Estimating the value of ecosystem services in Brazil using the Ecosystem Services Valuation Database: a short desk study

UPDATE REPORT

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Preface

The report provides a description of the methodology used to calculate summary monetary values for ecosystem services in Brazil, a detailed overview of the results and a discussion on the application of the data to the case study of cattle range expansion. Finally, the report touches upon the main caveats and limitations of the research approach and application.

This assignment contributes to the report 'Natural capital valuation: an incentive to protect nature' (Sustainable Finance group of S&P Global Ratings, 2021) based on the update of the Ecosystem Services Valuation Database (ESVD) with additional ecosystem values to improve the coverage and representation of ecosystem services on specific ecoregions in Brazil.

The work was performed between September and October 2021 by Stefanos Solomonides.

The author is grateful for the help from the core project team of the ESVD for their valuable support and advice during this assignment. Special thanks to Philipp Schaegner for creating the summary value table in R Studio.

Contents

1. Background

1.1 Objectives of this assignment

The objective of the current assignment performed for the Sustainable Finance group of S&P Global Ratings (SPGR) is to provide an indicative summary of monetary values of the ecosystem services provided by specific ecoregions in Brazil. This information will be used for a subsection of the report: 'Natural capital valuation: an incentive to protect nature' (SPGR, 2021).
To this end, the assignment updated the ESVD with additional ecosystem service values to improve the coverage and representation of ecosystem services for 5 selected ecoregions in Brazil.

1.2 Natural wealth of Brazil

Brazil is the most biologically diverse country in the world. It is classified at the top among the world's 17 megadiverse countries, and second only to Indonesia in terms of species endemism (CBD, 2021). It's rich ecoregions harbour immense biological diversity while some areas are recognised as globally important due to the scale of the ecosystem services they provide (e.g., global climate regulation by the Amazon rainforest). On one hand, as a globally important biodiversity hotspot, Brazil's natural areas have received huge attention from the scientific, political, and civil societies alike. Numerous conservation and finance initiatives have linked global knowledge and resources into projects on the ground, that aimed to halt the continuing loss of natural wealth in this extremely biodiverse country.

On the other hand, Brazil is also one of the leading countries in agricultural exports in the world. Major agricultural exports of the country include beef, soybeans, coffee, sugarcane and crop biofuels. Arguably, these resources have global supply chains, and their demand is driven by international market forces. Despite its capacity in resource production, Brazil is a country with a lot of inequality and huge wealth disparities. Among the rural population, the lack of access to technology, formal education and skills training hinder sustainable improvements in people's quality of life. In addition, the recent urban development of the last few decades has triggered huge urban sprawls that many times occur in the form of slums, where a lot of the unprivileged urban population must reside. As the segment of the population most dependent on natural resources and ecosystem services, the poor are therefore the most vulnerable to their degradation (CBD, 2021).

Global as well as local factors have put Brazil's natural wealth at great risk. These processes have resulted in significant land conversions over the years. The Convention on Biological Diversity (2021) has recognised habitat loss as (by far) *'the most significant cause driving species towards threatened status'.* Naturally, habitat loss also results in the loss of natural capital and reduction in the provision of ecosystem services (welfare effects).

This research, aims to shed light on the magnitude of such losses (in monetary terms), based on empirical evidence from relevant Ecosystem Services valuation literature. The results are applied specifically to natural ecosystem loss, as a result of cattle range expansion.

1.3 Ecosystem Services Valuation Database (ESVD)

One of the leading and most comprehensive studies on the economic importance of ecosystem services has been the Economics of Ecosystems and Biodiversity (TEEB) study (2005-2010). Within the context of this study, a database on monetary values of ecosystem services was developed by the Foundation for Sustainable Development (FSD) and published in 2010 (de Groot et al. 2010). The rationale for developing this database was to provide information on the economic benefits of biodiversity conservation, the costs of loss of biodiversity and the costs of in-action to halt biodiversity loss.

After the release of the TEEB Valuation Database the authors continued to develop the database under the name "Ecosystem Services Valuation Database" (ESVD) – see de Groot et al (2012). With financial support from the UK Department for Environment, Food and Rural Affairs (Defra) in 2019, the FAO in 2020 and 2021, and the Dutch Ministry of Agriculture, Nature and Food Quality (LNV) in 2020, the content and structure of ESVD was significantly updated to include more than 5,400 value records distributed across all biomes, services, and geographic regions. The ESVD has been further updated under the FAO-SOFO assignment (contribution to the upcoming 'The State of the World's Forests' report, UNEP & FAO, in press) and as part of the research for the paper 'Natural Capital Valuation: An Incentive to Protect Nature' (SPGR, 2021), to include now almost 6,800 value records.

To our knowledge, ESVD is the largest publicly accessible database ecosystem services values. See www.esvd.net and www.esvd.info.

2. Conceptual framework

2.1 Ecosystem Services

Many definitions of Ecosystem Services (ES) exist but in general it is agreed that ES are the direct and indirect contributions of ecosystems to human welfare. Similar to the discussion regarding the definition of ES, also many different classifications, or 'lists' exist, starting from Costanza et al. (1997) and Daily (1997) via the Millennium Ecosystem Assessment (MA, 2005), the TEEB study on The Economics of Ecosystems and Biodiversity (TEEB 2010), the Common International Classification of Ecosystem Services (CICES 2018), the NCP-list (IPBES, 2018) and most recent the SEEA-reference list (2021).

For this report we used the TEEB list as the main reference list, but we also include the CICES and SEEA classifications to improve compatibility.

