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Impacts of Land Use and Land Cover Change on Ecosystem Service Values in the Eastern Amazon

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Abstract: Since the publication of the Millennium Ecosystem Assessment report, the concept of ecosystem services has gained visibility around the world, as many of these services are seen as essential for human well-being and their activities, and represent, in addition, an opportunity for financial support for conservation strategies of ecosystems under threat. In this context, this work aims to estimate the monetary values associated with ecosystem services and the losses linked to LULC change in the period of 1985-2021 in the Gurupi river basin, in one of the most deforested regions of the Brazilian Amazon. The results show that the decrease in forest areas caused a loss of monetary value of ecosystem services of US$ 1961 million. The net gain in the analyzed period derived mainly from the increase in agricultural areas devoted to soybean cultivation, with a reduction in areas devoted to other food crops, which may represent a risk to food security in the region.

Keywords: Land use and land cover change; ecosystem services; ecosystems values; environmental valuation; Amazon.

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1. Introduction

The concept of ecosystem services has become increasingly important in the analysis of socio-environmental problems. This concept emphasizes functions arising from the interactions between different elements in nature. It is also a technical concept used to make environmental decisions based on financial and economic reasons, including monetary valuations (STEVENSON et al., 2021). These services can be distinguished into three or four categories, depending on the concept adopted. While the Millennium Ecosystem Assessment - MEA (2005) and The Economics of Ecosystems and Biodiversity - TEEB (2010) propose provision, regulation, support (habitat for TEEB) and cultural services, The Common International Classification of Ecosystem Services – CICES uses only three categories/sections (provision, regulation/maintenance and cultural) (POTSCHIN; HAINES-YOUNG, 2011). More recently, other concepts have emerged. The International Union for Conservation of Nature (IUCN) now exclusively uses “nature-based solutions” and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019) has interpreted ecosystem services as “contributions of nature to people”, within a broader framework.

It is possible to better approximate the economic debates regarding productive forms that exploit these services by applying new approaches that take into consideration the direct use value of environmental services by populations in regions with diverse biomes, such as the Amazon. The literature on historical ecology and archeology in these regions (CLEMENT et al., 2015, 2020; LEVIS et al., 2017, 2018) emphasizes that humanity has been increasingly involved in managing these biomes, mainly in order to ensure the productive and sustainable use of biodiversity resources.

Since the publication of the Millennium Ecosystem Assessment report (MEA, 2005), this topic has gained visibility around the world, as many of these services are seen as essential for human well-being and activities. They may represent, additionally, a great opportunity for financial support for conservation strategies for ecosystems under threat. This may be especially important in regions or countries where these resources are constantly threatened by pressure for their predatory exploitation, or for the conversion of more diverse systems into monocultures.

There have been, thus, several attempts to valuate ecosystem services, either from a social (SHERROUSE et al., 2011; PAUDYAL et al., 2018) or an economic/financial (COSTANZA et al., 1997; COSTANZA et al., 2014; SHARMA et al., 2019; STRAND et al., 2018) perspective. These assessments aim, for the most part, to simply show the magnitude of the importance of ecosystem services. However, they can also serve as a basis for policy planning and decision-making, such as payment for environmental services schemes, or the definition of priority areas for the implementation of development policies, with an emphasis on protecting ecosystems that have the highest values in terms of ecosystem services.

While advances have been made in this area, it seems that more thought should be given to the overemphasis that has recently been put on the notion that the preservation or conservation of biomes under threat, only and exclusively depend on valuation mechanisms which aim to provide direct financial compensation to the agents responsible for preserving them, without taking into account the productive role that the sustainable use of ecosystem resources has had over centuries.

We believe that the real economic and productive dynamics should not be seen as dissociated from the issue of preservation of ecosystem services. However, this view often permeates the logic of preservation and conservation of ecosystems in agro-extractive realities in regions such as the Amazon. Not all forms of agriculture should be seen as contrary to the preservation of ecosystem diversity. We mean that the economic/productive debate and its challenges should not be separated from the issues associated with the current discussion on valuation and payment of environmental services. In concrete terms, historically, the main reason for the development of sustainable production trajectories that allow for the preservation and conservation of the Amazon biome was not any strategy of direct monetization of its resources, but rather real production strategies that are based on diversity.

On the other hand, the most frequent current debate on environmental services starts from the opposite point of view. It assumes that real productive activities (those carried out by traditional communities and/or agro-extractivists in the Amazon) would not justify effective and economically viable strategies in the long term for the preservation of our diverse biomes. Something quite different from what has been observed in recent studies in different fields of investigation on agrarian dynamics in the Amazon.

We believe that it is possible to better assess the impacts of real economic dynamics and their possible effects on the values of environmental services through an alternative model. This model does not overlook the potential of environmental valuation's static analysis, but instead places these analyses in a dynamic context, which means that they are based on an open and multidisciplinary discussion. Observations of land use historical evolution and land cover dynamics in the Amazon associated with agrarian dynamics are an intrinsic part of this model.

