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## **META-REGRESSION FOR ECOSYSTEM SERVICE VALUATION OF THE BRAZILIAN PANTANAL**

Fernando Rodrigues Teixeira Dias

Doctorate Thesis of the Graduate Course in Earth System Science, guided by Drs. Pedro Ribeiro de Andrade Neto, and Cátia Urbanetz, approved in February 27, 2026.

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*“No Pantanal ninguém pode passar régua. Sobremuito quando chove. A régua é existidura de limite. E o Pantanal não tem limites.”*

*Manoel de Barros*



Ao meu filho, Daniel, minha motivação e inspiração, com todo o meu amor.

À memória de meus pais, Antonio e Normanda, cujos exemplos e amor  
seguem guiando meus passos.



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## ABSTRACT

The Brazilian Pantanal is wetland compound by a mosaic of grasslands, savannas, tropical forests, and freshwater ecosystems that covers 150.000 km<sup>2</sup> in the centre of South America. More than 90% of its area is owned by beef cattle ranchers. Although the natural landscape remains well preserved, it is increasingly threatened by intensification of beef cattle farming. Recent federal regulation has been passed on land use and cover change for the conservation of its ecosystem services. Estimating the ecosystem service values of Pantanal can support policy decisions on land use and conservation, for instance, through payment for ecosystem services. This PhD thesis assessed ecosystem service values from Pantanal and the effect of land use change on these values. For that, we applied meta-regression on hundreds of ecosystem service valuations studies selected from the Ecosystem Service Valuation Database (ESVD), a global database of ecosystem service valuations derived from scientific publications and technical reports. We translated existent national classifications of habitats and vegetation found in Pantanal to Ecosystem Functional Groups (EFGs) of the Global Ecosystem Typology (GET) and selected ESVD samples for meta-regression for these EFGs. To overcome data sparsity, we selected ESVD samples associated with EFGs similar to those found in Pantanal and used several statistical techniques. Meta-regression models were fitted to estimate the total ecosystem service value of EFGs and the impact of marginal changes in their areas. While data limitations restricted most estimations to the GET biome level, the model successfully differentiated impacts for changes on some EFGs, offering evidence to support policy decisions regarding forest-to-pasture conversion in the Pantanal. The results can support payment for ecosystem service policies to prevent land use and cover change for terrestrial ecosystems found in the Brazilian Pantanal that compromise its ecosystem integrity and services. The variation that remained from meta-regression suggest that more research is needed for the valuation of ecosystem services for freshwater and transitional terrestrial-freshwater ecosystems in the Pantanal, as well as more detailed maps for EFGs found in Pantanal. Methods and software code used can be adapted and applied to other regions.

Keywords: Ecosystem Accounting. Benefit transfer. Wetlands. Natural capital.



# META-REGRESSÃO PARA A VALORAÇÃO DOS SERVIÇOS ECOSSISTÊMICOS DO PANTANAL BRASILEIRO

## RESUMO

O Pantanal brasileiro é uma área úmida composta por um mosaico de campos, savanas, florestas tropicais e ecossistemas de água doce que abrange 150.000 km<sup>2</sup> no centro da América do Sul. Mais de 90% de sua área pertence a pecuaristas de corte. Embora a paisagem natural permaneça bem preservada, ela está cada vez mais ameaçada pela intensificação da pecuária bovina. Regulamentações federais recentes foram aprovadas sobre o uso e a cobertura da terra para a conservação de seus serviços ecossistêmicos. Estimar os valores dos serviços ecossistêmicos do Pantanal pode apoiar decisões políticas sobre o uso e a conservação da terra, por exemplo, por meio do pagamento por serviços ambientais. Esta tese de doutorado avalia os valores dos serviços ecossistêmicos do Pantanal e o efeito das mudanças no uso da terra sobre esses valores. Para isso, aplicamos meta-regressão em centenas de estudos de valoração de serviços ecossistêmicos selecionados do *Ecosystem Service Valuation Database* (ESVD), um banco de dados global de valorações de serviços ecossistêmicos derivados de publicações científicas e relatórios técnicos. O estudo traduziu classificações nacionais existentes de habitats e vegetação do Pantanal para Grupos Funcionais de Ecossistemas (EFGs) da Tipologia Global de Ecossistemas (GET) e selecionou amostras do ESVD para a meta-regressão desses EFGs. Para superar a escassez de dados, selecionamos amostras do ESVD associadas a EFGs semelhantes aos encontrados no Pantanal e usamos diversas técnicas estatísticas (Winsorização, Regressão Quantílica, *bootstrapping* e regularização Lasso). Modelos de meta-regressão foram ajustados para estimar o valor total dos serviços ecossistêmicos dos EFGs e o impacto de mudanças marginais em suas áreas. Embora as limitações de dados tenham restringido a maioria das estimativas ao nível de bioma da GET, o modelo diferenciou com sucesso os impactos para alguns EFGs, oferecendo evidências para apoiar decisões políticas relativas à conversão de florestas em pastagens no Pantanal. Os resultados podem ser usados para apoiar políticas de pagamento por serviços ambientais a fim de evitar mudanças no uso e na cobertura da terra para os ecossistemas terrestres encontrados no Pantanal brasileiro que comprometam a integridade e serviços de seus ecossistemas. A variação remanescente da meta-regressão sugere que mais pesquisas são necessárias para a valoração dos serviços ecossistêmicos de água doce e ecossistemas de transição terrestre-aquática no Pantanal, bem como mapas mais detalhados dos EFGs encontrados no Pantanal. Os métodos e o código de software utilizados podem ser adaptados e aplicados a outras regiões.

Palavras-chave: Contabilidade de ecossistemas. Transferência de benefícios. Áreas úmidas. Capital natural.



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## LIST OF ABBREVIATIONS

BSU	Basic Spatial Unit
CBD	Convention on Biological Diversity
CI	Confidence Interval
CNZU	National Committee for Wetlands (Comitê Nacional para as Zonas Úmidas)
EFG	Ecosystem Functional Group
EMBRAPA	Brazilian Agricultural Research Corporation (Empresa Brasileira de Pesquisa Agropecuária)
EO	Earth Observation
ESVD	Ecosystem Service Valuation Database
FAMATO	Mato Grosso Agriculture and Livestock Federation (Federação da Agricultura e Pecuária de Mato Grosso)
FPS	Sustainable Pantanal Farm (Fazenda Pantaneira Sustentável)
GBF	Kunming-Montreal Global Biodiversity Framework
GET	Global Ecosystem Typology
GLS	Generalized Least Squares
IBGE	Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística)
INPE	National Institute for Space Research (Instituto Nacional de Pesquisas Espaciais)
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
Lasso	Least Absolute Shrinkage and Selection Operator
LULUCF	Land Use, Land Cover Change, and Forests
MS	Mato Grosso do Sul state
MT	Mato Grosso state
NASA	National Aeronautics and Space Administration
N4C	Fourth National Communication of Brazil to the UNFCCC ((United Nations Framework Convention on Climate Change)
OLS	Ordinary Least Squares
PI	Prediction Interval
SEEA-EA	System of Environmental-Economic Accounting – Ecosystem Accounting
SEEA-EEA	System of Environmental-Economic Accounting – Experimental Ecosystem Accounting
SENAR-MT	National Service for Rural Apprenticeship of the Mato Grosso State (Serviço Nacional de Aprendizagem Rural de Mato Grosso)
S <sub>F</sub>	Freshwater training dataset
S <sub>T1</sub>	Tropical and subtropical forests training dataset
S <sub>T4+</sub>	Savannas and grasslands training dataset
S <sub>TF1</sub>	Palustrine wetlands training dataset
T1.2	Tropical and subtropical dry forests and thickets
T4.2	Pyric tussock savannas
T7.4	Urban and industrial ecosystems

T7.5	Derived semi-natural pastures and old fields
TF1.1	Tropical flooded forests and peat forests
TF1.3	Permanent marshes
TF1.4	Seasonal floodplain marshes
TF1.6	Boreal, temperate and montane peat bogs
UN	United Nations
VTT	Value Transfer Tool

## LIST OF SYMBOLS

### Latin Alphabet

- $n$  – Number of observations in a sample.
- $N$  – Number of independent bootstrap samples or total sample size.

### Greek Alphabet

- **$\tau$**  – Target quantile used in regression models (e.g., 0.10, 0.50, 0.90).

### Subscripts

- $Q_{10}$  – 10th percentile quantile, representing the lower tail of the distribution
- $Q_{50}$  – 50th percentile quantile (median)
- $Q_{90}$  – 90th percentile quantile, representing the upper tail of the distribution

### Special Symbols

- Int\$ – International dollars (standardized currency unit for 2020 based on purchasing power parity)
- % – Percentage



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## **1 INTRODUCTION**

Ecosystem services are the contributions of ecosystems to human well-being, communities, and economies. Healthy ecosystems are needed to keep these services, yet our environment faces challenges and risks acknowledged at local, national, and global levels. Consistent measurement of environmental changes and their connection to economic and human activity within economic and financial systems helps to ensure ecosystems and biodiversity are integrated into decision-making (UNITED NATIONS et al., 2021).

Some global standards were recently defined for the systematic assessment of the value of ecosystems for societies and the condition and extension of ecosystems to help policymakers, businesses, and society to understand the importance of conserving ecosystems and to incorporate their value in their decisions for the benefit of present and future generations.

### **1.1 The Kunming-Montreal Global Biodiversity Framework**

Adopted in 2022, the Kunming-Montreal Global Biodiversity Framework (GBF) represents a multilateral endeavour to halt and reverse the global decline of biodiversity by 2030, striving toward a 2050 vision of "living in harmony with nature", as stated at the Convention on Biological Diversity (CBD, 2022).

GBF has its scientific foundations on the Millennium Ecosystem Assessment (2005). Both initiatives are predicated on the understanding that biodiversity is not merely an environmental variable but the essential foundation for human well-being, economic prosperity, and planetary stability (MILLENNIUM ECOSYSTEM ASSESSMENT, 2005). The Millennium Ecosystem Assessment served as a pioneering diagnostic, detailing how ecosystem services (such as climate regulation, pollination, and water purification) underpin human societies (MILLENNIUM ECOSYSTEM ASSESSMENT, 2005). The GBF operationalizes this scientific legacy by shifting from the foundations laid by the Millennium Ecosystem Assessment to actionable, target-oriented policy (CBD, 2022). While the Millennium Ecosystem Assessment mapped the complex interactions between indirect and direct drivers of change and ecosystem services, the GBF

provides measurable mechanisms to manage these interactions systematically, to transform the warnings from the Millennium Ecosystem Assessment into a global mandate for local restorative actions (CBD, 2022; MILLENNIUM ECOSYSTEM ASSESSMENT, 2005).

Operating through a structured "global target, national action" approach, GBF encompasses four overarching goals (CBD, 2022):

- Goal A - Protect & Restore: To maintain and restore ecosystems, halting human-induced species extinctions.
- Goal B - Prosper with Nature: To ensure that biodiversity is used sustainably and that nature's contributions to people are valued and enhanced for future generations.
- Goal C - Share Benefits Fairly: To ensure that the benefits from genetic resources and traditional knowledge are shared fairly.
- Goal D - Invest and Collaborate: To ensure all countries have the technical and financial resources to succeed.

GBF defines a set of targets for these goals and indicators to track the progress of achieving them. The operationalization of GBF goals, targets and indicators relies on a technical foundation for translating global policy aspirations into actionable, cross-comparable indicators of ecosystem health at national and local levels through ecosystem accounting.

## **1.2 The System of Environmental-Economic Accounting – Ecosystem Accounting**

Ecosystem accounting is the systematic assessment of the contributions of ecosystems to human well-being, such as food provisioning, water purification, carbon sequestration, and recreational opportunities. At the core of GBF architecture is the System of Environmental-Economic Accounting-Ecosystem Accounting (SEEA-EA) published in March 2021 as the United Nations (UN) standard for ecosystem accounting. SEEA-EA provides the statistical infrastructure required to measure ecosystem extent and condition, and the flow of services to humanity. This new statistical framework "will enable countries to measure their natural capital and understand the immense contributions of nature

to our prosperity and the importance of protecting it” (UNITED NATIONS, 2021; UNITED NATIONS STATISTICAL COMMISSION, 2021).

SEEA-EA is part of the SEEA (System of Environmental-Economic Accounting), the “accepted international standard for environmental-economic accounting, providing a framework for organising and presenting statistics on the environment and its relationship with the economy [...] developed and released under the auspices of the United Nations, the European Commission, the Food and Agriculture Organization of the United Nations, the Organisation for Economic Co-operation and Development, International Monetary Fund and the World Bank Group” (UNITED NATIONS, 2023a). According to a 2022 global assessment, 92 countries had already implemented the SEEA and 41 of these 92 had compiled the SEEA-EA (UNITED NATIONS, 2023b).

SEEA-EA treats ecosystem assets as producing units that supply a bundle of services revealed through observable interactions between ecosystems and people, encompassing direct physical consumption, passive enjoyment, and indirect receipt. Crucially, these services are recorded as flows between ecosystem assets and economic units, such as businesses, governments, and households, thereby making visible the often-uncounted dependence of the economy and society on nature. By distinguishing services from the ultimate benefits (the goods and services people enjoy), the SEEA-EA allows for an integrated assessment of how changes in ecosystem extent and condition directly impact human well-being and economic production.

SEEA-EA categorizes these contributions into three primary types: provisioning services, regulating and maintenance services, and cultural services. Provisioning services represent the biophysical materials extracted or harvested from ecosystems, such as crops, timber, wild fish, and water supply. Regulating and maintenance services arise from the capacity of ecosystems to regulate ecological processes and biochemical cycles, providing critical buffer functions such as global climate regulation through carbon sequestration, air filtration, and flood mitigation. Finally, cultural services refer to the non-material, experiential interactions people have with the environment, including recreation-related

services, visual amenity, and the spiritual or symbolic significance attributed to specific natural features. Together, this reference list of services provides a standardized, pragmatic baseline for consistent measurement and international comparison.

Although the SEEA-EA was primarily designed for national ecosystem accounting, it could be used as a decision tool for subnational policy making “for environmentally defined areas such as water catchments, protected areas, biodiversity priority areas and coastal zones” (UNITED NATIONS et al., 2021, p. 15). For the conciliation and comparison of local, national and global assessments, GBF and SEEA-EA adopted a global ecosystem typology.

### 1.3 The Global Ecosystem Typology

The Global Ecosystem Typology (GET) facilitates the harmonization of diverse national ecosystem classifications into standardized Ecosystem Functional Groups (KEITH et al., 2020). By aligning SEEA-EA accounts with the standardized units defined by the GET, the GBF gains the spatial and ecological granularity required to monitor Headline Indicator B.1 effectively (UNITED NATIONS, 2023a).

GET has a structure consisting of six levels. The three upper levels differentiate the functional properties of ecosystems (KEITH et al., 2022, Appendix S3):

- **Level 1 (Realm):** “One of five major components of the biosphere that differ fundamentally in ecosystem organisation and function: terrestrial, freshwater, marine, subterranean, atmospheric”, including five transitional realms between two or three of them.
- **Level 2 (Functional biome):** “A component of a realm united by one or a few common major ecological drivers that regulate major ecosystem functions and ecological processes, derived from the top-down by subdivision of realms (level 1).”
- **Level 3 (Ecosystem Functional Group):** “A group of related ecosystems within a biome that share common ecological drivers promoting convergence of ecosystem properties that characterise the group. Derived from the top-down by subdivision of biomes.”

The complete list and description of all 110 EFGs, GET realms and biomes are available in Keith et al. (2022, Appendix S3) and are kept updated by International Union for Conservation of Nature (IUCN, 2022).

GET groups ecosystems that share the same functions under a single Ecosystem Functional Group (EFG). Each EFG is defined not only by its biotic composition or abiotic environment “per se”, but by an ecosystem assembly model (KEITH et al. 2022, p. 514), including abiotic and biotic drivers that shape the composition and characteristics of ecological assemblages. They are:

- The availability of resources: water, energy, nutrients, oxygen, and carbon.
- The ambient environment: climate seasonality, temperature, salinity, substrate, kinetic energy, geomorphology.
- Disturbance regimens: Fire, flood, storm, mass movement, igneous activity.
- Biotic interactions: competition, predation, pathogenicity, mutualism, facilitation.
- Human activity: Structural alteration, resource use, movement of biota, and climate change.

