Trees, Forests and People 10 (2022) 100334

Contents lists available at ScienceDirect

Trees, Forests and People

journal homepage: www.sciencedirect.com/journal/trees-forests-and-people

A first approximation to the Colombian Amazon basin remnant natural capital. Policy and development implications

César Augusto Ruiz-Agudelo [a,1,*], Francisco de Paula Gutiérrez-Bonilla [b], Angela María Cortes-Gómez [c], Andrés Suarez [d]

[a] *Doctoral Program in Environmental Sciences and Sustainability, Universidad Jorge Tadeo Lozano, Carrera 4 # 22-61, Bogotá, Colombia*
[b] *Facultad de Ciencias Ambientas e Ingeniería, Universidad Jorge Tadeo Lozano, Carrera 4 # 22-61, Bogotá, Colombia*
[c] *Doctorado en Estudios Ambientales y Rurales, Facultad de Estudios Ambientales y Rurales, Pontificia Universidad Javeriana, Cra. 7 #. 40 - 62, Bogotá, Colombia*
[d] *Department of Civil and Environmental, Universidad de la Costa, CUC, Calle 58 # 55-66, Barranquilla, Colombia*

ARTICLE INFO

Keywords:
Colombia
Amazon basin
Ecosystem services
Remnant natural capital
Economic values
Spatial models

ABSTRACT

The Amazon basin is one of the most extensive, biodiverse, and dynamic tropical forest ecosystems on the earth. The Colombian Amazon basin occupies an area of approx. 34 million hectares, located in the country's southeast. The literature about the economic valuation of ecosystem services (ES) and the spatial information on remnant natural resources in the Colombian Amazon basin was revised through various information sources to document the earliest approximation to the state, spatial distribution, and economic value of the remnant natural capital at the scale of biomes, specific ecosystems, and political-administrative units. Our assessment estimated a natural capital loss of 18.1 billion $/year (equivalent to 6.7% of Colombian GDP in 2020) and a remnant natural capital worth 153.9 billion $/year (57% of Colombia's GDP in 2020) for eight ecosystem services. This research founds that a potential expansion in extensive and intensive livestock production systems (in a ten-year projection) will generate an additional loss of remnant natural capital of approximately 9.1 billion $/year. Finally, considering that 63% of the remnant natural capital is represented in indigenous reservations and 28% in protected areas, it is essential that the political management of the Amazon Basin concentrate on strengthening these land management figures. Improving the governability of indigenous lands and incentive sustainable agricultural and cattle ranching production, are the principal political challenges.

1. Introduction

The importance of natural capital for human well-being has been widely recognized (Daily and Matson, 2008). The concept of natural capital refers to the living and non-living components of ecosystems (ecosystem assets) that provide a continuous flow of goods and services (Guerry et al., 2015; van den Belt and Blake, 2015). Through this approach, it is possible to understand that stocks of renewable and non-renewable natural assets promote direct and indirect benefits to people in the form of ecosystem services that sustain society (Hinson et al., 2022). Once this is understood, the time has come to include natural capital in decision-making, otherwise current and future human well-being can be drastically affected (Costanza et al., 1997; Daily and Matson, 2008). Natural capital is fundamental to enabling critical and irreplaceable functions (Ekins, 2003); however, natural capital and the ecosystem services derived from it are often undervalued by Governments, businesses and the public (Daily et al., 2009). Therefore, natural capital accounts are an important additional tool to inform sustainable development (Guerry et al., 2015). In this regard, valuation plays an important role (Costanza et al., 2014; Daily et al., 2009).

According to Strand and collaborators (2018), the significance of monetary valuations has encouraged several scientific efforts to generate total value estimates for the Amazon Forest's ecosystem services (Costanza et al., 1997, 2017). Recent works have highlighted the importance of calculating marginal ecosystem service values. It means, the cost (benefit) of conversion (preserving) an additional unit area of forest (Andersen et al., 2002; Strand, 2017), and estimated spatially explicit economic values for a range of ecosystem services provided by the Brazilian Amazon Forest, including a mapping of biodiversity resources and income loss for timber production through fire-induced

* Corresponding author.
E-mail address: cesara.ruiza@utadeo.edu.co (C.A. Ruiz-Agudelo).
[1] https://scholar.google.es/citations?user=vKoBH_8AAAAJ&hl=es

https://doi.org/10.1016/j.tfp.2022.100334
Received 11 May 2022; Received in revised form 4 September 2022; Accepted 11 September 2022
Available online 15 September 2022

degradation (Strand et al., 2018). What characterizes these studies carried out in the Amazon is that value levels are amply varying. For instance, the Brazilian Amazon Forest was assessed as having a total marginal value of US$1175ha/year in 1993 (Torras, 2000) and between US$431 and US$3135ha/year in 1995 (Andersen et al., 2002). More recently, de Groot and collaborators (2012) delivered a total average value of US$5264ha/year for 22 categories of ecosystem services throughout all tropical forests. These studies usually present average values for tropical forests without accounting for differences in land use and employ value homogenization to account for methodological differences across referenced valuation studies. Nevertheless, a synthesis of economic values has never been developed for the Colombian Amazon basin-provided ecosystem services (Ruiz-Agudelo et al., 2020).

The Amazon basin is one of the most important bioregions for the continent and the biosphere due to its biological, social, and cultural diversity and ecosystem services (Rice et al., 2018). Moreover, multiple pressures, both present and past, have threatened the region's sustainability and the provision of critical ecosystem services, adversely affecting worldwide human wellbeing (Gondim et al., 2017; Ruiz-Agudelo et al., 2020). Any attempt to an approximation to the value of the Amazon's remnant natural capital (Mora, 2019), the Colombian Amazon basin, in this case, constitutes a significant contribution to informed conservation and management of such a critical ecoregion.

Therefore, the literature about the economic valuation of ecosystem services (ES) and the spatial information about remnant natural resources after human transformation in the Colombian Amazon basin was revised using various sources of information. The objectives of this research were: (1) - To provide an account of the current state of knowledge about ecosystem services (ES) economic valuation in the Colombian Amazon Basin. (2) - To develop the first approximation to the state, spatial distribution, and economic value (in international dollars of the year 2020 -Int.$2020/year) of the current and future remnant natural capital of this basin regarding biomes, specific ecosystems, and political-administrative units.

2. Methods

2.1. Study area

Colombia is in the northwest of the South American continent and has a land area of 1′141,748 km2, a marine area covering 928,660 km2, a population of 48′258,494 (DANE, 2021), and is the fourth most populous country in the American continent. Most of its population inhabits the central (Andean) and north (Caribbean) regions. The country is divided into 32 geographic regions (departments) and a capital district (Bogotá) of 8879,000 inhabitants. In addition, according to the National Biodiversity Index provide (NBI) by the Convention on Biological Diversity in the Global Biodiversity Outlook 1 (https://www.cbd.int/gbo1/annex.shtml), Colombia is an outstanding mega-diverse country (NBI= 0.93/1).

The Colombian Amazon basin (Fig. 1) holds an area of approx. 34 million hectares and is located in the country's southeast. According to the Colombian hydrographic zoning map (IDEAM, 2010), the basin comprises the departments of Amazonas, Guaviare, Caquetá, Vaupes, Guainía, Putumayo, and Meta, Nariño, Huila, and Cauca to a lesser extent. There are heights above 4000 meters above sea level in its

Fig. 1. Study area. The Colombian Amazon basin.

watershed. Its population density is low (2.5 inhab/km2); however, it is regarded as one of the most dynamic regions in terms of internal migratory activities, mainly as a result of colonization during the early 20th century and forced displacement and violence during the period between 1985 and 2005 (Armenteras et al., 2019). The region's share of the national Gross domestic product (GDP) is 1.1%, explained by its scarce connectivity whit other regions. An exception is the most north-western portion of the Amazon, which has a comparatively significant population that generates around 81% of the regional income (Meisel et al., 2013; Armenteras et al., 2019). About 11.78% of the Colombian Amazon area is part of the National Park System, and 45.83% of it is indigenous reservations; most of these territories are categorized as forest reserves (Murcia et al., 2007).

The most serious environmental threat to the Colombian Amazon basin is deforestation due to land grabbing for pasture lands, illicit crops to a minor extent, and gold illegal mining (Armenteras et al., 2006; Davalos et al., 2011, 2016; Armenteras et al., 2019; Gonzalez-Gonzalez et al., 2021). Deforested areas are generally converted to pastures (Rodrigues et al., 2009; Lavelle et al., 2016). Biodiversity and ecosystem services loss become relevant as deforestation continues (Decaëns et al., 2018). Climate regulation, water cycling, and soil erosion are the ecosystem services most affected by the proliferation of pastures (Grimaldi et al., 2014). On the other hand, climate change will also significantly impact the distribution and biodiversity of Amazonian forests (Phillips et al., 2008). The latest generation of land-use models suggests that changes in rainfall due to deforestation may even be sufficient to cause ecological "tipping points" in some regions of the Amazon and transform tropical forests into deciduous forests or even savannahs (Malhado et al., 2010; Pires and Costa, 2013; Lovejoy and Nobre, 2018).

2.2. Methodological process

The paper is focused on vegetation natural capital stocks; using biomes and ecosystem types. For the estimation of the Remnant Natural Capital (RNC) in the Colombian Amazon basin, three phases were proposed (Fig. 2).

2.2.1. Phase 1: data standardization

Review and standardization of ecosystem services economic values. Several sources of information were examined in this paper to collect information on the Colombian Amazon Basin's ecosystem services economic valuation:

1 National and international peer-reviewed journals: A systematic literature search was conducted using journals whose papers contained the following search terms (in English and Spanish): Ecosystem services, economic valuation, valuation, Colombian ecosystems, biodiversity, ecosystem services valuation, ecosystem valuation, human wellbeing valuation, Amazon region, Colombian Amazon basin. Each search term was combined with Colombian municipality's and department's official names. Papers were sourced from the following science databases: Science Direct, SCOPUS, SCIELO, ISI Web of Knowledge, web of science, DIALNET, EBSCO, REDALYC, and Google Scholar.
2 Technical reports of Government environmental institutions: Document databases of the following Colombian Government institutions were reviewed: Ministry of Environment and Sustainable Development (MADS. https://www.minambiente.gov.co/), Regional Environmental Authorities (Regional Autonomous Corporations. https://www.asocars.org/), National natural parks of Colombia (https://www.parquesnacionales.gov.co/portal/es/), Biological Resources Research, Institute Alexander von Humboldt (IAvH Institute. http://www.humboldt.org.co/es), Amazon Institute of Scientific Research (SINCHI Institute. https://sinchi.org.co/), and Institute of environmental studies (IDEAM. http://www.ideam.gov.co/).
3 The web and several university (domestic or foreign) collections of books, theses, and working papers, in both Spanish and English.
4 Databases of Ecosystem services valuation. EVRI (Environmental Valuation Reference Inventory, https://www.evri.ca/en). EVRI is a searchable online database of studies on the economic valuation of environmental assets. Other valuation literature databases that were consulted included ESValues (https://esvalues.org/) and the Ecosystem Services Valuation. Database (ESVD. https://www.es-partnership.org/esvd/) (De Groot et al., 2020. The last version of December 2020).

