% of its TMV. This implies, although costs have not been incorporated in the monetary value estimates in my research and which thus net values are not provided, that logging (508 USD/ha/year) yields more than double the revenue from holding cattle for dairy and meat products (286 USD/ha/year). The opposite is true for the shifting agriculture land use, for which the timber yield accounts for nearly half (54%) of the annual yield from cultivating cassava crops. Raw materials that can be extracted from primary forest are timber and latex, which account for 307, and 3 USD/ha/year, respectively. The timber associated monetary value of 307 USD/ha/year is relatively high (21% of the TMV), especially when considering that this value is based on the natural vegetation regeneration rate (of 0.5 m^3/ha/year) which means that without taking into account any growth rate drawbacks or vegetation destructive casualties this value is a revenue from eternal characteristic. That latex has a relative low monetary value estimate is due to the low rubber tree density, ranging from 0.07-3.0 individual per hectare (Shanley, 2011). Concerning the medicinal resources which is in general an essential raw material for the global community, it has a value estimate of 24 USD/ha/year which is considered to be unique, since this raw material and associated estimated value is lost when forest conversions have taken place.

Climate regulation
For the climate regulation service, the highest monetary value is estimated for primary forest at 371 USD/ha/year, which for the shifting agriculture land use and the cattle pasture land use are 160 USD/ha/year and 128 USD/ha/year, respectively. The differences in these monetary values when compared, can be explained by the change in carbon stock due to forest clearing activities. Both the carbon stored in above and belowground vegetation (i.e. roots), as well as the soil organic carbon changes as a result of deforestation. Taking primary forest as the baseline, the carbon stock in shifting agriculture after forest conversion is 50% less than the original stock present in the forest, and the carbon stock in cattle pasture after forest conversion is 72% less than the original stock present in the forest. The carbon flux of primary forest has a value estimate of 20 USD/ha/year (a positive value indicates that the land use acts as a carbon sink, taking up carbon from the atmosphere). The value estimates of the carbon fluxes for shifting agriculture and cattle pasture are 3 USD/ha/year, and 28 UDS/ha/year, respectively. Note that the carbon flux for cattle pasture has a higher value estimate than for primary forest, which is due to a higher daily CO_2 uptake in the pasture compared to the forest. This is not surprising, since the growth of the vegetation is constantly renewed, while the cattle remove the biomass (Randow et al., 2004, pp. 22-23).

Pollination
For the pollination service, a monetary value could not be estimated for primary forest because its separate value is in primarily embedded in all other ecosystem services and hence their associated values (see Section 4.2.2). For the shifting agriculture land use, there is no monetary value addressed because the pollination of the cassava (*Manihot esculenta)* flowers by wild insect pollinators results in a larger seed-set which likely will not result in a (significant) productivity surplus. Therefore, a production function approach for estimating the surplus in monetary terms was not possible to conduct. Concerning the pollination service from cattle pasture, it is expected that deforestation and the management of grassland to feed cattle will result in an enormous decline in floral and nesting resources upon which pollinator species depend. Therefore the associated monetary value estimate is assumed to reach 0 USD/ha/year, or could become a negative value even when considering that without any wild-insect pollinator, pollination could not take place and thus can lead to adverse cascading effects (e.g. through decreased plant and tree species' sexual reproduction rates).

Genepool protection
The genepool protection service as the utmost monetary value estimate for primary forest, since it provides the natural habitat for all Amazonian forest species which is affected when land-use changes occur. The value estimates are calculated as a function of the total vegetation stand biomass, which for primary forest is 100%, for shifting agriculture 10%, and for cattle pasture approximately 0%.

Recreation and eco-tourism
For recreation and eco-tourism, the highest monetary value estimate is for primary forest (48 USD/ha/year). Some of this value could get lost when establishing a plot for practicing shifting agriculture, but may also increase because it is a land use of cultural importance since it is practiced across the globe for thousands of years. In addition, rural (i.e. riverine) communities in the study areas are dependent on the forest and will therefore always leave their forest surroundings mainly intact as long as they remain dependent on forest products (e.g. fruits). In contrast, the recreation and eco-tourism service from cattle pasture has an associated monetary value estimate of 0 USD/ha/year because it is assumed that tourists from wherever will not pay a visit to cows grazing on pasture for which Amazon mature primary forest had to be cleared.

Discounted values (s-PVs)
The s-PVs of the primary forest land use were estimated at 28,740 USD/ha (with a SDR of 0%), and 17,908 USD/ha (with a SDR of 5%). The s-PVs of the shifting agriculture land use were estimated at 32,140 USD/ha (with a SDR of 0%), and 20,027 USD/ha (with a SDR of 5%). The s-PVs of the cattle pasture land use were estimated at 18,440 USD/ha (with a SDR of 0%), and 11,490 USD/ha (with a SDR of 5%). From these discounted value estimates I conclude that the welfare effects from (forest converted) shifting agricultural land (i.e. to cultivate cassava crops) are largest considering merely the ecosystem services that have been taking into account in my research. The discounted value estimates are lowest for cattle pastures.

Monetary value aggregates per ecosystem service category
From the monetary value aggregate per ecosystem service category presented in Table 10, it can be stated that for each land use the highest aggregate value estimate represents the provisioning services. This service category mainly consists of food and raw materials. That the other service categories (i.e. regulating, habitat, and cultural) have significant lower aggregate value estimates is likely due to fact that not all ecosystem services (see Section 2.2.3 for the full list of services as proposed by TEEB, 2010) have been taken into account in this research due to time constraints. For regulating services category there are seven services not analysed. For the habitat services category, there is one service not analysed, and for the cultural services category there are four services not analysed. This does however not mean that each additional service taken into account will result in a change in the TMV (i.e. some are not relevant, or would hold a negligible monetary value estimate). Noteworthy are the monetary value estimates for habitat services and cultural services of the cattle pasture land use, which are for both 0 USD/ha/year. Although these estimates are estimated on speculative grounds, it does indicate that there is are significant monetary value losses in these service categories when primary forest is converted into cattle pasture.

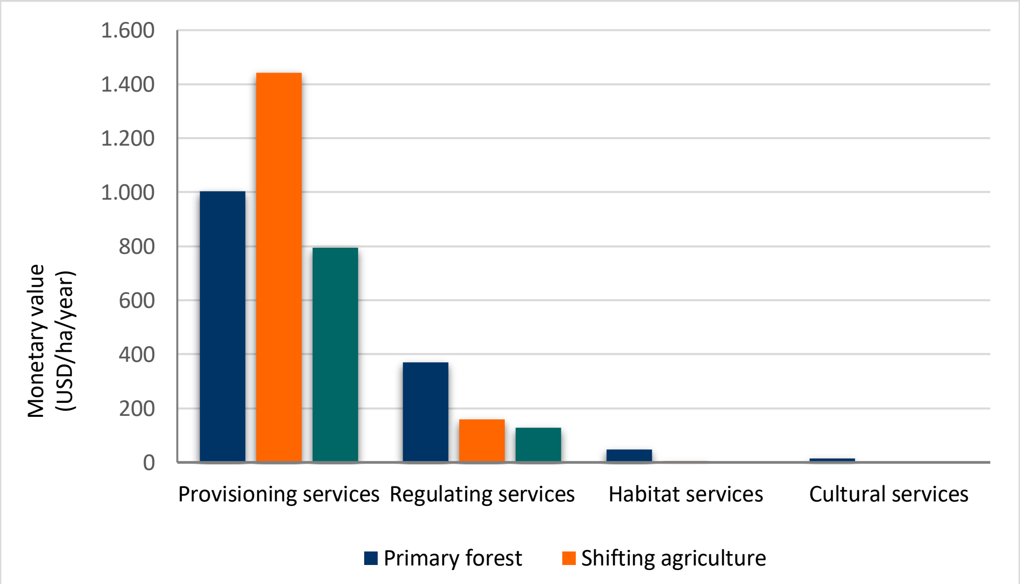

Figure 24: Monetary value aggregates in USD/ha/year per service category per land use (primary forest, shifting agriculture, and cattle pasture).

8. Planning and management implications (or the conservation and sustainable use of primary forest's ecosystem services)

Few planning and management implications emerge for the conservation and sustainable use of the ecosystem services provided primary forest and shifting agriculture with intact primary forest surroundings. This chapter also presents some recommendations for a further study.

The primary forest areas from Opção Verde contain many provisioning services (i.e. timber and non-timber forest products) that can be from great socio-economic importance to people with rural livelihoods. NTFPs can also function as a substitute for products from smallholders of cattle. The monetary value estimates of NTFPs are significantly higher than those from cattle products (i.e. meat). The potential harvest and trade of timber and NTFPs if done so according to sustainable use levels (see Section 4.1), can contribute to the conservation of the forest and its biodiversity. The NTFPs with the potential highest monetary returns include açaí, burití, tucumã and the brazil nut. These products can be used to establish social-ecological systems in which deforestation for land use changes from forest to shifting agriculture or cattle pasture is reduced and simultaneously promotes the conservation of intact primary forest.

When looking at the shifting agriculture land use, the monetary value yield of cassava crops give annually more monetary returns than timber and NTFPs from primary forest together (at least the sum of the monetary value estimates of those mere foods that are analysed in my research) (see the syntheses Sections 4.5 and 5.5). The combination of cultivating cassava crops and harvest and trade of NTFPs can potentially result in the highest monetary returns if surrounding forest areas remain intact. Because the cassava (*Manihot esc*. Cr.*)* is from great socio-economic and perhaps also cultural importance to rural communities, the inclusion of cassava cultivation seems essential in a socio-economic and ecological system in which is aimed at maximising conservation efforts.

Timber harvest leads to deforestation to a certain extent. Activities to harvest timber and to change primary forest into shifting agricultural land or cattle pastures are considered unsustainable as it likely leads to ecological deterioration. Even with increased sustainable harvesting methods (e.g. reduced impact logging) can result in collateral forest damage. I therefore advise to minimise or eliminate timber harvest from primary forest areas and focus on NTPFs to substitute timber monetary returns. Note that if timber harvest will be included in the possible management of forest areas, take into account that the harvest of timber can have many cascading effects at different spatiotemporal scales, affecting the ecosystem and the biodiversity.

For further research I recommend to expand the preliminary (Appendix I) and monetarily valued list (Section 4.1.1) of NTFPs. These NTFPs could be socio-economically important to rural community people and others that alter the forest landscape into different land uses, while simultaneously their harvests and trade can contribute to increased conservation of Opção Verde's primary forest areas. I also advise to study the socio-economic needs of rural communities and cattle holders to minimise halt practices that contribute to the ecological deterioration of forest areas. In addition, further exploration, analysis and valuation of the ecosystem services that have not been addressed in my research, but which can be important to understand and signify the value of primary forests, should also be further studied.

9. Discussion

Limited amount of land uses identified

Three most relevant land uses were identified. The underlying reason for their relevance was that within the study areas of my research, the land uses primary forest, shifting agriculture and cattle pastures represent combined the largest share of the total study surface area. Additional land uses are also present in the study areas but are considered to take up a minor share of the total study surface area. Because the focus of my study was to analyse effects of the eland use changes: primary forest into shifting agriculture and primary forest into cattle pastures, other (minor) land uses have not been taken into account.