In spite of the many bigger and smaller differences between the ES-definitions and lists, there is general agreement on the below three or four main types of ES:

- *Provisioning services* are the products or resources that can be harvested or extracted from ecosystems (e.g., food and raw materials);
- *Regulating services* are the benefits obtained from ecosystem processes that maintain environmental conditions beneficial to individuals and society (e.g., air quality, flood protection, biological control)
- *Habitat services* are the benefits of ecosystems providing space (habitat) for biodiversity protection and gene-pool maintenance (in-situ conservation of valuable genetic material). Some lists, like CICES, combine Regulating and Habitat services into one category.
- *Cultural services* are the experiential and intangible benefits related to the perceived or actual qualities of ecosystems, i.e. the non-material benefits from spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences, including the appreciation of the existence of diverse species).

2.2 Economic value

Economic value is a measure of the welfare that humans and societies gain from the production and consumption of goods and services. It is the quantified net benefit that humans and societies derive from a good or service, whether or not there is a market and monetary transaction for the good or service. *Economic value* is distinct from *economic activity* (also known as financial or exchange value), which is a measure of cash flows and is observed in markets. While *economic activity* from market transactions is often used to calculate *economic value*, *economic activity* is not in and of itself a measure of human benefit.

The economic value of ecosystem services can be measured by the concept of *Total Economic Value* (TEV). TEV is used to describe the comprehensive set of utilitarian values derived from a natural resource (Pearce and Turner, 1990). It is useful for identifying the different types of value that may be derived from an ecosystem. TEV comprises use values and non-use values.

Use values are the benefits derived from physical use of the resource. Direct use values may derive from on-site extraction of resources (e.g., plants, animals) or non-consumptive activities (e.g., recreation). Indirect use values are derived from off-site services or other processes that are impacted by the resource (e.g., flood protection, climate regulation). Option value is the value that people place on maintaining the option to use a resource in the future (e.g., the option to extract resources in the future).

Non-use values are derived from the knowledge that an ecosystem is maintained without regard for any current or future personal use. Non-use values may be related to altruism (maintaining an ecosystem for use by others), bequest (for future generations) and existence (preservation unrelated to any use) motivations. The constituent values of TEV are represented in Figure 1. It should be noted that the “total” in Total Economic Value refers to the inclusion of all components of utilitarian value rather than the sum of all value derived from a resource – i.e., the TEV framework can be used to assess marginal changes in value as well as total and average values.

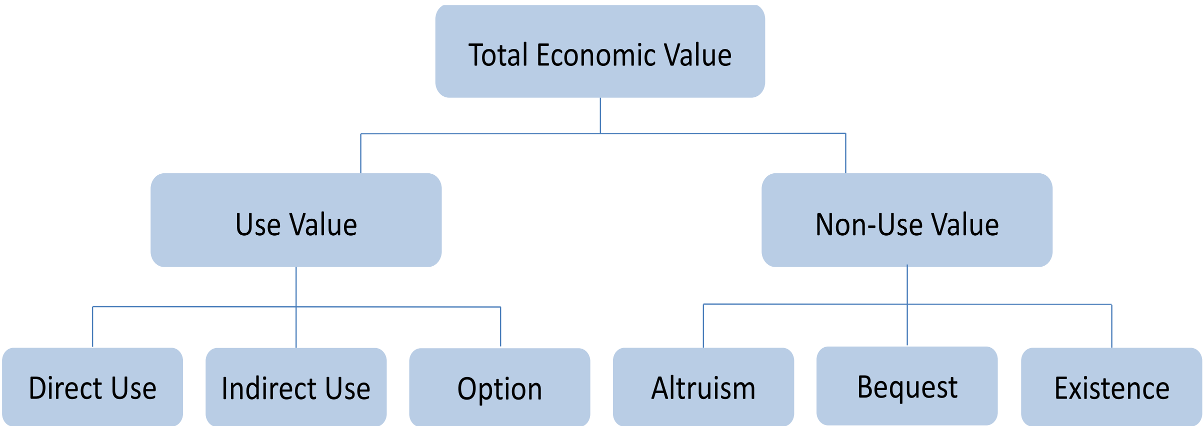

Figure 1: Components of Total Economic Value

3. Methods

For this data update, specific ecoregions of focus were defined based on existing information regarding the locations where land conversion had taken place, as a result of cattle range expansion. These are distinct systems with their own ecological characteristics. The identified ecoregions of interest are:

- Amazon rainforest: The amazon rainforest is one of the most biodiverse areas in the world with immense contributions to human welfare. The services provided of the amazon rainforest are considered as globally important (e.g. biodiversity preservation, global climate regulation) as well as critical for the national economy at various scales. The Amazon Biome, is defined as the area covered predominantly by dense moist tropical forest, with relatively small inclusions of several other types of vegetation (WWF, 2020). It covers an area of 7 million km2 and is the largest rainforest on earth stretching over nine countries: Brazil, Colombia, Peru, Venezuela, Ecuador, Bolivia, Guyana, Surinam, and French Guyana.15 About 60% of the Amazon rainforest lies in Brazil.
- Atlantic rainforest: The Atlantic rainforest is a moist tropical forest stretching from the north-eastern to the southern regions of Brazil and northern Argentina and south-eastern Paraguay. In the north-eastern part of Brazil, it occupies a thin coastal strip not exceeding 40 miles in width, while in the south it extends from the coast to as far as 200 miles inland (Nature Conservancy, 2021). Only a small fraction (around 15%) of the original area covered by Atlantic rainforest has not been converted, compared to 500 years ago. Despite severe degradation, it is still a system that harbours biological diversity of global importance. Furthermore, it provides essential ecosystem services to human settlements situated along the Atlantic coast of Brazil.
- Pantanal: The Pantanal is a tropical, freshwater wetland of close to 140,000 km2 in area located primarily in the Central-West of Brazil. The Pantanal is characterized by a varied patchwork of vegetative cover, in part due to variation in the annual and pluriannual flood cycles (Seidl, 2000). The Pantanal as an ecological region, is a mosaic of different ecosystems that includes forested wetlands, flooded grasslands, rivers, lakes, swamps and floodplains as well as forests and savannahs on dry land. However, the most important ecological feature in the Pantanal region is the water regime. This regime can render up to 70% of the Pantanal largely inaccessible to earth-borne creatures for as much as 6 months of the year because of inundation with flood waters (Seidl & Moraes, 2000).
- Cerrado: The Cerrado is a vast tropical savanna of Brazil and the largest savanna region in South America (WWF, 2020). Cerrado is the second biggest Brazilian biome and encompasses 2036,448 km2 (23.92% of the country's land area), it is a vast dry and hot savanna ecoregion, and hosts a wide variety of species. It has been recognised as the richest savanna in the world in terms of biodiversity. Unsustainable agricultural practices such as the expansion of soy croplands and cattle ranges, pose a serious threat to the long-term conservation of this important ecoregion.
- Caatinga: Caatinga is a xeric shrubland and thorn forest, which consists primarily of small, thorny trees that shed their leaves seasonally. Cacti, thick-stemmed plants, thorny brush, and arid-adapted grasses make up the ground layer. Many annual plants grow, flower, and die during the brief rainy season (UNESCO, 2021). It is a natural region particularly rich in flora diversity that lies in the hinterland of north-eastern Brazil. Caatinga extends over 900,000 km2 and encompasses part of the areas of 10 Brazilian states (da Silva et al, 2020). This ecoregion has been historically threatened by chronic anthropogenic disturbances. In addition, due to desertification effect, climate change is expected to further aggravate the impacts of these disturbances on biodiversity, particularly endemic plants (Silva et al, 2019).