As for the choice of studies concerning the economic valuation of the Colombian Amazon basin's ecosystem services, we defined a series of selection criteria based on the works of Ruiz-Agudelo et al. (2011), Ruiz-Agudelo and Bello (2014), and Ruiz-Agudelo et al. (2022). Our selection criteria included: (a) must have been conducted in the Colombian Amazon basin; (b) be an original case study; (c) provide information about the valuation method employed; (d) provide a

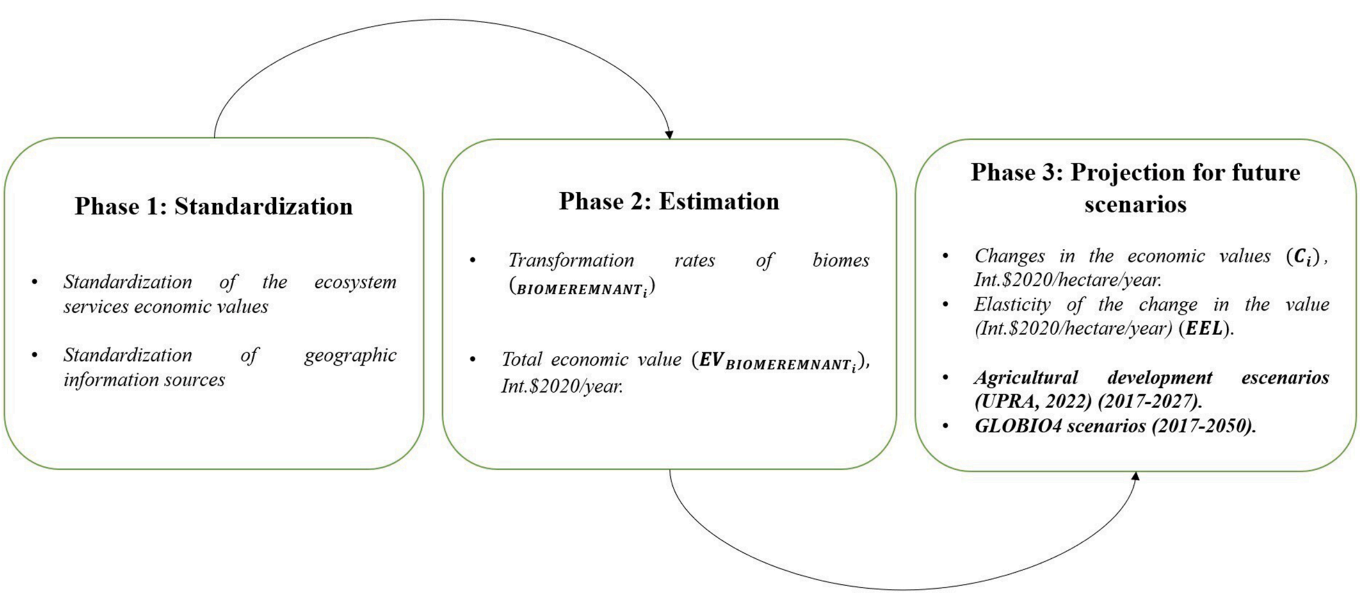

Fig. 2. Proposed phases to estimate the RNC in the Colombian Amazonian basin.

monetary value for any given ecosystem service and (e) provide a detailed location of the case study.

This research identified 26 cases studies (88 economic valuations of environmental goods or services - EVESs) dealing with the Colombian Amazon basin. Values are reported in the literature in a wide variety of currencies, price level per year, spatial units, temporal units, and beneficiary units. Following de Groot et al. (2020), the standard unit we used was Int.$2020 (USD adjusted for differences in purchasing power across countries), per hectare, and per year for the total number of beneficiaries. We applied a five-step standardization process: price level, currency, spatial unit, temporal unit, beneficiary unit, suggested by De Groot et al. (2020) and Ruiz-Agudelo et al. (2022). Finally, essential information was recorded from each study, including publication descriptors and geographic information (Supplementary material 1). The Amazon ecosystems/biomes were identified following the Colombian continental, coastal, and marine ecosystems map (IDEAM, 2017). Ecosystem names were homologated, according to the IUCN Global Ecosystem Typology 2.0 (Keith et al., 2020). This research applied the CICES V5.1 ecosystem services classification (Young and Potschin, 2018). The specific economic valuation method employed was documented for each value observed, following the categorization of economic valuation methods built by Brander et al. (2018) and De Groot et al. (2020).

Review and standardization of geographic information sources. The following sources of cartographic information were employed to estimate, and map lost and remnant natural capital in the Colombian Amazon basin:

1 To define the official limits of the Colombian Amazon Basin, we resorted to the Colombian Hydrographic Zoning map (IDEAM, 2013) on a scale of 1: 100000.
2 The information about political-administrative divisions (departments, municipalities, and villages) was retrieved from the official base cartography of the Agustín Codazzi Geographical Institute (IGAC, 2022) on a scale of 1:100000.
3 To define and map the biomes, original, transformed and natural (remnants), of the Colombian Amazon Basin, we turned to the information from the 2017 Colombian continental, coastal, and marine ecosystems map (V.2.1) (IDEAM; 2017) at 1:100000 scale. This map offers spatial information on the ecosystems and original, natural and transformed biomes and is the tool that the Colombian environmental authorities use to monitor the state of ecosystem transformation in the country.
4 To identify future threats to the RNC of the Colombian Amazon Basin, we referred to two specific sources:
   a SIPRA (Information System for Rural Agricultural Planning of Colombia) (UPRA, 2022a). Spatial information on the zoning of suitability was used at a scale of 1:100000 specifically for the following production systems: Angleton grass (*Dichantium aristatum, Dichantium anulatum*; UPRA, 2022b), beef production (UPRA, 2022c), Brachiaria grass (*Brachiaria decumbens*; UPRA, 2022d), Guinea grass (*Megathyrsus maximus,* UPRA, 2022e), Kikuyo grass (*Cenchrus clandestinus;* UPRA, 2022f), Bovine milk production (UPRA, 2022g), and Rice (*Oryza sativa*; UPRA, 2022h), considering that these productive systems entail the biggest threats to the ecosystems and biomes of the Colombian Amazon Basin.
   b GLOBIO4 Scenario data (https://www.globio.info/what-is-globio). The GLOBIO4 model (Schipper et al., 2020) produces spatial datasets with scenario outcomes for land use/cover. Here, we evaluated the changes in Colombian Amazon basin terrestrial biodiversity, expressed by the mean species abundance (MSA) metric, resulting from three of the shared socio-economic pathways (SSPs) combined with different levels of climate change (according to representative concentration pathways [RCPs]): a future oriented towards sustainability (SSP1xRCP2.6), a future determined by a politically divided world (SSP3xRCP6.0) and a future with continued global dependency on fossil fuels (SSP5xRCP8.5). All global model output datasets are in GeoTif raster format and use the WGS84 coordinate system on a 10-arc-second spatial resolution, this roughly equals 300×300 meters at the equator (Schipper et al., 2020).

2.2.2. Phase 2: estimation of the current RNC

Mapping the economic values of ecosystem services and first estimation of lost and remnant natural capital. According to the information sources detailed in the preceding sections, 92 specific biomes are reported (and 39 general ecosystems. Supplementary material 2) for the Colombian Amazon Basin. The following spatial analysis was applied to identify the transformation rates of biomes.

$$\boldsymbol{BIOMEREMNANT_i} = \boldsymbol{BIOMEORIGINAL_i} - \boldsymbol{BIOMETRANS_i}_{\,(2017)} \quad (1)$$

Where:

$\boldsymbol{BIOMEREMNANT_i}$, is the area in hectares of remnant biome i. Vector spatial information layer.
$\boldsymbol{BIOMEORIGINAL_i}$, is the prediction of the past (original) area in hectares of the Biome i, according to IDEAM (2017). This is a vector information layer.
$\boldsymbol{BIOMETRANS_i}_{\,(2017)}$, is the current transformed area in hectares (for conventional and extensive agricultural, livestock, mining, infrastructure, and other human interventions) of biome i, according to the information from the IDEAM (2017). This is a vector information layer.

i is correspondent with each of the 92 biomes reported in the Colombian Amazon Basin.

The economic values of the lost and RNC in the Colombian Amazon basin (Int.$2020/hectare/year) were obtained through the revision and standardization values process. The first approach to total economic value ($\boldsymbol{EV_{BIOMEREMNANT_i}}$) of each$\boldsymbol{BIOMEREMNANT_i}$, was estimated according to equation two (2):

$$\boldsymbol{EV_{BIOMEREMNANT_i}} = \boldsymbol{TEVES_{BIOMEREMNANT_i}} * \boldsymbol{BIOMEREMNANT_i} \quad (2)$$

Where:

$\boldsymbol{EV_{BIOMEREMNANT_i}}$ is the total economic value (Int.$2020/year) of$\boldsymbol{BIOMEREMNANT_i}$.
$\boldsymbol{TEVES_{BIOMEREMNANT_i}}$ are the total economic values (Int.$2020/hectare/year) of all ecosystem service documented for$\boldsymbol{BIOMEREMNANT_i}$.
$\boldsymbol{BIOMEREMNANT_i}$, is the extension in hectares of remnant biome i. Vector spatial information layer.

The total economic values (Int.$2020/hectare/year) of ecosystem services for$\boldsymbol{BIOMEREMNANT_i}$ was estimated as:

$$\boldsymbol{TEVES_{BIOMEREMNANT_i}} = \sum_{i=1}^{n} \boldsymbol{ESV_i} \quad (3)$$

Where:

$\boldsymbol{TEVES_{BIOMEREMNANT_i}}$ are the total economic values (Int.$2020/hectare/year) of all ecosystem service documented for$\boldsymbol{BIOMEREMNANT_i}$.
$\boldsymbol{ESV_i}$ is the economic value (Int.$2020/hectare/year) of each ecosystem service (*ES*) recorded for each$\boldsymbol{BIOMEREMNANT_i}$.

The economic value of each ecosystem service ($\boldsymbol{ESV_i}$) was estimated using equation four (4), derived from the model proposed by Costanza et al. (1997) and modified by Zhao and He (2018).

$$ESV_i = \sum A_k * V_k \quad (4)$$

Where:

ESV_i is the economic value (Int.$2020/hectare/year) of each ecosystem service (*ESi*), recorded on each$BIOMEREMNANT_i$.
A_k refers to the area (in hectares) of land use k within the$BIOMEREMNANT_i$.
V_k refers to the economic value of *SE*i for each type of land use k within$BIOMEREMNANT_i$.

Based on the above estimates, a database was built with the economic values of the remnant and lost natural capital of the 92 biomes of the Colombian Amazon basin (Supplementary material 3). Finally, those estimated economic values were mapped at the 1:100000 scale in the MAGNA-SIRGAS / Colombia Bogotá - Zone coordinate system. All spatial analyses were completed under the Spatial Analysis function of the R program, and all the maps were edited in QGIS (Version 3.16.15).

2.2.3. Phase 3: projection for future scenarios

Economic valuation of RNC in future agricultural development scenarios. Government spatial information on the projection of new areas with potential for agricultural growth was used (UPRA, 2022). These maps represent future scenarios for the expansion of crops and pastures for livestock (native and improved). The purpose of this spatial analysis was to identify potential losses of natural capital under these scenarios of conventional (intensive and extensive) agricultural expansion, simulating that such changes would be materialized in the period 2017 to 2027 (ten years).

The changes in the economic values (Int.$2020/hectare/year) of each ES (*ESVi*) for each remnant biome was calculated using equation five (5) according to Song and Deng (2017).

$$C_i = \frac{E_{end} - E_{start}}{E_{start}} \; x \; 100\% \quad (5)$$

Where:

C_i is the change in the estimated value (Int.$2020/hectare/year) of each ES (*ESVi*), for the$BIOMEREMNANT_i$.
Estart is the estimated economic value (Int.$2020/hectare/year) of each ES in 2017.
Eend is the estimated economic value (Int.$2020/hectare/year) of each ES in 2027 when the agricultural growth projections are materialized.

Following the elasticity concept of economics, which refers to the measurement of a variable's sensitivity to a change in another variable, elasticity *ESVi* is due to the percentage change in land use (by projected agricultural expansion) for each$BIOMEREMNANT_i$. The elasticity formula of Song and Deng (2017) was applied, thusly.

$$EEL = \left[\frac{(E_{end} - E_{start})/\, E_{start} \; x \; 100}{LCP}\right] \quad (6)$$

Where:

EEL is the elasticity of the change in the value (Int.$2020/hectare/year) of each ES, for$BIOMEREMNANT_i$. regarding changes in land use projected for agricultural expansion.
Estart is the economic value (Int.$2020/hectare/year) of each ES in 2017.
Eend is the economic value (Int.$2020/hectare/year) of each ES in 2027 when the agricultural growth projections are materialized.
LCP is the percentage of land conversion from a remnant biome (2017) to an area for conventional agricultural production (2027).