These drivers influence each other. For instance, human activity may add or change disturbance regimens and affect biotic interactions by changing the species pool; the ambient environment affects the available resources, etc. These drivers create evolutionary pressures that impact the ecosystem-level properties, such as productivity, diversity, trophic structure, physiognomy, life history and form, phenology, and ecophysiology. This ecosystem assembly model is then used to define each EFG by specifying different compositions and relative contributions of each of these drivers and the ecosystem-level properties resulting from them (KEITH et al., 2022 p. 515).

Levels 1 to 3 group the ecosystems by function, not by biotic composition. Suppose two ecosystems provide the same set of functions (and services to humankind). In that case, they are classified under the same EFG, regardless of

the biotic composition that contributes to its functions. Levels 4, 5, and 6 group ecosystems within the same ecosystem functional group by their biotic composition. GET definitions for levels 4, 5, and 6 types are as follows (KEITH et al., 2022, emphasis added):

- **Level 4**, or Regional ecosystem subgroups, are ecoregional expressions of an Ecosystem Functional Group (level 3). They are proxies for compositionally distinctive geographic variants that occupy different areas within the distribution of a functional group. These are derived from the top-down by subdivision of Ecosystem Functional Groups (KEITH et al., 2022).
- **Level 5**, or Global ecosystem types, are complexes of organisms and their associated physical environment within an area occupied by an ecosystem functional group. Global ecosystem types grouped into the same Ecosystem Functional Group share similar ecological processes but exhibit substantial differences in biotic composition. They are derived from the bottom-up (national or subnational), either directly from ground observations or by aggregating the lowest level, the Subglobal ecosystem types (KEITH et al., 2022).
- **Level 6**, or Subglobal ecosystem types, are subunits or nested groups of subunits within a global ecosystem type, with more compositional resemblance to one another than to other global ecosystem types, representing units of established classifications (e.g., at national level) (KEITH et al., 2022).

GET defines only the types of levels 1 to 3. Level 4 types are currently being developed by IUCN from the top down, by subdividing EFGs “based on biogeographic boundaries” (KEITH et al., 2022, p. 520). Level 4 and level 5 types are both grouped under level 3 types (EFGs), not being related to each other. This means that GET allows the definition of two alternate hierarchies sharing the first three levels: one using levels 1, 2, 3, and 4; and another using levels 1, 2, 3, 5, and 6.

Level 5 types will be defined as global, using bottom-up aggregations of national or subnational level 6 types, grouping them under separate EFGs. Level 5 will then serve as a semantic connection between EFGs, and national or subnational typologies adopted as level 6. Finding nationally or locally established classifications to which a crosswalk to EFGs can be defined is the recommended way to achieve a global map of ecosystems. Keith et al., present crosswalks of the Chile and Myanmar national typologies adopted as level 6 typologies, matching them to EFG types (KEITH et al., 2022, Appendix S3).

For SEEA-EA, each continuous area classified under the same EFG on the same average condition provides a set of ecosystem services. These services generate benefits for society that can be expressed in monetary terms to facilitate comparison and integration with economic accounts. Several methods have been developed to estimate this monetary value.

#### **1.4 Ecosystem service valuation methods**

The SEEA-EA utilizes the concept of exchange values for the monetary valuation of ecosystem services, ensuring compatibility with the System of National Accounts (SNA). This approach focuses on the prices at which services are, or would be, exchanged between a supplier (the ecosystem) and a user (an economic unit), explicitly excluding consumer surplus and non-use values which are often captured in broader welfare-based economic assessments. The framework establishes a clear preference ordering for valuation techniques, prioritizing those that rely on observable market data.

- **Directly Observable Prices:** The most preferred methods utilize prices from actual market transactions, when a specific ecosystem service is explicitly traded, such as stumpage values paid for timber harvesting, land rental prices where the rent reveals the value of biomass provisioning, or actual payments for ecosystem services (PES) if they are specifically targeted to a service flow.
- **Prices from Similar Markets:** When a direct price for a specific service is unavailable, the SEEA-EA framework allows for the use of market price equivalents. This involves identifying similar items traded in different

contexts and adjusting for quality and supply costs. For example, the value of non-marketed forest products like wild mushrooms can be estimated using the price of similar mushrooms sold in nearby markets, provided those markets are operating under similar circumstances.

- **Residual Value and Resource Rent:** This method calculates value by taking the total revenue from a marketed good (such as harvested rice) and deducting all produced inputs, labour, and capital costs. The remaining residual represents the contribution of the ecosystem asset.
- **Productivity Change Method:** This measures the ecosystem service as an input in a production function. The value is derived by calculating how a marginal change in the service supply (e.g., wild pollination) affects the output value of a marketed good (e.g., crop yield).
- **Hedonic Pricing:** This method decomposes the market prices or rental values of property to determine the portion of the price attributable to environmental characteristics, such as air quality or proximity to recreational spaces.
- **Averting Behaviour Method:** Estimates value based on what individuals spend to prevent or mitigate negative effects from the loss of a service, such as purchasing water filters to substitute for natural purification.
- **Travel Cost Method:** Used primarily for recreation-related services, it measures the actual expenditures (such as fuel and time) people incur to visit an ecosystem. The SEEA-EA uses these data to approximate an exchange value rather than to calculate consumer surplus.
- **Replacement Cost Method:** Estimates the cost of using a man-made substitute to provide the same contribution to benefits, such as building a water treatment plant to replace a wetland's filtration service.
- **Avoided Damage Cost Method:** Values services based on the damages they prevent, such as estimating potential property damage from floods that are mitigated by healthy ecosystems.
- **Simulated Exchange Value:** This method estimates the price and quantity that would prevail if a hypothetical market for the service existed. It utilizes demand functions (often derived from stated preference studies like

contingent valuation) combined with supply or cost functions to simulate a market-clearing price consistent with exchange value principles.

While common in environmental economics, stated preference methods that elicit willingness to pay are not used directly in the SEEA-EA because they typically measure welfare values (including consumer surplus) rather than exchange values. However, as noted, they can serve as an important input for the Simulated Exchange Value technique.

Primary studies for ecosystem services valuation often encounter high costs and long timelines (KUBISZEWSKI et al. 2022). This can be due to the intensive logistical requirements of methodologies like group valuation, which usually necessitate the organization of stakeholder workshops and potential participant payments. Technical complexity and the need for specialized personnel in fields also significantly increase the person-years and financial resources required to achieve higher precision. Researchers frequently face unpredictable data collection hurdles, including a lack of existing baseline data that forces expensive original survey implementation, as well as external environmental constraints like drought that can delay the research process. Because of all these challenges, the time required to conduct such primary studies is often incompatible with the time constraints associated with informing or supporting public policy. The completion of new primary studies would substantially delay timely analysis, highlighting the value of using existing databases to generate reliable estimates (KUBISZEWSKI et al. 2022).

### **1.5 Value transfer**

Value transfer, also known as benefit transfer, uses findings from existing original studies conducted in one or more specific locations to estimate welfare values or similar information for other locations (BRANDER 2013; BURKHARD; MAES, 2017). In a seminal work, Costanza et al. (1997) applies global mean of unit ecosystem service values to estimate the economic value of 17 ecosystem services from published studies.

More precise than global or regional averages, meta-analytic value transfer uses a value function estimated from the results of multiple primary studies to estimate ecosystem service values at policy sites. It allows for controlling differences between study and policy sites, such as population characteristics, area of ecosystem, and abundance of substitutes.

Meta-analytic value transfer is practical for consistently valuing multiple policy sites at local, national and global scale, but is analytically complex and requires detailed and standardized information from many primary studies (BURKHARD; MAES, 2017).

### **1.6 The Ecosystem Valuation Database (ESVD)**

A meta-analytic value transfer (DE GROOT et al., 2012) was the seed for the Ecosystem Valuation Database (ESVD), the largest collection of monetary valuation data on ecosystem services (BRANDER et al., 2025a). ESVD aims to make nature count in decision-making using reliable, accessible, and open-source information on the monetary value of ecosystem services through the standardization and curation of scientific publications on the estimated ecosystem service value of any part of the World. Since its publication, several studies have used or proposed ESVD for meta-analytic value transfer, all of them using ordinary or generalized least square methods (OLS/GLS) for a log-linear regression model (AMATUCCI et al., 2024; BRANDER et al., 2012; BRANDER et al., 2022; BRANDER et al., 2024; MAGALHÃES FILHO et al., 2021; VAN 'T HOFF et al., 2022).

Diversity of valuations in ESVD is challenging. Ecosystems services in ESVD were evaluated in different years (more than three decades), all over the world, for different ecosystems and services, using different valuation methods. Ecosystem areas and conditions are different, affecting service supply. Additionally, population and income affect demand, hence, the perceived value, i.e., the estimated willingness to pay. The diversity of valuations in ESVD makes consistency and standardisation challenging. Although ESVD valuations are standardized to dollars in 2020 using purchasing power parity (called

“International dollars”), these standardized values in ESVD range from cents to trillions, with median around Int \$ 300.00 per ha per year.

All studies that use ESVD for meta-analytic value transfer use similar log-linear regression models that requires suitable entries to guarantee satisfactory results. However, not all ESVD entries are useful for meta-regression. For instance, some source studies lack information needed for the estimation of the standardized value in international dollars. Some valuate different types of ecosystems and services, and it is not possible to separate their contribution.

ESVD has adhered to standards on ecosystem typologies and ecosystem services typologies since its inception. These standards have evolved and received more support recently, with the publication of the GBF, SEEA-EA and GET. ESVD ecosystem typology is very similar to GET. Not all services were evaluated for all ecosystems in ESVD. For value transfer, some assumptions must be made on which ecosystems in ESVD are similar enough to consider that they provide the same services, within similar value transfer functions. GET can be a way to select ESVD entries that represent similar ecosystems and services for meta-regression. Despite the growing use of ESVD for meta-analytic value transfer, challenges remain regarding the treatment of heterogeneous valuation concepts, consistent ecosystem classification aligned with GET, and systematic and transparent selection of ESVD entries for a specified policy site to each one or more meta-analytic value transfer functions are to be developed.

Our thesis proposes solutions for some of these challenges on using ESVD for meta-analytic value transfer for one important policy site for reaching Brazilian targets set for GBF through SEEA-EA: The Brazilian Pantanal, one of the main hotspots for ecosystem services worldwide.

## **1.7 The Brazilian Pantanal**

The Brazilian Pantanal is the world's largest continuous tropical wetland (TOMAS et al., 2019). Located at the Upper Paraguay River Basin, in the centre of South America, it covers around 150,000 km<sup>2</sup>. It is a complex of seasonally flooded savannas, seasonally flooded forests, swamps, riparian forests, rivers, lakes, and grasslands (TOMAS et al., 2019).

Until 2022, 15% of the pristine natural land vegetation in the Pantanal had been replaced, mainly by cultivated pastures, compared to just 5% until 1985 (MAPBIOMAS, 2023c). The National Institute for Space Research (Instituto Nacional de Pesquisas Espaciais) reported a 20.95% accumulated replacement of the vegetation land cover in the Pantanal (INPE, 2026). Agricultural suitability is low because of poor soil and the annual flooding. Extensive beef cattle production systems on natural grasslands is the main economic activity (90% of Pantanal land) in dynamic equilibrium with the flood and the conservation of Pantanal ecosystems, for two centuries already (BRAZ et al., 2020). Market competition for higher productivity and profitability is now pressuring for intensification of beef cattle land use in the Pantanal, by suppression of natural vegetation<sup>1</sup> for exotic pasture establishment.

Various recent initiatives and pieces of legislation can contribute to the sustainability of agricultural production and environmental protection in the Pantanal. The National Biodiversity Strategy and Action Plan (EPANB) 2025–2030 (BRASIL, 2025b) is Brazil's primary strategic instrument for fulfilling its commitments to the GBF. For the Pantanal, the EAPNB identifies climate change and the expansion of extensive cattle ranching as the primary threats to the biome. The plan aims to reverse biodiversity loss by 2030 by reducing threats, meeting human needs through sustainable use, and creating implementation tools. It emphasizes the role of indigenous peoples and family farmers as "guardians of biodiversity" and integrates environmental preservation with climate change mitigation, social justice, and economic resilience. Coordinated by the Ministry of the Environment and Climate Change, the strategy involves over 20 ministries and is supported by dedicated frameworks for financing, monitoring, and communication to ensure effective governance across all levels of government.

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<sup>1</sup> Here we use "natural vegetation suppression" instead of "native vegetation suppression" because it may include the suppression of exotic vegetation spontaneously grown, hence, natural.

The Brazilian Federal Law for the Protection of Native Vegetation (12.651/2012) establishes that only ecologically sustainable use is permitted in the Brazilian Pantanal, provided that the technical recommendations of official research bodies are considered. Furthermore, new suppressions of native vegetation for alternative land use are conditional upon authorization from the state environmental agency (BRASIL, 2012). In compliance with this law, a specific law (15.228/2025) was recently passed that provides for the use, conservation, protection, and recovery of the Pantanal biome (BRASIL, 2025a). Law 15.228/2025 established the Sustainable Pantanal Seal, which distinguishes economic activities and agricultural practices that are based on sustainability and result in the conservation of the biome's natural resources.

The federal law 14.119/2021 (BRASIL, 2021c) establishes the National Policy for Payment for Environmental Services, creating a legal framework to reward those who preserve or restore ecosystems. It prioritizes indigenous peoples, traditional communities, and family farmers as service providers and institutes the Federal Program for Payment for Environmental Services along with a national registry to ensure transparency and monitor the effectiveness of environmental investments across Brazil.

Law 6.160/2023 of the State of Mato Grosso do Sul, Brazil, established the percentages that rural landowners must maintain of native vegetation in the Pantanal (Mato Grosso do Sul, 2023). This law also created the Pantanal Climate Fund, related to the state policy on Payments for Environmental Services. The state fund (Decree 16.556/2025) will compensate those who preserve beyond the minimum established by law, in accordance with federal laws 14.119/2021 and 15.228/25.

Land use in the Pantanal of the state of Mato Grosso, Brazil, is regulated by Law 12.653/2023 (MATO GROSSO, 2023) and by Decree 774/2024 (MATO GROSSO, 2024). The regulatory framework for the Pantanal in Mato Grosso was based on scientific advice by Embrapa Pantanal (BRASIL, 2021a). This technical support integrated the conservation of biodiversity, ecological

processes, ecosystem services, while ensuring the maintenance of landscape connectivity.

The Sustainable Pantanal Farm (*Fazenda Pantaneira Sustentável* - FPS) program is underway in the Brazilian state of Mato Grosso, carry out by Embrapa Pantanal, FAMATO (the Mato Grosso Agriculture and Livestock Federation), which represents the interests of local producers, and SENAR/MT, the state's leading rural vocational training and extension service (EMBRAPA PANTANAL, 2025; SISTEMA FAMATO, 2024). The initiative has established itself as a model that combines science, innovation, and good agricultural practices to generate concrete results for the sustainability of the biome. FPS is an integrated solution that includes sustainability assessment of livestock farms through indicators, improvement and implementation of environmental legislation, rural extension, and the development of a certification seal for rural properties (SANTOS et al., 2016, 2017).

The Brazilian Pantanal is globally recognized as a hotspot for ecosystem services, providing critical contributions to both local livelihoods and global environmental stability (GUERRA, 2019; TOMAS et al., 2019). These services can be categorized into provisioning, regulating and maintenance, and cultural categories (GUERRA, 2019; TOMAS et al., 2019):

### **1.7.1 Provisioning services**

The Pantanal provides a variety of biophysical materials essential for economic activity and subsistence (TOMAS et al., 2019):

- Native pasture: The provision of native grasses for beef cattle production, the region's primary economic driver for centuries.
- Fisheries: Fish populations used for subsistence, commercial, and recreational fishing.
- Non-timber forest products: Wild food plants and medicinal resources, including native rice, fruits, and honey (TOMAS et al., 2019).
- Water supply: Fresh water for human consumption and agricultural use.