The methods used for this assignment follow the approach developed for updating the ESVD described in de Groot et al. (2020) with some modifications to focus on valuation studies for target ecosystem types and geographic locations.

3.1 Study retrieval

a) Literature search

The first step in the methodological process is the literature search through multiple channels to identify potentially relevant ecosystem service valuation studies. For this update, we sought available studies related to the economic valuation of environmental goods and services focused on specific ecosystem types in Brazil. A priority was given to peer-reviewed studies conducted by qualified authors within the relevant field.

The majority of the studies examined were published in peer reviewed journals. It must be highlighted that we have mainly focused on original articles providing new data to avoid double counting. However, a few studies that used secondary data were also included because they dealt with specific biomes of interest, for which primary valuation literature appears to be scarce (e.g. the Pantanal). In addition, some economic valuation studies of interest to this project have been identified in the ESVD repository and have been included in this update to provide a comprehensive overview on the value of natural capital in Brazil. Finally, a few studies published in Portuguese were retrieved from Brazilian journals.

The search strategy was conducted online using keywords related to the economic valuation of environmental goods and services focused on related ecosystems. The search terms used included two main components: economic valuation and the type of nature or service. Specific terms for economic valuation category were: value; valuation; economic value; stated preferences; contingent valuation; choice experiment; stated choice; willingness to pay. Terms according to the type nature or service were: ecosystem; ecosystem services; tropical rainforest; Atlantic rainforest; Caatinga; Cerrado; Pantanal; forest valuation; Wetland forested; Woodland & Shrubland; Grassland. Finally, to restrict the search results only for Brazil, a geographically oriented keyword was included (e.g. 'Brazil', 'Brazilian').

b) Criteria for screening valuation studies.

The purpose of this step is to screen the collected studies to ensure that they provide relevant useable data that can be entered into the ESVD. The studies collected for the meta-analysis consists of monetary value assessments. On many occasions multiple value estimates are taken from single studies if they represent different services, values or geographic locations. The criteria applied for identifying relevant studies include publication type (priority to peer reviewed studies); geographic location (focus on Brazil); Biome and ecosystem (focus on biomes of interest); valuation metric (limited to monetary metrics); valuation method (focus mainly on primary valuation methods whenever possible).

c) Bibliographic database of studies.

Based on their abstract, all studies considered as relevant were downloaded and included in the ESVD repository. An additional screening process was conducted to decide if they had to be included or not in the final database. The downloaded studies were saved in the ESVD repository and in a Google Drive folder with sub-folders for each biome. The collected studies were saved using the file name format: Author - Year - Title. Moreover, all studies were stored using a reference management software to manage all the bibliographic data called Zotero[1].

[1] https://www.zotero.org/groups/2923630/esvd/library

3.2 Database structure

a) General structure. The ESVD organises data in 106 columns with information on among others: bibliographic details; study site; biome; ecosystem service; valuation method; valuation result in original units; standardised value; review status.

b) Classification of ecosystem services. Ecosystem services are classified using the TEEB and CICES classifications. Recently, the SEEA classification has also been added using a conversion table linking the TEEB sub-service codes and SEEA service codes.

c) Classification of biomes and ecosystems. Study sites are classified in the ESVD into 15 biomes and 84 ecosystem types. Study sites can comprise multiple biomes and ecosystems. During this update, several different biomes & ecosystems of the ESVD classification were linked to the pre-defined ecoregions of interest (Table 1), based on the system descriptions found in the analysed literature.