Following this strategy, we consider that changes in land use and land cover, which influence the properties, processes, and components of ecosystems, have a direct impact on the values of ecosystem services (COSTANZA et al., 2014; SHARMA et al., 2019). This understanding would lead us to see the impacts of such changes more comprehensively, which can ultimately lead to raising funds to mitigate the consequences of human-environment interactions (HASAN et al., 2020).

Despite the importance of ecosystem services for the maintenance of nature and human activities, the increasing conversion and fragmentation of habitats in recent years, in addition to the current climate crisis, have altered the natural characteristics of ecosystems in several Brazilian biomes, mainly due to conversion into agricultural and urban areas (BUSTAMANTE et al., 2019). In the Amazon, land use change has been identified as a significant driver of change in ecosystem services (FOLEY et al., 2007; GARRET et al., 2021), such as carbon storage, water flow regulation, climate regulation, and regulation of vector-borne infectious diseases (FOLEY et al., 2007).

In eastern Amazon, in the Gurupi river basin, increasing anthropic transformations associated with the agrarian dynamics in the region occur mainly as the conversion of forest areas into agricultural and pasture areas (PEREIRA; VIEIRA, 2019). In degraded regions such as our study area, the valuation, and mapping of ecosystem services can represent an important tool that indicates how much loss arises from ecosystem degradation, as well as which are the priority areas for decision-making. Thus, aiding to avoid the loss of valuable services that ensure the maintenance of several activities and the well-being of the local population. Quilombola, indigenous, and rural producer communities compose most of the local population, as well as the population of urban centers.

For the effective valuation and mapping of ecosystem services, simple financial valuation is not enough. This mechanism is useful to highlight a supposedly existing use value, which has obvious implications for social well-being. However, it is yet to be determined to what extent financial and monetary valuation, organized in terms of these fictitious market simulation strategies, can express the real economic value of using ecosystems and/or the environmental services provided by them.

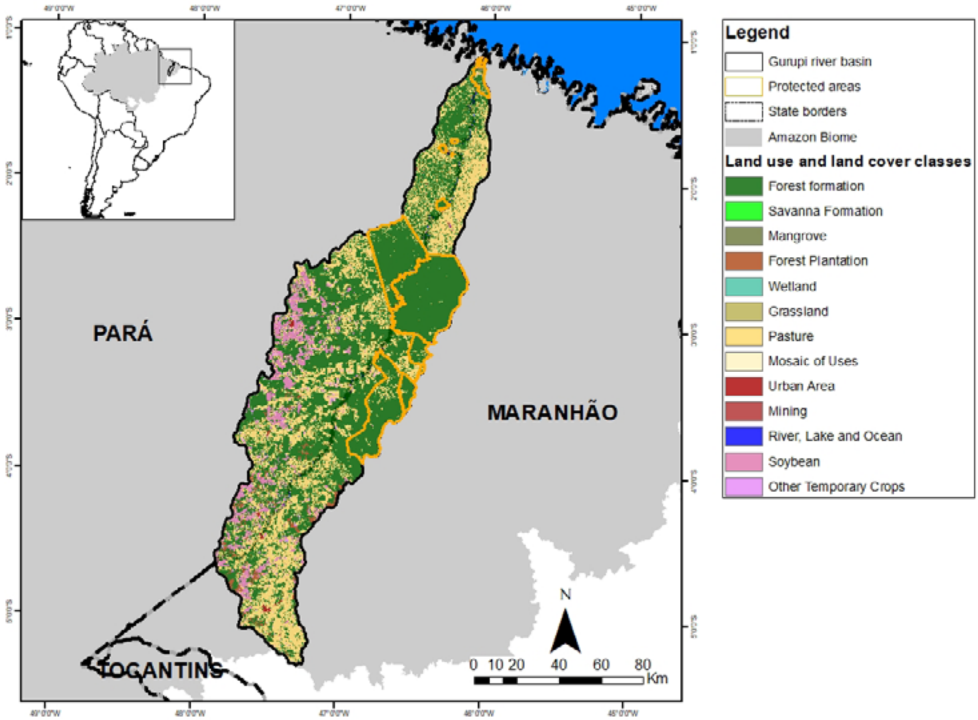
In this study, our objective is to advance this discussion, using estimation techniques as a basis to assess losses, measured in terms of ecosystem services' monetary values. These losses are associated with changes in land use and land cover in an important river basin, located in one of the most deforested regions of the Brazilian Amazon.