The LCP is estimated as follows:

$$LCP = \frac{\sum_{i=0}^{n} LUT_i}{\sum_{i=0}^{n} \Delta LUT_i} \; x \frac{1}{T} \; x \; 100\% \quad (7)$$

Where:

LCP is the percentage of land conversion from a remnant biome (2017) to an area of conventional agricultural production (2027).
LUTi is the estimated area in hectares of type i land use for a *BIOMEREMNANTi* in 2017.
Δ*LUTi*is the estimated area converted from type i land use (for a *BIOMEREMNANTi* in 2017) to new lands for conventional agricultural (in 2027).

T is the time interval (in years) of the period of change (in this case, ten years).

Economic valuation of RNC in future global change scenarios. We use the maps derived from the GLOBIO4 model (Schipper et al., 2020) downscaling to the Colombian Amazon basin. The models used were: 1. A future-oriented toward sustainability (SSP1xRCP2.6). 2. A future determined by a politically divided world (SSP3xRCP6.0). 3. A future with continued global dependency on fossil fuels (SSP5xRCP8.5). The models are expressed by the mean species abundance (MSA) metric and result from three shared socioeconomic pathways (SSPs) combined with different levels of climate change for the 2050 year. The changes in the economic values (Int.$2020/hectare/year) of each ES for each remnant biome were calculated using equations five (5), six (6), and seven (7). We define that *Estart* = 2017 and *E*end = 2050. Additionally, we suppose that the land cover change to non-natural cover in 2050.

3. Results

3.1. General overview of the Colombian Amazon basin's biomes and general ecosystems

According to this research, 92 biomes and 39 general ecosystems exist in the Colombian Amazon basin, which adds up to 34 million hectares. Approximate four million hectares have been transformed (for multiple anthropic activities), preserving a little more than 30 million hectares in their natural state. Fig. 3 show that three biomes have been 100% transformed (*Helobioma Picachos, Zonobioma Alternohidrico Tropical Huila- Caquetà, and Zonobioma Alternohidrico Tropical Picachos*; 5844 hectares), and 17 biomes have been transformed between 30% and 98% (3.4 million hectares). On the other hand, 35 biomes display no human intervention (Fig. 3A, Table 1S-Supplementary material 4). At an ecosystem scale (Fig. 3B, Table 2S-Supplementary material 4), the Livestock Agroecosystem (Approx. 2 million hectares), Mosaic agroecosystems of pastures and natural spaces (Approx. 639,748 ha), Transitionally transformed (Approx. 535,525 ha), and Secondary vegetation (Approx. 513,868 ha) are the most extensive in the Colombian Amazon Basin.

3.2. Economic values of the ecosystem services (EVES) identified in the Colombian Amazon basin

Based on the review and standardization of the EVES, monetary values were identified for eight (8) ecosystem services: habitat conservation (Maintenance of species' life cycles; incl. nursery service), opportunities for recreation and tourism, food, erosion prevention, water,

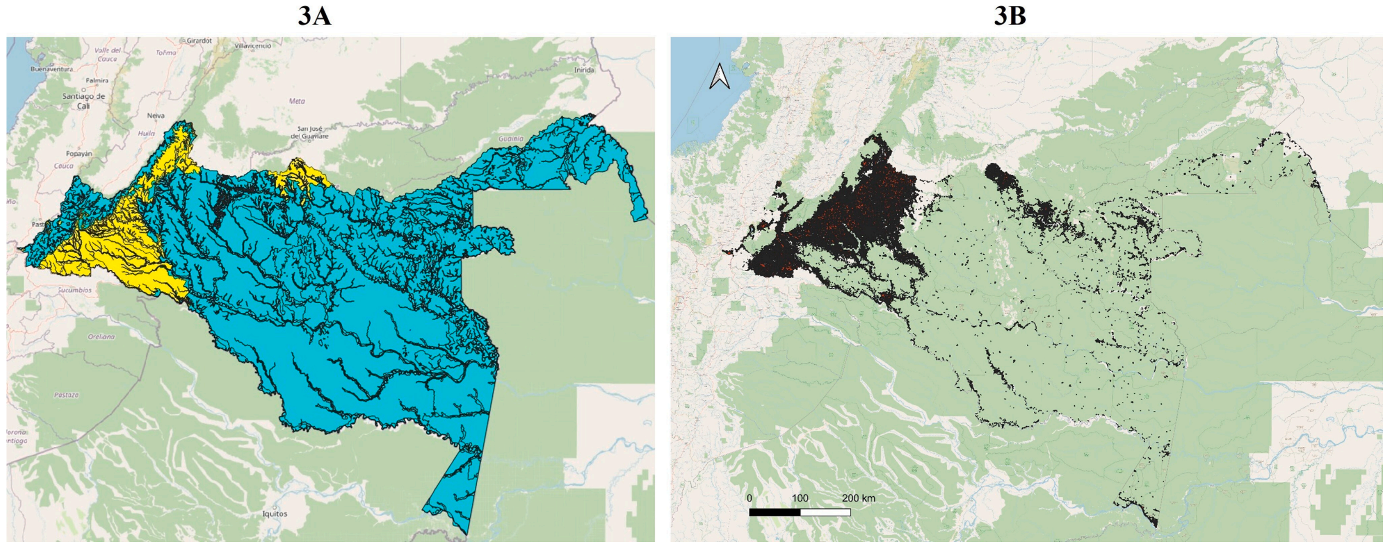

Fig. 3. 3A. Location of biomes with a human transformation between 30% and 100%. 3B. Location of transformed ecosystems.

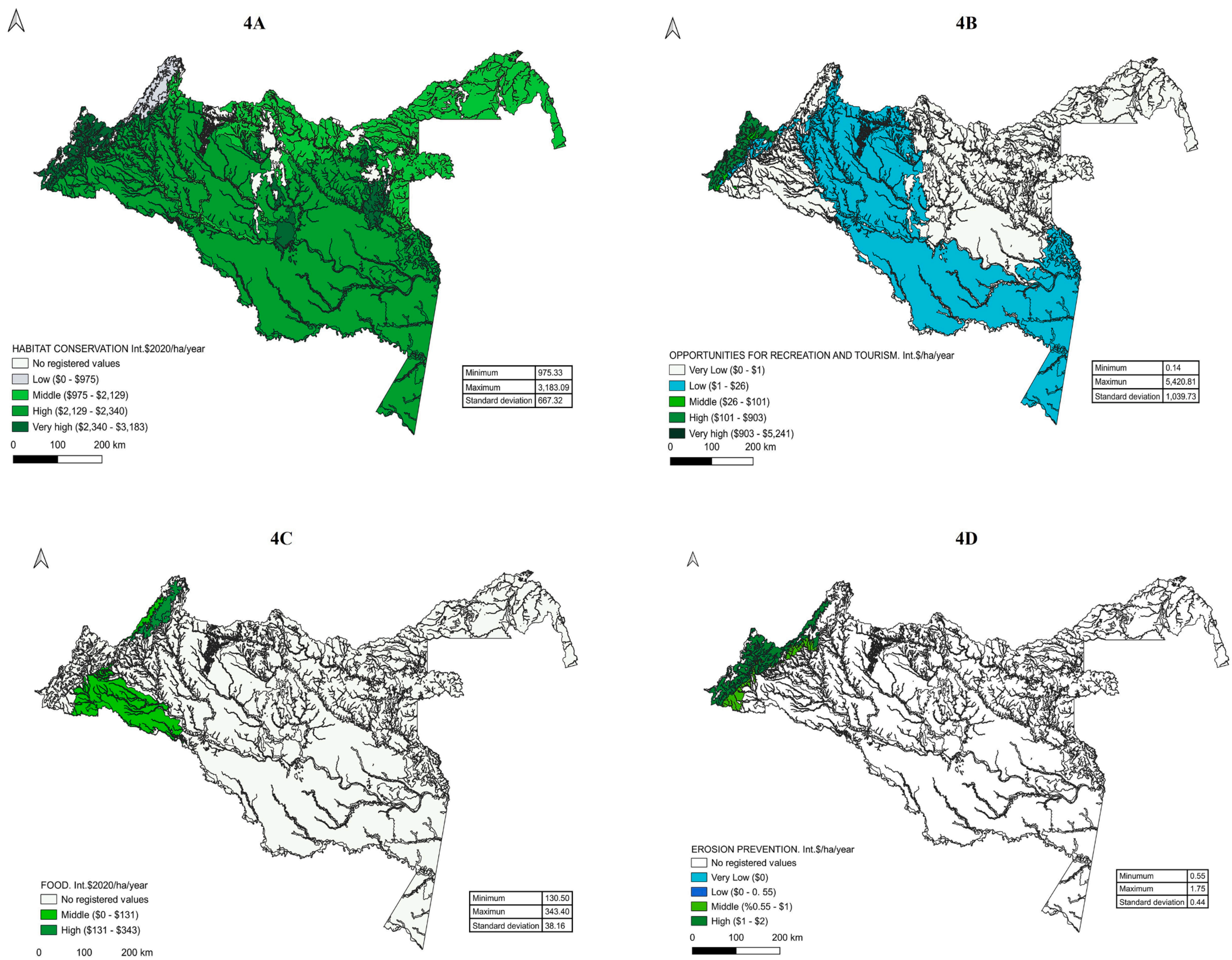

Fig. 4. A. Maps of the monetary value of ecosystem services (Int.$2020/ha/year): 4A. Habitat Conservation. B. Opportunities for recreation and tourism. 4C. Food. 4D. Erosion prevention. B. Maps of the monetary value of ecosystem services (Int.$2020/ha/year): 4E. Water. 4F. Climate regulation. 4G. Fishing. 4H. Biological control.

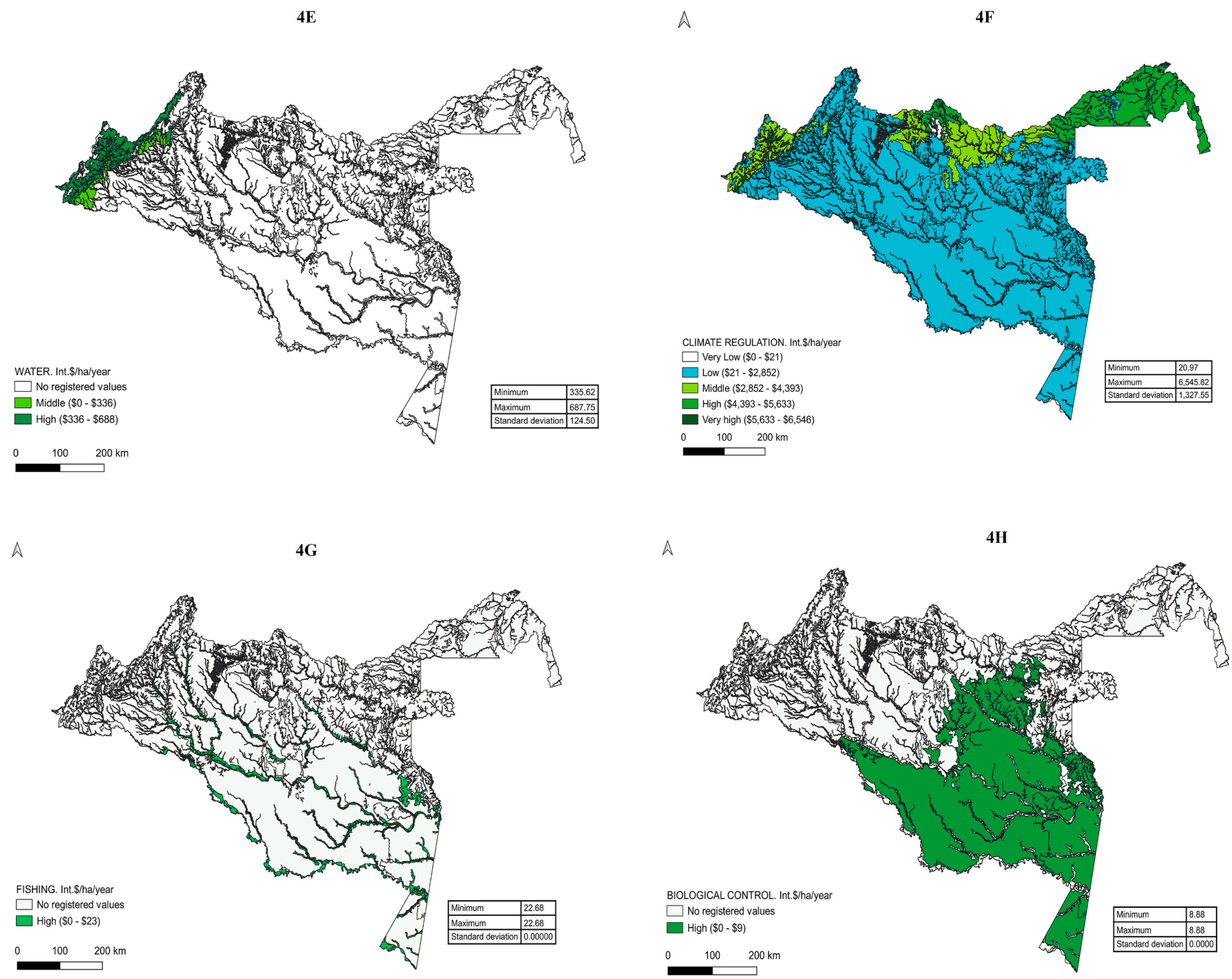

Fig. 4. (*continued*).