Table 1: Correlation of ecoregions with the ESVD Biome & Ecosystem classification

Ecoregion	**ESVD Biome**	**ESVD ecosystem**
Amazon rainforest	Tropical forests	Tropical rain forest
Atlantic rainforest	Tropical forests	Tropical rain forest
Pantanal	Inland wetlands Rivers & lakes Tropical forests Grass-/Rangeland	Wetlands, Forested (on alluvial soils) Swamps, marshes Floodplains Rivers Lakes, freshwater Tropical rain forest Savanna
Cerrado	Grass-/Rangeland Tropical forests	Savanna Tropical dry forest
Caatinga	Woodland & Shrubland	Mediterranean wood-& shrubland

3.3 Data cleaning

The data is cleaned by the ESVD team. For this purpose, an R- script has been developed to identify possible errors in the ESVD. This script identifies inconsistencies, typos and values that fall outside of plausible ranges. For example, if the Biome of a value estimate is specified to be Tropical Forests, then the Ecosystem variable must come from the Tropical forest biome. In this manner, variable combinations are automatically checked, and potential inconsistencies are flagged. All flagged issues are subsequently checked and, where necessary, corrected by the ESVD team. The following variables and combinations were checked:

1. Biome and Ecosystem
2. Ecosystem service text and Ecosystem service code
3. Country and Continent
4. Currency and Country
5. Valuation methods
6. TEEB ecosystem service classification and CICES classification
7. Value year and Publishing year
8. Country and Latitude and Longitude.

3.4 Value standardization

To allow comparability and synthesis of value observations it is necessary to standardize estimated values to a common currency, year of value, spatial unit, temporal unit and beneficiary unit. In the ESVD the standard units are Int.$ (i.e., USD adjusted for differences in purchasing power across countries), per hectare, per year for the total number of beneficiaries. The standardization process involves five steps to address each of these five dimensions: price level, currency, spatial unit, temporal unit, beneficiary unit.

a) Price level standardisation

Value estimates from primary valuation studies are reported at the general price level for a particular year, usually (but not always) the year in which the study was conducted. For example, a valuation study conducted in 2010 is likely to report values in the price level in that year. Inflation, however, causes general price levels in an economy to rise over time so that any given amount of money is worth less, in terms of the goods and services that it can purchase, over time. In order to compare value observations that were estimated in different years it is necessary to standardize values to a common price level year (i.e., accounting for differences in price levels over time). The selected base year for price levels in the ESVD is 2020.

This standardization can be made using available domestic price indices or GDP deflators that measure the annual rate of price change in an economy. GDP deflators were obtained from the World Bank World Development Indicators.[2]

The formula for the price level standardisation is:

$V_{2020} = V_t (D_{2020} / D_t)$

where:

V_{2020} = value observation at 2020 price level

V_t = value observation at study year price level

D_{2020} = GDP deflator index for the base year 2020

D_t = GDP deflator index for the study year

b) Currency standardisation

Value observations for ecosystem services may be reported in any currency. Primary valuation studies generally report values in the currency of the country in which the study site is located, or in US dollars (particularly if the results are intended for an international audience), or possibly in a third currency. To compare and synthesize value observations, it is necessary to convert all values to the same currency. The selected common currency for the ESVD is the International dollar (Int$), which represents the value of the US dollar in the United States in terms of purchasing power. Converting other currencies to Int$ involves using purchasing power parity adjusted exchange rates, which are

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[2] http://datatopics.worldbank.org/world-development-indicators/

available from the World Bank World Development Indicators. Value observations used in this analysis were mostly reported either in US Dollars ($) or Brazilian Reals (R$).

The formula for this adjustment is:

$V_{Int\$} = V_{LC} \times FX_{PPP}$

where:

$V_{in\$}$ = value observation in Int$

V_{LC} = value observation in local currency

FX_{PPP} = purchasing power parity adjusted exchange rate between the local currency and the USD

In cases where a value observation has already been converted into a second currency (often USD) using a standard market exchange rate, it is necessary to adjust this reported value to reflect differences in purchasing power. This involves converting the value reported in USD back into the local currency using the market exchange rate (ideally the rate that was used by the analyst for the primary study) and then converting it into Int$ using a PPP adjusted exchange rate.

c) Spatial unit standardisation

Value observations can be reported for different spatial dimensions of the ecosystem that provides the service, primarily either per unit area of the ecosystem (e.g. value/hectare of forest), per unit length of the ecosystem (e.g. value/km of river or shoreline) or for the total spatial extent of the ecosystem.

Values that are reported per unit of area can use multiple different areal units (e.g. m^2, hectares, km^2, acres etc.). In order to compare and synthesise value observations it is necessary to standardise values to the same spatial units. The selected common unit of area for the ESVD is one hectare since this was used in previous versions of the ESVD and also widely used in other value databases and publications. Converting values reported in other areal units involves multiplying them by an appropriate conversion factor (see Table 2).

Table 2: Conversion factors for areal units to hectares

Areal Unit	Conversion factor to hectares
Square feet	107,640
Square meters	10,000
Acres	2.471
Square kilometers	0.01
Square miles	0.003861

Values that are reported per unit of length of the ecosystem can use multiple different units (e.g. feet, meters, kilometers, miles etc.). In order to compare and synthesize value observations it is necessary to standardize values to the same unit of length. The selected common unit of length for the ESVD is one kilometer since this is used in previous versions of the ESVD and also widely used in other value databases and publications. Converting values reported in other units of length involves multiplying them by an appropriate conversion factor (see Table 3).

Table 3: Conversion factors for units of length to kilometers

Areal Unit	Conversion factor to km
Feet	3,280.8
Meters	1,000
Miles	0.6214

Values that are reported for the total spatial extent of the ecosystem need to be converted to per hectare terms by dividing by the ecosystem area (in hectares).

d) Temporal unit standardisation

Value observations can be reported for multiple different periods of time (e.g. per visit, day, week, month, year, or a period of multiple years). In order to compare and synthesise value observations it is necessary to standardise values to the same unit of time. The selected common unit of time for the ESVD is one year since this is used in previous versions of the ESVD and also widely used in other value databases and publications.

Values reported as present values over a specified period of time period should be converted to annual values using the discount rates quoted in the study. If no discount rate is quoted an appropriate local discount rate should be identified, e.g. through an online search.

e) Beneficiary standardisation

Value observations can be reported for multiple different units of beneficiary (e.g. per visitor, person, household, or for the total number of beneficiaries of the ecosystem service). In order to compare and synthesise value observations it is necessary to standardise values to the same specification of beneficiary. The selected common specification for the ESVD is the total population of beneficiaries. This can also be described as the ‘market size’ or ‘economic constituency’ for the ecosystem service in question.