2. Materials and methods

3.1 Study Area

The present work was carried out in the Gurupi river basin (GRB), in the eastern region of the Brazilian Amazon, covering about 35000 km2. The area was chosen because it is a cross-border region between the states of Pará and Maranhão (Figure 1), and it is located within the Belém Endemism Center, one of the most deforested areas in the Amazon (ALMEIDA; VIEIRA, 2010; BRAZ et al., 2016). Despite this, the Gurupi river basin has great ecological importance, as it contains key ecosystems such as forests, mangroves, and non-forest natural formations, in addition to agricultural areas, which together provide various ecosystem services. Moreover, the basin includes, partially or integrally, significant protected areas such as Conservation Units, Indigenous Lands and Quilombola Territories, as shown in Figure 1.

Figure 1 - Map of the study area (Gurupi River Basin), in eastern Amazon.



Source: This work, 2023. Database: ANA (2019), FUNAI (2019), IBGE (2019), INCRA (2019), MapBiomas (Collection 7), MMA (2019).

2.1 Data Collection

The economic values of ecosystem services for the Gurupi river basin were estimated to assess the impacts of land use and land cover changes on these services. In order to do this, a set of ecosystem services were analyzed. We considered the changes in land use and land cover over a period of 36 years (1985-2021).

2.1.1 Land use and land cover

The land use and land cover data used in the analysis of the Gurupi river basin were obtained from the MapBiomas project database (Collection 7), since annual mapping has taken place for the past 37 years, and the data is freely accessible. MapBiomas produces maps in a matrix format with a spatial resolution of 30 meters, based on the pixel-by-pixel classification of Landsat satellite images (SOUZA JÚNIOR et al., 2020), which can be accessed on the Google Earth Engine - GEE platform (MAPBIOMAS 7.0 https://plataforma.mapbiomas.org/). Using the project toolkit on GEE, we selected the territorial clipping for the boundary of the Gurupi river basin, with all the classes presented by MapBiomas (Figure 1).

To estimate the ecosystem services losses due to changes in land use and land cover, changes were quantified over 36 years (1985-2021), and over 10-year periods (1985-1995, 1995-2005, 2005-2015, 2015-2021) (Table 1), thus allowing for the assessment of decennial variations over the analyzed period.

Table 1- Changes in land use and land cover area by classes in the Gurupi river basin, eastern Amazon.

MapBiomas Classes 7.0	Area (ha)					Changes (ha)				
	1985	1995	2005	2015	2021	(1985-1995)	(1995-2005)	(2005-2015)	(2015-2021)	(1985-2021)
1. Forest	2713663.6	2456778.6	2098579.4	1947321.6	2028935.3	-256885.0	-358199.2	-151257.8	81613.7	-684728.3
1.1. Forest formation	2704488.5	2450183.8	2094294.2	1942874.7	2023039.4	-254304.7	-355889.6	-151419.5	80164.7	-681449.1
1.2. Savanna formation	5103.8	2512.2	298.5	430.7	1889.2	-2591.6	-2213.7	132.2	1458.5	-3214.6
1.3. Mangrove	4071.3	4082.6	3986.6	4016.2	4006.8	11.3	-96.0	29.6	-9.4	-64.5
2. Non forest natural formation	13945.9	8401.7	6872.5	6403.9	3037.2	-5544.2	-1529.2	-468.6	-3366.7	-10908.7
2.1. Wetland	9560.4	3937.1	2768.3	2644.7	1291.5	-5623.3	-1168.8	-123.6	-1353.2	-8268.9
2.2. Grassland	4383.2	4450.2	4090.8	3758.6	1745.8	67.0	-359.4	-332.2	-2012.8	-2637.4
2.3. Salt flat	2.2	14.5	13.4	0.5	0.0	12.3	-1.1	-12.9	-0.5	-2.2
3. Farming	743629.0	998729.2	1355912.5	1507100.9	1428120.1	255100.2	357183.3	151188.4	-78980.8	684491.1
3.1. Pasture	742486.1	996972.4	1299620.2	1295658.3	1128182.8	254486.3	302647.8	-3961.9	-167475.5	385696.7
3.2. Agriculture	1095.9	1291.2	33908.3	171471.6	251345.9	195.3	32617.1	137563.3	79874.3	250250.0
3.2.1. Temporary crops	10.2	10.5	30087.3	170585.6	250361.4	0.3	30076.8	140498.3	79775.8	250351.2
3.2.1.1. Soybean	0.0	0.0	9199.2	82471.4	211068.9	0.0	9199.2	73272.2	128597.5	211068.9
3.2.1.2. Other temporary crops	10.2	10.5	20888.1	88114.1	39292.5	0.3	20877.6	67226.0	-48821.6	39282.3
3.2.2. Perennial crops	1085.7	1280.7	3821.0	886.0	984.5	195.0	2540.3	-2935.0	98.5	-101.2
3.2.2.1. Other perennial crops	1085.7	1280.7	3821.0	886.0	984.5	195.0	2540.3	-2935.0	98.5	-101.2
3.3. Forest plantation	0.0	458.1	22379.0	39968.4	48568.8	458.1	21920.9	17589.4	8600.4	48568.8
3.4. Mosaic of uses	47.1	7.5	5.1	2.6	22.4	-39.6	-2.4	-2.5	19.8	-24.7
4. Non vegetated area	2028.9	4385.6	5722.2	7183.9	8709.6	2356.7	1336.6	1461.7	1525.7	6680.7
4.2. Urban area	1751.7	4010.0	5370.7	6708.0	7220.8	2258.3	1360.7	1337.3	512.8	5469.1
4.3. Mining	277.2	375.6	351.5	475.9	1488.8	98.4	-24.1	124.4	1012.9	1211.6
5. Water	4251.6	9230.7	10438.0	9514.7	8730.8	4979.1	1207.3	-923.3	-783.9	4479.2
5.1. River, lake, ocean	4251.6	9230.7	10438.0	9514.7	8730.8	4979.1	1207.3	-923.3	-783.9	4479.2