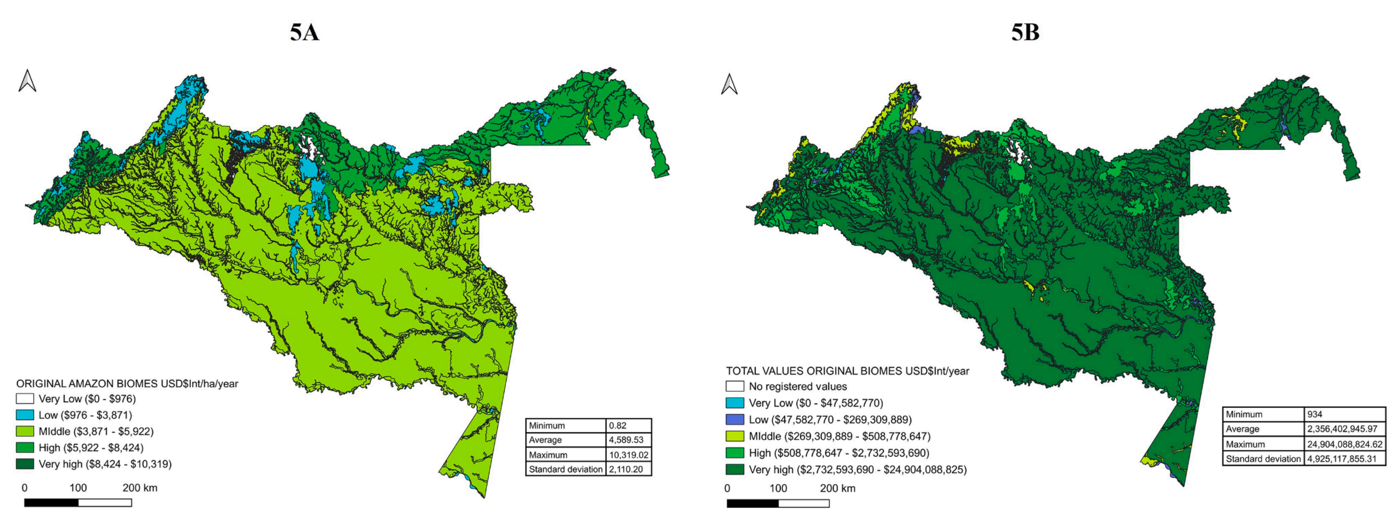

Fig. 5. Monetary value maps of original Colombian Amazon basin biomes: 5A. Average Int.$2020/ha/year. 5B. Int.$2020/year.

climate regulation, fishing, and biological control (Fig. 4, Supplementary material 5).

3.3. The first approach to the natural capital of Colombian Amazon basin original biomes

The natural capital of the Colombian Amazon basin's original biomes amounted to approx. 172 billion Int.$2020/year (Table 1S - Supplementary material 6). It is crucial to stress that this research documented no monetary values for 19 biomes, which add up to 205,000 ha (0.6% of the Colombian Amazon basin total extension). In Fig. 5A, the monetary values vary between 0.80 and 10,319 Int.$2020/ha/year (standard deviation of 2110). The lowest values appear in the original biomes: *Zonobioma Alternohidrico Tropical Picachos, Hidrobioma Alto Guayabero, Peinobioma Yari-Chiribiquete, Hidrobioma Huila-Caquetá*, and the *Orobioma de Páramo de Caquetá Influencia Cordillera Central*. On the other hand, the highest values (Int.$2020/ha/year) occur in the original biomes: *Orobioma Andino Cordillera Central, Hidrobioma Cordillera Central, Orobioma Subandino Cordillera Central*. The original Amazon biomes with the highest total economic values worth of natural capital (Supplementary material 6, Fig. 5B) are the *Zonobioma Húmedo Tropical Huitoto-Cahuinari* (25 billion Int.$2020/year), followed by *the Zonobioma Húmedo Tropical Yari-Chiribiquete* (23 billion Int.$2020/year) and the *Zonobioma Húmedo Tropical Apaporís* (21billion Int.$2020/year).

3.4. The first approach to natural capital loss in the Colombian Amazon basin biomes

There is an 18.099 billion Int.$2020/year loss of natural capital in 58 biomes (Table 2S -Supplementary material 6) and 11 general ecosystems (Table 3S - Supplementary Material 6). Natural capital losses, in Int.$2020/ha/year, vary between 0.82 (*Zonobioma Alternohidrico Tropical Picachos*) and 10,346.56 (*Orobioma Subandino Cordillera Central*), with a standard deviation of 1,766.80 (Fig. 6A). The biomes with the most relevant total losses of natural capital (due to anthropic transformation) are the *Zonobioma Húmedo Tropical Yari-Chiribiquete* (5.6 billion Int.$2020/year), followed by *Zonobioma Húmedo Tropical Alto Putumayo* (1.8 billion Int.$2020/year), *Zonobioma Húmedo Tropical Alto Caquetá* (1.7 billion), and *Zonobioma Húmedo Tropical Piedemonte Amazonas* (1.1 billion) (Table 2S - Supplementary material 6, Fig. 6B). At the scale of political-administrative divisions (Fig. 6C), Caquetá (9.7 billion Int.$2020/year), Putumayo (3.6 billion), and Guaviare (1.8 billion) are the Amazon basin departments with the most significant total losses of natural capital.

On the other hand, natural capital loss values vary between 3183 and 5931 Int.$2020/ha/year at the General Ecosystems level (Fig. 1S - Supplementary Material 6). The ecosystems with the highest total loss of natural capital (Int.$2020/year) in the Colombian Amazon basin are Livestock agroecosystem (7.4 billion), Mosaic agroecosystem of pastures and natural spaces (3 billion), Secondary vegetation (2.6 billion), Transitional transformed (2.5 billion), and Fragmented Forest with secondary vegetation (1 billion) (Table 3S and Fig. 2S - Supplementary Material 6).

3.5. The first approach to the remnant natural capital of Colombian Amazon basin biomes

The Colombian Amazon basin remnant natural capital amounts to 153.9 billion Int.$2020/year. The values of the remnant natural capital in Int.$2020/ha/year range between 975.33 and 10,290 with a standard deviation of 2,000.28 (Fig. 7A and Table 4S - Supplementary material 6). The total values of remnant natural capital in Int.$2020/year vary between 16,416 (*Hidrobioma Alto Guayabero)* and 24.6 billion (*Zonobioma Húmedo Tropical Huitoto-Cahuinari*) (Fig. 7B and Table 4S -Supplementary material 6). The Amazonian departments with the highest total values of remnant natural capital (Int.$2020/year) are Amazonas (48.6 billion), Caquetá (30.6 billion), and Vaupes (23.3 billion) (Fig. 7C).

At a General Ecosystems level, remnant natural capital values (Int.$2020/ha/year) vary between 1346 and 11,852 (Table 5S, Fig. 3S - Supplementary Material 6). The ecosystems with the highest total remnant natural capital (Int.$2020/year) in the Colombian Amazon basin are Humid basal forest (119.6 billion), Basal flooding forest (13.1 billion), Humid Andean Forest (5.2 billion), and Humid Sub- Andean Forest (3.9 billion) (Table 5S, Fig. 4S -Supplementary Material 6).

Finally, per our analyses, 63% of the remnant natural capital of the Colombian Amazon basin (96.5 billion Int.$2020/year) is represented in 156 Indigenous Reservations. On the other hand, 28% of remnant natural capital (43 billion Int.$2020/year) is contained in the 40 Natural Protected Areas (national, regional, and local) identified.

3.6. Probable loss of remnant natural capital during future socioeconomic development scenarios

3.6.1. RNC losses in future agricultural development scenarios

Our results suggest that if Angleton grass production systems were allowed to expand (in a 10-year scenario 2017-2027), about 1.6 billion Int.$2020/year would be lost (Table 1S - Supplementary material 7). The biomes most affected in their remnant natural capital would be *Zonobioma Húmedo Tropical Yari-Chiribiquete* (407 million Int.$2020/year), *Helobioma Alto Putumayo* (357 million), *Helobioma Yari-Chiribiquete* (165 million), and *Zonobioma Húmedo Tropical Piedemonte Amazonas* (102 million). In the case of beef production systems being allowed to expand (in a 10-year scenario 2017-2027), around 9.1 billion Int.$2020/year would be lost mainly in the *Zonobioma Húmedo Tropical Yari-Chiribiquete* (3.7 billion) and the *Zonobioma Húmedo Tropical del Alto Caquetá* (1.3 billion) (Table 2S - Supplementary material 7). The situation would be similar if the Brachiaria grass, Guinea grass, and bovine milk production systems were allowed to expand it would represent losses of approximately 9 billion, 9.1 billion, and 9.1 billion Int.$2020/year, respectively (Tables 3S, 4S, and 5S - Supplementary

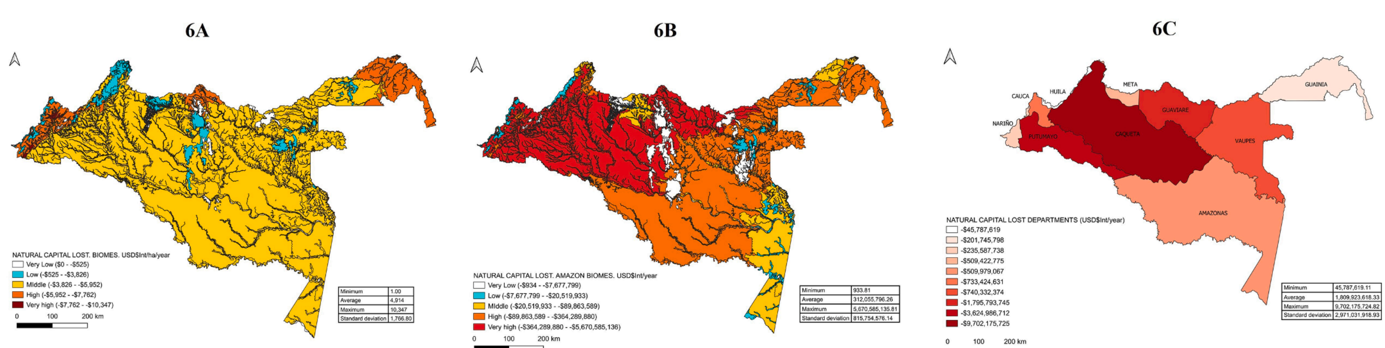

Fig. 6. Maps of monetary values of natural capital loss: 6A. Natural capital loss in Amazon biomes (Int.$2020/ha/year). 6B. Amazon biomes' total natural capital loss (Int.$2020/year). 6C. Amazon departments' total natural capital loss (Int.$2020/year).