For value observations reported per visitor it is necessary to multiple by the total number of visitors, which would ideally be reported in the study. Similarly, for value observations reported per person or per household it is necessary to multiple by the total number of people or households that benefit from the ecosystem service, which again would ideally be reported in the study. In cases where the study does not report the relevant number of beneficiaries over which to aggregate, secondary sources may be used.

3.5 Calculation and validation of Summary values

Standardized values are summarized for each ecosystem service and biome type. For each combination of ES and biome the mean value and number of value estimates are reported (see Table 4, section 5.2). To avoid the influence of some extreme valuations on the summary statistics, we excluded all outliers for each combination of ES and biome type. We then investigated the estimated mean values for plausibility. For some mean value that we judged as not meeting our expectations, we made manual checks and validations. Therefore, we investigated the distributions of the values of the individual combination of ES and biome type. We then re-visited the primary valuation studies if value estimates seemed suspicious. Based on our findings, some manual adjustments were made for very few mean value estimates, such as overruling the automated outlier exclusion rule (by excluding additional values). We also deleted three mean values for specific combinations of ES and forest type as the mean values seemed unplausible and as they were based only on very few valuations. It is important to point out that for the calculation of summary values, the following records were not considered:

1. Records referring to a combination of biomes and/or services
2. Estimates produced with Value Transfer method

As a result, only a portion of the records collected were suitable for calculating summary mean values (see Results, section 5.2).

4. Results

4.1 Description of data update

Prior to this update, the ESVD contained 156 value records for Brazil. At the end of it, the total number of relevant records rose to 451 (i.e., 295 records were added). From the total number of records, 62 were excluded as they referred to biomes which were outside the scope of this project (e.g. records on cultivated areas and mangroves). Thus, the final number of records that were used for further analysis was 389. Please note that in the descriptive overview, the information for Pantanal is provided aggregated for all the relevant biomes, but the same could not be done for the summary statistics due to methodological constrains (i.e. only values with 1 biome & 1 service are included in the summary statistics, see section 4.5).

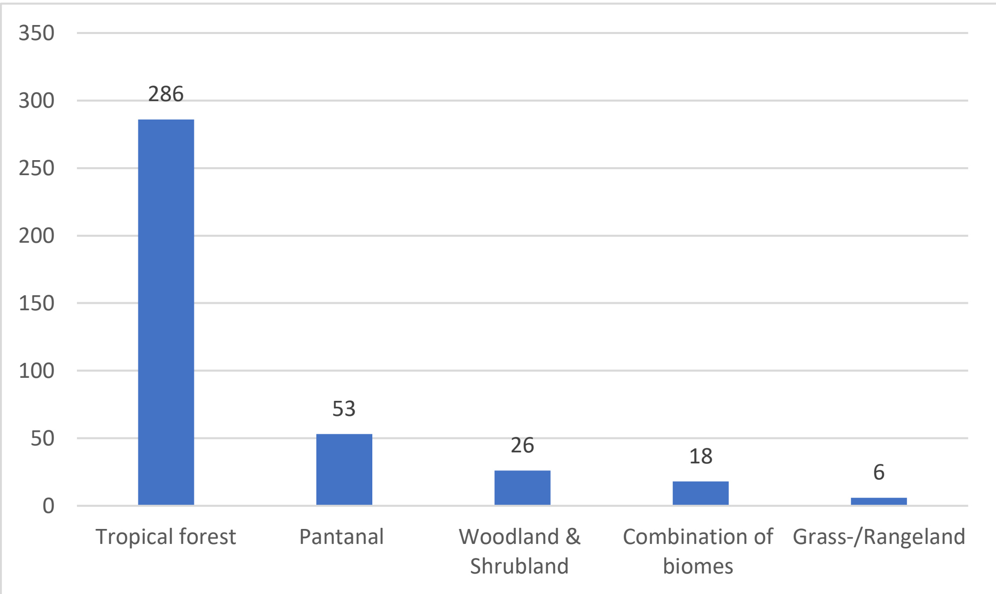

Figure 2: Number of records per biome

The majority of these records are on Tropical forest (286), which was expected considering the huge interest of ES experts towards the Amazon rainforest (Figure 2). The Atlantic rainforest has also been studied extensively, as it makes up a significant portion of the Tropical forest values (≈135).

Following, the ecoregion with the most records is the Pantanal (translates to several biome types in the ESVD classification) with 53 recorded values. For Woodland & Shrubland (Caatinga), there are 26 values while 18 values referred to a combination of biomes. It is worth mentioning here that most (14) of the values on combined biomes refer to study sites covered by a mix of tropical forest with Cerrado (savanna). Finally, only 6 value records could be linked exclusively to Grass-/Rangeland (Cerrado).

Naturally, in terms of studies analysed, Tropical forest were again at the top (Figure 3). In total, 23 studies on Tropical forest were analysed. For the other biomes, the studies analysed during this update were fewer. More specifically, there were 4 studies for both the Pantanal and Grass-/Rangeland (Cerrado), while for Woodland & Shrubland (Caatinga) 3 studies were analysed (same as for Combination of biomes).