Assumptions regarding the identification of the shifting agriculture land use

For identifying the shifting agriculture land use, field observations at merely one site of a riverine community were conducted. Remotely sensed maps from Face the Future (2018) indicated that there are multiple sites in and near the study areas deforested for practicing shifting agriculture. However, because of a limited amount of time and available resources, observing and examining multiple sites was not possible. Therefore it was assumed that all sites at which shifting agricultural activities were practices, were done so to cultivate cassava (*Manihot esculenta* Crantz) crops. This assumption was based on reported literature findings in which was found that the cassava crop is a staple food in Brazil and from great socioeconomic and also cultural importance to rural communities in Brazil. Therefore, even though it is not clear whether all of the shifting agricultural land in the study areas cultivate the same crop type, the assumption that most (if not all) sites for practicing shifting agriculture are used to cultivate cassava crops is treated as highly certain.

Limited number of ecosystem services included in this study

Different typologies and categorisations of ecosystem services exist (i.e. Costanza, 1997; MA, 2005; TEEB, 2010; CICES, 2010; and IPBES, 2018). I used TEEB's (2010) typology because it contains ecosystem services with most detailed specifications and is most inclusive in comparison with the ecosystem services typologies of Costanza (1998); MA (2005); CICES (2017) and IPBES (2018).

There exist many important additional ecosystem services than those addressed in my research that are not taken into account in the ecosystem services analysis and valuation. This has resulted in that a limited set of ecosystem services was addressed. This is mainly due the limited amount of time that was assigned to conduct my research which is a major limitation of my study. The limited amount of ecosystem services and thus also the limited amount of monetary value estimates has affected the results of my research in the way that the total monetary value estimate for the primary forest land use is an underestimate of the forest's real total monetary value. To which extent the effects of deforestation into the shifting agriculture or cattle pasture land uses affect the total monetary value estimates of those analysed in my research are not known. It depends how such changes affect the underlying forest's structures and processes and consequently those of the transformed land uses, for a specific spatiotemporal scale.

Because the total monetary value estimate for the primary forest land use is considered to be an underestimate, it implies that the true total monetary value should be much higher. This means that in reality, the total monetary value of the primary forest land use exceeds the total monetary values of the shifting agriculture and the cattle pasture land uses. This also means that when forest conversion (into shifting agriculture or cattle pastures) takes place, the relative monetary value changes could be much larger than currently issued.

Proxies for analysing ecosystem services in biophysical units

For analysing the ecosystem services of my research in biophysical units, these should be considered as proxies that are representative for the specific services. The underpinned structures and processes that bring about the complex functioning of the land uses primary forests, shifting agriculture and cattle pastures and the relative change therein when forest conversions are taking and have been taking place, are too complex to analyse and translate into biophysical units considering the limited amount of time that was assigned to my research. For this reason, proxies were used which represent the complex functioning of (parts of) the ecosystem and consequently the services it provides. Although proxies are in fact translations of the ecosystem's functioning in simplified terms, the proxies that were used for my research adequately represent the underpinning structures and processes that provide the ecosystem services.

Uncertainties regarding biophysical data and monetary value estimates

Uncertainties remain for the estimates in the change of the carbon stock value when forest is converted into land for shifting agriculture or cattle pasture. The relative changes have been estimated according to percentage losses from timber extraction (vegetation above and below-ground i.e. roots) and from soil (organic carbon). However it is highly dependent on various local factors whether the relative change in carbon stock is the same for any hectare of Amazon primary forest (e.g. actual amount vegetation stock, vegetation types, how timber extraction takes place). This likely resulted in marginal errors. These errors are demonstrated through visualisations in which the minimum and maximum monetary value estimates per service category are presented where possible.

With regard to the uncertainty of the monetary value estimates (i.e. which is demonstrated by providing the minimum and maximum values), the relative differences between the total monetary value estimates between the three distinct land uses remain similar when deducting or adding the uncertainties. The sensitivity analyses has no significant implications for the comparative analysis in which the total monetary value estimates of the three land uses are compared. With the inclusion of the sensitivity analyses, the shifting agriculture remains the land use with the highest total monetary value estimate, followed by primary forest and cattle pasture, respectively.

Assumptions regarding monetary value estimates

For the methods and approaches of the monetary valuation of the ecosystem services, minor uncertainties exist in the obtained market values of the fruits and nuts from markets in Manaus and Coari. The product values at local markets represent the actual mechanism of supply and demand, reflecting what consumers are willing to spend on (forest) products. Note however that socio-ecological externalities are often not incorporated in market values of current economic systems. This implies that the costs that are incorporated in specific market products (for example of less sustainably sourced products) should be much higher. This has implications for total monetary value estimates of specific land uses from which products can be harvested in increased or decreased sustainable ways as the relative differences in monetary values between sustainable and less sustainable products would be much higher and thus also the differences in total net monetary value estimates of entire land uses would be much higher.

With regard to the social cost of carbon which was 25-30 USD per tonne of carbon as proposed by Stern (2007) it is arguable whether this addressed cost value is one that will be applicable for any given moment in the future. I argue that as long as the atmospheric concentration of GHGs are increasing, which results in increased radiative forcing and in turn leads to increased climatic changes, calls for adapting the social cost of carbon to these increases. When considering the current rate of GHGs that are being emitted into the atmosphere, it is expected that in a future time period the SCC will increase. This will have consequences for the value estimates of the carbon stock and fluxes of the land uses, resulting in higher value estimates than currently reported. Uncertainties remain for the carbon flux of the cattle pasture land use since the GHG emissions from maintaining cattle (i.e. CH_4 due to cows expelling air from stomachs and due faecal excretion) have not been taken into account in the quantification and valuation of the flux. For the shifting agriculture land use, the carbon returns to the soil as a result of biomass burning have not been taken into account in estimating the carbon stock and associated monetary value.

For the monetary value estimate of the genepool protection service (i.e. the value of biodiversity), the estimate (taken from Horton et al., 2003) is based on the willingness to pay of residents of the United Kingdom and Italy. A WTP study on itself already holds uncertainty to some extent because responses are based on how the context of the study undertaken and the questions asked are understood, on individual preferences and socio-economic status, and on the mere knowledge of the problem presented in the study prior to the questioning. However, it does represent the amount of monetary value people attach to the ecosystem and biodiversity. There exist a major limitation in this type of value attachment because it is the willingness of the global community to pay for biodiversity that is the factor limiting to what extent the value of biodiversity can be translated into monetary terms (Fearnside, 1999, pp. 14).

10. Conclusions and recommendations

In this chapter, conclusions are given per research question (see Section 1.4) and recommendations are formulated.

Land uses in and near the study areas

RQ1 was *"which land uses are relevant in analysing Opção Verde's forest areas and how are these land uses defined and characterised?"* Three relevant land uses were identified in and near the study areas which are: (I) primary forests, (II) shifting agriculture (to cultivate the staple food cassava *Manihot esculenta* Crantz), and (III) cattle pastures (in the form of smallholder cattle farming). The first land use 'primary forest' is defined as intact mature dense-canopy moist tropical broadleaf forest. It is the land use habitually found in abundance and which dominates in and near the study areas. The second land use was identified through field observations at a riverine community alongside the Urucu River who had cleared forest areas in their livelihood surroundings to establish plots for shifting agricultural land. A rural people's plot to cultivate cassava crops often the size less than one hectare and is located in forest adjacent areas near community villages. One village (of approximately 20 – 25 people) typically has one to a few hectares for cultivation. The third land use was identified through an explorative study, in which was found that the development of cattle pastures is the primary indirect cause of deforestation in Brazil (Fearnside 2005; Fearnside, 2008; McAlpine et al., 2010). Both the shifting agriculture and cattle pasture land uses are established by deforestation activities following the slash-and-burn principle. The cattle in this land use is held by smallholders which clear forest areas of around 3 hectares on average. Land-use changes for cattle pastures could be a threat of deforestation to Opção Verde's forest areas that are located in the northwest region of Manaus in a future time period. The main reason for this is because the forest areas are in the proximity of the BR-174 highway, which increases forest accessibility.

Stakeholders and stakeholder groups

RQ2 was *"which relevant stakeholders are involved in or affected by the land uses from RQ1?"* A stakeholder analysis was carried out to identify which relevant stakeholders and stakeholder groups benefit from or are affected by the (change in) ecosystem services which are provided by primary forest areas or another land use. Based on the influence-interest matrix, I conclude that the central government, governmental agencies, industrial companies and research institutions have relatively high influence in the conservation or use of primary forest areas. Stakeholders who depend on (intact) primary forest areas and the ecosystem services these provide, are considered to be utmost interested. I therefore conclude that when stakeholders who depend on the forest's services and use these in sustainable ways, they can contribute to increase conservation efforts which can lead to long-term conservation of the primary forests in the study areas.

Ecosystem services per land use

RQ3 was *"which ecosystem services are provided by the identified land uses of RQ1 and how can these be measured and quantified?"* To understand which ecosystem services were brought about per land use, a typology from TEEB (2010) was used as a baseline, in combination with a desk study to assess accordingly the relative changes on the services in biophysical terms. The ecosystem services that were analysed in my research for each land use were: food; water; raw materials (i.e. latex and timber); medicinal resources; climate regulation; pollination; genepool protection; and recreation and eco-tourism. Before the ecosystem services could be valued in monetary terms, they were analysed and quantified in biophysical units. For the quantification in biophysical units, indicators were selected in which the units allowed for measuring the effects of the land-use changes on the ecosystem services. This was an essential step in order to be able to analyse the relative changes in the ecosystem's associated monetary value estimates.

There exist many other ecosystem services that are considered to be from great socio-economic significance but have not been analysed in my research. It is therefore recommended to analyse, quantify and value those in further studies to signify the (economic) value of intact primary forest and to address which monetary returns from sustainably using the forest can substitute for less sustainable utilisation activities. In conclusion, deforestation into land for shifting agriculture or cattle pasture has profound effects on the services which intact mature primary forest provides. This is especially true for the soil carbon and vegetation carbon stocks, as well as for the carbon fluxes which are all significantly reduced. Land-use changes from primary forest to shifting agriculture or cattle pasture has detrimental effects on the pollination service (i.e. by speculating the change in the floral and nesting resources upon which wild pollinator species depend). Each ecosystem service per land use has been quantified and valued according to different valuation methods and approaches (see Section 2 and Chapters 4, 5, and 6).

Monetary value estimates
RQ4 was *"what are the total monetary values and (social) present values of these land-use based ecosystem services?"* The sum of all individual services associated monetary value estimates resulted in total monetary values per land use, which were compared to each other. From this comparison, I conclude that concerning the ecosystem services food, water, raw materials, medicinal resources, climate regulation, genepool protection, and recreation and eco-tourism, the shifting agriculture land use has the highest total monetary value estimate (1,607 USD/ha/year), followed by primary forest (1,437 USD/ha/year), and cattle pasture (922 USD/ha/year).

The total monetary value estimate of the primary forest land use is 1,437 USD/ha/year with a minimum monetary value estimate of 1,168 USD/ha/year and a maximum monetary value estimate of 1,699 USD/ha/year. The TMV consists of the four service categories provisioning services (1,002 USD/ha/year with a minimum value of 769 USD/ha/year and a maximum value of 1,232 USD/ha/year); regulating services (371 USD/ha/year with a minimum value of 337 USD/ha/year and a maximum value of 405 USD/ha/year); habitat services (48 USD/ha/year); and cultural services (14 USD/ha/year).