### **1.7.2 Regulating and maintenance services**

Ecosystem processes in the Pantanal maintain environmental health and mitigate natural disasters (GUERRA, 2019; TOMAS et al., 2019):

- Regulation of river discharge: The Pantanal acts as a natural reservoir that regulates the flow of the Paraguay River, mitigating downstream flooding.
- Sediment regulation: Native vegetation in the plateau and lowland areas provides sediment control services, preventing soil erosion.
- Climate and carbon services: The biome helps maintain regional microclimates through its evapotranspiration processes. Additionally, its soils and vegetation contribute to carbon sequestration, helping to mitigate global climate change.
- Soil quality maintenance: The Pantanal hydrological cycles maintain soil quality and nutrient replacement.

### **1.7.3 Cultural and habitat services**

The Pantanal provides non-material benefits that are central to its global identity and local heritage (TOMAS et al., 2019):

- Tourism and recreation: The region is a destination for ecotourism, specifically jaguar-viewing safaris, birdwatching, and sport-fishing.
- Cultural heritage: The wetland supports the livelihoods of indigenous, riverine, and traditional communities, whose traditional knowledge and social structures are deeply intertwined with the flood-pulse cycle.

Estimating the ecosystem service value of Pantanal can support or improve policies on payment for ecosystem services and initiatives for sustainable land use, and conservation, helping the Brazilian government to meet its GBF targets. There are few studies for ecosystem service valuation developed in the Pantanal (MASSAROLI et al., 2021; SEIDL; MORAES, 2000; SEIDL et al., 2000; SHRESTHA; SEIDL; MORAES, 2002), but there are many more ecosystem service valuation studies around the world for ecosystems that provide similar services that can be found in the ESVD for meta-analytic value transfer.

## **1.8 Objective**

The objective of this thesis is to estimate the value of ecosystem services for the Brazilian Pantanal, aligned with the global standards GBF, SEEA-EA and GET, using innovative techniques for meta-analytic value transfer based on ESVD. To fulfil this objective, this thesis addresses the following research questions:

- How can ecosystems of the Pantanal be classified according to the Global Ecosystem Typology (GET)?
- How can ESVD entries be systematically selected to support meta-analytic value transfer to the Brazilian Pantanal as a policy site?
- What is the estimated total ecosystem service value provided by Pantanal ecosystems?
- What is the estimated marginal loss (or gain) in ecosystem service value associated with land use and cover conversion in the Pantanal?

## **1.9 Thesis development plan**

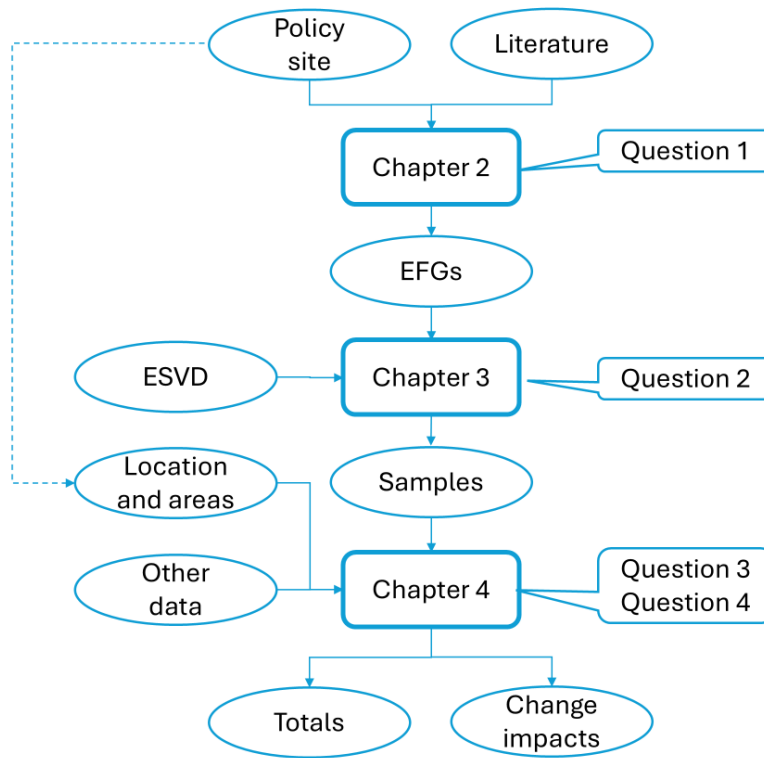
We present the thesis as articles that investigate the research questions, summarized in Figure 1.1.

Chapter 2 answers the first question by reviewing the literature, looking for existing ecosystem classification systems applied to the chosen policy site, the Brazilian Pantanal, to identify its EFGs.

Chapter 3 answers the second question by presenting and applying a protocol to select samples from ESVD for meta-regression for the EFGs found in the Brazilian Pantanal identified in Chapter 2.

Chapter 4 answers the remaining two questions by developing meta-regression models from samples selected in the Chapter 3, applying these models to the EFGs identified in Chapter 2, estimating the total value of ecosystem services these EFGs provide, and the impact of marginal conversion of these ecosystems on Pantanal total ecosystem service value. The location and area of study sites from ESVD samples and for the EFGs found in the policy site are used to obtain additional numeric variables for the regression models from other data sources.

Figure 1.1 - The thesis development plan.



## 2 TYPOLOGIES FOR ECOSYSTEM ACCOUNTING FOR THE BRAZILIAN PANTANAL<sup>2</sup>

### 2.1 Introduction

Healthy ecosystems are essential for our well-being, communities, and economies, yet our environment faces challenges and risks acknowledged at local, national, and global levels. To ensure ecosystems and biodiversity are integrated into decision-making, consistent measurement of environmental changes and their connection to economic and human activity is crucial, especially within economic and financial systems (UNITED NATIONS et al., 2021, p. 2).

Ecosystem accounting is the systematic assessment of the contributions of ecosystems to human well-being, such as food provisioning, water purification, carbon sequestration, and recreational opportunities. It can help policymakers, businesses, and society to understand the importance of conserving ecosystems and to incorporate their value in their decisions for the benefit of present and future generations.

In March 2021, the 52<sup>nd</sup> United Nations Statistical Commission adopted the System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA-EA) as the official United Nations (UN) standard for ecosystem accounting as a new statistical framework that “will enable countries to measure their natural capital and understand the immense contributions of nature to our prosperity and the importance of protecting it” (UNITED NATIONS, 2021; UNITED NATIONS STATISTICAL COMMISSION, 2021). At the occasion, the Secretary-General of the United Nations, António Guterres, argued that:

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<sup>2</sup> This chapter is an adapted version of the paper:  
DIAS, F. R. T.; URBANETZ, C.; ANDRADE, P. R. Typologies for ecosystem accounting for the Brazilian Pantanal. *Wetlands Ecology and Management*, Dordrecht, v. 33, 2025.  
<https://doi.org/10.1007/s11273-025-10068-x>  
The authorization for reproduction in this thesis is available in the Annex A.

The adoption of this economic and environmental framework is a historic step towards transforming the way we view and value nature. No longer will we allow mindless environmental destruction to be considered as economic progress (UNITED NATIONS, 2021).

SEEA-EA is part of the SEEA (System of Environmental-Economic Accounting), the “accepted international standard for environmental-economic accounting, providing a framework for organising and presenting statistics on the environment and its relationship with the economy [...] developed and released under the auspices of the United Nations, the European Commission, the Food and Agriculture Organization of the United Nations, the Organisation for Economic Co-operation and Development, International Monetary Fund and the World Bank Group” (UNITED NATIONS, 2023a). According to a 2022 global assessment, 92 countries had already implemented the SEEA and 41 of these 92 had compiled the SEEA-EA (UNITED NATIONS, 2023b).

Although the SEEA-EA was primarily designed for national ecosystem accounting, it could be used as a decision tool for subnational policy making:

The SEEA-EA is primarily intended to support national level policy decision making with a focus on connecting information about multiple ecosystem types and services to macro-level economic information (e.g., measures of national income, output, value added, consumption and wealth). At the same time, the theory and practice of ecosystem accounting is applicable at subnational scales. For example, ecosystem accounts can be used to support decision making for individual administrative areas such as provinces and urban areas, and for environmentally defined areas such as water catchments, protected areas, biodiversity priority areas and coastal zones. (UNITED NATIONS et al., 2021, p. 15).

Coherence between national and subnational policies demands compatibility between ecosystem typologies used for ecosystem assets at the subnational and national levels.

This work searches the scientific and grey literature for ecosystem, vegetation, or habitat typologies applied or proposed for the Brazilian Pantanal, the world's largest tropical wetland. The Pantanal has an annual dynamic that stores water during the rainy season and gradually releases it, making it difficult to define typologies for its ecosystems. The Pantanal's main economic activities are extensive cattle ranching and fishing, which are dependent on the ecosystem services of providing forage and fish resources. Therefore, it is essential to maintain its ecosystem services over time to ensure the economic viability of such activities.

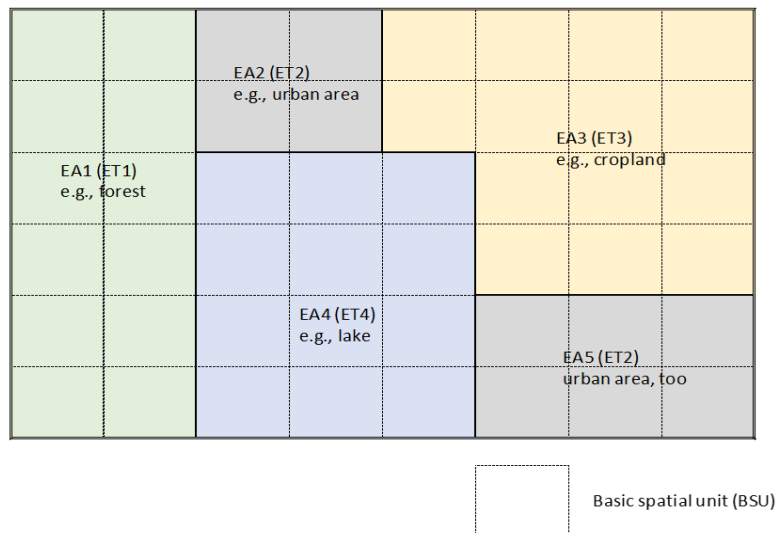
We looked for established typologies for ecosystem, vegetation, or habitat applied to the Pantanal that could be proxies for ecosystem types to be used for SEEA-EA. We analysed the typologies found in the literature, investigating their degree of compliance with the Global Ecosystem Typology from the International Union for Conservation of Nature (IUCN) and what would be required to make them fully compliant with such typology. The definition of ecosystem types for the Pantanal based on an internationally accepted classification can expand international cooperation aimed at conserving the ecosystem services in the largest continuous wetland area. In addition, this information can support national and international policies that encourage the adoption of good agricultural practices, facilitating access to international incentive funds for economic activities carried out in ways that preserve its ecosystem services.

## **2.2 Background**

SEEA-EA defines concepts and processes for ecosystem accounting. An ecosystem is “a dynamic complex of plant, animal, and micro-organism communities and their non-living environment interacting as a functional unit” (CBD, 2016). SEEA-EA can be applied to an ecosystem accounting area divided into ecosystem assets. Ecosystem assets are contiguous regions of the basic spatial units of the same ecosystem type at the same ecosystem condition. A basic spatial unit is a “geometrical construct representing a small spatial area” (UNITED NATIONS, 2021, p. 58). Usually, basic spatial units (BSU) will be squared grid cells of the same size, but other polygonal representations may be

used. The ecosystem condition of the BSU is evaluated using quality indicators chosen considering the BSU ecosystem type, the ecosystem accounting area, the purpose of the ecosystem accounting exercise, and restrictions on data and resources available for the ecosystem accounting exercise (Figure 2.1).

Figure 2.1 - An illustrative example of an ecosystem accounting area.



The rectangle inside the double border), its ecosystem assets (coloured polygons with single line borders), ecosystem types (each colour), and basic spatial units (the smallest rectangles with dotted line borders). Ecosystem assets and types in the figure are just examples that do not represent the SEEA-EA ecosystem typology.

Source: Adaptation from United Nations et al. (2021).

Ecosystem assets of the same ecosystem type deliver the same ecosystem services. The amount of each ecosystem service provided by one ecosystem asset is proportional to the ecosystem extension and related to the ecosystem asset condition. Ecosystem services have value to humankind that may be assessed. The natural capital represented by each ecosystem asset can be assessed by the estimated net present value of the ecosystem services provided by the ecosystem asset. For these accounting processes, SEEA-EA defines five types of ecosystem accounts: three physical and two monetary, three related to ecosystem assets (physical: extent and condition, monetary: value), and two related to ecosystem service flows (physical: quantity, monetary: value).

In its formal version adopted by the United Nations, SEEA-EA adopts the IUCN Global Ecosystem Typology (GET) as the global standard ecosystem typology

for ecosystem accounting that “enables national-level accounts to be scaled up and compared by countries”. They recommend that “existing national ecosystem classification schemes be used for ecosystem accounting wherever possible” and “local ecological expertise should be applied to determine the most appropriate cross-referencing” to GET (UNITED NATIONS, 2021, p. 62).

The IUCN Global Ecosystem Typology has a structure consisting of six levels. The three upper levels differentiate the functional properties of ecosystems (KEITH et al., 2022, Appendix S3):

**Level 1 (Realm):** “One of five major components of the biosphere that differ fundamentally in ecosystem organisation and function: terrestrial, freshwater, marine, subterranean, atmospheric”, including five transitional realms between two or three of them.

**Level 2 (Functional biome):** “A component of a realm united by one or a few common major ecological drivers that regulate major ecosystem functions and ecological processes, derived from the top-down by subdivision of realms (level 1).”

**Level 3 (Ecosystem Functional Group):** “A group of related ecosystems within a biome that share common ecological drivers promoting convergence of ecosystem properties that characterise the group. Derived from the top-down by subdivision of biomes.”

In its 2.1 version, the IUCN Global Ecosystem Typology defines 10 Realms and 25 Biomes (Table 2.1). The Pantanal is mentioned as an example for the EFG TF1.4 Seasonal floodplain marshes, one of the seven EFGs of the single Biome TF1 Palustrine wetlands of the Transitional Freshwater-Terrestrial Realm, although Pantanal has many ecosystems of many EFGs from this (e.g., TF1.3 Permanent marshes) and other realms and biomes (e.g., F1.5 Seasonal lowland rivers, F2.3 Seasonal freshwater lake, F3.5 Canals, ditches and drains). The complete list and description of all 110 EFGs, their realms, and biomes of the IUCN Global Ecosystem version 2.1 are available in Keith et al. (2022, Appendix S3) and are kept updated by IUCN (2022).

Table 2.1 - Ecosystem Functional Groups (EFGs) per Realm and Biome.

Realm / Biome	Number of EFGs
<b>Freshwater</b>	<b>22</b>
F1 Rivers and streams	7
F2 Lakes	10
F3 Artificial fresh waters	5
<b>Freshwater-Marine</b>	<b>3</b>
FM1 Semi-confined transitional waters	3
<b>Freshwater-Terrestrial</b>	<b>7</b>
TF1 Palustrine wetlands	7
<b>Marine</b>	<b>24</b>
M1 Marine shelves	10
M2 Pelagic ocean waters	5
M3 Deep sea floors	7
M4 Anthropogenic marine systems	2
<b>Marine-Freshwater-Terrestrial</b>	<b>3</b>
MFT1 Brackish tidal systems	3
<b>Marine-Terrestrial</b>	<b>7</b>
MT1 Shoreline systems	4
MT2 Supralittoral coastal systems	2
MT3 Anthropogenic shorelines	1
<b>Subterranean</b>	<b>3</b>
S1 Subterranean lithic systems	2
S2 Anthropogenic subterranean voids	1
<b>Subterranean-Freshwater</b>	<b>4</b>
SF1 Subterranean freshwaters	2
SF2 Anthropogenic subterranean freshwaters	2
<b>Subterranean-Marine</b>	<b>3</b>
SM1 Tidal subterranean systems	3
<b>Terrestrial</b>	<b>34</b>
T1 Tropical-subtropical forests	4
T2 Temperate-boreal forests & woodlands	6
T3 Shrublands & shrubby woodlands	4
T4 Savannas and grasslands	5
T5 Deserts and semi-deserts	5
T6 Polar-alpine	5
T7 Intensive land-use systems	5
<b>General Total</b>	<b>110</b>

Source: Adapted from Keith et al. (2022).