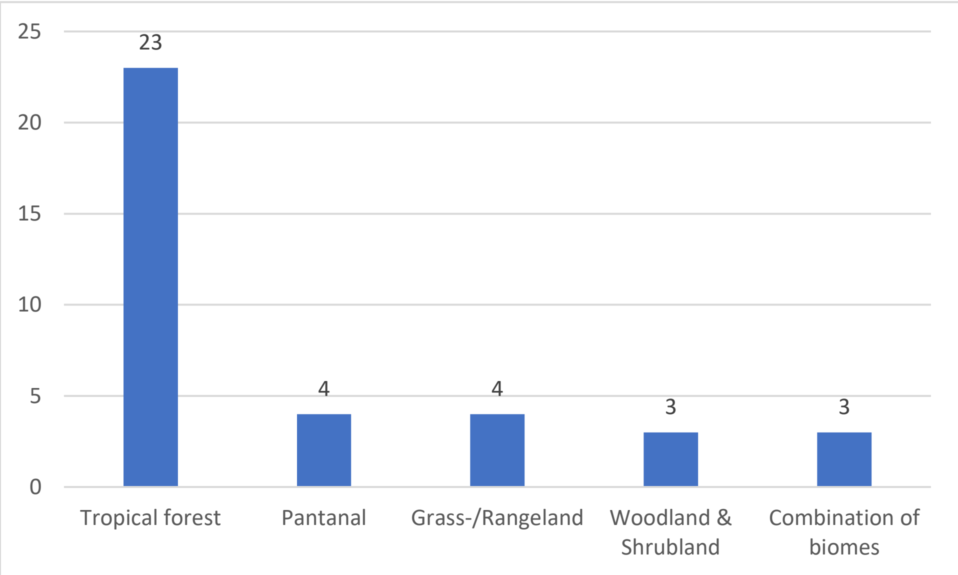

Figure 3: Number of studies per biome

Regarding the distribution of value records over the different ecosystem services, Pollination has the biggest share with 82 values (Figure 4). This reflects the significance of natural ecosystems to agriculture, a sector of pivotal importance to Brazil's national economy. Following pollination, the ESs with the most value records are Raw materials and Existence, bequest values (both with 57 values). On one hand, this indicates the contributions of natural ecosystems in the provision of resources, both at a commercial level from industries (e.g. timber in forestry) as well as at a subsistence level (e.g. fuelwood from rural populations). On the other hand, from this research it has been revealed that non-use values are crucial for Brazil's natural capital. This is represented by the research emphasis towards the estimation of the existence values attributed to the Amazon rainforest (mainly), by people living in countries other than Brazil. Furthermore, many of the values were estimated for a combination of different ES (42), which is quite common in ES valuation research. Moreover, there are several estimates related with climate regulation services (30). The latter highlights how natural ecosystems can aid in climate change mitigation (at a global level), but also generate alternative income streams for landowners through carbon credits (at a local level). Finally, other ES that are strongly represented in the dataset are Genetic resources, which reflects the biological richness of Brazil's natural world, and Waste treatment attributed to the capacity of ecosystems to regulate the quality of critical resources, such as water (both these services have 28 values).

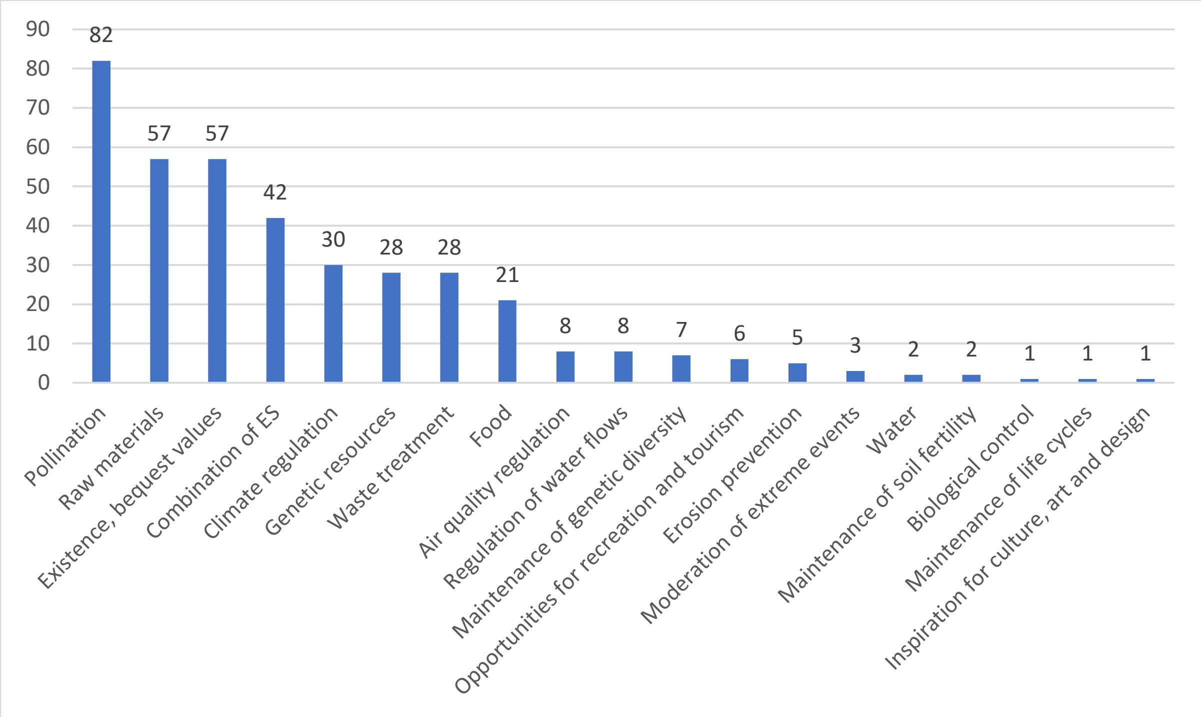

Figure 4: Number of records per ecosystem service

In terms of methodological approach, most of the value records (88) were estimated with the Production Function method (Figure 5). This is explained by the strong influence of natural ecosystem functions on important economic sectors, such as agriculture. Contingent Valuation (57) has extensively been used to estimate welfare benefits provided by Brazil's ecosystems, which is linked to the importance of non-use values mentioned earlier. Besides that, estimates calculated with Damage Cost Avoided make up a significant portion of the dataset (53), most of them being related to the capacity of natural ecosystems to reduce the costs for water treatment (regulating services). Finally, the combination of valuation methods is frequently used (50), followed by Market Prices (48).