The total monetary value estimate of the shifting agriculture land use is 1,608 USD/ha/year with a minimum monetary value estimate of 1,436 USD/ha/year and a maximum monetary value estimate of 1,776 USD/ha/year. The TMV consists of the four service categories provisioning services (1,443 USD/ha/year with a minimum value of 1,286 USD/ha/year and a maximum value of 1,597 USD/ha/year); regulating services (160 USD/ha/year with a minimum value of 145 USD/ha/year and a maximum value of 174 USD/ha/year); habitat services (5 USD/ha/year); and cultural services for which the monetary value could not be estimated because of the lack of data.

The total monetary value estimate of the cattle pasture land use is 923 USD/ha/year with a minimum monetary value estimate of 860 USD/ha/year and a maximum monetary value estimate of 987 USD/ha/year. The TMV consists of the four service categories provisioning services (795 USD/ha/year with a minimum value of 742 USD/ha/year and a maximum value of 846 USD/ha/year); regulating services (128 USD/ha/year with a minimum value of 118 USD/ha/year and a maximum value of 141 USD/ha/year); habitat services (0 USD/ha/year); and cultural services (0 USD/ha/year).

The s-PVs of the primary forest land use were estimated at 28,740 USD/ha (with a SDR of 0%), and 17,908 USD/ha (with a SDR of 5%). The s-PVs of the shifting agriculture land use were estimated at 32,140 USD/ha (with a SDR of 0%), and 20,027 USD/ha (with a SDR of 5%). The s-PVs of the cattle pasture land use were estimated at 18,440 USD/ha (with a SDR of 0%), and 11,490 USD/ha (with a SDR of 5%). From these discounted value estimates I conclude that the welfare effects from (forest converted) shifting agricultural land (i.e. to cultivate cassava crops) are largest considering merely the ecosystem services that have been taking into account in my research. The discounted value estimates are lowest for cattle pastures.

Implications and recommendations
RQ 5 was *"what are the planning and management implications for conserving Opção Verde's forest areas and what should be recommended for the sustainable use of their forests?"* Few planning and management implications emerge for the conservation and sustainable use of the ecosystem services provided primary forest and shifting agriculture with intact primary forest surroundings.

The primary forest areas from Opção Verde provide many provisioning services (i.e. timber and non-timber forest products) that can be from great socio-economic importance to people with rural livelihoods. NTFPs can also function as a substitute for products from smallholders of cattle. The monetary value estimates of NTFPs are significantly higher than those from cattle products (i.e. meat). The potential harvest and trade of timber and NTFPs if done so according to sustainable use levels (see Section 4.1), can contribute to the conservation of the forest and its biodiversity. The NTFPs with the potential highest monetary returns include açaí, burití, tucumã and the brazil nut. These products can be used to establish social-ecological systems in which deforestation for land use changes from forest to shifting agriculture or cattle pasture is reduced and simultaneously promotes the conservation of intact primary forest.

When looking at the shifting agriculture land use, the monetary value yield of cassava crops give annually more monetary returns than timber and NTFPs from primary forest together (at least the sum of the monetary value estimates of those mere foods that are analysed in my research) (see the syntheses Sections 4.5 and 5.5). The combination of cultivating cassava crops and harvest and trade of NTFPs can potentially result in the highest monetary returns if surrounding forest areas remain intact. Because the cassava (*Manihot esc*. Cr*.)* is from great socio-economic and cultural importance to rural communities, the inclusion of cassava cultivation seems essential in a socioeconomic-ecological system to maximise conservation efforts.

I recommended to explore ecosystem services that are provided at the time when the forest is inundated by river water (or the várzea seasonal floodplain) and what the (cascading) effects and changes in the services and values are when land-use changes have been or are taking place. I also recommend to use the analyses of the ecosystem services of my research for exploring the teleconnections between these in the terrestrial zones and the services in the aquatic zones. By doing so, the effects of land use changes on the ecosystem services in both zones can increasingly be understood, which will contribute to establish and all-encompassing understanding of Brazilian Amazon forests in which the complexity of its services and interconnections between them can be valued thoroughly.

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Appendix I – Fruits provided by Brazilian Amazon primary forest

Through market research in Manaus and Coari in Brazil, and in combination with an explorative study, a comprehensive list of Amazonian forest fruits is made (Table 11). The density and productivity of many of these fruits are not reported yet and in these terms still poorly understood today. Further research is necessary in order to analyse what the economic value (e.g. in monetary terms) of these fruits are. Note that it is expected that the vast amount of Amazon forest holds fruits and other edibles that are still unknown to date.

Table 11: Fruits that can be found in mature primary tropical forest in the Brazilian Amazon.

Number	Ecosystem service category	Specification	Reference
	Provisioning		
1	Food		
	Fruits	Abiu	
		Açai *(Euterpe oleracea)*	Feira da ADS, 2019
		Acerola	Feira da Panair, 2019
		Avaça-boi	Rabelo, 2012
		Babacu	
		Bacaba	Rabelo, 2012
		Bacuri	Rabelo, 2012
		Biribá	Rabelo, 2012
		Blackberry jam fruit	Blancke, 2016
		Brazilian guava	Blancke, 2016
		Burití	Rabelo, 2012
		Cacahuillo	Blancke, 2016
		Cacao de monte	Blancke, 2016
		Camu-camu	Rabelo, 2012
		Cannonball tree	Blancke, 2016
		Castanha-cajú	Adolpho Lisboa, 2019
		Castanha-sapucaia	Clemente Vieira, 2019
		Charichuelo	Blancke, 2016
		Chupa chupa	Blancke, 2016
		Cogo-de-guariba	Rabelo, 2012
		Cubiu	Rabelo, 2012
		Cupuaçu	Feira da ADS, 2019
		Genipap/Jenipapo Jenipapo (juice)	Feira Rural
		Giant granadilla	Blancke, 2016
		Guava	Feira da Banana, 2019
		Graviola	Feira da ADS
		Guaba	Blancke, 2016
		Guaçatumba (wild honey tree)	Blancke, 2016
		Guama machete	Blancke, 2016
		Guarana	Rabelo, 2012
		Inajá	
		Ingá-açu	Feira da Ceasa
		Ingá-cipó	Rabelo, 2012
		Ipé-roxo	
		Jamaica cherry	Blancke, 2016
		Jatobá	Rabelo, 2012
		Malabar chestnut	Blancke, 2016
		Mamoncillo	Blancke, 2016
		Mapati	
		Maracujá do mato	
		Marajá-do-igapó	Rabelo, 2012
		Marimari	Rabelo, 2012

	Mountain soursop	Blancke, 2016
	Murici-amarelo	Rabelo, 2012
	Nance	Blancke, 2016
	Needle flower tree	Blancke, 2016
	Pajurá	Rabelo, 2012
	Passionfruit (yellow)	Blankce, 2016
	Patauá	Rabelo, 2012
	Peanut butter fruit	Blancke, 2016
	Pepino-do-mato	Rabelo, 2012
	Pimenão	Feira da ADS
	Pink shower tree	Blancke, 2016
	Piquiá	Rabelo, 2012
	Pitombá	Rabelo, 2012
	Pupunha	Rabelo, 2012
	Puruí	Rabelo, 2012
	Rambutan	Feira da Banana
	Sapota Solimôes	Rabelo, 2012
	Soncoya	Blancke, 2016
	Sorvinha	Rabelo, 2012
	Sugar apple	Blancke, 2016
	Tamarind (juice)	Rabelo, 2012
	Taperebá	Feira da Panair
	Taperebá (juice)	Rabelo, 2012
	Tucumã	Feira da ADS
	Umari	Rabelo, 2012
	Uvilla	Blancke, 2016
	Uxi	Rabelo, 2012

Appendix II – Market values of Amazonian fruits and nuts

In Table 12 all the provisioning services that have been assessed throughout the entire time span of my research (i.e. fruits and nuts) are presented with associated monetary values that have been obtained from markets in Manaus and Coari in Brazil, or from literature findings.

Table 12: Market values of Brazilian Amazonian fruits and nut species that can be found in mature primary forest.

	Ecosystem service category	Ecosystem service or benefit	Market value	Reference or location
	Provisioning services			
1	Food			
	NTFP	Abiu	0.50 – 1.00 R$/unit or 5.00 R$/15 units	Rabelo, 2012
		Açai *(Euterpe oleracea)*	12.0 R$/L (juice with water; intended to drink) 15.0 R$/L (juice without water; intended to drink) 25.0 R$/L (juice without water; intended to eat) Average of 6.25 US 2007/2008 dollar/basket	Feira da ADS
		Acerola (juice)	10 R$/L 5.0 R$/L	Feira da Panair Feira da Banana
		Avaça-boi	0.50 – 1.00 R$/unit or 2.00 – 4.00 R$/kg	Rabelo, 2012
		Bacaba	3.0 R$/L (fresh fruit)	Rabelo, 2012
		Bacuri	2.0 R$/8 units (Bacuripari)	Rabelo, 2012
		Biribá	5.0 – 10 R$/2 – 3 units (size dependent)	Rabelo, 2012
		Burití	2.0 R$/24 units	Rabelo, 2012
		Camu-camu	40 R$/20 kg	Rabelo, 2012
		Caquí (Kaki)	2.0 R$/kg	Feira Rural
		Castanha-cajú	10 R$/100 g 70 R$/kg	Feira da ADS Adolpho Lisboa
		Brazil nut	350 R$/53 kg	Trade platform Lake Coari
		Castanha-sapucaia	2.0 R$/200 g	Clemente Vieira
		Cogo-de-guariba	0.50 – 1.00 R$/unit	Rabelo, 2012
		Cubiu	4.0 R$/kg	Rabelo, 2012
		Cupuaçu (whole fruit)	0.50 – 2.0 R$/unit (small) or 2.0 – 5.0 R$/unit (large) 5.0 R$/3 units 2.0 - 3.0 R$/unit (size dependent) 7.0 R$/L	Rabelo, 2012 Feira da ADS Feira Rural
		Cupuaçu (juice)		Feira da Banana
		Copaiba		
		Goiaba	5.0 R$/kg	Feira da Banana
		Graviola (whole fruit)	5.0 R$/kg	Feira da ADS
		Graviola (juice)	15 R$/L 10 R$/L	Feira da Panair Feira da Banana
		Guarana	Roasted seeds 30 R$/kg *(two other forms also marketed)*	Rabelo, 2012
		Inajá	-	-
		Ipé-roxo	-	-
		Ingá-açu	2.0 R$/3-4 units 1.0 R$/unit 2.0 R$/net (200 g)	Rabelo, 2012 Feira da Ceasa Feira Rural
		Ingá-cipó	2.0 – 3.0 R$/3 units (price varies due period high/low supply)	Rabelo, 2012
		Jatobá	1.0 – 3.0 R$/12 units (market dependent)	Rabelo, 2012
		Jenipapo Jenipapo (juice)	2.0 R$/200 g 20 R$/80-90 units 5.0 R$/L	Feira Rural Rabelo, 2012 Feira da Banana
		Maracujá	2.0 R$/12 units or 3.0 R$/8 units	Rabelo, 2012