IUCN Global Ecosystem Typology groups ecosystems that share the same functions under a single Ecosystem Functional Group (EFG). Each EFG is defined not only by its biotic composition or abiotic environment “per se”, but by

an ecosystem assembly model (KEITH et al. 2022, p. 514), including abiotic, biotic, and anthropic drivers that shape the composition and characteristics of ecological assemblages. They are:

- The availability of resources: water, energy, nutrients, oxygen, and carbon.
- The ambient environment: climate seasonality, temperature, salinity, substrate, kinetic energy, geomorphology.
- Disturbance regimens: Fire, flood, storm, mass movement, igneous activity.
- Biotic interactions: competition, predation, pathogenicity, mutualism, facilitation.
- Human activity: Structural alteration, resource use, movement of biota, and climate change.

These drivers influence each other. For instance, human activity may add or change disturbance regimens and affect biotic interactions by changing the species pool; the ambient environment affects the available resources, etc. These drivers create evolutionary pressures that impact the ecosystem-level properties, such as productivity, diversity, trophic structure, physiognomy, life history and form, phenology, and ecophysiology. This ecosystem assembly model is then used to define each EFG in the IUCN Global Ecosystem Typology by specifying different compositions and relative contributions of each of these drivers and the ecosystem-level properties resulting from them (KEITH et al., 2022 p. 515).

Levels 1 to 3 group the ecosystems by function, not by biotic composition. Suppose two ecosystems provide the same set of functions (and services to humankind). In that case, they are classified under the same ecosystem functional group (EFG), the level 3 of IUCN Global Ecosystem Typology, regardless of the biotic composition that contributes to its functions. Levels 4, 5, and 6 group ecosystems within the same ecosystem functional group by their biotic composition. The IUCN Global Ecosystem Typology definitions for levels 4, 5, and 6 types are as follows (KEITH et al., 2022, emphasis added):

**Level 4**, or Regional ecosystem subgroups, are ecoregional expressions of an Ecosystem Functional Group (level 3). They are proxies for compositionally distinctive geographic variants that occupy different areas within the distribution of a functional group. These are derived from the top-down by subdivision of Ecosystem Functional Groups (KEITH et al., 2022).

**Level 5**, or Global ecosystem types, are complexes of organisms and their associated physical environment within an area occupied by an ecosystem functional group. Global ecosystem types grouped into the same Ecosystem Functional Group share similar ecological processes but exhibit substantial differences in biotic composition. They are derived from the bottom-up (national or subnational), either directly from ground observations or by aggregating the lowest level, the Subglobal ecosystem types (KEITH et al., 2022).

**Level 6**, or Subglobal ecosystem types, are subunits or nested groups of subunits within a global ecosystem type, with more compositional resemblance to one another than to other global ecosystem types. These represent units of established classifications (e.g., at national level), in some cases arranged in a sub-hierarchy of multiple levels, derived directly from ground observations (KEITH et al., 2022).

Keith et al. (2022) use types and typology interchangeably with classes and classification system, although the first two terms were chosen to name the IUCN Global Ecosystem Typology. Other classification systems or typologies attribute different meanings to types and classes (for instance, the Land Cover Classification System - LCCS, in DI GREGORIO; JANSEN, 2000). Still, a discussion of possible different uses of the terms types and class is not the objective of this work, so, for the sake of clarity and conformance to IUCN Global Ecosystem Typology, in this paper we use types instead of classes and typology instead of classification system, even when class and its correlates are used in the original publication mentioned. The only exception is the name of the Brazilian Vegetation Classification System (IBGE, 1992, 2012) because it is a direct translation from Portuguese.

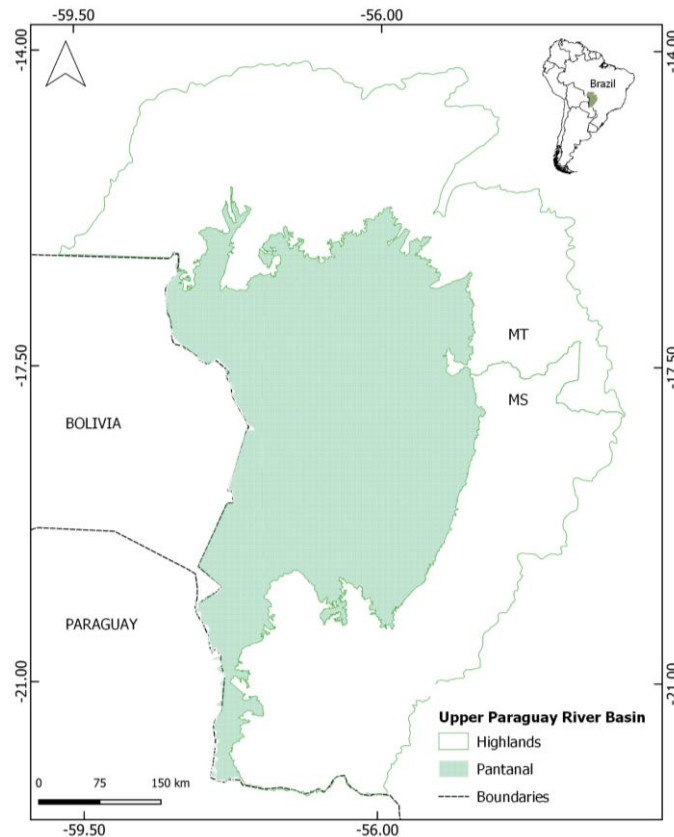
The current version of the IUCN Global Ecosystem Typology (2.1) defines only the types of levels 1 to 3. Level 4 types are currently being developed by IUCN from the top down, by subdividing EFGs “based on biogeographic boundaries” (KEITH et al., 2022, p. 520). Level 4 and level 5 types are both grouped under level 3 types (EFGs), not being related to each other. This means that IUCN Global Ecosystem Typology allows the definition of two alternate hierarchies sharing the first three levels: one using levels 1, 2, 3, and 4; and another using levels 1, 2, 3, 5, and 6.

Level 5 types will be defined as global by IUCN, using bottom-up aggregations of national or subnational level 6 types, grouping them under separate EFGs. Level 5 will then serve as a semantic connection between EFGs, and national or subnational typologies adopted as level 6. Keith et al., present crosswalks of the Chile and Myanmar national typologies adopted as level 6 typologies, matching them to EFG types (KEITH et al., 2022, Appendix S3).

### **2.3 Study area**

The Pantanal is the world's largest tropical wetland, a large depression basin in the Upper Paraguay River Basin, in the centre of South America (Figure 2.2). It covers around 140,000 km<sup>2</sup> in Brazil, 15,000 km<sup>2</sup> in Bolivia, and 5,000 km<sup>2</sup> in Paraguay (JUNK et al., 2009; TOMAS et al., 2019).

Figure 2.2 - The Brazilian Pantanal Biome.



Map of the Upper Paraguay River Basin (white area) and the Brazilian Pantanal Biome (green area). MT is the Mato Grosso state. MS is the Mato Grosso do Sul state.

Source: Embrapa Pantanal (2023).

The Pantanal landscape is a complex of many different ecosystems, e.g., flooded savannas, seasonally flooded forests, swamps, riparian forests, rivers, lakes, and grasslands. Costanza et al., mention the Pantanal as “one of the main hotspots for ecosystem services worldwide” (1997). The Pantanal is home to vigorous populations of wild animals that are endangered in other regions (TOMAS et al., 2019). The Pantanal provides ecosystem services that are globally and locally critical, such as the regulation of river discharge and local microclimates, water security, provision of native pasture and fishing resources, habitat for threatened species, and wintering ground for migratory species (TOMAS et al., 2019).

The major threats to the Brazilian Pantanal ecosystems are land-use changes in surrounding areas (e.g., Brazilian Amazon Biome<sup>3</sup>, Brazilian Cerrado Biome<sup>4</sup>, Bolivian Chaco), the unsustainable intensification of cattle ranching, large infrastructure projects, and climate change (TOMAS et al., 2019), to which the authors add wildfires. The presence of extensive grassland areas containing native forage plant species has determined the region's suitability for extensive beef cattle farming. Its great extent as a wetland has determined its suitability for fishing and fishing tourism. Most of the Brazilian Pantanal is privately owned, meaning that its conservation and the maintenance of its ecosystem services depend almost exclusively on rural producers' good use of the land. Although more than 90% of the Brazilian Pantanal area is private and has been used for cattle ranching for more than 200 years (BRAZ et al., 2020), the annual flood has kept away other agricultural and human exploitation of the Brazilian Pantanal territory and more intensive land use. Until 2022, land use has replaced only 15% of the natural land vegetation in the Brazilian Pantanal (MAPBIOMAS, 2023c), which makes it one of the most preserved Brazilian biomes. Nevertheless, an additional loss of more than 3% of natural vegetation in the next 30 years was projected by land-use change scenarios (GUERRA et al., 2020).

The Brazilian Pantanal could be a subnational ecosystem accounting area for the Brazilian SEEA-EA. For an ecosystem accounting below the EFG level and fitted to the Brazilian Pantanal, we need IUCN Global Ecosystem Typology level 6 types for the Brazilian Pantanal. Even if the ecosystem accounting for the Brazilian Pantanal is kept at the EFG level, the knowledge that would come with this national or subnational established classification could help to improve EFG classification models for the Brazilian Pantanal. Establishing ecosystem

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<sup>3</sup> Brazilian biomes are defined by IBGE using concepts that do not match the biome definition used by IUCN Global Ecosystem Typology to its level 2 types. In cases where the context is not clear enough, we use "Brazilian biomes" meaning the concept and delimitation published by IBGE (2019). IBGE definition of the Brazilian Pantanal biome is the concept we use to define the Brazilian Pantanal.

<sup>4</sup> The Brazilian savanna.

typologies for the Brazilian Pantanal is especially challenging. The existing space-time dynamics is mainly established by the annual cycles of flooding and drought, its main ecological drivers. It results in rapid changes in the environment, making it difficult to establish clear boundaries. The main economic activities carried out in the world's largest continuous wetland strictly depend on ecosystem services to exist and perpetuate themselves over time, especially provisioning services. For this reason, methodologies such as ecosystem accounting could contribute to the classification and mapping of these services. They can help to assess the Brazilian Pantanal's natural capital and monitor its quality. In addition, it can be the first step before evaluating the best agricultural practices that are carried out to maintain these services and support the creation of public policies that encourage the adoption of good agricultural practices or that finance rural producers who adopt sustainable production systems.

## **2.4 Method**

This paper reviews the literature, searching for ecosystem, habitat, or vegetation typologies that could represent Subglobal ecosystem types (GET level 6 types) for the Brazilian Pantanal. As we are looking for ecosystem typologies for the SEEA-EA application at the subnational level, we focused our search on typologies that were applied or proposed for the Brazilian Pantanal. From now on, we use both Pantanal and Brazilian Pantanal to mean the portion of the Pantanal wetland in the Brazilian territory, i.e., the Brazilian Pantanal biome as defined by IBGE (2019), unless specified otherwise.

The methodology used three steps:

- 1) A thorough search of publications on mapping, classification, or identification of Pantanal's ecosystems, habitats, or vegetation.
- 2) A selection of the typologies found considering their adoption for the Pantanal.
- 3) An evaluation of each typology, investigating whether it is compliant to the most recent IUCN Global Ecosystem Typology.

In the first step, we used Google Scholar as a systematic review with snowballing (WOLLING, 2014) to search for publications published in 2000 or afterwards, selecting relevant titles that satisfied any of the following queries:

In English:

- Pantanal AND ("ecosystem mapping" OR "habitat mapping" OR "vegetation mapping" OR "mapping of vegetation" OR "mapping of habitats" OR "mapping of ecosystems" OR "mapping of the vegetation" OR "mapping of the habitats" OR "mapping of the ecosystems")
- Pantanal AND ("ecosystem classification" OR "habitat classification" OR "vegetation classification" OR "classification of vegetation" OR "classification of habitats" OR "classification of ecosystems")
- Pantanal AND ("ecosystem typology" OR "habitat typology" OR "vegetation typology" OR "typology of vegetation" OR "typology of habitats" OR "typology of ecosystems")

In Brazilian Portuguese:

- Pantanal AND ("mapeamento de ecossistemas" OR "mapeamento de habitats" OR "mapeamento de vegetação" OR "mapeamento dos ecossistemas" OR "mapeamento dos habitats" OR "mapeamento da vegetação")
- Pantanal AND ("classificação de ecossistemas" OR "classificação de habitats" OR "classificação de vegetação" OR "classificação dos ecossistemas" OR "classificação dos habitats" OR "classificação da vegetação")
- Pantanal AND ("tipologia de ecossistemas" OR "tipologia de habitats" OR "tipologia de vegetação" OR "tipologia dos ecossistemas" OR "tipologia dos habitats" OR "tipologia da vegetação")

We then checked their abstracts, selecting those that use or propose a vegetation, habitat, or ecosystem typology and were applied to the Brazilian Pantanal<sup>5</sup>. After that, we:

- Excluded repeated publications.
- Read full content and excluded publications that use or propose a typology that has only one or two levels or a few types (usually land use and cover typologies).
- Finally, for each selected publication, we searched recursively on its references and publications that cited it, applying the same selection criteria above until no new publication was found (WOHLIN, 2014).

The second step selected the ecosystem, habitat, or vegetation typologies found in the publications for evaluation:

- We grouped the publications according to the typology they use or mention.
- We selected the publications that better describe typologies that could be considered national or subnational and established, either “de jure” (formally adopted by a governmental institution) or “de facto” (used by many different authors).

The third step evaluated the typologies selected:

- We ignored the EFGs that do not occur in the Pantanal (e.g., marine, temperate, or boreal ecosystems) or that were out of the declared scope of the given typology.

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<sup>5</sup> Considering our focus, publications in Spanish would be useful if they used or proposed typologies that included the Brazilian Pantanal, not only the Pantanal in Bolivia or Paraguay. Just to be sure, we applied Spanish versions of our search strings, and no publication passed the first step of our Method.

- We grouped the remaining lowest-level types by realm or biome in the IUCN Global Ecosystem Typology, when possible (Terrestrial, Freshwater, etc.).
- For each of the lowest level types of the typology being evaluated, we inspected the description of each EFG of the same group for any contradiction to the type definition, i.e., anything meaning that could exist an area of this type that would not be considered part of that EFG.
- All EFGs with no contradiction to the type description were selected as matches. When more than one EFG matched a type, it is theoretically possible to have an area of this type for which it is not possible to exclude any of these EFGs without additional information.
- If no satisfying EFG was found, we selected the one with fewer important contradictions, adding notes to explain the contradiction.

## 2.5 Results and discussion

There are 55 publications found after the first step, classified into three groups, considering the typologies used, proposed, or mentioned:

**IBGE:** We found 38 publications that use some version of the Brazilian Vegetation Classification System published by the Statistics and Geography Brazilian Institute - “Instituto Brasileiro de Geografia e Estatística”, IBGE (1992, 2012), or the “on press” version of it (VELOSO et al., 1991), sometimes combined with the “Technical Land Use Manual” also from IBGE (2006, 2013). We comment on some of them as follows:

- Silva et al. (2000) propose minor adaptations to the Brazilian Vegetation Classification System (IBGE, 1992) specifically for Pantanal, splitting types by dominant species.
- Oliveira-Filho (2009) “offers a new system of physiognomic and ecologic classification and nomenclature for the vegetation of tropical and subtropical South America east of the Andes” based on IBGE (1992), with the highest level being 16 phyto-physiognomies optionally classified by climate regime, leaf renewal regime, thermal domain, altitudinal range, and substrate.