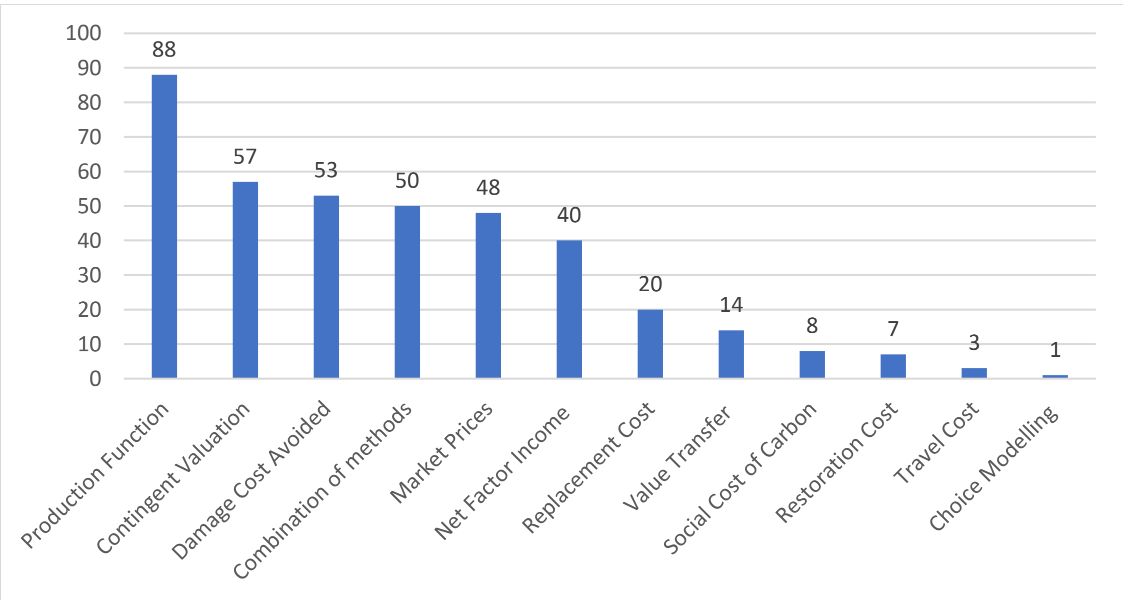

Figure 5: Number of records per valuation method

4.2 Summary of annual values

From the total number of records collected, 287 were excluded from the calculation of annual values. Thus, the final number of records included in the summary value table is 164. Seven records were automatically excluded by the outlier exclusion filter and 2 records were manually excluded due to methodological considerations and suspicious value estimates. The remaining excluded records were either on a combination of biomes (and/or services) or they were estimated using Value Transfer.

Table 4 gives the average monetary value per ES for each biome type. Note that an empty cell does not necessarily mean that the biome type does not provide that service, but rather that insufficient value records were available to calculate an average value.

From Table 4, it can be derived that there is high variation in the values of ecosystem services across biome types. In addition, it can be observed that most available values are on Tropical forests which to a certain degree, also explains the disproportionate variation in sum biome values (as well individual ES values for the different biomes of interest). For Tropical forests, the values show a similar variation across different ES, with Climate regulation making up 60% of the estimated total biome value. Other ESs with comparatively higher values are Genetic resources, Waste treatment (primarily for water purification), Maintenance of genetic diversity and Pollination (primarily for crop pollination). It can also be argued that there are significant welfare benefits provided by the Regulating services of Tropical forests in the country. From this preliminary study, using 124 individual value points, the total value for a representative hectare of Tropical in Brazil, was estimated to be **4741** Int$2020/ha/year. Finally, it is concluded that further research is required on the remaining biomes of interest in order to gain meaningful insights about the welfare benefits that these systems provide to society.

Table 4: Mean values per ecosystem service / biome combination and number of value estimates in parentheses (International dollars per hectare per year; 2020 price level; outlier exclusion IQR 1.5 of log transformed values)

Ecosystem services / biomes	Inland wetlands	Rivers & lakes	Tropical forests	Woodland & Shrubland	Grass-/rangeland
Food			6 (1)		
Water		378 (1)			
Raw materials	4 (32)		96 (19)		
Genetic resources			554 (4)		
Medicinal resources					
Ornamental resources					
Air quality regulation					
Climate regulation			2,915 (6)	73 (3)	168 (3)
Moderation of extreme events			46 (1)		
Regulation of water flows			3 (5)		
Waste treatment			417 (24)		
Erosion prevention			67 (1)		
Maintenance of soil fertility					
Pollination			216 (54)		
Biological control					
Maintenance of life cycles					
Maintenance of genetic diversity			374 (4)		
Aesthetic information					
Opportunities for recreation and tourism			NA (1)		
Existence, bequest values			47 (4)	7 (1)	
Inspiration for culture, art and design					
Spiritual experience					
Information for cognitive development					

Ecosystem services / biomes	Inland wetlands	Rivers & lakes	Tropical forests	Woodland & Shrubland	Grass-/rangeland
Sum	**4 (32)**	**378 (1)**	**4,741 (124)**	**80 (4)**	**168 (3)**

5. Discussion

5.1 Key messages

Although in general mean values should be used with great care (de Groot et al, 2020) there are some important messages to be drawn. For example, this research has revealed that the potential economic benefits provided by one hectare of tropical forest in Brazil are worth 4741 Int$/year. Communicating these monetary values, and welfare benefits can help to create more awareness among the general public, governments, business and NGO's to take nature more into account in everyday decision making.