		6 R$/kg	Feira da Banana
	Maracujá do mato		
	Maracujá (juice)	15 R$/L	Feira da Panair
	Marajá-do-igapó	2.0 R$/bunch; 5.0 R$/3 bunches	Rabelo, 2012
	Marimari	0.50 R$/unit or 2.0 R$/3 - 5 units	Rabelo, 2012
	Murici-amarelo	5.0 R$/2 L or 3.0 R$/500 g	Rabelo, 2012
	Pajurá	5.0 R$/3 – 4 units	Rabelo, 2012
	Patauá	2.0 R$/2 L (fresh fruit)	Rabelo, 2012
	Pepino-do-mato	2.0 R$/3 – 4 units	Rabelo, 2012
	Pimenão	5.0 R$/kg	Feira da ADS
	Piquiá	3.0-5.0 R$/3 – 4 units (market dependent) 1.0 R$/unit	Rabelo, 2012 Feira Rural
	Pitombá	2.0 – 4.0 R$/50 units (market dependent)	Rabelo, 2012
	Pupunha	1.0-15 R$/clustered bunch (natural form) (size dependents)	Rabelo, 2012
	Puruí	3.0 R$/6 – 12 units	Rabelo, 2012
	Rambutan	5.0 R$/kg	Feira da Banana
	Sapota Solimôes	5.0 R$/3 units (small) or 10.0 R$/3 units (large)	Rabelo, 2012
	Sorvinha	4.0 R$/12 or 24 units (amount of unit depends on start or apex of season)	Rabelo, 2012
	Tamarind (juice)	15 R$/L	Feira da Panair
	Taperebá	40 R$/30 kg	Rabelo, 2012
	Taperebá (juice)	5.0 - 10 R$/L	Feira da Banana Feira da Panair
	Tucumã	2.0 – 3.0 R$/12 units or 4.0 – 7.0 R$/12 units (mixed sizes and tastes, and homogeneity in shape and size) 10.0 R$/20 units	Rabelo, 2012 Feira da ADS
	Umari	2.0-3.0 R$/7 – 12 units	Rabelo, 2012
	Uxi	2.0-4.0 R$/10 units	Rabelo, 2012

Appendix III – List of interviews with marketers and traders, and key informants, and summaries with main findings of the interviews per theme

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The following interviews were carried out, with corresponding dates, names, or agencies where applicable.

18/03/2019

- Interview 1 – Marketer 1 (Feira da Banana): Patricia, 33 years old
- Interview 2 – Marketer 2 (Feira da Banana): Andre
- Interview 3 – Marketer 3 (Feira da Moderna): Heimoeda

19/03/2019

- Interview 4 – IBAMA (Brazilian Institute of Environment and Natural Resources): Hugo Ferreira
- Interview 5 – INPA (National Institute of Amazonian Research): Rita Mesquita

20/03/2019

- Interview 6 – ADS (Agency for the Sustainable Development of Amazonas): Tomás Sanches
- Interview 7 – Marketer 4 (Feira da ADS)

26/03/2019

- Interview 8 - Marketer 5 (Feira do Produtor Rural)
- Interview 9 – Marketer 6 (Streetmarket just outside Feira do Produtor Rural)
- Interview 10 – IDAM (Institute of Sustainable Agricultural and Forestry Development of the State Amazonas): Ricardo

27/03/2019

- Interview 11 – Canoe man (Ribeirinho)

28/03/2019

- Interview 12 – Children (from local community), (village Barro Alto)
- Interview 13 – School teacher for children from rural communities, (village Barro Alto)
- Interview 14 – Fransisca, 51 years (villager of Nossa Senhorá)
- Interview 15 – Sebastián (villager of Nossa Senhorá)
- Interview 16 – Aniude, 34 years (villager of Esperanza *or* on maps 'Terra Vermelha)

29/03/2019

- Interview 17 – Rogero & Manuel (villagers Nazareda Dailingh *or* on maps: 'Nossa Sénhora Nazaré')

30/03/2019

- Interview 18 – Butcher 1 (beef) (Mercado Municipal Clemente Vieira)
- Interview 19 – Marketer (game species) (Street outside Mercado Municipal Clemente Vieira)
- Interview 20 – Butcher 2 (beef) (Mercado Municipal Clemente Vieira)
- Interview 21 – Butcher 3 (beef) (Mercado Municipal Clemente Vieira)
- Interview 22 – 'Cabocla Industria' Management of Castanha processing factory Coari

02/04/2019

- Interview 23 – Cassava (macaxeira) agricultural farmer: Robert, 45 years old

- Interview 24 – Mr. Gerison, landowner at the Rio Grande region)

Analysed interviews

Markets and NTFP

From the markets visited in Manaus (public fair, banana fair, Ceasa port fair, Adolpho Lisboa municipal market, and the organic food fair) and Coari (farmers' market, Clemente Vieira municipal market), each marketer that has been interviewed stated that all the products that were offered at the markets come from Amazon forest areas in the region (Patricia, interview 1; Andre, interview 2; Heimoeda, interview 3; ,arketer 4, interview 7; Marketer 5, interview 8; and marketer 6, interview 9). The products sold at markets in Manaus come mainly from from Rio Preto da Eva (municipality Northeast of Manaus), and Manacapuru (municipality east of Manaus) (Tomás Sanches, ADS, interview 6; Patricia, interview 1). Most of the products are transported from the forest areas to the markets by truck (Andre, interview 2). However, Tomás Sanches from ADS (interview 6) explained that concerning the products at the ADS fair, it is season dependent whether products come from regional Amazon forest areas, or from other Brazilian States (e.g. Roreima, Rondônia) (Tomás Sanches, ADS, interview 6). In the case of the latter, the products are transported by airplane to Manaus. The reason to get food from other States when these cannot be taken from regional forest areas, is to provide customers a continual variety and diversity of products (Tomás Sanches, ADS, interview 6). At the Farmers' market in Coari, it is free to stall and sell your products (Marketer 5, interview 8). At markets in Manaus such as the Modern fair however, marketers have to pay a fee for stalling and selling products (Andre, interview 3).

In Coari, one marketer was selling wild meat at his stall in a street just outside the Farmers' market. He gets the wild meat (or game) from various different forest areas in the surroundings of Coari. He sold meat from animals such as tapir and armadillo, but the type of meat which he sells differs daily (Marketer 6, interview 9). It is cheaper to buy wild meat than farmed meat (e.g. beef, pork). Although selling wild meat on markets is considered as an illegal activity, Hugo Ferreira from IBAMA (interview 4) stated that "to date, a lot of wild animals from the Amazon forest are being consumed, mainly by elderly people."

Rural communities at the Urucu River

Rural communities who live near OV's forest areas in the region Southwest of Coari, commonly established their villages alongside the Urucu River. From the villages visited (Barro Alto, Nossa Senhorá, and Esperanza), each are inhabited by approximately 20 – 30 people. Besides the fact that the River is used as a medium for transportation, one of the main reasons for establishing their villages alongside the Urucu River is because fish is their main protein source. Also the Brazil nut, which is taken from the surrounding forest areas, is an important dietary food or income source. Other forest products that are used for consumption are tucumã , mango, inga, açaí, cupuacu, and cocoa. When the Brazil nut is used as an income source, these are traded on markets in Coari. A school teacher at the Barro Alto village has stated that many communities clear small patches of forest in their surrounding area to cultivate crops (e.g. bananas, cashews). But over the years, this small-scale deforestation has led to a decrease in amount of animal species for game.

Another product that is extracted from the forest is timber. Timber is primarily used for construction purposes such as houses and canoes for the community. It is not use for trade or selling purposes. In addition, communities use water from the Urucu River as a water source for consumptive purposes (i.e. drinking, and cleaning) (Interview 15)

A problem that the community at the Nossa Senhorá village has experienced is River bank erosion at various sites. Fransisca (Nossa Senhorá village, interview 14) stated that "the reason that erosion takes place is because of the waves that are brought about by boats from the oil company Petrobas, which' passes their village every day." The people at this village are afraid that they can lose their houses because of this erosion. Another issue of concern which various people from different communities have said is that it is currently very hard to get enough fish as a food source. A cause for decreased fish populations in the Urucu River could be that there is a lot of commercial fishing taking place. Sebastián (Nossa Sénhora, interview 15) has stated that "commercial fishing is done with nets, the River is being fished out. There is little amount of fish left for the local people, that is why we have chicken and dogs."

The communities at the Nossa Senhorá village and the Nazareda Dailingh village both had cassava cultures. At the Nossa Senhorá village, a cassava processing-plant was located where they produce farinha. The farinha is shipped by boat, and traded on markets in Coari.

Brazil nut

The Brazil nut is an important protein source for rural communities which live alongside the Urucu River. When fish and animal species from the forest are difficult to get, the Brazil nut substitutes their dietary animal protein. But the Brazil nut is mainly used as a forest product for trade. Yet, the Brazil nut is not produced every year and it is thus not possible to sell Brazil nuts on the market continuously (Marketer, Feira do Produtor Rural, Interview 8). The quantity of Brazil nuts that the tree gives depends on whether influences. The canoe man (interview 11) has stated that: “increased temperatures results in increased amounts of Brazil nuts.” Brazil nuts and açaí berries are products that give favourable profits when sold on the Farmers’ Market in Coari (Canoe man, interview 11). Aniude, a villager from the local community at Esperanza stated that “there are a large amount of Brazil nut-trees in the forest.” However, he also stated that “there are no Brazil nuts this year” (Aniude, villager of Esperanza, interview 16). Ricardo from IDAM (interview 10) has stated that: “the Brazil nut is, together with açaí, cacao, guarana, and coffee, the most valuable product to sell on the market.”

A man who delivered his Brazil nuts per small motorboat at a Brazil-nut storage and trading place in the Coari lake (formed by the Rivers Coari, Urucu, and Arauá) which he gathered from the forest in the region of the Paraná Copeá River, received a bit less than 7.0 R$/kg nuts (including shells) or 350 R$/’hecto’ (box with a volume of 100 L, equal to 53 kg of Brazil nuts including shell) (Gerison, landowner Rio Grande, interview 24). A Castanha processing factory in Coari (Cabocla Industria) pays 300 R$/’hecto’ (Cabocla Industria management, interview 20). Even though the selling price of the Brazil nut fluctuates monthly, Cabocla Industria sells the Brazil nuts according to quality and size. They distinguish five classes of nut quality and size including: broken; bruised; small; medium; large; and extra-large. The selling prices, or value, per kilogram of the classes are: 30 R$; 35 R$; 40 R$; 46 R$; 48 R$; and 50 R$; respectively (Cabocla Industria management, interview 20). The sizes medium and small are most common. Cabocla Industria ships their Brazil nuts in vacuumed plastic bags that are put in cardboard boxes, mainly to São Paulo.

Cassava cultivation

(Rogero and Manuel, villagers of Nazareda Dailingh, interview 17). Location: Nazareda Dailingh (or village Nossa Sénhora Nazaré)

A local community is settled in the form of a small village alongside the Urucu River at Nazareda Dailingh, Southwest of Coari. In this village live not more than 30 people. This village has a cassava culture of approximately 70 m^2. The people have used the slash-and-burn principle for establishing the culture. It was observed that trees were cut with a machete (due to the bumpy and irregular ends of the tree stumps), and tree stumps and plant litter were black from the burning process. The wood that is extracted is being used for construction purposes in the village (e.g. housing, canoes).