Source: This work, based on data from MapBiomas Collection 7.0.

2.1.2 Types and values of ecosystem services

The values for the monetary units of each ecosystem service used in this analysis were obtained from the Ecosystem Services Value Database -ESVD, updated version of 2021 (FOUNDATION FOR SUSTAINABLE DEVELOPMENT, 2021), available at https:/ /www.esvd.net/esvd. This database is a continuation of "The Economics of Ecosystems and Biodiversity" (TEEB) database and the current version contains 6700 records of average monetary values of ecosystem services, derived from 950 case studies, standardized in international dollars/hectare/year, 2020 price level (FOUNDATION FOR SUSTAINABLE DEVELOPMENT, 2021). The data matrix contains information on 23 ecosystem services across 16 biomes.

There are several definitions of ecosystem services in the literature. However, one of the most prominent is the Millennium Ecosystem Assessment (MEA, 2005) definition as "the benefits people obtain from nature". Nevertheless, there are other definitions, such as the ones provided by the Economics of Ecosystems and Biodiversity (TEEB), the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) and the Common International Classification of Ecosystem Services (CICES). In this study, we use the Ecosystem Economics and Biodiversity classification (TEEB, 2010), as it is used in the ESVD database.

2.2 Data Analysis

2.2.1 Selection of ecosystem service values

First, we selected classes from MapBiomas Collection 7 , discarding those that did not have an ecosystem equivalent to those listed by the ESVD (Table 2). In the case of 'Mosaic of Uses', there is no equivalent class that encompasses both agriculture and pasture, so it was discarded. The ‚Urban Areas' class, although providing important ecosystem services, required a distinction between which areas correspond to blue and green infrastructure, such as lakes, canals, ponds, forests, fields, parks, etc., which was not possible. The salt flat and mining classes also do not have equivalent ecosystems in the database.

Table 2 – Classes of land use and cover of the MapBiomas project (Collection 7.0), according to the ecosystems listed by the Ecosystem Services Value Database -ESVD.

Classes (MapBiomas 7.0)	Equivalent Ecosystem (ESVD)
Forest formation	Tropical forests
Savanna formation	Savanna
Mangrove	Mangrove
Wetlands	Inland Wetlands
Grassland	Rangelands, natural grasslands and savannas

Salt flat	**
Pastures	Pasture
Agriculture	Cropland
Mosaic of Uses	**
Forest Plantation	Plantations
Urban Area	**
Mining	**
River, Lake and Ocean	Rivers and Lakes

Source: This work. ** No equivalent ecosystem found.

We used the Benefit Transfer Method to calculate the economic value of the Gurupi River basin, as in Costanza et al. (1997, 2014) and Sharma et al. (2019). This method estimates the value of an ecosystem service in a given place, based on information from other areas of study. Even though this method involves many complexities on a regional scale, it is helpful for increasing society's awareness and interest in ecosystem services and also for evaluating scenarios of changes in land use and land cover (COSTANZA et al., 2014).

To define the values of the ecosystem services of the Gurupi river basin, a series of filters were applied to the ESVD database in order to select the values that best represented the ecological and socioeconomic context of the study area. First, as in De Groot et al. (2020), we only selected values that could be standardized in US$/hectare/year, which reduced the database from 6784 records to 2930. We then removed the records that had the Value Transfer Method as the evaluation method, as well as records corresponding to ecosystems in continents that do not have tropical forests, which reduced the database to 1129 records. Subsequently, we excluded the highest 3% and the lowest 3% in an attempt to reduce the effects of possible outliers (DE GROOT et al., 2020). Thus, we estimated the values of 1062 records. The number, mean and standard deviation for each ecosystem service are shown in Table 3.

Table 3 – Total number, mean and standard deviation by ecosystem service (US$/hectare/year; 2020 price level).