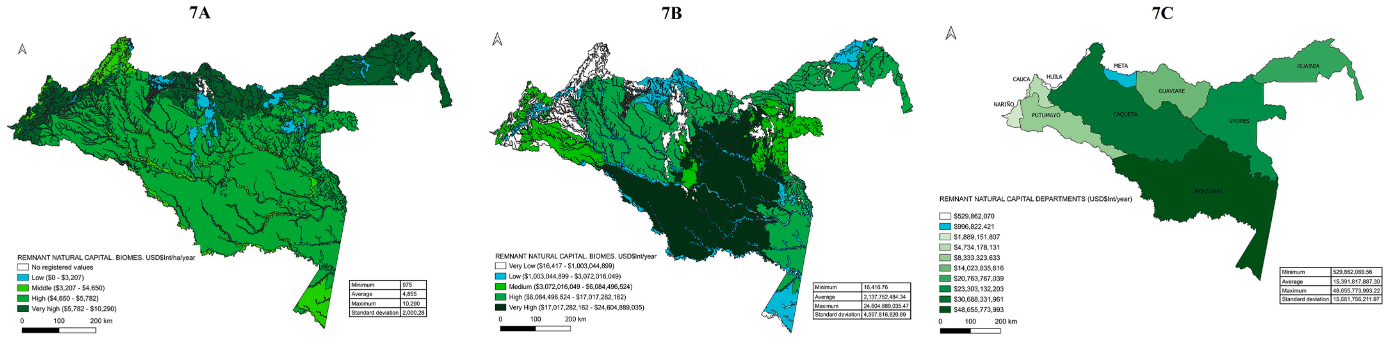

Fig. 7. Maps of remnant natural capital monetary value: 7A. Remnant natural capital of Amazon biomes (Int.$2020/ha/year). 7B. Remnant natural capital of Amazon biomes (Int.$2020/year). 7C. Total remnant natural capital of Amazon departments (Int.$2020/year).

material 7). Now, if an expansion in rice crops is encouraged, losses of 4.7 billion Int.$2020/year of remnant natural capital are expected, mainly in the *Zonobioma Húmedo Tropical Yari-Chiribiquete* (1.3 billion) and the *Zonobioma Húmedo Tropical del Alto Caquetá* (938 million) (Tables 6S - Supplementary material 7). Finally, losses in remnant natural capital are projected at 848 million Int.$2020/year under a Kikuyo grass expansion.

3.6.2. RNC losses in future global change scenarios

Our results on the downscaling of the GLOBIO4 models to the Colombian Amazon basin indicate that under a scenario of continued global dependency on fossil fuels (SSP5xRCP8.5), they wait for additional losses of the remnant natural capital of 24 billion Int.$2020/year, by 2050 (Fig. 8A). Under the scenario of a future determined by a politically divided world (SSP3xRCP6.0), additional losses of 17 billion Int.$2020/year are estimated (Fig. 8B). Finally, the scene where they estimate the minor losses (by 2050), is a future-oriented toward sustainability (SSP1xRCP2.6), with a value of 12 billion Int.$2020/year (Fig. 8C).

4. Discussion

4.1. Economic values of Colombian Amazon basin ecosystem services and restrictions on available information

This approximation for the Colombian Amazon basin aligns with

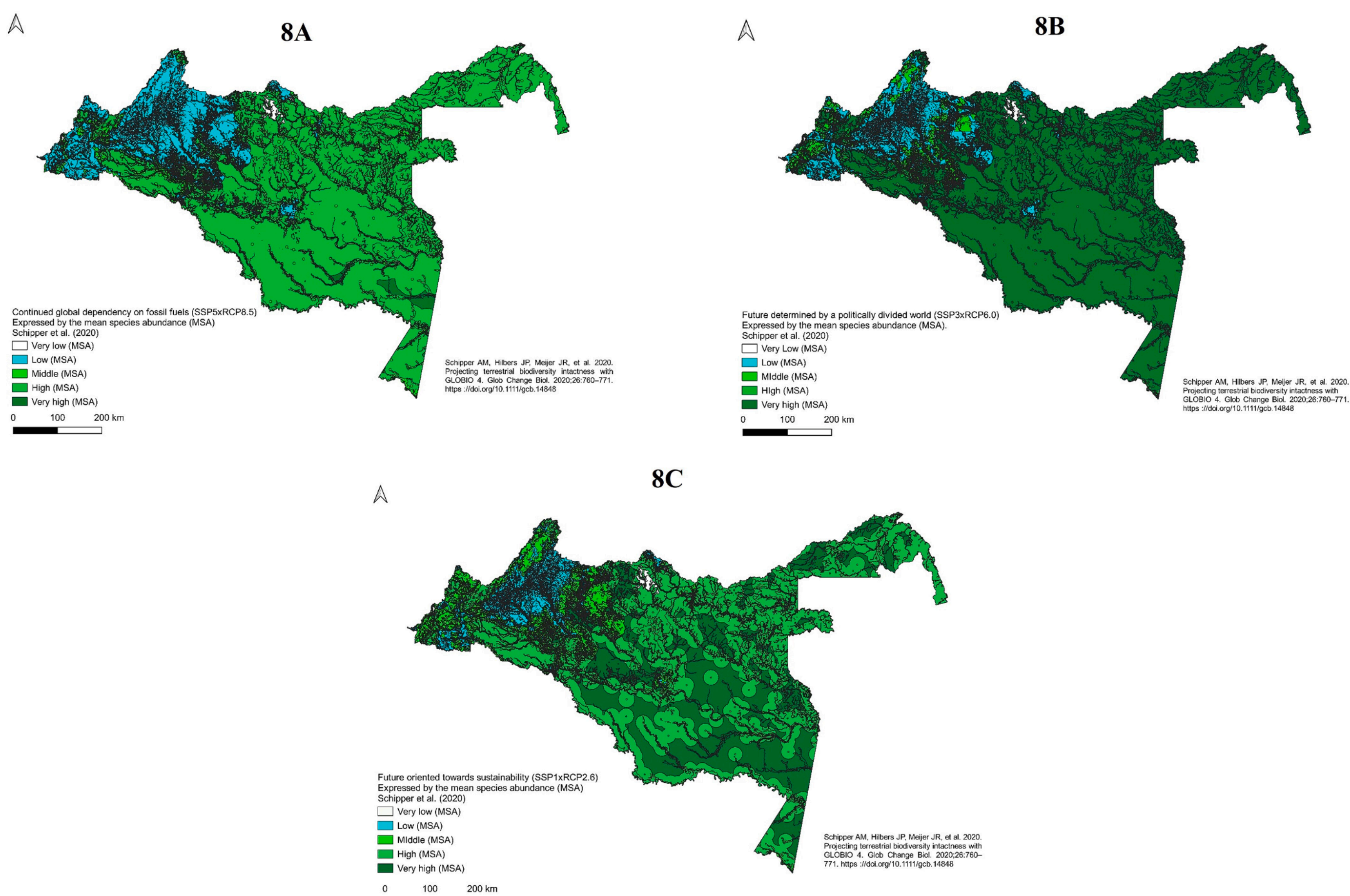

Fig. 8. 8A. Global dependency on fossil fuels (SSP5xRCP8.5): 8B. Future determined by a politically divided world (SSP3xRCP6.0). 8C. Future oriented toward sustainability (SSP1xRCP2.6).

Strand and collaborators (2018), pointing out that existing assessments vary widely and those values have increased dramatically in recent years, at least in the Amazon region. In this vein, broad variability patterns are reported by Andersen and collaborators (2002): between US $431 and US$3135 ha/year in 1995 for the Brazilian Amazon Forest (11 Ecosystem services). De Groot et al. (2012) reached a total average value of US$5264 ha/year for 22 ecosystem services in all tropical forests in synthesizing 665 value estimates in 2007; Costanza et al. (2014) reached similar conclusions (US$5382 ha/year). A more recent study Strand et al. (2018), also on the Brazilian Amazon, reported much lower values for four ecosystem services: between US$56.72 and US$737 ha/year, which stem from adopting a singular methodological approach (income losses from additional deforestation). The foregoing shows that the methodological approach is responsible, to a reasonable extent, for the variability reported regarding the monetary values of the ecosystem services assessed concerning their different contributions. It is also evident that there is little knowledge about the economic values of the ecosystem services provided by the Amazon rainforest; for the Colombia case, this research represents the first approximation in that vein.

This research shows that estimates of monetary valuation of individual ecosystem services vary significantly; for this reason, these results should be interpreted as a first approximation that can be complemented further research. Future research on some ESs is necessary, such as waste treatment, pollination, moderation of extreme events, medicinal resources, soil fertility, cultural and spiritual, and maintenance of genetic diversity, which have been poorly studied, in order to have a better understanding of these processes and ecosystem services and their contribution to the natural capital of the Colombian Amazon basin.

In the context of the Colombian Amazon basin, there are many benefits to valuing ecosystem services, such as the informed implementation of economic instruments, including paying for ecosystem services, but its importance is further reaching. Monetary valuation of ecosystem services can assist policymakers in managing different human wellbeing elements, providing grounds for economic and environmental sustainability. In a spatially explicit context, it can complement biodiversity assessments to more accurately identify areas that are key for sustaining provision of critical ecosystem services and therefore priority for protection (Potapov et al., 2017; Armenteras et al., 2019).

4.2. The present and future of the Colombian Amazon basin's RNC. Implications of this first approximation

4.2.1. Natural capital losses in the Colombia Amazon basin

The increasing pressure for energy, water resources, and fertilizers, and the worldwide expansion of areas for construction, farming, and livestock (Solomon et al., 2019), may exacerbate the tension over limited natural resources and may also damage the ability to sustain the supply of ecosystem services (Foley et al., 2005). This situation is also underway in the Colombian Amazon Basin. According to Armenteras and collaborators (2019), Colombia has a high rate of intact forests and several fronts of dynamic colonization and deforestation. Unfortunately, NW Amazonia has become one of the newest hotspots for forest loss in the Amazon basin. Saatchi et al. (2021) developed a tropical forest vulnerability index to detect and evaluate the vulnerability of global tropical forests to threats across space and time and showed the Forests in the Americas as extensively vulnerable to anthropic stressors.

Our results are comparable to those reported by Franklin and Pindyck (2018), who estimated the present value of lost economic benefits per hectare of deforestation at 3789 US$ per hectare for seven ESs in the great Amazon basin across nine countries. Higher colonization pressures may explain the remarkably high deforestation rates in the departments of Caquetá and Putumayo, together with the expansion of the frontiers of agriculture and intensified illegal coca growing (Correa-Ayram et al., 2020; Gutiérrez-Sanín, 2021).

The repercussions of the losses in natural capital in the Colombian Amazon Basin can be analyzed from two approaches: 1. The impacts of deforestation in the Amazon and the degradation on biodiversity and ecosystem services, and 2. The socioeconomic effects from the natural capital perspective:

1 According to Matricardi et al. (2020), deforestation, along with forest degradation and climate change, are the most critical threats to tropical forest ecosystems. The average annual rate of forest loss in the tropics raised about 30% in the 2010s regarding the 2000s, reaching 3.7 M ha (Butler, 2019; Hansen et al., 2019). Tropical forest ecosystems often host biodiversity hotspots, particularly threatened by habitat loss and degradation (Myers et al., 2000; Negret et al., 2021). Such an accelerated forest loss in the tropics is putting biodiversity (Martins et al., 2021) and ecosystem services at stake (Navarrete et al., 2016; UICN, 2017; Carvalho et al., 2020; Ruiz-Agudelo et al., 2020).
2 Different economics studies suggest that this is one of the least prosperous areas in Colombia, which is reflected in the population's comparatively poor welfare conditions. Among the explanatory factors associated with this backwardness, Meisel-Roca and collaborators (2013) argue that the region's geographic and economic isolation has constrained the conformation of regional economies and, thereby, economic growth. The gross domestic product (GDP) expressed in current international dollars, translated through the purchasing power parity (PPP) conversion factor of Colombia for 2020, was 270.3 billion (World Bank, 2022). This implies that the natural capital lost in the Amazon is equivalent to 6.7% of the Colombian 2020 GDP, a significant percentage when considering that the contribution of the Amazonian departments to the Colombian GDP (for 2020) amounts to approximately 0.23% (DANE, 2022).