When the cassava is ready to harvest, the plant is being pulled out of the soil entirely. At the village they have built a cassava-processing plant for producing farinha (flour). Rogero and Manuel have stated that “every community in the region here has a cassava-processing plant. The revenue of the produced farinha is 100 R$/ bag, which generates an income of approximately 1000 R$/month. Farinha is sold at markets in Coari. They say that farinha is more profitable than the Brazil nut in their case. .” Another community (village Nossa Senhorá) has a cassava-processing plant for producing farofa. Sebastián (villager of Nossa Senhorá, interview 15) has explained that farofa in the plant is produced according to a stepwise approach, including: (i) pealing of the cassava; (ii) a generator that runs on petroleum crushes the raw pealed cassava to pulp; (iii) the pulp is pressed to reduce as much liquid as possible; (iv) the pressed pulp is sieved; (v) the substance is fried in a large round ‘paella-like’ pan with a stove that runs on firewood. The juice from the pulp pressing process is captured and sold on a market. The rest-product from the crushing process (i.e. hard and soft filaments) are used to make a sort of pudding for private consumption. The produced farofa from this plant yields 15 bags per month at a total profit of 1500 R$ (Sebastián, villager of Nossa Senhorá, interview 15). The firewood that is used for frying the pulp comes from the forest.

The cassava crops at the culture in Nazareda Dailingh are cultivated for a time period of 5 – 6 years. After this period of time, the soil is not fertile enough anymore to be able to produce crops of significant quality. They leave the cassava culture fallow to let the soil regenerate its fertility, and shift to an adjacent forest area where the slash-and-burn principle is performed again (Rogero and Manuel, villagers of Nazareda Dailingh, interview 17). The fallow period varies but is currently decreased to approximately 5 years (Joslin et al., 2011; Jakovac et al., 2017). Secondary vegetation grows in this period. After the fallow period it was observed that the former cassava culture now was used to cultivate banana crops. This area with banana crops (from approximately 1 hectare) is not considered as a culture since the bananas are used for private consumptive purposes and not as cash crops (Interview 17).

A former cassava culture was now utilised as a monoculture-like banana culture. These bananas are used only for private consumption. They harvest the bananas three times a year, which is a prosperous food source for the community.

(Robert, cassava farmer, interview 22). Location: Lake Santana (West of Manaus)

“People who live in Amazon forest areas that cannot get enough food from the forest in order to sustain themselves, consider cutting down forest to start a small cassava culture” (Robert, cassava farmer, interview 21). The cassava culture that Robert has, however, was not created by cutting down trees because the plot he grows cassava crops on was already deforested. The area used to be cattle pasture. His reason to start a cassava culture was because the forest did not provide him enough fruits and nuts. Local cassava farmers in this region generally have a plot of one hectare in size, which is also the case for this plot. The reason that local people plant cassava (macaxeira), and not another type of crop is because cassava is the easiest to grow, without putting much effort during the year. The costs for creating a cassava culture of one hectare are estimated on an approximate of 1000 R$. Robert is considering expanding his cassava culture.

A total of four people help this cassava farmer for the entire year. The planting of the cassava is done during the start of the wet season, while harvesting is done during the dry season. Concerning water irrigation, this cassava culture does not have an irrigation system, but instead uses water from rainfall which is enough for the crops to grow. Some farmers however do have an irrigation system, which is more beneficial to crop growth.

Two common fertilisers to improve crop growth exist that are generally used among cassava farmers, a brown one and a white one. Robert uses the white one, which is an industrial fertiliser. This fertiliser costs 25 R$ per bag of 40 kg, which is entirely used once per year.

This cassava culture can be harvested once in every 8 months. One harvest yields approximately 200 bags of cassava roots, with approximately 60 kg per bag. This farmer sells his cassava roots when harvested all at once to either people at the Manaus Modern Fair, or someone comes with a car to ship his cassava to elsewhere. Transport costs to bring the cassava to the market are estimated to be 200 R$ when transported with a small car, or 500 R$ when transported with a truck. The total revenue of one harvest is 14,000 R$. The marketers either retail the roots in the raw form or process the roots into products such as farinha, farofa, bolo, fariabranca, tapioca, and tapioquinha.

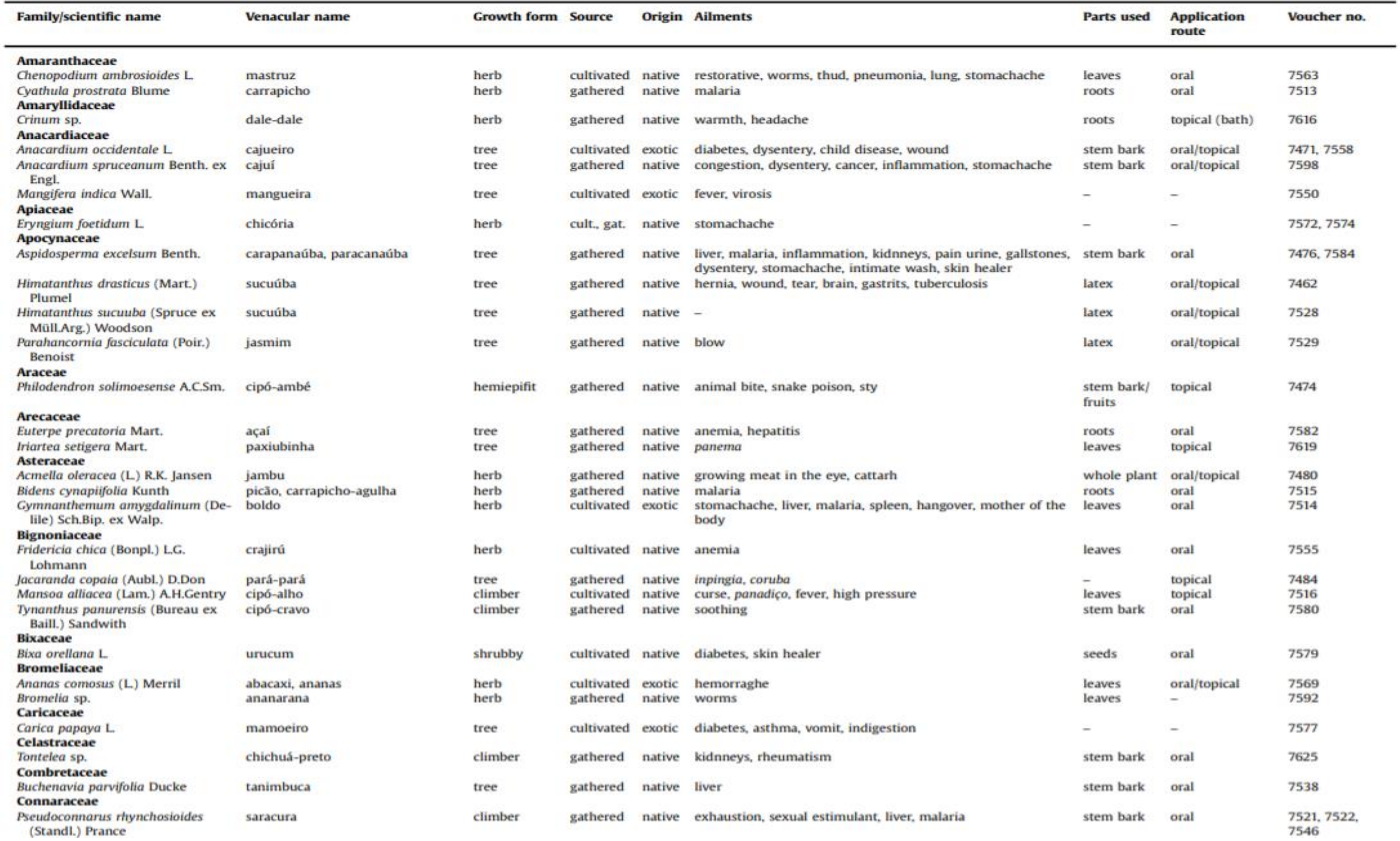
This farmer forms with a total of 20 cassava farmers in the region a cooperative. They have established this cooperative because it could give them increased chances for receiving possible governmental support (e.g. subsidies, better retirement compensation). The main issues or challenges which this cassava farmer faces is the intrusion of insects such as crickets and large ants, which could affect his cassava crops.

Cattle and beef products

From the ten beef meat providers at the Clemente Vieira market in Coari, three take their meat from local beef producers (Butcher 2, interview 19). The beef from local beef producers near Coari have small-scale cattle pasture (Butcher 1, interview 18). The rest of the beef meat providers let the meat they offer shipped by boat from Altamira, Monte Allegra, and Óbidos, Pará (Butcher 2, interview 19; Butcher 3, interview 20). Soy is often an important product that is used for cattle fodder in Brazil (Butcher 3, interview 20). The prices of beef at the Clemente Vieira market in Coari vary from 13 – 22 R$/kg (Butcher 1 – 3, interviews 18 – 20). Hugo Ferreira from IBAMA has stated that one of the main reasons of deforestation is to establish cattle pasture (interview 4).

Appendix IV – Medicinal plants used by riverine communities at Rio Jauaperi

Table 13: Medicinal plants that have been collected through the study of five riparian communities at Rio Jauaperi in the Brazilian Amazon by Pedrollo et al. (2016). Per medicinal plant is specified its family and scientific name, vernacular name, growth form, source, origin, ailments, parts used, application route, and voucher number from Herbarium EAFM (from Pedrollo et al., 2016, pp. 115-118).