- Carlini and Silva (2014, 2015) map 62 types from IBGE (1992) to the Upper Paraguay River Basin and the portion of the Pantanal in the Brazilian state of Mato Grosso do Sul, covering two-thirds of the whole Pantanal.
- Silva (2017) uses the Brazilian Vegetation Classification System in a region of Pantanal (Aquidauana) to “analyse the changes in land use and vegetation cover in the years 1984, 1993, 2000 and 2015 and simulate a future scenario for the year 2050”. This is the only publication found that applies the latest published version of the Brazilian Vegetation Classification System (IBGE, 2012). Ten other publications after 2012 use the first version (IBGE, 1992), possibly because most of the mapping was already done before 2012, resulting from federal or state projects (RADAMBRASIL, GeoMS, Probio Pantanal).
- Boaventura and Pereira (2021) do not cite any version of the Brazilian Vegetation Classification System, but they seem to use it, considering the types mentioned.

**CNZU:** We found 14 publications that propose or mention a habitat typology developed for Pantanal and generalised for other Brazilian wetlands, proposed to and approved by the Brazilian Wetland National Committee - “Comitê Nacional para as Zonas Úmidas”, or CNZU, in Portuguese, established by the Brazilian Environment Ministry. We comment on some of them as follows:

- Junk et al. (2014) and Cunha et al. (2015) were accepted as the official typology for Brazilian wetlands and their habitats by the CNZU (BRASIL, 2015). For the Pantanal, this typology proposes 56 macrohabitats: 49 natural and seven anthropogenic. Macrohabitats is the name Junk et al. (2014, 2018) gave to the types of the lowest level of the proposed typologies.
- Junk et al. (2018) applied Junk et al. (2014) to three large Brazilian floodplains: the forested Amazonian *várzeas* and *igapós*, and the savanna floodplains of the Upper Paraguay River to demonstrate the applicability of this system in comparative inter- and intra-wetland studies and therefore

its utility in assessing environmental changes, including those arising from global climate change.

- After a workshop in 2017, Cunha et al. (2021) proposed an update on their published wetland ecosystem typology (CUNHA et al., 2017), adding habitats specific to Pantanal in Mato Grosso do Sul state, raising the typology to a total of 74 macrohabitats (65 natural and nine anthropogenic).
- Cunha et al. (2023) is a translated version of Cunha et al. (2021) to Brazilian Portuguese.

**MapBiomias:** an initiative of the Greenhouse Gas Emissions Estimates System of the Climate Observatory, a non-governmental organisation in collaboration with a network of NGOs, universities, and technology companies that provide maps on land use and land cover change (2023b). MapBiomias typology is an aggregation of types from the Brazilian Vegetation Classification System (IBGE, 1992, 2012) into a smaller number of land use and cover types. Some IBGE types that span multiple Brazilian biomes may be grouped differently by MapBiomias depending on the biome in which they occur (MAPBIOMAS, 2023a). We found 17 publications that applied maps and data from Mapbiomas to the Brazilian Pantanal. For instance, Vieira et al. (2019) used MapBiomias data to “provide a panorama of the current network of PAs [protected areas] in Brazil, examine the biases of protection in relation to slope and land use intensity, and determine whether biases vary between biomes” and Overbeck et al. (2022) use MapBiomias to “suggest key research needs to advance our understanding of the ecology and conservation values of Brazil’s grassy ecosystems”.

**N4C:** an acronym for Fourth National Communication of Brazil to the United Nations Framework Convention on Climate Change (BRASIL, 2021b). N4C calculated the balance of greenhouse gas emissions and carbon fixation per Brazilian state and Brazilian biome per sector of human activity. Land use, land cover change, and forests (LULUCF) is one of the sectors. N4C uses a typology breakdown of land use and cover categories set by the Intergovernmental Panel

for Climate Change (IPCC, 2019). We grouped here the reports and other documents from N4C for the Brazilian Pantanal biome.

**Reviews:** We found three other publications that do not fit the four groups above. All of them are literature reviews: Oliveira-Costa (2002) and Sandeville Jr (2004) are reviews on national and international vegetation typologies. Coutinho and Lopes (2017) is a historical review of national vegetation typologies.

As a result of applying the second step described in the Method section, we selected four typologies to evaluate the compatibility of their lower-level types to the IUCN Global Ecosystem Typology. We did this by applying the third step in the Method section to each one of them, as follows.

- CNZU

Cunha et al. (2021, 2023) is a macrohabitat classification based on hydrology and vegetation types for policymaking and management of the Brazilian Pantanal. It is a recent update of Nunes da Cunha and Junk (2014) that has provided the scientific basis for the Federal Law of the Pantanal (BRASIL, 2012) and is recommended by the CNZU of the Ministry of the Environment (CNZU, 2015). Cunha et al. (2021, 2023) added 18 macrohabitats exclusively occurring in the Pantanal of Mato Grosso do Sul state to the 56 macrohabitats identified by Nunes da Cunha and Junk (2014) for the Brazilian Pantanal. Both publications classify macrohabitats in six Functional units, separating anthropogenic areas and different hydrologic regimens: anthropogenic, permanently aquatic, predominantly aquatic, predominantly terrestrial, permanently terrestrial, permanently waterlogged or shallowly flooded. Each functional unit is divided into subclasses that represent typical vegetation found (e.g., areas covered by herbaceous plants, shrubs, and small groups of trees) or specify the hydrology even more (e.g., river channels, lakes). The update on Junk et al. (2014) proposed by Cunha et al. (2021, 2023) was not submitted for approval by the CNZU yet, but we evaluated the latter instead of the former because it has improvements on the previous version, such as including macrohabitats from Pantanal in the Mato Grosso do Sul state.

For each macrohabitat proposed by Cunha et al. (2021, 2023), we selected the EFG that best fits the macrohabitat, as described in the third step of the Method section, with the following adaptations: First, we discarded the Subterranean Realm and Transitional Realms to or from it because Cunha et al. (2021, 2023) did not specify any subterranean macrohabitat. Second, we did the matching process described in the third step of the Method section after grouping the remaining 36 EFGs in six sets, one for each Functional Unit mentioned by Cunha et al. (2021, 2023), which represents a concept similar to "Realm" in IUCN Global Ecosystem Typology:

- Nine macrohabitats from Anthropogenic Areas to five EFGs in the F3 Artificial fresh waters and five EFGs in the T7 Intensive land-use systems biomes.
- Ten macrohabitats from Permanently Aquatic Areas to 13 EFGs in the Freshwater Realm, not in the F3 Artificial fresh waters biome.
- Ten macrohabitats from Permanently Terrestrial Areas to nine EFGs in the Terrestrial Realm, not in the T7 Intensive land-use systems biome.
- 45 remaining macrohabitats of temporary terrestrial and aquatic areas to five EFGs in the Transitional Freshwater-Terrestrial Realm.

As a result of this process, 14 distinct EFGs were matched to the 74 macrohabitats in Cunha et al. (2021, 2023). Each macrohabitat was matched to a single EFG, three of them with the same minor contradiction: These three macrohabitats are degraded forests, with usually only palm trees and no (or very few) arboreous trees, but the EFG found to be less contradicting to them was T1.2 Tropical and subtropical dry forests and thickets (Table 2.2).

Table 2.2 - Ecosystem Functional Groups (EFGs), the macrohabitats and vegetation classes in the Brazilian Pantanal.

Realm / Biome / EFG			CNZU	IBGE
<b>Freshwater</b>			<b>15</b>	<b>1</b>
F1 Rivers and streams	F1.2	Permanent lowland rivers	1	1
	F1.5	Seasonal lowland rivers	4	
F2 Lakes	F2.2	Small permanent freshwater lakes	5	
	F2.3	Seasonal freshwater lakes	2	
F3 Artificial fresh waters	F3.2	Constructed lacustrine wetlands	2	
	F3.5	Canals, ditches, and drains	1	
<b>Terrestrial</b>			<b>16</b>	<b>27</b>
T1 Tropical-subtropical forests	T1.2	Tropical and subtropical dry forests and thickets	6	3
T4 Savannas and grasslands	T4.2	Pyric tussock savannas	5	17
T7 Intensive land-use systems	T7.1	Annual croplands	1	1
	T7.4	Urban and industrial ecosystems	1	1
	T7.5	Derived semi-natural pastures and old fields	3	5
<b>Transitional Freshwater-Terrestrial</b>			<b>43</b>	<b>7</b>
TF1 Palustrine wetlands	TF1.1	Tropical flooded forests and peat forests	12	5
	TF1.3	Permanent marshes	7	1
	TF1.4	Seasonal floodplain marshes	24	
<b>General Total</b>			<b>74</b>	<b>35</b>

Number of types of macrohabitats in “CNZU” (CUNHA et al. 2021, 2023) and vegetation types in “IBGE” (CARLINI; SILVA, 2014, 2015) that match each EFG found from the IUCN Global Ecosystem Typology, after applying the third step described in the Method section. Cells with more than one EFG associated show the number of types that share those EFGs. For the individual match of each EFG to each type in CNZU and IBGE typologies, see Appendix A.

- IBGE

The Brazilian Vegetation Classification System (IBGE; 1992, 2012) is a comprehensive system for classifying vegetation types across Brazil that is widely adopted. Developed by the Brazilian Institute of Geography and Statistics (IBGE), this manual provides a hierarchical framework that integrates floristic, physiognomic, and ecological criteria to categorize Brazil's remarkably diverse plant life. It offers detailed descriptions of vegetation formations, associations, and ecological zones, accompanied by illustrative keys and diagnostic characteristics. This manual is a reference for Brazilian researchers, environmental agencies, and land-use planners, facilitating consistent mapping, monitoring, and conservation efforts across Brazilian landscapes (IBGE, 2012).

Its influence extends beyond national borders, often serving as a model for vegetation studies in other Neotropical regions (VELOSO et al., 1991). The Brazilian Vegetation Classification System (IBGE, 1992, 2012) has been and continues to be applied to the Brazilian Pantanal many times, one of which is Carlini and Silva (2014, 2015). The first version of the Brazilian Vegetation Classification System (IBGE, 1992) was used many times to classify land cover of the Pantanal using satellite images, aerial photographs, and field observation, while the most recent version (IBGE, 2012) was mentioned only by publications that did not map it to the whole Pantanal, so we evaluated the 1992 version instead of the most recent 2012 version. This does not jeopardise our evaluation because the vegetation types present in Pantanal did not change their codes or definitions from the 1992 version to the 2012 version.

Considering Carlini and Silva (2014, 2015), we matched each one of the 62 vegetation IBGE types (1992, 2012) found in the Upper Paraguay River Basin of the Mato Grosso do Sul state to one or more EFG, as described in the third step of the Method section, with the following adaptations:

- We ignored: (i) the Subterranean Realm and transitions to or from it because Carlini and Silva (2014, 2015) does not mention subterranean types, and IBGE (1992) also does not include them; (ii) six ecotones and three enclaves found by Carlini and Silva (2014, 2015), as they represent transition areas between types already represented in the list to be matched to EFG; and (iii) eight vegetation types with no area in the Pantanal (one ecotone and one enclave among them).
- Every type in Carlini and Silva (2014, 2015) that describes the same anthropogenic final land use for different pristine vegetation regions was considered as one type that represents its final land use (three different land use types representing 15 vegetation types).
- We matched the remaining 18 EFGs in the Freshwater Realm to the only type for water bodies in the IBGE Vegetation Classification System (1992).
- We did the matching process described in the Method section after separating the 34 remaining vegetation types and 18 EFGs into three sets:

- Seven anthropogenic types to the remaining five EFGs in the T7 Intensive land-use systems biome.
- 20 remaining natural types without riparian, alluvial, fluvial, lacustrine, or floodplain vegetation to the remaining nine EFGs of the Terrestrial Realm, not in the T7 Intensive land-use systems.
- Seven natural types with riparian, alluvial, fluvial, lacustrine, or floodplain vegetation, to the remaining five EFGs in the Freshwater-Terrestrial Realm.

As a result of this process, 18 Freshwater EFGs were matched to the type for water bodies, and eight distinct EFGs were selected, three of them anthropogenic. The description of the IBGE vegetation type “Riparian Vegetation, Alluvial (Arboreal, Bush, Herbaceous) - along rivers” matches the description of three EFGs: TF1.1 Tropical flooded forests and peat forests, TF1.3 Permanent marshes, TF1.4 Seasonal floodplain marshes. Another type matches two of these three EFGs: “Pioneer Formations, Vegetation with fluvial and/or lacustrine-arboreal (Cambarazal), Bush (Espinheiral, Saranzeiro, Macega, Pateiral, Pimenteiral), Herbaceous (Pirizal, Caetezal, Brejo, and Bacero) influence” matches TF1.3 and TF1.4. All other 32 IBGE vegetation types match a single EFG each (Table 2.2).

- MapBiomas

Only six MapBiomas types represent natural ecosystems that occur in the Pantanal. All but Rocky Outcrop match two or more EFG (Appendix A).

- N4C

We applied the third step in the Method section to N4C land use and land cover typology with the following adaptations:

- We discarded the Subterranean Realm and Transitional Realms to or from it because N4C does not have a Subterranean type. For the same reason, we discarded the Freshwater Realm.
- We discarded the terrestrial types that do not occur in the Pantanal.
- We matched wetland types to Freshwater EFG.

- We matched N4C types that represent managed land cover or anthropogenic land uses to anthropogenic EFG of terrestrial and transitional freshwater-terrestrial biomes, and the remaining N4C types to non-anthropogenic EFG of terrestrial and transitional freshwater-terrestrial biomes. As a result of this process, one N4C type is a placeholder for the areas not observed or classified, ten N4C types match two or more EFG, nine N4C types match one EFG each, all of them anthropogenic, the remaining six N4C types match the same non-anthropogenic EFG (Appendix A).

## **2.6 Final remarks**

In this work, we searched for ecosystem, vegetation, and habitat typologies applied to or proposed for the Brazilian Pantanal that could serve as proxies to level 6 ecosystem types from the IUCN Global Ecosystem Typology, a requirement for subnational SEEA-EA for the Brazilian Pantanal.

Through a two-step literature search, we found four typologies: the most cited national vegetation and habitat typologies, which were either applied to or developed for Pantanal, and the two most known land use and cover typologies used for environmental management in Brazil, looking for proxies for ecosystem typologies for use of SEEA-EA on Pantanal. Notably, none of the publications found mention SEEA-EA or the IUCN Global Ecosystem Typology, probably because these two frameworks were published very recently.

In the third step, we evaluated the four typologies and checked if they satisfy the two requirements from the IUCN Global Ecosystem Typology for level 6 typology: 1) if the typology is established at the national or subnational level, and 2) if each of their ecosystem types could be classified under a single EFG. The land use and cover typologies used by Mapbiomas and the Fourth National Communication of Brazil to the United Nations Framework Convention on Climate Change were considered too coarse for natural vegetation and, as such, not suitable for SEEA-EA. The habitat typology proposed by Cunha et al. (2021, 2023) and the Brazilian Vegetation Classification System defined by IBGE (1992,

2012) include types for habitat and natural vegetation that could be adapted for SEEA-EA use. Each has its own pros and cons, discussed as follows.

- The IBGE vegetation classification system (IBGE, 1992, 2012)

The Brazilian Vegetation Classification System (IBGE, 1992, 2012) has often been used to map the Pantanal vegetation using Earth Observation (EO) data. Nevertheless, to be used as an IUCN Global Ecosystem Typology level 6 established system for the Pantanal, it requires some updates. For instance, two types satisfy the description of more than one EFG each. Splitting these type definitions would allow the new type result of the splits to be matched to one single EFG each. Finally, single water bodies type in IBGE (1992, 2012) must be split at least at the EFG level.