Ecosystem services	N	Mean	Standard Deviation
Food	245	1943,24	5442,95
Water	25	972,40	1500,57
Raw materials	246	1400,81	5269,02
Genetic resources	4	508,13	210,67
Medicinal resources	53	3,51	6,55

Ornamental resources	6	0,39	0,43
Air quality regulation	6	670,60	801,24
Climate regulation	62	1231,23	2700,73
Moderation of extreme events	46	1148,17	2191,21
Regulation of water flows	17	493,16	1424,82
Waste treatment	46	1045,36	2292,78
Erosion prevention	29	5888,98	11827,87
Maintenance of soil fertility	45	199,62	429,37
Pollination	43	242,32	553,07
Biological control	1	0,29	0,00
Maintenance of genetic diversity	20	3402,73	9993,86
Maintenance of life cycles	11	3706,30	6634,97
Aesthetic information	5	2542,93	3386,96
Opportunities for recreation and tourism	57	3433,23	9257,42
Inspiration for culture, art and design	3	1297,01	1833,19
Information for cognitive development	3	1018,74	1427,70
Existence, bequest value	24	1703,55	4464,02
Spiritual experience	1	80,28	0,00
Unspecified, or a collection of ES	64	1937,93	5333,62
Total	1062	1616,03	5332,73

Source: This work, based on the ESVD database (2021).

Based on this basic matrix, we conducted a more thorough analysis and selection process. Using filters, we selected classes/ecosystems equivalent to MapBiomas and their services, and analyzed and selected, whenever possible, values from study areas with characteristics similar to the present study. In total, we selected 210 values for 15 ecosystem services, grouped into six classes/ecosystems, most of them estimated for forest and mangrove ecosystems (Table 4). Some ecosystem services have more records of estimated values than others, for example, pollination and raw material have 43 and 41 estimates respectively, while for other ecosystem services information is limited or even nonexistent. The average values calculated for each ecosystem service, according to each class, were used as a constant in international value per hectare/year, 2020 price level (Table 4).

Table 4 – Number, mean and standard deviation of values for ecosystem services for the Gurupi River basin (US$/hectare/year; 2020 price level).

Land Use / Land Cover Classes	N	Mean	Standard Deviation
Forest			
Food	5	73,36	40,89
Raw Materials	18	776,81	2070,58
Genetic resources	4	508,13	210,67
Climate regulation	5	1225,50	1349,50
Moderation of extreme events	1	41,56	0,00
Regulation of water flows	6	9,74	15,35
Pollination	43	242,32	553,07
Savannas			
Climate regulation	3	114,94	59,67
Biological control	2	1,21	0,99
Mangrove			
Food	25	2200,83	5037,26
Raw materials	6	991,26	1415,32
Climate regulation	13	241,53	298,59
Waste treatment	3	33,39	24,29
Maintenance of life cycles	1	24189,76	0,00
Opportunities for recreation and tourism	12	5997,13	11287,57489
Existence, bequest value	4	7211,22	8199,04
Agriculture			
Food	5	9409,16	721,49
Forest Plantation			
Raw materials	17	7819,34	11937,23
Medicinal resources	2	9,36	4,31
Maintenance of soil fertility	34	106,11	128,30
River, lake and ocean			
Water	1	153,21	0,00
Total	210		

Source: This work, based on the ESVD database (2021).

3.2.2 Estimate of the economic value of ecosystem services

To estimate the total economic value of GRB's ecosystem services (ESV), we first calculated the total value per hectare for each class/ecosystem (VTC) from the sum of the average values of their respective ecosystem services (Table 4). The ESV was then calculated from the sum of each type of class/ecosystem area multiplied by the total value per hectare of each class (VTC), for each year (Equation (1)).

$$ESV_i = \sum(Area_{ki} \times VTC_k) \qquad (1)$$

Where ESVi (expressed in US$/hectare/year) is the total estimated value of ecosystem services for year i, $Area_{ki}$ is the area (ha) of the class/ecosystem k for a given year i, and VTC is the total estimated value per class k.

We were able to calculate possible losses in economic value of ecosystem services due to changes in land use and land cover by comparing the total economic value of ecosystem services estimated in 1985, 1995, 2005, 2015, 2021.

3. Results

3.1 Land Use and land Cover Changes in the Gurupi River Basin

MapBiomas data from collection 7 show that in 2021 the main types of land use and land cover in the GRB were forest (58.3%) and farming (41.1%). Over the past 36 years, GRB's landscape has undergone several changes, with substantial losses in forest areas (25%) and an increase in areas linked to farming (92%) (Table 1).

Although pasture areas account for 79% of farming areas, the increase in farming areas over the last 36 years has also been driven by the expansion of crop areas, which have increased from 1096 to 251346 hectares mostly as a result of the expansion of soybean cultivation. During this period, urbanized areas (312%) and mining activities also increased (437%).