Family/scientific name	Venacular name	Growth form	Source	Origin	Ailments	Parts used	Application route	Voucher no.
Amaranthaceae								
Chenopodium ambrosioides L.	mastruz	herb	cultivated	native	restorative, worms, thud, pneumonia, lung, stomachache	leaves	oral	7563
Cyathula prostrata Blume	carrapicho	herb	gathered	native	malaria	roots	oral	7513
Amaryllidaceae								
Crinum sp.	dale-dale	herb	gathered	native	warmth, headache	roots	topical (bath)	7616
Anacardiaceae								
Anacardium occidentale L.	cajueiro	tree	cultivated	exotic	diabetes, dysentery, child disease, wound	stem bark	oral/topical	7471, 7558
Anacardium spruceanum Benth. ex Engl.	cajuí	tree	gathered	native	congestion, dysentery, cancer, inflammation, stomachache	stem bark	oral/topical	7598
Mangifera indica Wall.	mangueira	tree	cultivated	exotic	fever, virosis	–	–	7550
Apiaceae								
Eryngium foetidum L.	chicória	herb	cult., gat.	native	stomachache	–	–	7572, 7574
Apocynaceae								
Aspidosperma excelsum Benth.	carapanaúba, paracanaúba	tree	gathered	native	liver, malaria, inflammation, kidnneys, pain urine, gallstones, dysentery, stomachache, intimate wash, skin healer	stem bark	oral	7476, 7584
Himatanthus drasticus (Mart.) Plumel	sucuúba	tree	gathered	native	hernia, wound, tear, brain, gastrits, tuberculosis	latex	oral/topical	7462
Himatanthus sucuuba (Spruce ex Müll.Arg.) Woodson	sucuúba	tree	gathered	native	–	latex	oral/topical	7528
Parahancornia fasciculata (Poir.) Benoist	jasmim	tree	gathered	native	blow	latex	oral/topical	7529
Araceae								
Philodendron solimoesense A.C.Sm.	cipó-ambé	hemiepifit	gathered	native	animal bite, snake poison, sty	stem bark/ fruits	topical	7474
Arecaceae								
Euterpe precatoria Mart.	açaí	tree	gathered	native	anemia, hepatitis	roots	oral	7582
Iriartea setigera Mart.	paxiubinha	tree	gathered	native	*panema*	leaves	topical	7619
Asteraceae								
Acmella oleracea (L.) R.K. Jansen	jambu	herb	gathered	native	growing meat in the eye, cattarh	whole plant	oral/topical	7480
Bidens cynapiifolia Kunth	picão, carrapicho-agulha	herb	gathered	native	malaria	roots	oral	7515
Gymnanthemum amygdalinum (Delile) Sch.Bip. ex Walp.	boldo	herb	cultivated	exotic	stomachache, liver, malaria, spleen, hangover, mother of the body	leaves	oral	7514
Bignoniaceae								
Fridericia chica (Bonpl.) L.G. Lohmann	crajirú	herb	cultivated	native	anemia	leaves	oral	7555
Jacaranda copaia (Aubl.) D.Don	pará-pará	tree	gathered	native	*inpingia, coruba*	–	topical	7484
Mansoa alliacea (Lam.) A.H.Gentry	cipó-alho	climber	cultivated	native	curse, *panadiço*, fever, high pressure	leaves	topical	7516
Tynanthus panurensis (Bureau ex Baill.) Sandwith	cipó-cravo	climber	gathered	native	soothing	stem bark	oral	7580
Bixaceae								
Bixa orellana L.	urucum	shrubby	cultivated	native	diabetes, skin healer	seeds	oral	7579
Bromeliaceae								
Ananas comosus (L.) Merril	abacaxi, ananas	herb	cultivated	exotic	hemorraghe	leaves	oral/topical	7569
Bromelia sp.	ananarana	herb	gathered	native	worms	leaves	–	7592
Caricaceae								
Carica papaya L.	mamoeiro	tree	cultivated	exotic	diabetes, asthma, vomit, indigestion	–	–	7577
Celastraceae								
Tontelea sp.	chichuá-preto	climber	gathered	native	kidnneys, rheumatism	stem bark	oral	7625
Combretaceae								
Buchenavia parvifolia Ducke	tanimbuca	tree	gathered	native	liver	stem bark	oral	7538
Connaraceae								
Pseudoconnarus rhynchosioides (Standl.) Prance	saracura	climber	gathered	native	exhaustion, sexual estimulant, liver, malaria	stem bark	oral	7521, 7522, 7546

Family/scientific name	Venacular name	Growth form	Source	Origin	Ailments	Parts used	Application route	Voucher no.
Costaceae								
Costus cf. *spicatus* (Jacq.) Sw.	cana-de-índio	herb	cultivated	native	exhaustion	–	–	7603
Crassulaceae								
Kalanchoe pinnata (Lam.) Pers.	courama	herb	cult., gat.	exotic	flu, cattarh, antibiotic, wound	leaves	oral	7506, 7556, 7560
Cucurbitaceae								
Cayaponia botryocarpa C.Jeffrey	cipó-alho-bravo	climber	gathered	native	itch, insect repelent	leaves	topical	7540
Dilleniaceae								
Doliocarpus spraguei Cheeseman	cipó-d'agua	climber	gathered	native	stomach wash, restorative	stem bark	oral	7519
Euphorbiaceae								
Euphorbia prostrata Aiton	bacurauzinho	herb	cultivated	native	diabetes	leaves	oral	7575
Euphorbiaceae								
Jatropha gossypiifolia L.	pião-roxo	shrubby	cultivated	exotic	fever, pneumonia, sinusitis, headache, teeth pain, child disease	leaves	topical	7509, 7566
Fabaceae Caesalpinioideae								
Caesalpinia ferrea (Mart. ex Tul.) L.P. Queiroz	jucá	tree	cultivated	exotic	headache, stomach	fruits	oral	7512
Fabaceae Caesalpinioideae								
Campsiandra comosa Benth. *	acapurana	tree	gathered	native	blow, dysentery, hemorróidas	stem bark	oral	7497, 7517
Copaifera multijuga Hayne	copaíba	tree	gathered	native	flu, cattarh, throat, lung, infection, inflammation, blow, skin healer, kidnneys	stem bark/ stem oil	oral/topical	7596
Copaifera sp.	copaíba	tree	gathered	native	–	–	–	7594
Crudia amazonica Spruce ex Benth.	orelha-de-cachorro	tree	gathered	native	worms	stem bark	oral	7600
Hymenaea parvifolia Huber	jatobá	tree	gathered	native	inflammation, fever, flu, cough, throat, cattarh, tuberculosis, asthma, lung, anemia, liver, rheumatism, menstrual regulator	stem bark/ leaves	oral	7597
Hymenaea sp.	jatobá	tree	gathered	native	–	stem bark	oral	7511
Peltogyne paniculata Benth.	itaubarana	tree	gathered	native	stomachache, dysentery	stem bark	oral	7496
Phanera splendens (Kunth) Vaz	escada-de-jabuti, cipó-de-jabuti	climber	gathered	native	kidnneys	–	–	7467, 7494, 7549
Senna alata (L.) Roxb.	mata-pasto-da-folha-larga	shrubby	gathered	native	*curuba*	leaves	topical	7620
Senna occidentalis (L.) Link	mangerioba	shrubby	gathered	native	cancer, inflammation, malaria, high pressure	leaves	oral	7609
Senna sp.	mata-pasto	shrubby	gathered	native	*curuba*	leaves	topical	7488
Fabaceae Mimosoideae								
Inga ramiflora (Benth.) Barneby & J. W.Grimes	ingarana	tree	gathered	native	animal bite	–	–	7470
Parkia discolor Spruce ex Benth.	arara-tucupi	tree	gathered	native	yellow fever, hemorrhoids	stem bark	oral	7482
Fabaceae Papilionoideae								
Aeschynomene sp.	quebra-pedra	shrubby	gathered	native	kidnney stone	–	oral	7622
Deguelia rariflora (Mart. ex Benth.) G.P. Lewis & Acev.-Rodr. *	timbó	climber	gathered	native	wound cleaner, toxic plant	roots	oral	7486
Vatairea guianensis Aubl.	fava	tree	gathered	native	itch, *impingia*	stem bark	oral	7595
Gentianaceae								
Potalia resinifera Mart.	matuguá, matuguá-branco	shrubby	gathered	native	snake poison	leaves	topical	7562, 7585, 7611
Goupiaceae								
Goupia glabra Aubl.	cupiúba	tree	gathered	native	itch, dysentery, spleen, liver	–	oral	7531
Heliconiaceae								
Heliconia acuminata Rich.	bananarana	herb	gathered	native	animal bite, abortive	leaves	topical	7588
Humiriaceae								
Endopleura uchi (Huber) Cuatrec.	uxi, uxi-liso	tree	gathered	native	stomachache, dysentery, hemorrhoids, intestinal infection, blow, inflammation, mother of the body, liver, hepatitis, tuberculosis, pain urine, anemia, anticoncepcional, menstrual regulator, hemorraghe	stem bark/ seeds	oral	7613
Hypericaceae								
Vismia cayennensis (Jacq.) Pers.	lacre	tree	gathered	native	itch, curuba	leaves	topical	7508

Vismia guianensis (Aubl.) Choisy	lacre	tree	gathered	native	itch, curuba	leaves	topical	7460
Iridaceae								
Eleutherine bulbosa (Mill.) Urb.	marupaí	herb	cultivated	native	dysentery	roots	oral	7576
Lamiaceae								
Mentha spicata L.	hortelãzinho	herb	cultivated	exotic	cólica infantil, child disease, pain de ouvido	leaves	oral/topical	7565
Ocimum basilicum L.	alfavaca, basílico	herb	cultivated	exotic	flu, headache, eyes	leaves	oral	7557, 7573
Ocimum campechianum Mill.	alfavaca	herb	cultivated	native	flu, headache	leaves	oral	7502
Plectranthus amboinicus (Lour.) Spreng.	malvarisco	herb	cultivated	exotic	flu, headache	leaves	oral	7501
Plectranthus ornatus Codd	boldinho	herb	cultivated	exotic	pain-de-barriga	leaves	oral	7491, 7564
Lauraceae								
Aniba canellila (Kunth) Mez	preciosa	tree	gathered	native	fever, headache, stomachache	stem bark	oral	7561
Ocotea aciphylla (Nees & Mart.) Mez	louro-namuí	tree	gathered	native	blow, tear, rheumatism, itch	resin	topical	7591
Ocotea olivacea A.C.Sm.	jarumã	tree	gathered	native	hemorrhoids	leaves	oral	7610
Persea americana Mill.	abacateiro	tree	cultivated	exotic	heart	leaves	oral	7567
Lecythidaceae								
Bertholletia excelsa Bonpl.	castanheira	tree	cult., gat.	native	anemia, sexual diseases, stomachache, liver, malaria, wound, dysentery, pain urine, urine infection, swelling	stem bark	oral	7463
Malpighiaceae								
Banisteriopsis sp.	cipó-tuiri	climber	cultivated	native	liver, malaria, hepatitis	leaves	oral	7465
Malpighiaceae								
Lophanthera longifolia (Kunth) Griseb.	cuiarana	shrubby	cult., gat.	native	allergy, itch	leaves	topical	7478, 7571
Malvaceae								
Luehea sp.	tartaruguinha-branca	tree	gathered	native	hemorrhoids	stem bark	oral	7623
Mollia sp.	tartaruguinha-preta	tree	gathered	native	exhaustion, headache	leaves	topical	7624
Marantaceae								
Calathea allouia (Aubl.) Lindl.	ariá	herb	gathered	native	kidnneys			7608
Meliaceae								
Carapa guianensis Aubl.	andiroba	tree	cultivated	native	insect repelent, infection, inflammation, flu, blow, wound	seed oil	topical	7464
Guarea pubescens (Rich.) A.Juss.	jatoá	tree	gathered	native	flu, cattarh, emetic	stem bark	oral	7518
Menispermaceae								
Abuta grandifolia (Mart.) Sandwith	bota, cipó-da-bôta, pitomba	tree	gathered	native	stomachache, inflammation, gastrits, abortive	stem bark	oral	7489, 7586, 7601, 7612
Moraceae								
Brosimum parinarioides Ducke	amapá	tree	gathered	native	sexual stimulant, weak chest, lung, cough, tuberculosis, liver	stem bark	oral	7472
Naucleopsis krukovii (Standl.) C.C. Berg	muiratinga	tree	gathered	native	infection, gastrits	-	-	7539
Naucleopsis ulei (Warb.) Ducke	matuguá-preto	tree	gathered	native	snake bite	leaves	topical	7615
Sorocea guilleminiana Gaudich.	matuguá	shrubby	gathered	native	snake bite	leaves	topical	7520
Musaceae								
Musa x paradisiaca L.	bananeira	herb	cultivated	exotic	abortive	–	–	7554
Myrtaceae								
Psidium acutangulum DC.	goiabarana	tree	cultivated	native	dysentery	stem bark	oral	7590
Psidium guajava (L.) Radd.	goiabeira	tree	cultivated	exotic	dysentery	leaves	oral	7547
Syzygium cumini (L.) Skeels	azeitona	tree	cultivated	native	dysentery	stem bark	oral	7568
Syzygium malaccense (L.) Merr. & L. M.Perry	jambo	tree	cultivated	exotic	dysentery	leaves	oral	7589
Passifloraceae								
Passiflora cf. *acuminata* DC.	maracujá-do-mato	climber	gathered	native	soothing, tachycardia, hemorraghe	flowers	oral	7505
Passiflora edulis Sims	maracujá-peroba	climber	gathered	native	heart, glicosis control	leaves	oral	7499
Passiflora micropetala Mart. ex Mast.	maracujá-de-rato	climber	gathered	native	intestinal wash	leaves	oral	7504
Phytolaccaceae								
Petiveria alliacea L.	mucuracaá	herb	cultivated	exotic	aborrecimento, curse, stomachache, headache, children's bath, mother of the body	leaves	topical	7507
Piperaceae								
Piper hostmannianum (Miq.) C.DC.	rabo-de-lontra, pimenta-de-lontra, pimenta-do-reino-brava, canela-de-jacamim	shrubby	gathered	native	growing meat in the eye	leaves	eyedrop	7485, 7553, 7617