It is noteworthy that IBGE has exercised an experimental version of SEEA-EA, the SEEA-EEA, the extra “E” meaning “experimental” (UNITED NATIONS STATISTICS DIVISION, 2014). In this pilot SEEA-EEA for Brazil, the IUCN Global Ecosystem Typology has not been established yet as a SEEA-EEA standard ecosystem typology, nor has the Brazilian Vegetation Classification System been used. Instead, one ecosystem accounting area was selected to represent each of the six Brazilian biomes. We believe that IBGE will be responsible for updating Brazilian ecosystem accounting in the following years, using the latest version of SEEA-EA that requires the IUCN Global Ecosystem Typology, with EFG as the ecosystem types. Having an updated Brazilian Vegetation Classification System (IBGE, 1992, 2012), which is EFG compliant, would facilitate this process.

- The Pantanal macrohabitat typology (CUNHA et al., 2021, 2023)

Each macrohabitat proposed by Cunha et al. (2021, 2023) implies one and only one EFG, although three macrohabitats seem to slightly contradict the EFG chosen as the best match to their descriptions: The EFG “T1.2 Tropical subtropical dry forests and thickets” has “forest” in its name and description. However, the three macrohabitats matched to it are degraded forests covered by only palm trees, with very few or no arboreal trees.

Cunha et al. (2021, 2023) updated the typology of Junk (2014), which has been approved by the CNZU (2015). We found no mapping using Cunha et al. (2021, 2023) typology to Pantanal, not even for the Junk et al. (2014) version. Junk et al. (2018) use it but do not map it to the Pantanal, maybe because these typologies were defined very recently, being very specific for the Pantanal and other Brazilian wetlands and not entirely compatible with the Brazilian Vegetation Classification System. There are only examples and comments in Cunha et al. (2021, 2023) concerning regions where some macrohabitats can usually be found. Therefore, Cunha et al. (2021, 2023) is not quite a “de facto” or “de jure” established macrohabitat typology for Pantanal or other wetlands in Brazil yet, although we believe it has a great chance to become so.

- Comparing IBGE (1992, 2012) and Cunha (2021, 2023)

We now compare the results from matching EFG to Cunha et al. (2021, 2023) macrohabitat types and to the subset of IBGE vegetation types found in the Pantanal by Carlini and Silva (2014, 2015), explaining some decisions made and the limitations of the study.

Neither Cunha et al. (2021, 2023) nor Carlini and Silva (2014, 2015) define or even mention any subterranean macrohabitat or vegetation type, but it is not the scope of this work to discuss whether there are subterranean ecosystems in Pantanal.

Although Pantanal has some areas with exotic pasture (*Brachiaria* spp.), livestock cannot be considered intensive there, so we chose EFG “7.5 Derived semi-natural pastures and old fields” instead of “T7.2 Intensive livestock pastures” to match livestock land use types to Cunha et al. (2021, 2023) and IBGE (1992, 2012) types.

The sets of EFGs for Terrestrial and transition Terrestrial-Freshwater realms matched to Cunha et al. (2021, 2023) and IBGE (1992, 2012) types are the same, but Cunha et al. (2021, 2023) are much more detailed for Freshwater and Freshwater-Terrestrial, with 43 macrohabitats matching three Freshwater-Terrestrial EFGs and 15 macrohabitats matching six Freshwater EFGs, while IBGE (1992, 2012) has only one type for water bodies and only seven vegetation

types matching the same three Freshwater-Terrestrial EFGs. IBGE (1992, 2012) is more detailed for anthropogenic land use, although this does not make much difference for the Pantanal, as there are few different types of land use there. It is interesting to note that almost half of the IBGE types found by Carlini and Silva (2014, 2015) in the Pantanal (17 out of 35) match the EFG T4.2 Pyric tussock savannas”, which matches less than 7% (5 out of 74) of Cunha et al. (2021, 2023) macrohabitats, while this relation inverts for the three Transitional Freshwater-Terrestrial EFGs found: 43 in 74 for Cunha et al. (2021, 2023) and 7 in 35 for IBGE (1992, 2012). Maybe the mapping done by Carlini and Silva (2014, 2015) did not consider that some of the areas of the Pantanal classified under terrestrial vegetation types are seasonally flooded, although they do not exhibit any riparian, alluvial, lacustrine, or floodplain vegetation.

IBGE (1992, 2012) is an established national vegetation classification defined by an institution of the Brazilian government (IBGE), widely used in Brazil. It has not been submitted to CNZU because it is not specific to wetlands, the subject of CNZU's scope. The potential use of a vegetation classification as an ecosystem typology is part of the work of this article, as we compared the descriptions of the vegetation classes to EFG descriptions. Wetlands are the subject of Junk et al. (2014), submitted to and approved by the CNZU to be recommended to the Environment Ministry of Brazil (BRASIL, 2015). Cunha et al. (2021, 2023) is an update that adds macrohabitats from southern Pantanal to Junk et al. (2014) and, as far as we know, was not submitted to CNZU, and is not in wide use yet. Being a national vegetation classification system, IBGE offers too few ecosystems to match freshwater and transitional terrestrial-freshwater EFG, while Cunha et al. (2021, 2023), developed for Pantanal specifically, satisfy the IUCN Global Ecosystem Typology requirement for level 6 types: one type, one EFG.

Although we considered only the Brazilian Vegetation Classification System (IBGE, 1992, 2012) types found by Carlini and Silva (2014, 2015) on 63% of the Brazilian Pantanal (the area inside the Mato Grosso do Sul state), we believe that the most important (if not all) vegetation types within Pantanal were considered, at least for EFG matching. The same set of matched EFGs was found for Cunha et al. (2021, 2023), corroborating this idea. To guarantee a complete IUCN GET

level 6 typology based on adaptations to the Brazilian Vegetation Classification System (IBGE, 1992, 2012) would also require considering the remaining 37% of the Pantanal located in the Mato Grosso state to be sure that no vegetation type is left out.

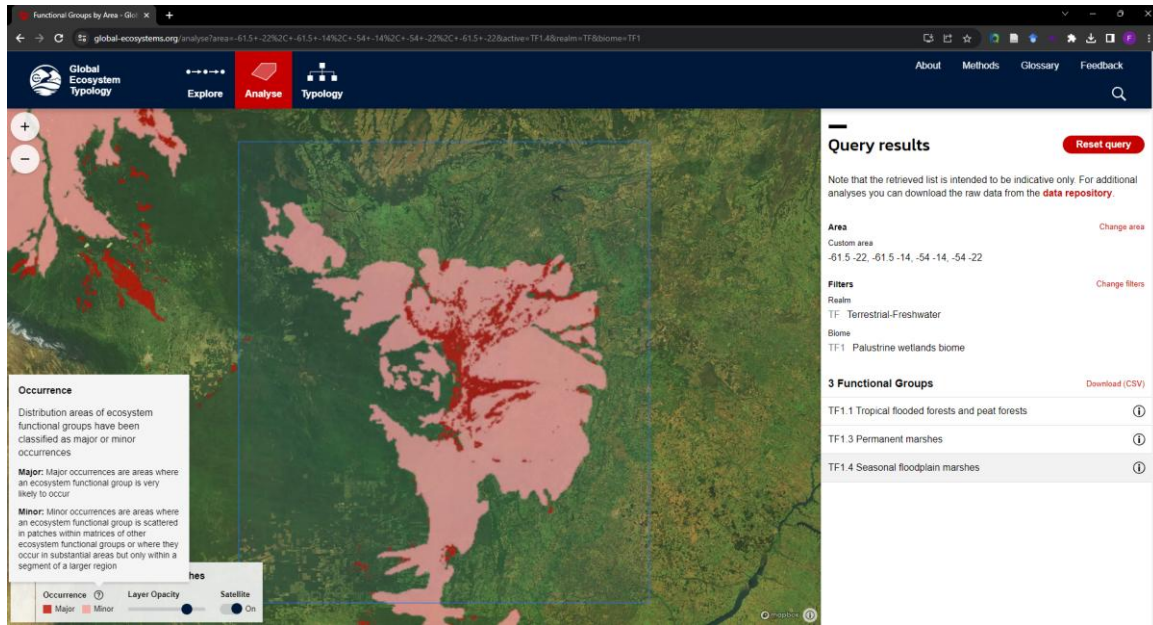
All publications found by the first step described in the Method section mention national, traditional denominations for ecosystems, habitats, and vegetation types and species. Given their focus on Pantanal habitats, Cunha et al. (2021, 2023) added some local, traditional denominations used by *pantaneiros*, the people who live in the Pantanal. These local denominations are important not only for communication, but their existence signals relevant differences for those whose survival depends on knowledge of the Pantanal. As such, they are clues for relevant differentiation of ecosystem features and functions.

- Applying EFG classification to the Pantanal

IUCN (2022) provides classification EFG maps for countries, regions, or any custom area. A data repository is also provided (KEITH et al., 2021). The produced maps are not sharp delineations of the ecosystems of any given EFG but show two levels of confidence in finding an EFG at any given region, instead. For each EFG selected, the IUCN Global Ecosystem mapping represents the occurrence of the EFG by major occurrence layers and minor occurrence layers:

- Major: Major occurrences are areas where an ecosystem functional group is very likely to occur.
- Minor: Minor occurrences are areas where an ecosystem functional group is scattered in patches within matrices of other ecosystem functional groups or where they occur in substantial areas but only within a segment of a larger region (IUCN, 2022).

Figure 2.3 - Seasonal floodplain marshes on Pantanal and surroundings.



Map of the Global Ecosystem IUCN page for the EFG TF1.4 Seasonal floodplain marshes on Pantanal and surroundings. The red areas are those with major occurrence and pink areas are those with minor occurrence.

Source: IUCN (2022).

The IUCN Global Ecosystem mapping does not delineate ecosystem assets, as each pixel could be under layers of major and minor occurrences for more than one EFG (Figure 2.3). IUCN believes this information can help researchers, policymakers, decision-makers, and other stakeholders to decide and to feedback knowledge to IUCN models for EFG mapping (KEITH et al., 2022, p. 515-516).

Trying the IUCN Global Ecosystem Typology site for Pantanal shows that much improvement can be made on the models for mapping EFGs to this region (Figure 2.3). To improve the EFG map for Pantanal produced by the classification models used by IUCN (2022), and possibly to detail lower IUCN Global Ecosystem Typology levels, we need classification models based on knowledge from local experts. This knowledge could come from adjusted global classification models for EFG or local models for IUCN Global Ecosystem Typology level 6 that fit EFG. In this sense, IBGE (1992, 2012) and Cunha et al. (2021, 2023) typologies could help to build better classification models for the IUCN Global Ecosystem Typology.

As commented previously, the Brazilian Vegetation Classification System (IBGE, 1992, 2012) was mapped many times to the Pantanal, but the habitat typology proposed by Cunha et al. (2021, 2023) has yet to be mapped. Classification models from Earth Observation (EO) and field observation data for Cunha et al. (2021, 2023) for SEEA-EA could be developed based on classification models for the Brazilian Vegetation Classification System (IBGE, 1992, 2012) extensively used for Pantanal, with adaptations to fit these two typologies together and to EFGs from IUCN Global Ecosystem Typology. The feasibility or complexity of automatic or semiautomatic classification processes for mapping ecosystem typologies to the Pantanal was not considered a criterion for selecting the assessed typologies. The selection, improvement, or development of classification models based on the assessed typologies is planned for future work.

Land cover changes in the Pantanal mainly result from seasonal variations in the annual flood pulse, wildfires, and cattle grazing. However, land cover change cannot be automatically translated to a condition or type change of an ecosystem asset. Some land cover changes define the ecosystem type and the ecosystem asset identity and must be factored out from seasonal variations that are more enduring. A criterion to decide whether a land cover change configures a change in the type of an ecosystem asset or if it is just a change in its condition is the set of ecosystem services the ecosystem asset provides, but even this may be elusive or depending on the decision making needs that drive and define the ecosystem accounting process, such as the ecosystem accounting period and the ecosystem service typology.

The period of the time series used to classify an ecosystem can even depend on the ecosystem type itself. For instance, the macrohabitat 6.2.7 Drained areas for agricultural use from Cunha et al. (2021, 2023) that matches EFG T7.1 Annual croplands may take years to be recognized as such. To identify ecosystem types defined by phenomena that take different periods, e.g., the annual pulse flood and human intervention, we need classification models based on Earth Observation (EO) data that have more than just one or two images per year (e.g., rainy season and dry season, for Pantanal), but that can provide a more detailed

and complete time series of EO data during the year, monthly, or more frequently (CAMARA, 2021).

- Applying our results or method to other regions

Our work successfully translated national typologies to IUCN Global Ecosystem Typology. If one of the typologies evaluated is used to classify ecosystems in other regions, then the translation produced by our work could be used for national SEEA-EA application to those regions with no adaptation. This may be the case for the Pantanal in Bolivia and Paraguay. In any case, our method can be adapted to search in scientific literature for typologies applied to any region or country.

- The contribution to SEEA-EA

Defining a level 6 ecosystem typology for the Brazilian Pantanal, as defined by IUCN Global Ecosystem Typology, is a first step for a subnational SEEA-EA for the Brazilian Pantanal that mirrors its ecosystems. Even if a level 6 cannot be achieved for now, either because it is too difficult to map ecosystem types too detailed to the territory, or because we cannot estimate ecosystem flows and services at that level, mapping the set of 15 EFG matched by our work to Cunha et al. (2021, 2022) and IBGE types found in the Pantanal by Carlini and Silva (2014, 2015) would be an achievement, considering that the Brazilian first exercise of the experimental version of SEEA-EA by IBGE (2021a) considered the whole Pantanal as a single ecosystem asset. For the next exercise, IBGE could use our work to improve its level of detail for the Pantanal and other Brazilian biomes, if not for level 6, at least for EFG level.

### **3 A PROTOCOL FOR SELECTING ECOSYSTEM SERVICES VALUATION DATABASE ENTRIES FOR VALUE TRANSFER**

#### **3.1 Introduction**

While healthy ecosystems underpin social well-being, community stability, and economic prosperity, the environment remains subject to mounting risks recognized across local, national, and global scales. Mitigating these threats requires the formal integration of biodiversity and ecosystem health into the core of decision-making processes, as the continued loss of ecosystem services poses significant threats to global economic stability (COSTANZA et al., 2014).

Establishing a consistent standard system for measuring environmental fluctuations and their intricate links to economic and human activity is essential particularly for the alignment of economic and financial systems with natural capital preservation (UNITED NATIONS et al., 2021).

Ecosystem accounting systematically evaluates the contributions of nature to human well-being, such as resource provisioning and climate regulation, enabling the integration of natural capital into sustainable decision-making, by enhancing the quality of information integrated from different sources for policy-making (VARDON et al., 2018).

A significant milestone was reached in March 2021 when the UN Statistical Commission adopted the System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA-EA). The establishment of this global standard provides a rigorous, standardized methodology for linking environmental health to economic prosperity, ensuring that natural capital is treated with the same statistical importance as produced capital (HEIN et al., 2022).

To ensure global consistency and comparability, SEEA-EA formally adopted the IUCN Global Ecosystem Typology (GET) as its reference classification for ecosystem assets (UNITED NATIONS et al., 2021). This hierarchical system, defined by Keith et al. (2020), categorizes ecosystems based on their functional traits and ecological processes rather than simple vegetation structure. By standardizing these definitions, the typology enables countries to map and value

diverse ecosystems, from tropical rainforests to urban green spaces, using a unified language that aligns national accounts with global environmental standards. SEEA-EA states that ecosystem accounting should be done at the third level of GET, i.e., Ecosystem Functional Group (EFG) level.

Value transfer, also known as *benefit transfer*, uses findings from existing original studies conducted in one or more specific locations, the study sites, to estimate welfare values or similar information for other locations, the policy sites (BRANDER, 2013; BURKHARD; MAES, 2017). Value transfer offers a cost-effective method to estimate ecosystem service values for national-scale accounting and decision-making in line with SEEA-EA, despite remaining methodological challenges (GRAMMATIKOPOULOU et al., 2023). Burkhard and Maes (2017) classify value transfer methods into three broad approaches, with their respective weakness and strengths:

- Unit value transfer selects appropriate values from existing primary valuation studies for similar ecosystems and socio-economic contexts and adjusts unit values to reflect differences between the study and policy sites (usually for income and price levels). It is simple, but unlikely to account for all factors that determine variation in values between study and policy sites, and value information for highly similar sites is rarely available.
- Value function transfer uses a value function derived from a primary valuation study to estimate ecosystem service values at policy sites. It allows differences between study and policy sites to be controlled for (e.g., differences in population characteristics) but requires detailed information on the characteristics of policy sites.
- Meta-analytic function transfer uses a value function estimated from the results of multiple primary studies to estimate ecosystem service values at policy sites. It allows differences between study and policy sites to be controlled for (e.g., differences in population characteristics, area of ecosystem, abundance of substitutes, etc.), too, and is practical for consistently valuing large numbers of policy sites but requires detailed information on the characteristics of policy sites and is analytically complex.