3.2 Estimate of the value of ecosystem services in the Gurupi river basin

Based on the areas of GRB land use and land cover classes and the ESVD database, we estimated the economic value of 13 ecosystem services by six class/ecosystem types as well as the total economic value of GRB ecosystem services. The total estimated value for the year 2021 was US$ 8737 million per year (2020 price level), as shown in Table 5. This value refers to the average values found in the ESVD database, which we assume as the constant unit value per unit area. If the minimum and maximum values were considered, the total estimated value for GRB would range from USD 2872 to USD 30894 million per year in 2021, respectively. It should be noted that the results presented in this paper consider the values available in the ESVD database, therefore, they represent only a portion of the ecosystem services.

Table 5 – Economic value of estimated ecosystem services for land use and land cover classes in the Gurupi river basin for different years and periods.

LULC* Classes	ESV (Million US$ per year) **					Changes in the ESV*** (Million US$ per year)				
	1985	1995	2005	2015	2021	1985-1995	1995-2005	2005-2015	2015-2021	1985-2021
Forest	7782,0	7050,2	6026,2	5590,5	5821,1	-731,7	-1024,0	-435,7	230,7	-1960,8
Savanna formation	0,6	0,3	0,0	0,1	0,2	-0,3	-0,3	0,0	0,2	-0,4
Mangrove	166,4	166,8	162,9	164,1	163,7	0,5	-3,9	1,2	-0,4	-2,6
Agriculture	10,3	12,1	319,0	1613,4	2365,0	1,8	306,9	1294,4	751,6	2354,6
Forest Plantation	0,0	3,6	177,6	317,1	385,4	3,6	173,9	139,6	68,2	385,4
River, Lake and Ocean	0,7	1,4	1,6	1,5	1,3	0,8	0,2	-0,1	-0,1	0,7
Total	7959,9	7234,5	6687,3	7686,7	8736,8	-725,3	-547,2	999,3	1050,1	776,9

Source: This work, based on the ESVD database (2021).

*LULC – Land use and Land cover

**2020 price level

***ESV – Ecosystem services value

Forest areas delivered the highest value of ecosystem services in all analyzed years (Table 5). In 1985, the first year of the analysis, mangrove areas were the second largest contributor, but over the 36 years, this situation changed due to the expansion of agriculture and forest plantation.

Although agricultural areas account for only 7% of the total GRB area, the food provision service had a high estimated value per unit area (ha) (Table 5).

Changes in the total economic value of ecosystem services due to land cover and land use changes in the Gurupi river basin resulted in losses over the 1985-1995 and 1995-2005 periods, mostly due to a decrease in forest area (Table 5). In the later periods, from 2005-2015 and 2015-2021, there was a net gain, caused mainly by the increase in agricultural and forest plantation areas.

Over the past 36 years, forest ecosystems have lost nearly US$1961 million in ecosystem services value, which represents the greatest loss in the studied period (Table 5). Only in the last 6 years (2015-2021) did this trend change, with forest areas showing a gain of R$ 231 million. This probably resulted from an increase in forested area of approximately 8165 hectares in the region.

Additionally, savannas and mangroves suffered ecosystem service losses of US$ 0.4 million and US$ 2.6 million, respectively. Mangrove areas, despite representing only a small portion of the Gurupi river basin (0.12%), contributed US$ 164 million in 2021. The services provided by the mangrove ecosystems have a high economic value for the GRB, mainly with respect to the maintenance of life cycles, existential/bequest value, opportunities for recreation and tourism, and food supply (Table 4).

Classes linked to agriculture and forest plantation had a net gain in ecosystem services value of US$2355 and US$385 million, respectively, over the past 36 years. The 'rivers, lakes and oceans' ecosystem also had a net gain, despite the area loss in the 2005-2015 and 2015-2021 periods. The only estimated value for this class refers to water supply, however, other services such as food supply (e.g. fish, shrimp, crab etc.) are also widely used by local communities along the GRB, both for subsistence and income generation.

4. Discussion

This study showed that the decrease in forest areas resulting from changes in land use caused a very significant monetary value loss of ecosystem services (US$ 1961 million dollars, approximately 25%) between 1985 and 2021 (Table 5). In an area of frontier expansion such as the Gurupi region, it is common for forests to be converted into pastures and agriculture, which has caused considerable forest losses (PEREIRA; VIEIRA, 2019). In any case, it is notable that these transformations were intensified, mainly in the period from 1995 to 2005. Although we know that the dynamics of land use are the main vector of changes in the flows of ecosystem services provided by watersheds (ANDRADE et al., 2012) there are few studies that show the magnitude of ecosystem service losses in financial terms.