Piper marginatum Jacq.	elixir-paregórico	shrubby	cultivated	native	stomachache	leaves	oral	7481
Piper peltatum L.	caapeba	herb	gathered	native	swelling, liver, malaria, pain nas costas, infection, eryzipelas	leaves	oral	7459
Plantaginaceae								
Scoparia dulcis L.	vassourinha	herb	cultivated	native	blow, eryzipelas, infections	leaves	topical	7626
Poaceae								
Cymbopogon citratus (DC.) Stapf	capim-santo, capim-limão	herb	cultivated	exotic	flu, stomachache	leaves	oral	7493, 7570
Polygonaceae								
Symmeria paniculata Benth.	jacaré-café, carauaçu	tree	gathered	native	dysentery, pain-de-barriga, hemorrhoids, exhaustion, *panema*	roots/ stem bark	topical/oral	7583
Rhamnaceae								
Ampelozizyphus amazonicus Ducke	saracura-mirá	climber	gathered	native	fever, stomachache, gastrits, úlcera, inflammation, liver, malaria, pain, rheumatism, sexual estimulant	roots/ stem bark	oral	7581
Rhizophoraceae								
Cassipourea guianensis Aubl.	marapuãma, muirapuãma	tree	gathered	native	aphrodisiac, blood thickener	roots	oral	7541, 7542
Rubiaceae								
Coffea canephora Pierre ex A. Froehner	café	shrubby	cultivated	exotic	eryzipelas	leaves	topical	7468, 7578
Retiniphyllum sp.	caferana	tree	gathered	native	hemorrhoids	leaves	oral	7527
Rutaceae								
Citrus aurantium L.	laranjeira	tree	cultivated	exotic	liver, heart, stomach, malaise, stomachache, bad digestion	leaves	oral	7548
Citrus limon (L.) Burm. f.	limoeiro	tree	cultivated	exotic	stomachache, headache	leaves	oral	7495
Rutaceae								
Zanthoxylum rhoifolium Lam.	limorana-brava	tree	gathered	native	stomachache (low doses)	leaves	oral/ topical	7487
Salicaceae								
Casearia sp.	piranheira	tree	gathered	native	stomachache, dysentery	leaves	oral	7530
Sapindaceae								
Paullinia cupana Kunth	guaraná	climber	cultivated	native	restorative, dysentery	seeds	oral	7604
sp. 1	canela-de-velho	tree	gathered	native	aphrodisiac, stimulant	–	–	7593
Sapotaceae								
Elaeoluma schomburgkiana (Miq.) Baill.	caramuri	tree	gathered	native	stomachache, malaria	stem bark	oral	7525
Pouteria elegans (A.DC.) Baehni	caramuri	tree	gathered	native	stomachache, malaria	stem bark	oral	7475
Selaginellaceae								
Selaginella amazonica Spring	nambaia, samambaia	herb	gathered	native	fatigue, asthma, skin healer, blow	–	–	7490
Siparunaceae								
Siparuna guianensis Aubl.	caapitiú	tree	gathered	native	child disease	leaves	topical	7599, 7605
Solanaceae								
Physalis angulata L.	canapú	herb	gathered	native	hepatitis	–	–	7587
Solanum crinitum Lam.	jurubeba	tree	gathered	native	liver	–	oral	7466
Solanaceae								
Solanum lycopersicum L.	tomate	herb	cultivated	exotic	inflammation, blow, eryzipelas	fruto	oral	7559
Solanum sessiliflorum Dunal	cubiu	herb	cultivated	native	diabetes	fruto	oral	7498, 7552
Solanum stramoniifolium Jacq.	jurubeba	shrubby	cultivated	native	liver	–	oral	7602
Strelitziaceae								
Phenakospermum guyannense (Rich.) Endl. ex Miq.	sororoca	tree	gathered	native	blow, dysentery, hemorrhoids	leaves	oral/ topical	7469
Urticaceae								
Pourouma bicolor Mart.	vick-da-mata	tree	gathered	native	pain, flu, headache, breathe, rheumatism, curuba, thud	stem bark/ fruit	topical	7535
Verbenaceae								
Lippia alba (Mill.) N.E.Br.	cidreira	shrubby	cultivated	native	soothing, insomnia, pain, fever, flu	leaves	oral	7492
Zingiberaceae								
Alpinia zerumbet (Pers.) B.L.Burtt & R.M.Sm.	vindicá	herb	cultivated	exotic	nausea, child bath, hepatitis	leaves	topical	7500
Curcuma longa L.	açafroa	herb	cultivated	exotic	throat pain, eryzipelas	roots	oral	7606

Appendix V – Discounted monetary values and s-PVs of the TMVs of each land use

The TMVs of each land use have been discounted according to a SDR of 0% and a SDR of 5%, resulting in s-PVs. For each year in the future, the discounted monetary value, and s-PVs of all three land uses are given in Table 14 below.

Table 14: Discounted monetary values and s-PVs of the TMVs of each land use.

Land use	**Primary forest**		**Shifting agriculture**		**Cattle pasture**	
Social discount rate	SDR = 0%	SDR = 5%	SDR = 0%	SDR = 5%	SDR = 0%	SDR = 5%
Time period (t)	0%	5%	0%	5%	0%	5%
1	1437	1368,6	1607	1530,5	922	878
2	1437	1303,4	1607	1457,6	922	836,3
3	1437	1241,3	1607	1388,2	922	796,5
4	1437	1182,2	1607	1322,1	922	758,5
5	1437	1125,9	1607	1259,1	922	722,4
6	1437	1072,3	1607	1199,2	922	688
7	1437	1021,2	1607	1142,1	922	655,2
8	1437	972,6	1607	1087,7	922	624
9	1437	926,3	1607	1035,9	922	594,3
10	1437	882,2	1607	986,6	922	566
11	1437	840,2	1607	939,6	922	539
12	1437	800,2	1607	894,8	922	513,4
13	1437	762,1	1607	852,2	922	489
14	1437	725,8	1607	811,6	922	465,7
15	1437	691,2	1607	773	922	443,5
16	1437	658,3	1607	736,2	922	422,4
17	1437	627	1607	701,1	922	402,3
18	1437	597,1	1607	667,7	922	383,1
19	1437	568,7	1607	636	922	364,9
20	1437	541,6	1607	605,7	922	347,5
s-PV	28740	17908	32140	20027	18440	11490

Appendix VI – Forest areas of Opção Verde in the Manaus-region and Coari-region

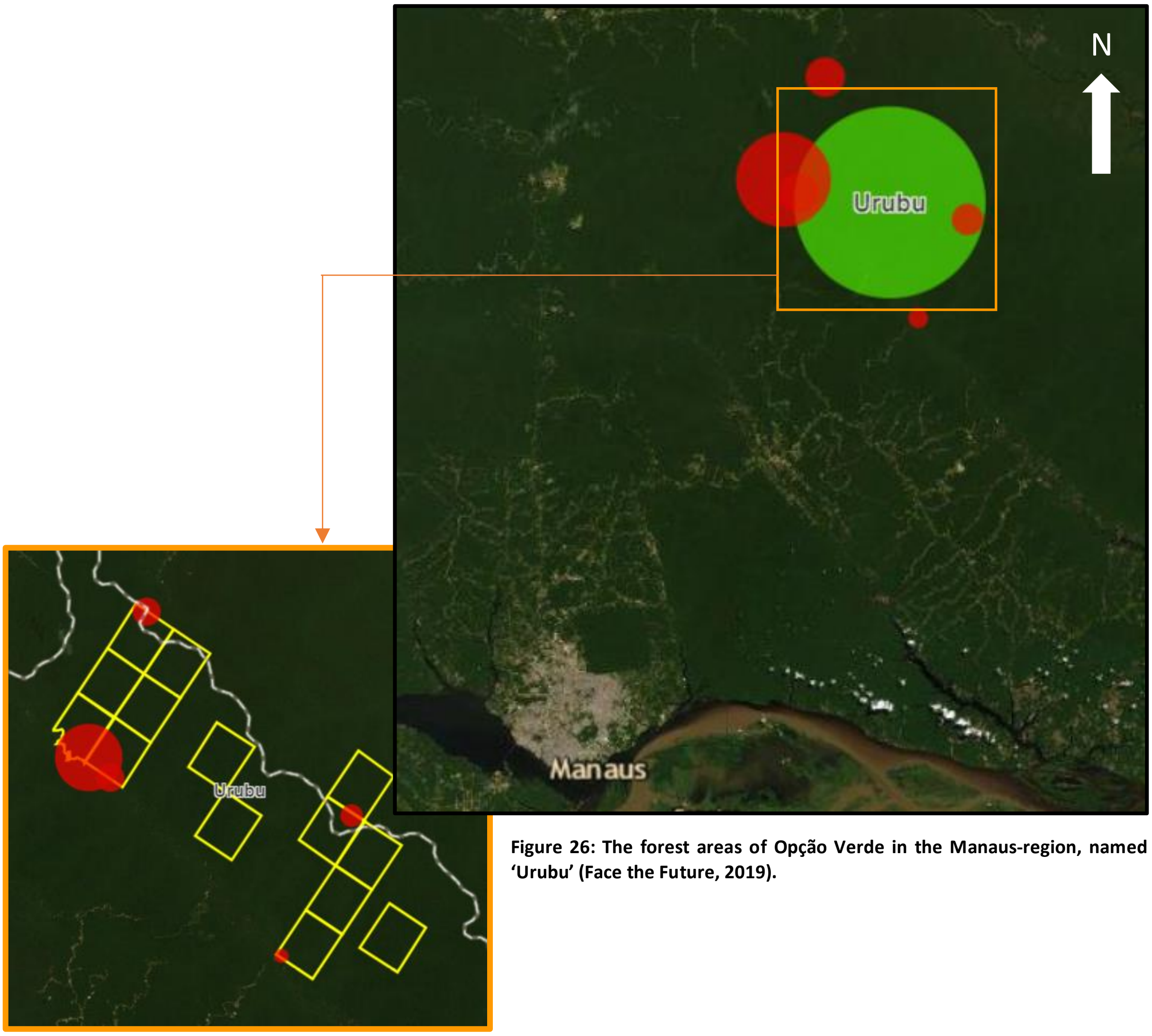


Figure 26: The forest areas of Opção Verde in the Manaus-region, named 'Urubu' (Face the Future, 2019).