Interest in value transfer methods has been growing. Besides Burkhard and Maes (2017), Brander (2013) provides guidelines for conducting value transfer studies, including recommendations for selecting appropriate primary studies, estimating transfer errors, and conducting sensitivity analyses, and a comprehensive overview of the state of the art in value transfer methods, including a review of the literature on value transfer methods and their applications. Other guidelines can be found in Johnston and Bauer (2020) and Johnston et al. (2021).

Costanza et al. (1997) used a unit value transfer approach to estimate the “economic value of 17 ecosystem services for 16 biomes, based on published studies and a few original calculations” as between US\$16 and US\$54 trillion per year. An updated of Costanza et al. (1997) estimation by De Groot et al. (2012) was the seed for the development of ESVD, the Ecosystem Service Valuation Database.

The ESVD is the largest collection of monetary valuation data globally. It aims to make nature count in decision-making using reliable, accessible, and open-source information on the monetary value of ecosystem services through the standardization and curation of scientific publications on the estimated ecosystem service value of any part of the World.

Magalhães Filho et al. (2021) use ESVD to estimate meta-analytic functions for services from 12 biomes<sup>6</sup> and found that meta-analytic transfer performs better than unit value transfer, especially when using local explanatory variable values instead of the mean global averages. Brander et al. (2022) discuss how to handle the variety of value concepts (welfare values, exchange values, etc.) in the ESVD for value transfer consistent with SEEA-EA, specifically for the estimation of meta-analytic functions. Van 't Hoff et al. (2022) present four case studies of expected changes in ecosystem service values using value transfer methods based on ESVD. Aziz et al. (2023) compared ecosystem service valuations compiled from ESVD with local and regional derived unit values. Brander et al.

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<sup>6</sup> Using the ESVD definition for biomes.

(2024) present a synthesis of studies found in ESVD, highlighting the importance of the ESVD as a comprehensive and standardised database for ecosystem service valuation, which can be used to inform policy decisions and support sustainable development. They also discuss the challenges and limitations of using ESVD data for value transfer, including data quality, representativeness, and transferability and emphasize the need for further research to improve the robustness and applicability of value transfer methods in different contexts.

ESVD provides a Value Transfer Tool (VTT) with meta-analytic functions, one function per ESVD biome (for instance, Inland wetlands). Each meta-analytic function is obtained by regression using ESVD variables of ESVD entries as well as explanatory variables from other (non-ESVD) public sources. ESVD variables Value Year, Longitude, and Latitude are used for getting data for these explanatory variables from other sources (BRANDER et al., 2025b). A meta-analytic function based on ESVD can accelerate ecosystem service valuation for SEEA-EA. Brander et al. (2012) define a meta-analytic function for valuating ecosystem services from wetlands around the world and is cited by ESVD as “an explanation of the approach” used by VTT (BRANDER et al., 2025b).

The Pantanal is a complex of seasonally flooded savannas and forests, swamps, riparian forests, rivers, lakes, and grasslands. It is a key area for the provision of ecosystem services globally, according to Costanza et al. (1997). It provides habitat for threatened species, wintering ground for migratory species, and ecosystem services such as the regulation of river flow, provision of native pasture, and fishing resources (TOMAS et al., 2019).

There are few studies for ecosystem service valuation developed in the Pantanal, but there are many more ecosystem service valuations in ESVD for regions around the world with ecosystems like those found in the Pantanal. VTT could be used to estimate ecosystem services' value for the Pantanal. The VTT estimations (and all meta-analytic works mentioned that used ESVD) follow the ESVD ecosystem typology, that is similar but different from GET, the one used by SEEA-EA. VTT provides one meta-analytic function per ESVD biome (not GET

biome), and the values estimated would consider ecosystems not found in Pantanal, adding bias and uncertainty.

This article proposes a protocol for selecting ESVD entries for value transfer to be applied to an intended region for SEEA-EA application. The protocol implementation associates ESVD entries with EFGs, select those that satisfy requirements for meta-analytic function development for EFGs found in the intended region. It also suggests ESVD source studies to review and EFGs and services to prioritize for adding new source studies to ESVD. The Brazilian Pantanal is used as a case study to test the protocol.

### **3.2 Methods**

The protocol is made of the following steps:

- Get the content of the latest ESVD version available.
- Apply a crosswalk that translates ESVD ecosystem typology to GET.
- Select ESVD entries based on meta-analytic function requirements.
- Select ESVD entries associated to EFGs found in an intended region.

The meta-analytic function requirements to select ESVD entries were based on VTT documentation (BRANDER et al., 2025b). To make the protocol effective, only ESVD variables needed for meta-analytic function development are evaluated (Appendix B). The selection criteria are:

- One EFG per ESVD entry

The crosswalk from ESVD ecosystem typology to GET searched for a one-to-one relationship between an EFG to the ESVD ecosystem type or types associated with the ESVD entry. When a one-to-one relationship could not be established, a many-to-one or many-to-many relationship was established. A recent publication from IUCN proposes an approach for many-to-many relationships for crosswalking GET to any typology, using percentages to represent the probabilities for the relationships (KEITH et al., 2025). Considering that it is not possible to attribute the share of the monetary value in the ESVD to each of the multiple EFGs, our protocol selects only ESVD entries associated with one EFG

as result from our crosswalk from ESVD ecosystem typology to GET. This requirement is analogous to the current VTT's requirement of one ESVD ecozone per ESVD entry, adapted to use GET as the ecosystem typology.

- One SEEA service per ESVD entry

When an ESVD entry is associated with multiple services, the valuation it represents cannot be divided between its services, so only ESVD entries associated with a single SEEA service are selected.

- Standardised value must be a positive value

The standardised value (variable Int\$ Per Hectare Per Year) is the ecosystem service value used for meta-analytic function development and must not be empty. The largest cause of standardised values being empty is that the original value estimated by the source study cannot be standardised if, for example, no information is provided to assess the area and period of valuation. Besides, although ecosystem service values can technically be zero or negative, a non-positive value may lead the user to review the source study, to check if it is what was intended.

- Valuation method must be defined and not include value transfer

Valuation methods must not be empty, equal to value transfer methods (VT), or include multiple methods.

- Valuation year and site coordinates must have acceptable values

As in VTT, the valuation year and site coordinates (variables Value Year, Longitude, and Latitude) will be used to search data from other sources for meta-analytic function development. These variables must not be empty, non-numeric, or out of bounds, i.e., longitude and latitude must be in the valid range (-180 and +180 and -90 and +90), and the valuation year must be an integer between 1970 and 2025.

- Study site must have its area informed

The study site area is used by VTT regression models for considering the effect of diminishing returns as the offer of ecosystem services increase.

- ESVD entry must not come from a duplicated source study

Variable StudyId is intended to uniquely identify each source study contributing one or more ESVD entries. However, some studies have similar titles with different StudyId, which may indicate redundancy or conflicting data among the corresponding entries.

In this article, we use the term *issue* to mean that a ESVD entry does not satisfy one of the selection criteria above. It is important to note that this does not directly indicate that an ESVD entry or any of its attributes is incorrect or that this ESVD entry cannot be used for other purposes.

Arguably, including ESVD entries associated with EFGs much different from those found in the region where an estimation by value transfer is expected, may add bias and uncertainty that could be avoided. To assess this, we compared median and variation of standardized values and the number of ESVD entries selected by the protocol from ESVD, with those found for a limited set of EFGs found in an intended region. In our case study, the Pantanal is this intended region, considering the importance of its ecosystem services and wetlands' ecosystem services in general.

For this comparison, we used the set of EFGs found in the Brazilian Pantanal proposed by Dias et al. (2025). From that set, we excluded EFG T7.1 Annual croplands, because it occurs in just a few small areas in the Brazilian Pantanal, and opening new areas for croplands is forbidden. Also, ESVD has many more entries for annual croplands worldwide than the other Pantanal EFGs, and these entries could bias future meta-analytic functions for terrestrial EFGs (Table 3.1).

Table 3.1 - EFGs found in the Brazilian Pantanal.

<b>Realm / Biome / EFG</b>		
<b>Freshwater (F)</b>		
F1 Rivers and streams	F1.2	Permanent lowland rivers
	F1.5	Seasonal lowland rivers
F2 Lakes	F2.2	Small permanent freshwater lakes
	F2.3	Seasonal freshwater lakes
F3 Artificial fresh waters	F3.2	Constructed lacustrine wetlands
	F3.5	Canals, ditches, and drains
<b>Terrestrial (T)</b>		
T1 Tropical-subtropical	T1.2	Tropical and subtropical dry forests
T4 Savannas and	T4.2	Pyric tussock savannas
T7 Intensive land-use systems	T7.1	Annual croplands
	T7.4	Urban and industrial ecosystems
	T7.5	Derived semi-natural pastures and
<b>Transitional Terrestrial-Freshwater (TF)</b>		
TF1 Palustrine wetlands	TF1.1	Tropical flooded forests and peat
	TF1.3	Permanent marshes
	TF1.4	Seasonal floodplain marshes

Source: Dias et al. (2025).

### 3.3 Results

The protocol was implemented in Python programming language (PYTHON SOFTWARE FOUNDATION, 2026). Computational workflows were managed in Jupyter Notebooks (PROJECT JUPYTER, 2026) and integrated via the Quarto publishing system (POSIT, 2026). The software code and auxiliary files can be found in Dias (2026).

The ESVD version SEP2025V1.0, used in this article, contains 12,390 valuations for 37 SEEA ecosystem services distributed across 29 biomes, 103 ecozones, 3,012 locations in 166 countries. Each ESVD entry corresponds to a valuation of one or more SEEA services of one or more ecosystems from a study site, with these and other data extracted from a source study. Each valuation has a set of variables. Ecosystems are classified in a three-level structure: ESVD Biome, ESVD Ecozone, and ESVD Ecosystem (Appendix B).

All valuations in ESVD are standardised to international dollars, a hypothetical currency unit that allows the comparison of the monetary value of goods and services across countries, by adjusting the value of the US dollar to the same purchasing power in all countries (DE GROOT et al., 2012). The ESVD database uses 2020 purchasing power and exchange rates.

For SEEA-EA, SEEA ecosystem service typology and GET ecosystem typology must be used. SEEA services are already informed as a ESVD variable, but ESVD follows its own ecosystem typology, defined years before GET was published. ESVD ecosystem typology is a hierarchy of three levels: ESVD biomes, ESVD ecozones and ESVD ecosystems. A comparison between ESVD ecosystem typology and GET not yet published was obtained from ESVD team (Appendix B).

ESVD ecosystem typology translates quite well to GET at EFG level, but not perfectly. The selection criteria are based on those used by VTT, but with the association of ESVD entries to GET for compatibility with SEEA-EA. As far as we know, it is the first time ESVD is used using GET as the ecosystem typology. The crosswalk from ESVD ecosystem typology is based on ESVD team work not yet published. It is largely complete now, but will probably be adjusted and refined further during applications in the coming years. The crosswalk defines 66 EFGs from 66 ESVD ecosystems. 31 EFGs from 32 ESVD ecozones regardless of ESVD ecosystems, two EFGs from two ESVD biomes, regardless of ESVD ecozones and ecosystems. 11 EFGs are not associated with any ESVD ecosystem, and other 11 ESVD ecosystems are not associated with any EFG. We applied the crosswalk of ESVD ecosystem classification to GET to all ESVD entries. 73% resulted associated with a single EFG each.

Applying the proposed protocol to the 13 EFGs found in the Pantanal, we found 1,448 ESVD entries associated with these EFGs, but only 485 ESVD entries satisfy all selection criteria, for 12 EFGs: 55% entries for terrestrial EFGs, 31% for transitional terrestrial-freshwater EFGs, 14% for freshwater EFGs, 79% for three EFGs only. As for the broader ESVD, most entries fail more than one selection criterion, most of them associated to multiple SEEA services or with

empty or non-positive standardised values. ESVD entries associated with multiple EFGs were filtered by the selection of ESVD entries associated with EFGs found in Pantanal each (Table 3.2).

Table 3.2 - ESVD entries with issues for Pantanal EFGs.

Type of issue	Number of issues per ESVD entry				Total
	1	2	3	4	
Multiple SEEA services	220	117	96	3	436
Standardised value is empty or non-positive	132	349	103	3	587
No study site area	82	233	104	3	422
Valuation method includes VT or is multiple	28	16	11	-	55
From a duplicated study	18	16	7	3	44
No SEEA service	5	3	-	-	8
No coordinates	1	-	-	-	1

Each issue represents a selection criterion for meta-regression that is not satisfied by an ESVD entry.

We found four source studies that mention the Pantanal in their title associated with 53 ESVD entries valuating 19 SEEA ecosystem services, none of them pass all selection criteria (Appendix B).

The number of ESVD entries and services valued varies widely per EFG and SEEA service category. Terrestrial (T) and transitional Terrestrial-Freshwater (TF) EFGs are associated with many more ESVD entries and services than Freshwater (F) EFGs, possibly reflecting differences in interest and funding of research whose results are available in ESVD, not the relevance, or value of ecosystems and services studied. Provisioning and Regulating services are found associated with many more ESVD entries than Cultural and Non-use services, but this may be explained by the higher number of services under the first two categories. The number of ESVD entries associated with Cultural

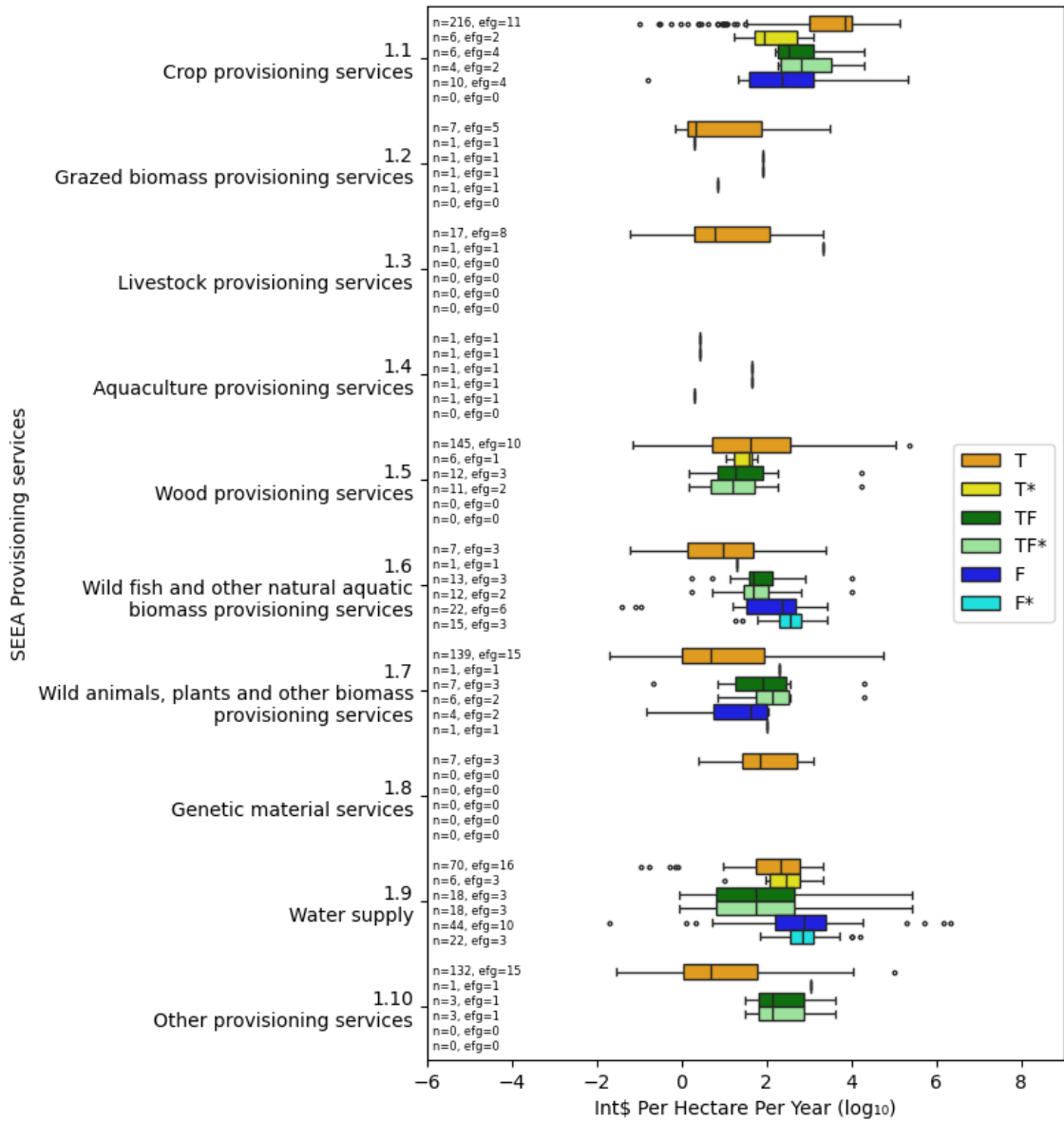
services and Non-use is interestingly high for T7.4 - Urban and industrial ecosystems and TF1.3 - Permanent marshes (Table 3.3).