The results show that the dynamics of land use in the Gurupi river basin between 1985 and 2021 had a positive impact on the total value of services provided. However, there were losses in the decades 1985-1995 and 1995-2005. Changes in land cover configuration caused a net gain of 9.8%, with agricultural areas that had their areas increased contributing the most to this gain. The high values of ecosystem services estimated for agricultural areas (an increase of US$ 2344.6 million between 1985 and 2021) should be viewed with caution, since 84% of the agricultural areas in the Gurupi river basin are occupied by soybean crops, destined mainly for export. Thus, while this recent shift has increased food production, it has weakened natural ecosystem functions provided by forests, such as climate regulation, water quality, and pollination. These soybean crop areas, according to data from MapBiomas (COLLECTION 7), are concentrated mainly in the southwest portion of the basin, in the municipalities of Paragominas, Ulianópolis and Dom Eliseu, in the state of Pará.

The decrease in mangrove areas is worrisome, since these areas are important nurseries for marine life (WHITFIELD, 2017), sheltering a diversity of fish and other seafood, which are important sources of food for the local population. In addition, mangrove areas provide a set of cultural services such as recreation and tourism, as well as religious and educational values, which have been the focus of numerous studies (MOORE et al, 2022). Agricultural areas play a significant role in the local economy of the municipalities in eastern Amazon. However, agricultural production is concentrated on a few crops, including açaí, cassava, soybeans, black pepper and cocoa (BORGES et al., 2020). According to the authors, most of the crop production in Pará depends on ecosystem services such as pollination by animals, which has been estimated to have a high economic value for the region.

In addition to the agricultural areas, forest plantation areas also increased significantly during the analyzed period. This may be related to the expansion of eucalyptus plantations in the agricultural frontier of the Legal Amazon of Maranhão (OLIVEIRA, 2019), as well as in the municipalities of Dom Elizeu, Paragominas, Rondon do Pará and Ulianópolis, which concentrate more than 90% of the planted forests in Pará (ALMEIDA; VIEIRA, 2022). The estimated value for this class/ecosystem corresponds to the following ecosystem services: supplying of raw materials, medicinal resources, and maintenance of soil fertility. It should be noted that tree plantations do not restore diverse and complex environments such as forests (ALMEIDA; VIEIRA, 2022). Therefore, eucalyptus monocultures should not be considered in ecological restoration projects.

Forest areas are essential for the maintenance of life on Earth, as they provide essential services, such as food provision, water, raw materials, medicinal resources, among others. In addition, forests play an important role in climate regulation, air quality, seed dispersal, pollination, pest control, moderation/regulation of extreme events, habitat provision and biodiversity protection (BROCKERHOFF et al., 2017). These forest areas are mainly concentrated in the basin's protected areas, such as indigenous and quilombola territories and conservation units, which have been important for the conservation of forest fragments in the region (PEREIRA; VIEIRA, 2019). However, increased deforestation and degradation, due to illegal logging and forest fires, pose a risk to the maintenance and provision of ecosystem services and also to the physical integrity and well-being of traditional populations (CELENTANO et al. al., 2018). It should be noted that the deforestation and degradation of large forest areas in the Amazon also affect the surrounding areas, reducing soil moisture and increasing the frequency of forest fires, and, consequently, affecting productivity, thus compromising key ecosystem services (FOLEY et al., 2007).

Implications for Payment for Environmental Services

There are many types of values associated with ecosystem services, which can be monetary (economic) or non-monetary (sociocultural). The attribution of monetary value to ecosystem services is a hot topic in the literature, and some controversy arises from the argument that it facilitates the commoditization of nature (MARTIN-ORTEGA, 2019; ROBERTSON, 2011). However, this valuation is essential when analyzing large regions, where it would be impossible, from a financial and human resource perspective, to assess the sociocultural significance of all local social groups. Furthermore, the value or importance given to a set of ecosystem services differs across cultures. In this regard, monetary assessment constitutes a more pragmatic conservation tool that could be used to inform and raise awareness about losses that could be avoided with conservation measures, and to base the development of initiatives and mobilization for the elaboration of payment schemes for environmental services.

Payment for environmental services can be used as an incentive mechanism in local Amazonian communities, such as traditional communities of the Gurupi region, to reduce deforestation and forest degradation through conservation actions and activities, thus promoting improved ecosystem services and local livelihoods. It is pertinent to note that the National Policy for Payments for Environmental Services (Law No. 14,119) has recently been implemented in Brazil (BRASIL, 2021). It acknowledges the importance of human activity in maintaining, recovering and improving environmental services, and may serve as an effective means for promoting forest restoration. Under Law No. 14,119, indigenous lands, quilombola territories, and other areas legitimately occupied by traditional populations may be subject to the Federal Program for Payment for Environmental Services (PFPSA).

In the Amazon region, such programs, if well-designed and implemented, can cause positive social and environmental changes, as long as they address key aspects. They should take into account the combination of financial incentives and the promotion of production activities based on diversity, i.e. agroforestry systems, among others. It is also critical to promote training and equitable and transparent participation for the population (MONTERO-DE-OLIVEIRA et al, 2023), in addition to inspection strategies aimed at improving program performance (NAIME et al, 2022).