4.2.2. The current RNC in the Colombian Amazon basin

Other studies have advanced global and national estimates of ecosystem services' economic value. At a global assessment level, de Groot and collaborators (2012) estimated the value of one hectare of tropical forest at 5264 (Int.$/ha/year, 2007), while Costanza et al. (2014) estimated the same value at 5382 (2007$/ha/year), these evaluations involve 20 ESs and are close to our estimates in the Colombian Amazon Basin's biomes and ecosystems which is, on average, 4855 (Int. $2020/ha/year). Now, at a national assessment level, the contributions of Kubiszewski et al. (2017) and Hernández-Blanco et al. (2020) become relevant as they estimated the total value of ecosystem services in Colombia (under different scenarios) at 717 billion USD/year in 2011. More recently, Jiang et al. (20221), in their mapping of the global value of terrestrial ecosystem services by country, estimates the value of seven ES (by calculating the Gross Ecosystem Product- GEP) for Colombia at 2.2 trillion dollars.

Reduction in annual production of ecosystem services would be on the order of 57% of the reported GDP for the country in 2020, a significant percentage that welcomes rethinking the ecoregion's importance. It also invites new management strategies to enhance the multiple socioeconomic benefits of sustainably using the remnant natural capital of the Colombian Amazon}. According to Fedele and collaborators (2021), the proportion of people highly dependent on nature in the Amazon basin ranges between 40% and 60%. This high dependency represents a new challenge for remnant natural capital management, which must ensure a sustainable flow of vital benefits (natural housing materials, energy from biomass, water from natural sources, among others) for a human population highly dependent on these.

At the scale of biomes and political-administrative divisions, the remnant natural capital is concentrated in Colombian Amazon basin-specific sectors (Fig. 7). This situation is explained (partly) by the land management schemes implemented in these territories. De Los Rios (2022) points out that the evidence suggests that the creation of Protected Areas and indigenous Reserves has helped reduce deforestation in the Colombian Amazon. Furthermore, he proved that the overlap of

Protected Areas and indigenous Reserves significantly reduces deforestation. Therefore, indigenous Peoples have shaped and managed vast tracts of the Amazon rainforest for millennia, and their role is fundamental in conserving biodiversity (Fernández-Llamazares et al., 2021), ecosystem services, and natural capital.

4.2.3. The future of Colombian Amazon basin remnant natural capital

This contribution focused on the possible losses of remnant natural capital due to the expansion of seven agricultural production systems, under the assumption that these productive systems (intensives and extensive) represent the major threats to the remnant biomes of the Colombian Amazon Basin. Our results show that an expansion of beef production systems (in a 10-year scenario) have a negative impact generated new losses of remnant natural capital.

According to Polanía-Hincapie and collaborators (2021), cattle ranching accounts for the most significant land use in the Amazon region of Colombia. Those poorly managed pasture systems typically entail soil compaction, acidification, losses in organic matter, and soil erosion, leading to soil health impairments and ecosystem services losses. Livestock production in the tropics has been widely questioned because of the adopted production system, which involves establishing grass monocultures with fewer animals per hectare (stocking rate) after cutting and burning the native vegetation (Tapasco et al., 2019). Currently, cattle ranching in the Colombian Amazon Basin is a significant concern; Colombia has become the second hotspot for Amazon Basin deforestation after the Brazil deforestation arc (Coca-Castro et al., 2013; IDEAM, 2017). The possibility of expanding livestock production activities poses an unmistakable threat to the conservation and sustainable use of the remnant natural capital in the short- and medium-term. This future loss of remnant natural capital could be mitigated if practices such as silvopastoral systems were implemented. For example, Polanía-Hincapie et al. (2021) showed that introducing silvopastoral systems was an efficient strategy to heal the physical quality of the soil, the systems' biomass, and the capture soil carbon capacity for different areas of the Colombian Amazon. The massive implementation of these silvopastoral systems and more precise environmental zoning of these economic activities constitute an important policy challenge for Amazon management in Colombia.

On the other hand, Schipper and collaborators (2020) found considerable variation in projected biodiversity change among different world regions for the GLOBIO4 scenarios. For the Colombian Amazon basin case, the minor losses of RNC are in the sustainability scenario (SSP1xRCP2.6) scenario. According to this contribution, effective measures to halt or reverse the decline of terrestrial biodiversity and natural capital should not only reduce land demand but also focus on reducing or mitigating the impacts of other pressures (e.g., the climate change impacts). In this way, another policy challenge is to identify the scenario that configures the smallest losses and that allows for maintaining the Amazon ecoregion resilience (Ruiz et al., 2020).

4.3. Uncertainties

According to Sumarga et al. (2015), regarding the spatial analysis of ES values, a key issue in mapping ecosystem values is the generalization error when a benefit transfer approach is used (Plummer, 2009; Liu et al., 2010). This first approximation shows how three aspects of our mapping approaches can reduce generalization error. Firstly, by only using empirical data from specific cases within the Colombian Amazon basin (Sumarga and Hein, 2014); this way, the potential error from transferring values can be minimized. Secondly, by presenting the spatial variation of ecosystem services inside a land cover type by applying interpolation. Thirdly, by detailing the mapping units by breaking down cover types in the Colombian Amazon Basin. In synthesis, our results build on a far more refined approach to ecosystem services valuation than those adopted by most studies.

This spatially explicit first approach to some critical natural capital components significantly enhances our ability to plan land use where protection or sustainable use in different natural regions must be prioritized. Decision-makers need to remain prudent about two aspects of our work: First, our maps represent values for different groups at different levels of society, for deforestation may incur economic losses to individual production activities or miss opportunities to capture societal benefits; second, our maps do not provide sufficient guidance where value components that may contradict each other overlap. For instance, regions with high timber values may overlap with highly biodiverse areas, which benefit different social groups.

Future research should focus, in greater detail, on the potential future impacts of the expansion of other economic activities such as legal and illegal mining (Rodríguez- Zapata and Ruiz-Agudelo, 2021), oil and gas exploitation (Codato et al., 2019), palm oil (Ocampo-Peñuela et al., 2018), and the expansion of other types of agricultural systems (Rodríguez et al., 2021). In addition, to estimate the tradeoffs between conservation and livestock and agriculture sustainable practices implementation.

5. Conclusions

Our research estimated a natural capital loss worth 18.1 billion Int.$2020/year (equivalent to 6.7% of Colombian GDP in 2020) and a remnant natural capital for eight ecosystem services worth 153.9 billion Int.$2020/year (57% of Colombia's GDP in 2020). Multiple challenges arise from this first approximation. First, a broader assessment and valuation of the multiple ecosystem services of the Colombian Amazon is necessary; this is an urgent endeavor to measure with more certainty its remnant natural capital and the social benefits derived from this. Second, these results invite new management strategies to enhance the multiple socioeconomic benefits derived from sustainably using the remnant natural capital of the Colombian Amazon (e.g., promote the use of economic instruments such as Payments for Ecosystems Services focusing on the most valuable areas). Third, given that 63% of the remnant natural capital is located in Indigenous Reservations and 28% in Protected Areas, strengthening indigenous land sustainable management and efficiency of the protected areas is essential; this last challenge directly involves the Colombian Government. Finally, future planning and zoning for productive activities in the Colombian Amazon Basin must be more careful to avoid further loss of natural capital.

CRediT authorship contribution statement

César Augusto Ruiz-Agudelo: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Francisco de Paula Gutiérrez-Bonilla:** Writing – original draft, Writing – review & editing. **Angela María Cortes-Gómez:** Writing – original draft, Writing – review & editing. **Andrés Suarez:** Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.tfp.2022.100334.

References

Andersen, L.E, Granger, C.W, Reis, E.J, Weinhold, D., Wunder, S., 2002. The Dynamics of Deforestation and Economic Growth in the Brazilian Amazon, 282. Cambridge Univ. Press, Cambridge, 2002.

Armenteras, D., Murcia, U., Gonzalez, Y.M., Baron, O.J., Arias, J.E., 2019. Scenarios of land use and land cover change for NW Amazonia: impact on forest intactness. Glob. Ecol. Conserv. 17, e00567. https://doi.org/10.1016/j.gecco.2019.e00567.

Armenteras, D., Rudas, G., Rodriguez, N., Sua, S., Romero, M., 2006. Patterns and causes of deforestation in the Colombian Amazon. Ecol. Indic. 6, 353–368. https://doi.org/10.1016/j.ecolind.2005.03.014.

Brander, L.M., van Beukering, P., Balzan, M., Broekx, S., Liekens, I., Marta-Pedroso, C., Szkop, Z., Vause, J., Maes, J., Santos-Martin, F., Potschin-Young, M. (2018). Report on economic mapping and assessment methods for ecosystem services. Deliverable D3.2 EU Horizon 2020 ESMERALDA Project, Grant agreement No. 642007.

Butler, R.H., 2019. Tropical Forests' Lost Decade: The 2010s. Mongabay Environmental News. https://news.mongabay.com/2019/12/tropical-forests-lost-decade-the-2010s/.

Carvalho, S., Oliveira, C., Strandsbjer-Pedersen, J., Manhice, H., Lisboa, F., Norguetf, J., de Wit, F., Duarte-Santos, F., 2020. A changing Amazon rainforest: historical trends and future projections under post-Paris climate scenarios. Glob. Planet. Chang. 195, 103328 https://doi.org/10.1016/j.gloplacha.2020.103328.

Coca-Castro, A., Reymondin, L., Bellfield, H., Hyman, G. (2013). Land use status and trends in Amazonia. Report for Global Canopy Programme and International Center for Tropical Agriculture as part of the Amazonia Security Agenda.

Codato, D., Pappalardo, S.E., Diantini, A., Ferrarese, F., Gianoli, F., De Marchi, M., 2019. Oil production, biodiversity conservation and indigenous territories: towards geographical criteria for unburnable carbon areas in the Amazon rainforest. Appl. Geogr. 102, 28–38. https://doi.org/10.1016/j.apgeog.2018.12.001.

Correa-Ayram, C.A., Etter, A., Díaz-Timoté, J., Rodríguez-Buriticá, S., Ramírez, W., Corzo, G., 2020. Spatiotemporal evaluation of the human footprint in Colombia: four decades of anthropic impact in highly biodiverse ecosystems. Ecol. Indic. 117, 106630 https://doi.org/10.1016/j.ecolind.2020.106630.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387 (6630), 253–260. https://doi.org/10.1038/387253a0.

Costanza, R., de Groot, R., Braat, L., Kubiszewski, I., Fioramonti, L., Sutton, P., Farber, S., Grasso, M., 2017. Twenty years of ecosystem services: how far have we come and how far do we still need to go? Ecosyst. Serv. 28, 1–16. https://doi.org/10.1016/j.ecoser.2017.09.008.

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S.J., Kubiszewski, I., Farber, S., Turner, R.K., 2014. Changes in the global value of ecosystem services. Glob. Environ. Chang. 26, 152–158. https://doi.org/10.1016/j.gloenvcha.2014.04.002.

Daily, G.C., Matson, P.A., 2008. Ecosystem services: from theory to implementation. Proc. Natl. Acad. Sci. U. S. A. 105 (28), 9455–9456. https://doi.org/10.1073/pnas.0804960105.

Daily, G.C., Polasky, S., Goldstein, J., Kareiva, P.M., Mooney, H.A., Pejchar, L., Ricketts, T.H., Salzman, J., Shallenberger, R., 2009. Ecosystem services in decision making: time to deliver. Front. Ecol. Environ. 7 (1), 21–28. https://doi.org/10.1890/080025.