In the context of this case study, these insights highlight the negative externalities caused by natural ecosystem loss as a result of cattle range expansion in Brazil. Such externalities are currently not being internalised by beef processors, thus underestimating the socio-economic costs of increased meat production. In the long term, this underestimation will have significant negative welfare effects to society and other economic sectors that critically depend on natural capital. Therefore, the consideration of natural capital and ecosystem services is of pivotal strategic importance for the long-term sustainability of livestock industry. Such information can serve as warning signs regarding the sustainability of the industry itself since the continuation of the current expansion trend will exacerbate the loss of natural capital until a critical threshold is reached. Passing this threshold point would essentially mean that meat production results in a negative overall welfare trade-off for society as a whole, due to the reduction in the provision of essential ES. Simultaneously, at the policy level, the same information can be used to draw legislation that aims to reduce the negative impacts and generate positive trade-offs to society. Examples could include the determination of taxes for damaging practices or the setting of appropriate levels for payments for ecosystem services (PES) and subsidies for practices that preserve natural capital. Overall, the results of this research suggest that there is an urgent need of the industry to explore ways through which the impacts of livestock rearing on natural capital can be mitigated.

One general observation, is that there is great discrepancy in the availability of data on the economic (welfare) effects of different natural systems in Brazil, depending on the type. Specifically, the availability of data for Tropical forests is significantly greater, compared to the other biomes of interest. This is reflected by the availability of value records (that could be standardised in a common set of units) used in Table 4. Apart from Tropical forest, it has not been possible to obtain enough suitable data for the other biomes assessed. The calculation of the mean annual values for Inland wetlands, Rivers & Lakes, Grass-/rangeland and Woodland & Shrubland, was performed using a very small number of estimates (especially when compared to Tropical forest). Consequently, it can be argued that the mean values produced here are underestimating the real benefits provided by these systems in Brazil and should be used with great care. To a great extent, this also explains the huge differences between the sum values for the different biomes. Further research is required in order to gain insights about the contributions of the understudied biomes and fill in the gaps observed in the current summary table. It should be expected that this would result in greater sum annual values for the other biomes, which would be more representative of the real situation in Brazil.

With regard to the use of these values for assessing the impacts of cattle range expansion on natural capital, it needs to be stressed out that the availability of data has strong effects on the model output. For example, it has been possible to estimate indicative values for Tropical forest, due to the increased availability of standardised value estimates for this biome. In this case, it can be argued that the values used are representative (though not 'final'), based on the analysis of a substantial amount of value points on the different services. As a result, the model output can be trusted more easily, since the dataset used for calculating the parameters is stronger. On the contrary, it is very likely that the real welfare costs are underestimated when applying the mean annual values in Grass-rangeland and Woodland & Shrubland areas where land conversion has taken place. This is again due to the availability of standardised values, which in the case of these two biomes are very scarce. This information is critical when using such values for modelling purposes or for interpreting model results. Ultimately, due to the enormous differences in data availability, the mean annual values of Tropical forests are not comparable with the other biomes assessed.

5.2 Caveats and limitations

Although we went to great length to ensure that the values in ESVD underlying the summary table calculations are as robust as possible, several caveats and limitations should be kept in mind when using these data.

Time limitations: The update presented here, was carried out in a very short time frame. To the author's knowledge, the studies used here present the best available information on the socio-economic benefits provided by the biomes of interest. Nonetheless, considering the depth of related literature (particularly on tropical forests), it is expected that the reported values will change as more data and relevant studies become available. Thus, the values presented here should not be considered as 'final'.

Limited value data for some biomes and ecosystem services: As it can be seen in the summary table, the different biomes (and services) are not equally represented in the analysis. This is due to the availability of related studies that could provide useful data. The data included in this update are greatly skewed towards tropical forests which is to a certain extent natural. At the same time, this represents the overall focus of ES valuation research in Brazil with tropical forests receiving the merit of scientific attention. On the contrary, other biomes with significant welfare contributions remain relatively unstudied. One of the takeaways from this research is that further primary valuation studies are needed for the Cerrado, Pantanal and Caatinga ecoregions to gain a better understanding of the benefits provided by the specific systems. Furthermore, for some biome types and ecosystem services there are many data, but many cells remain empty. This means that the total values computed for each biome type are likely to be underestimates and will increase as more data become available and the gaps can be filled. It should be noted, however, that the summary values presented in Table 4 are only based on 164 value records (despite having 389 relevant records). The main reasons for this limitation are that reported values could not be standardized to a common set of units and that many reported values are on multiple biomes and (or) ecosystem services. Although these data cannot be included in the computation of summary values, they are potentially useful to decision makers and so are retained and searchable within the ESVD.

Records have not yet been externally reviewed: The data contained in the ESVD is subject to an on-going review process by invited expert reviewers (de Groot et al, 2020). Thus, the records added during this update have not yet been peer reviewed. Due to this external review process, the data used for the analysis are subject to change.

Trade-offs between ecosystem services: In computing total values from each biome type (Table 4) we make the assumption that all ESs can be supplied and used simultaneously. In practice there are likely to be trade-offs between some ESs. In many cases, the level of sustainable activity for one ecosystem service may not be compatible with the sustainable level of another. For instance, there is a likely trade-off between the harvesting of timber and use for recreational and other tourist activities. Such trade-offs introduce further complexity to any analysis, since it becomes necessary to consider how one use of one ES affects other potential uses and values. This has not been possible in the computation of the summary values presented here.

Average and marginal values: The ESVD contains data on the value of the annual flow of ES (average values) and also data on *changes* in the annual value of ES (marginal values). Changes in annual values are typically due to a change in ecosystem extent and/or condition. Average and marginal values have been summarised jointly, but it should be noted that the ESVD contains information to distinguish between the value of flows and changes in flows of ES.

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