On the other hand, it is necessary to consider that these strategies make sense when associated with a structuralist vision of the evolution of agrarian dynamics in the region. This would imply a more detailed study of the technological standards and economic rationality currently present in the region. This, in turn, would include organizing the forms of occupation and decision making regarding the different forms of land use and land cover.

5. Conclusion

The Ecosystem services framework allows for an interface between ecosystem functions and human well-being and activities. Assuring the sustainability of ecosystems and their natural resources requires understanding and acknowledging the value of benefits derived from these services. However, it is essential to assess the role of different land use and land cover models as effective mechanisms for the efficient use of ecosystem services.

Although the Ecosystem Services Valuation Database has some limitations, mainly regarding the scarcity of data on many important ecosystem services for the Amazon region, the estimate of the economic value of ecosystem services for the Gurupi river basin, based on this database, has proved to be an important tool for analyzing and estimating the magnitude of economic and financial losses linked to changes in native ecosystems in the region‘s landscape.

This study showed that the decrease in forest areas resulted in a significant monetary loss in terms of ecosystem services. The net gain in the last 36 years derived mainly from the increase in agricultural areas. However, this data must be analyzed with caution, for although agricultural areas provide ecosystem services such as food, in the Gurupi river basin, most of these areas are used for soybean crops, which is not a priority to ensure food security in the region. In addition, forest areas provide a greater diversity of ecosystem services, which include provision, regulation/maintenance and also cultural services.

Information on the value of ecosystem services and their variation due to changes in land use and land cover is important and can serve to raise the awareness of different actors, from the most varied fields (whether from civil society, business or politics) about how much is lost or not gained by not conserving or restoring areas of high ecological and economic value in the Amazon region.

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Impacto das Mudanças de Uso e Cobertura da Terra nos Valores dos Serviços Ecossistêmicos no leste da Amazônia

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São Paulo. Vol. 27, 2024
Artigo Original

Resumo: Desde a publicação do relatório da Avaliação Ecossistêmica do Milênio, o conceito de serviços ecossistêmicos tem ganhado visibilidade ao redor do mundo, pois muitos desses serviços são vistos como essenciais para o bem-estar humano e suas atividades, e podem representar, de maneira adicional, uma oportunidade de apoio financeiro para estratégias de conservação dos ecossistemas sob ameaça. Nesse contexto, esse trabalho tem como objetivo estimar os valores monetários associados aos serviços ecossistêmicos e as perdas associadas às mudanças de uso e cobertura da Terra no período de 1985-2021 na bacia do rio Gurupi, localizada em uma das regiões mais desmatadas da Amazônia brasileira. Os resultados mostram que a diminuição nas áreas de florestas refletiu em uma perda de valor monetário de serviços ecossistêmicos de US$ 1961 milhões. O balanço positivo no período analisado foi derivado principalmente do aumento de áreas agrícolas, entretanto, a maior parte dessas áreas correspondem ao plantio de soja. No período analisado houve redução das áreas destinadas ao plantio de outras culturas destinadas à alimentação, o que pode representar um risco à segurança alimentar da região.

***Palavras-chave*:** Mudanças no uso e cobertura da Terra; serviços ecossistêmicos; valores ecossistêmicos; valoração ambiental; Amazônia.

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Impacto del Cambio de Uso de Suelo y Cobertura en los Valores de Los Servicios Ecosistémicos en la Amazonía Oriental

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Artículo Original

Resumen: Desde la publicación del informe Evaluación de los Ecosistemas del Milenio, el concepto de servicios ecosistémicos ha ganado visibilidad en todo el mundo, ya que muchos de estos servicios se consideran esenciales para el bienestar humano y sus actividades, y pueden representar, además, una oportunidad de apoyo financiero para estrategias de conservación de ecosistemas en peligro de extinción. En este contexto, este trabajo tiene como objetivo estimar los valores monetarios asociados a los servicios ecosistémicos y las pérdidas asociadas a los cambios de uso y cobertura del suelo en el período 1985-2021 en la cuenca del río Gurupi, ubicada en una de las regiones más deforestadas. de la Amazonía brasileña. Los resultados muestran que la disminución de las áreas forestales se reflejó en una pérdida de valor monetario de los servicios ecosistémicos de US$ 1961 millones. El saldo positivo en el período analizado se derivó principalmente del aumento de las áreas agrícolas, sin embargo, la mayor parte de estas áreas corresponden al cultivo de soja. En el período analizado, hubo una reducción de las áreas destinadas a la siembra de otros cultivos alimentarios, lo que puede representar un riesgo para la seguridad alimentaria de la región.

Palabras-clave: Cambio en el uso/cobertura del suelo; servicios ecosistémicos; valores del ecosistema; valoración ambiental; Amazonía.

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