DANE (Departamento Administrativo de Estadística). (2022). Available in: https://www.dane.gov.co.

DANE información para todos, censo nacional de población y vivienda. https://www.dane.gov.co/index.php/estadisticas-por-tema/demografia-y-poblacion/censo-nacional-de-poblacion-y-vivenda-2018/cuantos-somos, 2021 (accessed 13 April 2021).

Davalos, L.M., Bejarano, A.C., Hall, M.A., Correa, H.L., Corthals, A., Espejo, O.J., 2011. Forests and drugs: coca-driven deforestation in tropical biodiversity hotspots. Environ. Sci. Technol. 45 (4), 1219–1227. https://doi.org/10.1021/es102373d.

Davalos, L.M., Sanchez, K.M., Armenteras, D., 2016. Deforestation and coca cultivation rooted in twentieth-century development projects. Bioscience 66 (11), 974–982. https://doi.org/10.1093/biosci/biw118.

de Groot, R., Brander, L., Solomonides, S. (2020). Update of global ecosystem service valuation database (ESVD). FSD report No 2020-06 Wageningen, The Netherlands (58 pp). Available via: https://www.es-partnership.org/wp-content/uploads/2020/08/ESVD_Global-Update-FINAL-Report-June-2020.pdf.

de Groot, R., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L.C., ten Brink, P., van Beukering, P., 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosyst. Serv. 1 (1), 50–61. https://doi.org/10.1016/j.ecoser.2012.07.005.

De Los Rios, C., 2022. The double fence: overlapping institutions and deforestation in the Colombian Amazon. Ecol. Econ. 193, 107274 https://doi.org/10.1016/j.ecolecon.2021.107274.

Decaëns, T., Martins, M.B., Feijoo, A., Oszwald, J., Doľedec, S., Mathieu, J., Arnaud de Sartre, X., Bonilla, D., Brown, G.G., Cuellar Criollo, Y.A., Dubs, F., Furtado, I.S., Gond, V., Gordillo, E., Le Clec'h, S., Marichal, R., Mitja, D., de Souza, I.M., Praxedes, C., Rougerie, R., Ruiz, D.H., Otero, J.T., Sanabria, C., Velasquez, A., Zararte, L.E.M., Lavelle, P., 2018. Biodiversity loss along a gradient of deforestation in Amazonian agricultural landscapes. Conserv. Biol. 32, 1380–1391. https://doi.org/10.1111/cobi.13206.

Ekins, P., 2003. Identifying critical natural capital conclusions about critical natural capital. Ecol. Econ. 44 (2–3), 277–292. https://doi.org/10.1016/S0921-8009(02)00278-1.

Fedele, G., Donatti, C., Bornacelly, I., Holeae, D., 2021. Nature-dependent people: mapping human direct use of nature for basic needs across the tropics. Glob. Environ. Chang. 71, 102368 https://doi.org/10.1016/j.gloenvcha.2021.102368.

Fernández-Llamazares, A., López-Baucells, A., Velazco, P.M., Gyawali, A., Rocha, R., Terraube, J., Cabeza, M., 2021. The importance of indigenous territories for conserving bat diversity across the Amazon biome. Perspect. Ecol. Conserv. 19 (1), 10–20. https://doi.org/10.1016/j.pecon.2020.11.001.

Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentice, I.C., Ramankutty, N., Snyder, P.K., 2005. Global consequences of land use. Science 309 (5734), 570–574. https://doi.org/10.1126/science.1111772.

Franklin, S., Pindyck, R., 2018. Tropical forests, tipping points, and the social cost of deforestation. Ecol. Econ. 153, 161–171. https://doi.org/10.1016/j.ecolecon.2018.06.003.

Gondim, M.G., de Goés, G., de Jesus-Pinto, T., 2017. Protected areas in the Amazon: forest management, conflict and social participation. Acta Sci. Hum. Soc. Sci. 1 (39), 63–70.

Gonzalez-Gonzalez, A., Villegas, J.C., Clerici, N., Salazar, J.F., 2021. Spatial-temporal dynamics of deforestation and its drivers indicate need for locally-adapted environmental governance in Colombia. Ecol. Indic. 126, 107695 https://doi.org/10.1016/j.ecolind.2021.107695.

Grimaldi, M., Oszwald, J., Doľedec, S., Hurtado, M., del, P., de Souza Miranda, I., Arnauld de Sartre, X., de Assis, W.S., Castaneda, E., Desjardins, T., Dubs, F., Guevara, E., Gond, V., Lima, T.T.S., Marichal, R., Michelotti, F., Mitja, D., Noronha, N.C., Delgado Oliveira, M.N., Ramirez, B., Rodriguez, G., Sarrazin, M., da Silva, M.L., Costa, L.G.S., de Souza, S.L., Veiga, I., Velasquez, E., Lavelle, P., 2014. Ecosystem services of regulation and support in Amazonian pioneer fronts: searching for landscape drivers. Landsc. Ecol. 29, 311–328. https://doi.org/10.1007/s10980-013-9981-y.

Guerry, A.D., Polasky, S., Lubchenco, J., Chaplin-Kramer, R., Daily, G.C., Griffin, R., Ruckelshaus, M., Bateman, I.J., Duraiappah, A., Elmqvist, T., Feldman, M.W., Folke, C., Hoekstra, J., Kareiva, P.M., Keeler, B.L., Li, S., McKenzie, E., Ouyang, Z., Reyers, B., Vira, B., 2015. Natural capital and ecosystem services informing decisions: from promise to practice. Proc. Natl. Acad. Sci. U. S. A. 112 (24), 7348–7355. https://doi.org/10.1073/pnas.1503751112.

Gutiérrez-Sanín, F., 2021. Tough tradeoffs: coca crops and agrarian alternatives in Colombia. Int. J. Drug Policy 89. https://doi.org/10.1016/j.drugpo.2021.103156.

Hansen, A., Barnett, K., Jantz, P., Phillips, L., Goetz, S.J., Hansen, M., Venter, O., Watson, J.E.M., Burns, P., Atkinson, S., Rodríguez-Buritica, S., Ervin, J., Virnig, A., Supples, C., De Camargo, R., 2019. Global humid tropics forest structural condition and forest structural integrity maps. Sci. Data 6 (1), 232. https://doi.org/10.1038/s41597-019-0214-3.

Hernández-Blanco, M., Costanza, R., Anderson, S., Kubiszewski, I., Sutton, P., 2020. Future scenarios for the value of ecosystem services in Latin America and the Caribbean to 2050. Curr. Res. Environ. Sustain. 2. https://doi.org/10.1016/j.crsust.2020.100008.

Hinson, C., O'Keeffe, J., Mijic, A., Bryden, J., Van Grootveld, J., Collins, A.M., 2022. Using natural capital and ecosystem services to facilitate participatory environmental decision making: results from a systematic map. People Nat. 1–17. https://doi.org/10.1002/pan3.10317. February.

IDEAM (Instituto de Hidrología, Meteorología y Estudios Ambientales) (2013). Zonificación y codificación de unidades hidrográficas e hidrogeológicas de Colombia, Bogotá, D. C. ISSN: 2346-4720. Disponible via: http://documentacion.ideam.gov.co/openbiblio/bvirtual/022655/MEMORIASMAPAZONIFICACIONHIDROGRAFICA.pdf.

IDEAM- Instituto de Estudios Ambientales. (2017). Mapa de Ecosistemas continentales, costeros y marinos de Colombia. Versión 2.1. 100K. 2017. Available via: http://www.ideam.gov.co/web/ecosistemas.

IDEAM, Instituto de Hidrología, Meteorología y Estudios Ambientales. (2017). Décimo tercer boletín de alertas tempranas de deforestación (AT-D) cuarto trimestre 2017.

IGAC (Instituto Geográfico Agustín Codazzi). (2022). Datos abiertos cartografía y geografía. Avaliable via: https://geoportal.igac.gov.co/contenido/datos-abiertos-cartografia-y-geografia.

Instituto de Estudios Ambientales -IDEAM. (2010). Mapa de zonificación hidrológica de Colombia. http://www.ideam.gov.co/web/ecosistemas, 2010 (accessed 01 january 2021).

Keith, D.A., Ferrer-Paris, J.R., Nicholson, E., Kingsford, R.T., 2020. The IUCN Global Ecosystem Typology 2.0: Descriptive Profiles for Biomes and Ecosystem Functional Groups. IUCN, Gland, Switzerland. https://doi.org/10.2305/IUCN.CH.2020.13. ISBN: 978-2-8317-2077-7.

Kubiszewski, I., Costanza, R., Anderson, S., Sutton, P., 2017. The future value of ecosystem services: global scenarios and national implications. Ecosyst. Serv. 26, 289–301. https://doi.org/10.1016/j.ecoser.2017.05.004.

Lavelle, P., Doledec, S., de Sartre, X.A., Decaëns, T., Gond, V., Grimaldi, M., Oszwald, J., Hubert, B., Ramirez, B., Veiga, I., de Souza, S., de Assis, W.S., Michelotti, F., Martins, M., Feijoo, A., Bommel, P., Castaneda, E., Chacon, P., Desjardins, T., Dubs, F., Gordillo, E., Guevara, E., Fonte, S., del Pilar Hurtado, M., Lena, P., Lima, T., Marichal, R., Mitja, D., Miranda, I., Otero, T., Praxedes, C., Poccard, R., de Robert, P., Rodriguez, G., Sanabria, C., Tselouiko, S., Velasquez, A., Velasquez, E., Velasquez, J., 2016. Unsustainable landscapes of deforested Amazonia: an analysis of the relationships among landscapes and the social, economic and environmental profiles of farms at different ages following deforestation. Glob. Environ. Chang. 40, 137–155. https://doi.org/10.1016/j.gloenvcha.2016.04.009.

Liu, S., Costanza, R., Farber, S., Troy, A., 2010. Valuing ecosystem services theory, practice, and the need for a transdisciplinary synthesis. Ann. N. Y. Acad. Sci. (Ecol. Econ. Rev.) 1185, 54–78.

Lovejoy, T.E., Nobre, C., 2018. Amazon tipping point. Sci. Adv. 4, eaat2340. https://doi.org/10.1126/sciadv.aat2340.

Malhado, A.C.M., Whittaker, R.J., Malhi, Y., Ladle, R.J., Ter Steege, H., Phillips, L.E,O.C., Aragão, T.R., Baker, L., Arroyo, S., Almeida, N., Higuchi, T.J., Killeen, A.,