Figure 25: The georeferenced borders of the Urubu forest areas of Opção Verde, indicated with yellow rectangles.

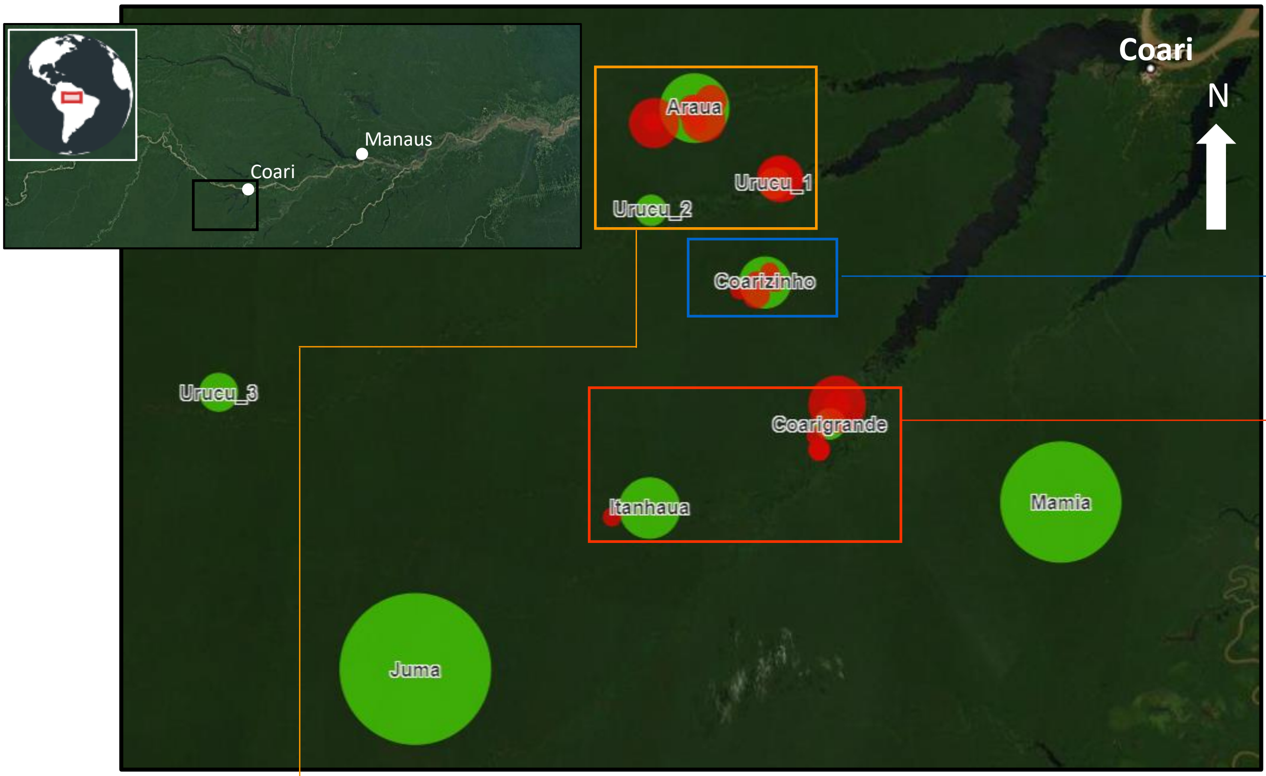


Figure 27: Forest areas of Opção Verde in the Coari-region, southwest of Coari in the north of the Brazilian Amazon.

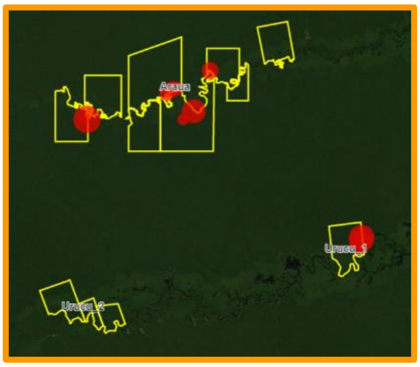


Figure 28: The georeferenced borders of the Araua, Urucu I, and Urucu II forest areas, indicated with yellow rectangles.

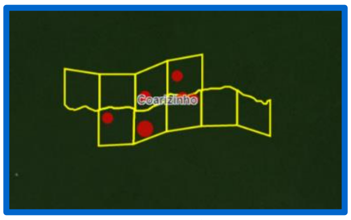


Figure 29: The georeferenced borders of the Coarizinho forest area, indicated with yellow rectangles.

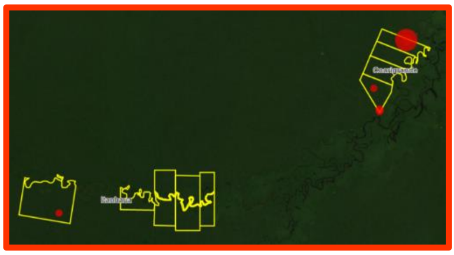


Figure 30: The georeferenced borders of the Itanhaua and Coarigrande forest area, indicated with yellow rectangles.

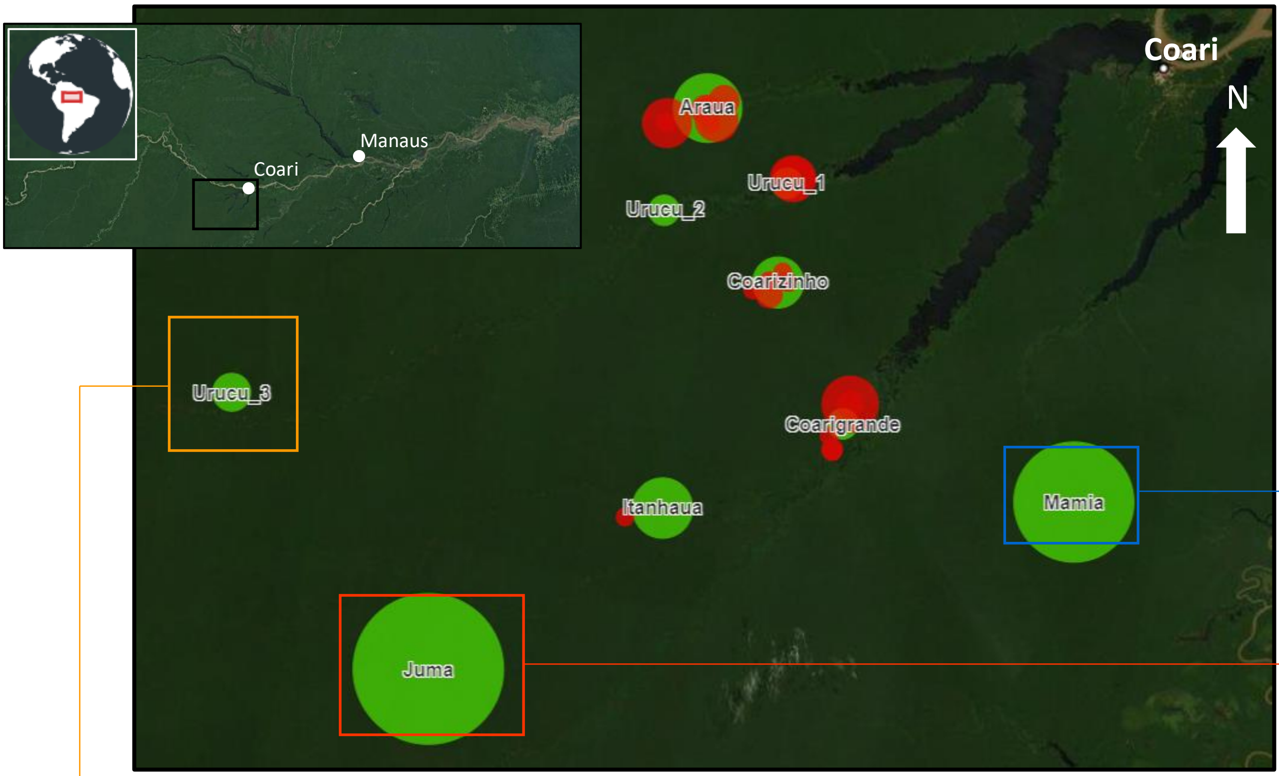


Figure 31: Forest areas of Opção Verde in the Coari-region, southwest of Coari in northern Brazil.

Figure 32: The georeferenced borders of the Urucu III forest area, indicated with a yellow rectangle.

Figure 33: The georeferenced borders of the Mamia forest area, indicated with a yellow rectangle.

Figure 34: The georeferenced borders of the Juma forest area, indicated with yellow rectangles.

Appendix VII – Data management plan

In this appendix, the data management plan (DMP) is presented which is based on templates from the Environmental System Analysis Group. The DMP provides a description of what data is collected during my research, how that data has been used, and what will be done with the collected data after my research is finished. In the DMP, the following aspects are addressed: data management roles; types and amount of research data; sharing and ownership; documentation and metadata; short term storage; and long-term storage.

Data management roles

In consultation with both my supervisors, I am the one primarily responsible for managing the collected data. When my research is finished, the raw and processed data will be shared with both my supervisors, as well as with the Opção Verde foundation so that they can use it for future purposes (e.g. for possible follow-up study). The raw data will not be made publicly accessible, but this MSc thesis will be made publicly accessible in accordance with my supervisors at the WUR MSc thesis online platform.

Types and amount of research data

The data from the provisioning services for the primary forest land use are primarily retrieved during market research. This data includes types of forest products (i.e. fruits, nuts, medicinal plant and tree species), and market prices. Also, interviews with key stakeholders are summarised according to themes. These summaries are in a storyline presented in an Appendix of my research. Furthermore, many of the data used for the ecosystem services analyses and the ecosystem services-valuation analyses are retrieved from literature findings. This includes theoretical backgrounds on the functioning of ecosystem services (i.e. the biophysical structures and processes), as well as the quantification according to a measurable indicator. The amount of raw data is estimated at 500 MB, and the data used from literature findings which is incorporated in my research is estimated at 10 MB (which is the size of this document).

Sharing and ownership

My research may be shared with anyone, but not used without consulting the author and supervisors of my research. The interviewees which are mentioned in the Appendix should not in any case be mentioned, since some want to be anonymous. Furthermore, there are no privacy issues unless stated otherwise when my supervisors are sharing this document.

Documentation and metadata

The raw data that is obtained during field work is noted down, and which is scanned and uploaded online in the OneDrive so that is accessible for the Opção Verde Foundation, and will be shared with the Environmental Systems Analysis Group by copying the files into their database. All other data is organised in folders, which are shared with the secretary of the research department.

Short term storage

The data, literature findings, and all documents are stored both on the C drive on my private PC, and on the C drive on the WUR PC. Also, back-ups are regularly made daily on an online drive and an external drive.

Long term storage

After finishing my research, I intend to store all the files and my research document privately for the long term. The files will be stored on an external hard drive. Also, members from the Opção Verde foundation likely store the shared files and my research document also for the long-term. How they will store the files is not known yet.

Nature does not recognise itself as nature. We name her as such. And in that name an image is contained: our image of nature. To a certain extent, this image says something about nature, but even more it expresses how we see ourselves in relation to nature.

- Matthijs G.C. Schouten