Monteagudo, N.C.A., Pitman, A., Prieto, R.P., Salomão, R., Vásquez-Martínez, W.F., Laurance, W., Ramírez, A., 2010. Are compound leaves an adaptation to seasonal drought or to rapid growth: evidence from the Amazon rainforest. Glob. Ecol. Biogeogr. 19, 852–862.
Martins, R., Brito, J., Dias-Silva, K., Leal, C., Leit, R., Oliveira, V.C., Oliveira-Júnior, J., Ferraz, S., de Paula, F., Roque, F., Hamada, N., Juen, L., Nessimian, J., Pompeu, P., Hughes, R., 2021. Low forest-loss thresholds threaten Amazonian fish and macroinvertebrate assemblage integrity. Ecol. Indic. 127, 107773 https://doi.org/10.1016/j.ecolind.2021.107773.
Matricardi, E.A.T., Skole, D.L., Costa, O.B., Pedlowski, M.A., Samek, J.H., Miguel, E.P., 2020. Long-term forest degradation surpasses deforestation in the Brazilian Amazon. Science 369 (6509), 1378–1382. https://doi.org/10.1126/science.abb3021.
Meisel, A., Bonilla, L., Sanchez, A. (2013). Geografía económica de la Amazonia Colombiana 106. https://repositorio.banrep.gov.co/handle/20.500.12134/3109.
Mora, F., 2019. The use of ecological integrity indicators within the natural capital index framework: the ecological and economic value of the remnant natural capital of México. J. Nat. Conserv. 47 (July 2018), 77–92. https://doi.org/10.1016/j.jnc.2018.11.007.
Murcia, U., n.d. (2007). Resumen Ejecutivo. Proyecto “Identificación de los motores, agentes y causas subyacentes de la deforestación en el Departamento del Putumayo: Valle del Sibundoy, municipios de Villa garzón y Puerto Leguizamo”. Murcia, U., Mazorra, A., Salazar, C., López, M., Arcila, O., Alonso, J., Agudelo, E., Núñez, M., Escobar, M., Quintero, L., Rodríguez, O., Vargas, G., Garzón, F., Pérez, H., Cárdenas, D., Sua, S., Zubieta, M., Barrera, J., Carrillo, M., Leticia, X., Hernández, M., Cardona, G., Pena, C., Giraldo, B., Rodríguez, C., Betancourt, B., Caicedo, D., Blanco, J., Acosta, L., Castro, W., Rendon, M., 2007. Balance anual sobre el estado de los ecosistemas y el ambiente de la Amazonia colombiana 2007. https://books.google.com.co/books?hl=es&lr=&id=r9w_AwAAQBAJ&oi=fnd&pg=PA1&ots=ht9pNaAe_J&sig=nXcvUdhgk_jad1dmp_bTBV87dAc&redir_esc=y#v=onepage&q&f=false.
Myers, N., Mittermeier, R.A., Mittermeier, C.G., Da Fonseca, G.A., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403 (6772), 853–858. https://doi.org/10.1038/35002501.
Navarrete, D., Sitch, S., Aragao, L., Pedroni, L., Duque, A., 2016. Conversion from forests to pastures in the Colombian Amazon leads to differences in dead wood dynamics depending on land management practices. J. Environ. Manag. 171, 42–51. https://doi.org/10.1016/j.jenvman.2016.01.037.
Negret, P.J., Maron, M., Fuller, R.A., Possingham, H.P., Watson, J.M.E., Simmonds, J.S., 2021. Deforestation and bird habitat loss in Colombia. Biol. Conserv. 257, 109044 https://doi.org/10.1016/j.biocon.2021.109044.
Ocampo-Peñuela, N., García-Ulloa, J., Ghazoul, J., Etter, A., 2018. Quantifying impacts of oil palm expansion on Colombia’s threatened biodiversity. Biol. Conserv. 224, 117–121. https://doi.org/10.1016/j.biocon.2018.05.024.
Phillips, O.L., Lewis, S.L., Baker, T.R., Chao, K.J., Higuchi, N., 2008. The changing Amazon forest. Philos. Trans. R. Soc. B 363, 1819–1827. https://doi.org/10.1098/rstb.2007.0033.
Pires, G.F., Costa, M.H., 2013. Deforestation causes different subregional effects on the Amazon bioclimatic equilibrium. Geophys. Res. Lett. 40, 3618–3623. https://doi.org/10.1002/grl.50570.
Plummer, M.L., 2009. Assessing benefit transfer for the valuation of ecosystem services. Front. Ecol. Environ. 7 (1), 38–45. https://doi.org/10.1890/080091, 9.
Polanía-Hincapie, K.L., Olaya-Montes, A., Cherubin, M.R., Herrera-Valencia, W., Ortiz-Morea, F.A., Silva-Olaya, A.M., 2021. Soil physical quality responses to silvopastoral implementation in Colombian Amazon. Geoderma 386, 114900. https://doi.org/10.1016/j.geoderma.2020.114900.
Potapov, P., Hansen, M.C., Laestadius, L., Turubanova, S., Yaroshenko, A., Thies, C., Smith, W., Zhuravleva, I., Komarova, A., Minnemeyer, S., Esipova, E., 2017. The last frontiers of wilderness: tracking loss of intact forest landscapes from 2000 to 2013. Sci. Adv. 3 (1) https://doi.org/10.1126/sciadv.1600821.
Rice, J., Rodríguez-Osuna, V., Zaccagnini, M.E., Bennet, E., Buddo, D., Estrada-Carmona, E., Garbach, K., Vogt, N., Barral, M.P. (2018). Setting the scene. Pages 1-52 in J. Rice, C. S. Seixas, M. E. Zaccagnini, M. Bedoya-Gaitán, and N. Valderrama, editors. The regional assessment report on biodiversity and ecosystem services for the Americas. Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany.
Rodrigues, A.S.L., Ewers, R.M., Parry, L., Souza, C., Veríssimo, A., Balmford, A., 2009. Boom-and-bust development patterns across the amazon deforestation frontier. Science 324 (80), 1435–1437. https://doi.org/10.1126/science.1174002.
Rodríguez, L., Suarez, J.C., Pulleman, M., Guaca, L., Rico, A., Romero, M., Quintero, M., Lavelle, P., 2021. Agroforestry systems in the Colombian Amazon improve the provision of soil ecosystem services. Appl. Soil Ecol. 164, 103933 https://doi.org/10.1016/j.apsoil.2021.103933.
Rodríguez-Zapata, M.A., Ruiz-Agudelo, C.A., 2021. Environmental liabilities in Colombia: a critical review of current status and challenges for a megadiverse country. Environ. Chall. 5, 100377 https://doi.org/10.1016/j.envc.2021.100377.
Ruiz–Agudelo, C.A., Bello, C., 2014. ¿El valor de algunos servicios ecosistémicos de los Andes colombianos?: Transferencia de beneficios por meta-análisis. Univ. Sci. 19 (3), 301–322. https://doi.org/10.11144/Javeriana.SC19-3.vase.
Ruiz-Agudelo, C.A., Bello, C., Londoño-Murcia, M.C., Alterio, H., Urbina-Cardona, N., Buitrago, A., Gualdrón-Duarte, J., Olaya-Rodríguez, H., Cadena-Vargas, C., Zárate, M.L., Polanco, H., Urciullo, F., Arjona-Hincapie, F., Rodríguez-Mahecha, J.V., 2011. Protocolo para la valoración económica de los servicios ecosistémicos en los Andes colombianos, a través del método de transferencia de beneficios. Reflexiones sobre el Capital Natural deColombia No. 1. Conservación Internacional Colombia, Bogotá, D.C, p. 53. ISBN: 978-958-99731-4-1.
Ruiz-Agudelo, C.A., Gutiérrez-Bonilla, F.,de P., Cortes-Gómez, A.M. (2022). The economic valuation of ecosystem services in colombia. challenges, gaps, and future pathways. Submitted to Environmental and Resource Economics.
Ruiz-Agudelo, C.A., Mazzeo, N., Díaz, I., Barral, M.P., Piñeiro, G., Gadino, I., Roche, I., Acuña, R., 2020. Land use planning in the Amazon basin: challenges from resilience thinking. Ecol. Soc. 25 (1), 8. https://doi.org/10.5751/ES-11352-250108.
Saatchi, et al., 2021. Detecting vulnerability of humid tropical forests to multiple stressors. One Earth 4, 988–1003. https://doi.org/10.1016/j.oneear.2021.06.002.
Schipper, A.M., Hilbers, J.P., Meijer, J.R., et al., 2020. Projecting terrestrial biodiversity intactness with GLOBIO 4. Glob. Chang. Biol. 26, 760–771. https://doi.org/10.1111/gcb.14848, 2020.
Solomon, N., Segnon, A.C., Birhane, E., 2019. Ecosystem service values changes in response to land-use/land-cover dynamics in dry afromontane forest in Northern Ethiopia. Int. J. Environ. Res. Public Health 16 (23), 15. https://doi.org/10.3390/ijerph16234653.
Song, W., Deng, X., 2017. Land-use/land-cover change and ecosystem service provision in China. Sci. Total. Environ. 576, 705–719. https://doi.org/10.1016/j.scitotenv.2016.07.078.
Strand, J., 2017. Modeling the marginal value of rainforest losses: a dynamic value function approach. Ecol. Econ. 131, 322–329.
Strand, J., Soares-Filho, B., Costa, M.H., et al., 2018. Spatially explicit valuation of the Brazilian Amazon forest’s ecosystem services. Nat. Sustain. 1, 657–664. https://doi.org/10.1038/s41893-018-0175-0.
Sumarga, E., Hein, L., 2014. Mapping ecosystem services for land use planning, the case of central Kalimantan. Environ. Manag. 54, 84–97. https://doi.org/10.1007/s00267-014-0282-2.
Sumarga, E., Hein, L., Edens, B., Suwarno, A., 2015. Mapping monetary values of ecosystem services in support of developing ecosystem accounts. Ecosyst. Serv. 12, 71–83. https://doi.org/10.1016/j.ecoser.2015.02.009.
Tapasco, J., LeCoq, J.F., Ruden, A., 2019. The livestock sector in Colombia: toward a program to facilitate large-scale adoption of mitigation and adaptation practices. Front. Sustain. Food Syst. 3, 17. https://doi.org/10.3389/fsufs.2019.00061.
Torras, M., 2000. The total economic value of Amazonian deforestation, 1978–1993. Ecol. Econ. 33, 283–297.
UICN. (2017). Red list of threatened species. Version 2016, 4.
UPRA (Unidad de Planificación Rural Agropecuaria) (2022). Sistema de Información Para la Planificación Rural Agropecuaria, SIPRA, Available via: https://sipra.upra.gov.co/.
UPRA (Unidad de Planificación Rural Agropecuaria). (2022). Zonificación de aptitud para el cultivo Pasto Angleton (Dichantium aristatum, Dichantium anulatum) en Colombia, a escala 1:100.000. Bogotá (Colombia). Available via https://sipra.upra.gov.co/.
UPRA (Unidad de Planificación Rural Agropecuaria). (2022). Zonificación de aptitud para la Producción de carne bovina en Colombia, a escala 1:100.000. Bogotá (Colombia). Available via https://sipra.upra.gov.co/.
UPRA (Unidad de Planificación Rural Agropecuaria). (2022). Zonificación de aptitud para el cultivo Pasto Brachiaria (Brachiaria decumbens) en Colombia, a escala 1: 100.000. Bogotá (Colombia). Available via https://sipra.upra.gov.co/.
UPRA (Unidad de Planificación Rural Agropecuaria). (2022). Zonificación de aptitud para el cultivo Pasto Guinea (Megathyrsus maximus) en Colombia, a escala 1: 100.000. Bogotá (Colombia). Available via https://sipra.upra.gov.co/.
UPRA (Unidad de Planificación Rural Agropecuaria). (2022). Zonificación de aptitud para el cultivo Pasto Kikuyo (Cenchrus clandestinus) en Colombia, a escala 1: 100.000. Bogotá (Colombia). Available via https://sipra.upra.gov.co/.
UPRA (Unidad de Planificación Rural Agropecuaria). (2022). Zonificación de aptitud para la Producción de leche bovina en Colombia, a escala 1:100.000. Bogotá (Colombia). Available via https://sipra.upra.gov.co/.
UPRA (Unidad de Planificación Rural Agropecuaria). (2022). Zonificación de aptitud para el cultivo Arroz (Oryza sativa) en Colombia, a escala 1:100.000. Bogotá (Colombia). Available via https://sipra.upra.gov.co/.
van den Belt, M., Blake, D., 2015. Investing in natural capital and getting returns: an ecosystem service approach. Bus. Strateg. Environ. 24 (7), 667–677. https://doi.org/10.1002/bse.1895.
World Bank (2022) Data world bank. Available in: https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.CD?end=2020&locations=CO&start=1990&view=chart, https://datos.bancomundial.org/pais/colombia?view=chart.
Young, H., Potschin, M., 2018. Common international classification of ecosystem services (CICES) V5.1. Guidance on the Application of the Revised Structure. Fabis Consulting Ltd, The Paddocks. Chestnut Lane, Barton in Fabis, Nottingham, NG11 0AE, UK. Available via: https://cices.eu/content/uploads/sites/8/2018/01/Guidance-V51-01012018.pdf.
Zhao, M., He, Z., 2018. Evaluation of the effects of land cover change on ecosystem service values in the upper reaches of the heihe river basin, Northwestern China. Sustainability 10 (12), 4700. https://doi.org/10.3390/su10124700.