Table 3.3 - ESVD entries with no issue per EFG and SEEA service category.

		Service category							
		Provisioning		Regulating		Cultural		Non-use	
EFG	EFG name	n	serv	n	serv	n	serv	n	serv
F1.2	Permanent lowland rivers	8	3	1	1	2	2	4	1
F2.2	Small permanent freshwater lakes	10	2	4	4	8	2	-	-
F2.3	Seasonal freshwater lakes	-	-	-	-	2	1	1	1
F3.2	Constructed lacustrine wetlands	-	-	4	3	1	1		
F3.5	Canals, ditches, and drains	20	2	-	-	1	1	-	-
T1.2	Tropical and subtropical dry forests and thickets	12	5	16	5	-	-	2	1
T4.2	Pyric tussock savannas	1	1	6	2	-	-	-	-
T7.4	Urban and industrial ecosystems	7	3	144	6	43	4	19	1
T7.5	Derived semi-natural pastures and old fields	4	3	5	4	10	1	-	-
TF1.1	Tropical flooded forests and peat forests	1	1	-	-	-	-	-	-
TF1.3	Permanent marshes	19	6	17	8	19	4	8	1
TF1.4	Seasonal floodplain marshes	36	7	24	6	21	3	5	1

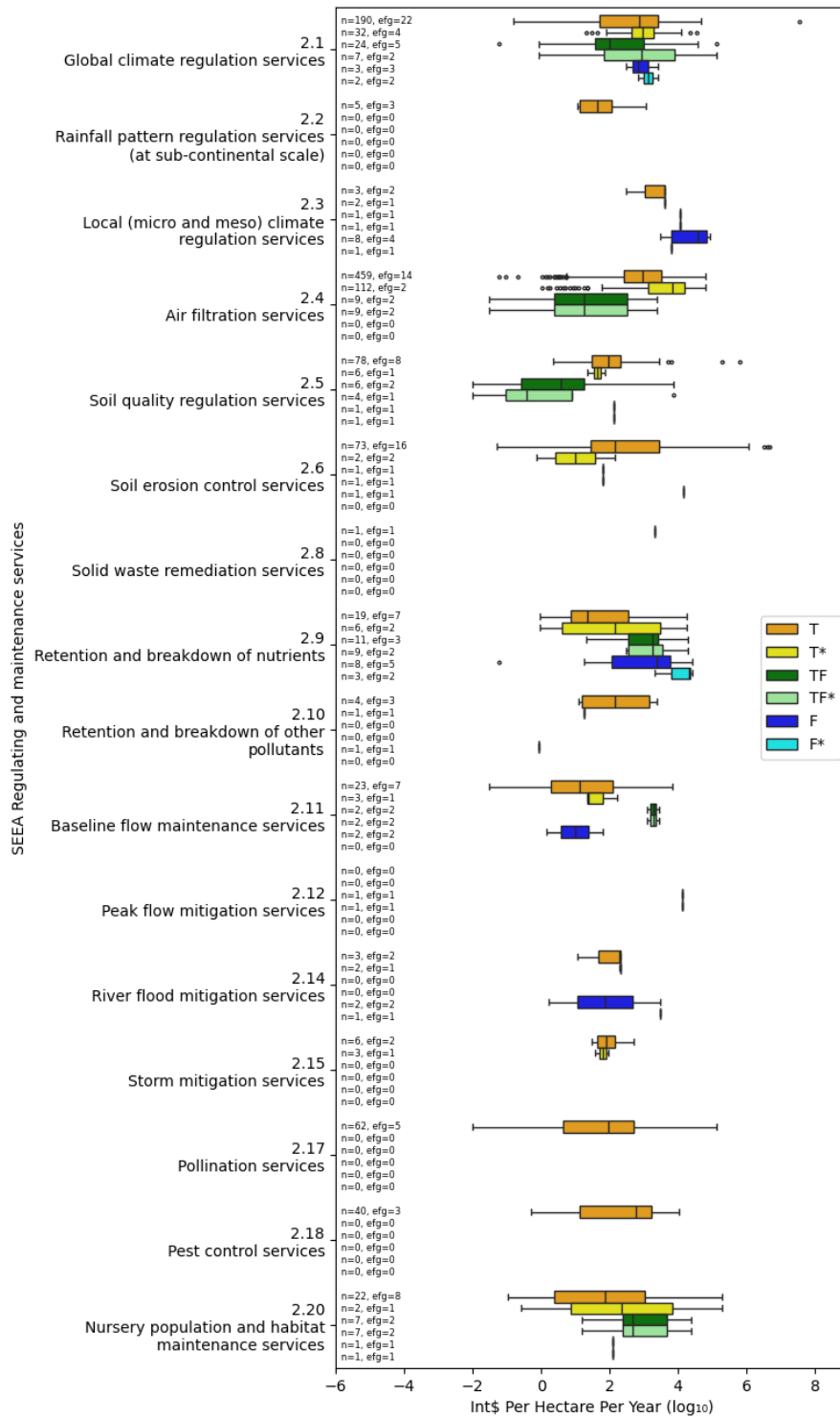
Column 'n' is the number of entries found with no issue, column 'serv' is the number of distinct SEEA services found for these entries.

Figure 3.1 - Standardised values of provisioning services.



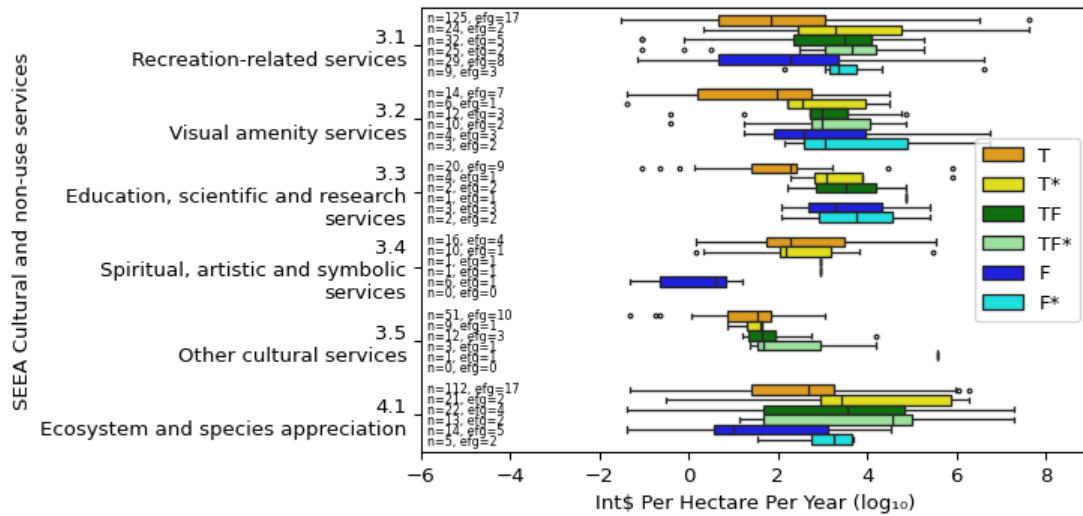
Logarithmic box plot of standardised values of Provisioning services for all EFGs from Terrestrial (T), transitional Terrestrial-Freshwater (TF), and Freshwater (F) realms, and for EFGs found in Pantanal (T\*, TF\* and F\*). *n*= is the number of ESVD entries found for each service and case, *efg*= is the number of distinct EFGs or combinations of EFGs.

Figure 3.2 - Standardised values of regulating services.



Logarithmic box plot of standardised values of Regulating services for all EFGs from Terrestrial (T), transitional Terrestrial-Freshwater (TF), and Freshwater (F) realms, and for EFGs found in Pantanal (T\*, TF\* and F\*). *n*= is the number of ESVD entries found for each service and case, *efg*= is the number of distinct EFGs or combinations of EFGs.

Figure 3.3 - Standardised values of cultural and non-use services.



Logarithmic box plot of standardised values of Cultural and Non-use services for all EFGs from Terrestrial (T), transitional Terrestrial-Freshwater (TF), and Freshwater (F) realms, and for EFGs found in Pantanal (T\*, TF\* and F\*). n= is the number of ESVD entries found for each service and case, efg= is the number of distinct EFGs or combinations of EFGs.

For terrestrial EFGs, selecting EFGs found in Pantanal changes median and reduces variations, outliers, and the number of ESVD entries available per service (Figures 3.1, 3.2, and 3.3). These changes come from the different EFGs evaluated, with different capacities for providing each service, conditions, and other differences in supply and demand. These changes suggest that it would be better to consider only EFGs from the intended region, i.e., the Brazilian Pantanal, for selecting ESVD entries used as samples to develop a meta-analytic function to estimate its ecosystem services' values, but the number of ESVD entries would be much reduced for terrestrial EFGs. Values for EFGs from the transitional Terrestrial-Freshwater (TF) and Freshwater (F) realms do not change much, but the number of ESVD entries with no issues for meta-analytic function development are already small.

Empty standardised values were found for 394 entries for some Pantanal EFGs, 11 entries have standardised values reported as zero, and none have negative standardised values (Appendix B).

248 ESVD entries with no issue for Pantanal EFGs are based on 36 studies that are also sources for 120 ESVD entries with some issues according to our protocol. We decided that a study that is a source for an ESVD entry with issues

does not jeopardize the confidence in any ESVD entry with no issue that results from the same study. To decide it otherwise would require getting back to the underlying studies, which is not a requirement for our protocol. Besides, each source study inherently includes variation between the valuations that come from it. One possible source of this variation might be that there is no standard way of reporting a valuation study, which creates more difficulties in interpreting studies.

The ESVD variables Ecosystem Condition and Protection Status could be useful for meta-analytic function transfer, but there are only 140 and 333 ESVD entries with one defined value for Pantanal EFGs and no issue in these columns, respectively. So, for meta-analytic function development, these two variables will come from other sources searching by latitude, longitude, and valuation year, as VTT does.

Other variables are not used by our protocol because they can be inferred from others or just split multi-valued variables (e.g. ecosystems and services codes and descriptions). A subset of non-redundant ESVD variables was chosen for the protocol, e.g. codes instead of descriptions, multi-valued instead of single-valued variables. One non-obvious redundancy is the country (or countries) of the study site when compared to the latitude, longitude, year of valuation, and site scale. These possible conflicts were not investigated by our protocol.

### **3.4 Discussion**

Selecting only ESVD entries associated with EFGs found in Pantanal reduced their variations and outliers, indicating a better fit of the data, but reduced the number of ESVD entries available as samples for meta-analytic functions, even if we define one meta-analytic function per GET realm. Grazed biomass and livestock provisioning services are especially relevant for Pantanal, but the number of ESVD entries for these services that pass the selection criteria are too small, and reduced to one entry only, for both services, when only Pantanal EFGs are selected.

Reviewing source studies to fix their ESVD entries may increase the number of ESVD entries available for meta-analytic development for Pantanal EFGs. The developed protocol may be used or adapted to find those source studies whose

ESVD entries are easier to fix, or more useful as samples for meta-analytic function development (Appendix B):

- Standardised value calculation demands data from other ESVD variables. Some conditions on these variables may suggest ESVD entries where empty or non-positive standardised values would be easier to fix.
- Source studies for EFGs with few entries should be reviewed first.
- Source studies in the same region or country as the intended region may be more representative.
- The missing SEEA service name may be inferred from other variables.
- An ESVD entry associated with multiple EFGs or multiple SEEA services may be split after review.

Before engaging in reviewing ESVD entries and their source studies, looking for possible fixes, users must consider that ESVD entries are the result of careful analysis of their source studies and included as disaggregated as possible. For instance, splitting the valuation per EFG or SEEA service is probably hard or not possible using information from source studies, for ESVD entries where this split was not done. Besides, most of the ESVD entries have been peer-reviewed already, and the possibilities of fixing these ESVD entries may have been retried and discarded by this peer-review process. The ESVD variable *Reviewed* signals that an ESVD entry has passed this peer-reviewing process by external experts (DE GROOT et al., 2020). Having been reviewed by this peer-reviewing process does not guarantee that the ESVD entry can be used for value transfer using meta-analytic functions. For instance, this peer-review process may lead to the conclusion that it is not possible to calculate the standardised value for an ESVD entry, even though an original value was estimated, because no information is provided by the source study to assess the area, period of valuation or beneficiaries (Appendix B), leaving it empty as a result of the review. As we stated in Methods, not satisfying the protocol's selection criteria do not mean that an ESVD entry or any of its variables are incorrect. We found that 67% of the ESVD entries selected for Pantanal by our protocol are not signalled as reviewed, and 63% of the ESVD entries for the Pantanal not selected by the protocol are

signalled as reviewed. We do not use the ESVD variable Reviewed in our protocol because we do not require source study review to select ESVD entries for value transfer, but the user may want to review source studies not reviewed yet, either to be sure that those that pass the protocol's selection criteria had already passed peer review, or to fix ESVD entries that do not pass the protocol's selection criteria, collaborating to improve ESVD using its peer-review process.

A more promising way would be to relax the constraint of selecting only ESVD entries associated with EFGs found in Pantanal, allowing the inclusion of all or some EFGs from the same GET biome, same GET realm, or EFGs for some reason believed to be considered like EFGs found in Pantanal, using the EFGs as dummy variables, as VTT already does for SEEA services. Finding the best set of EFGs to be selected per meta-analytic function demand a balance of number of ESVD samples available for meta-regression and the risk of biasing the estimations with EFGs that are extraneous to the Pantanal. Trying different regression models and different sets of EFGs demand an iterative process for testing many alternative meta-analytic functions that is left for future work.

Another possible way to increase the number of ESVD samples for regression for Pantanal EFGs is using a regression model that could handle ESVD entries associated with multiple services or multiple EFGs. For instance, we may assume that all services associated with a ESVD entry were evaluated under the same conditions defined by all other variables, and that the standardized value informed for the ESVD entry is the sum of the standardized value of the individual services. Although these assumptions may not hold for all ESVD entries, the number of ESVD entries for Pantanal EFGs whose only issue are the association with multiple services or EFGs is tempting (Table 3.3).

### **3.5 Final remarks**

Our protocol associates ESVD entries to GET and selects those that can be used for meta-analytic value transfer functions. The selection of samples associated to Pantanal EFGs only, produces significant different medians and reduces variations of standardised values per ecosystem service, but reduces the number of ESVD entries available for Pantanal too, in such a way that might jeopardize

the statistical power of meta-regression models. Reviewing ESVD entries to fix them to pass selection criteria for meta-regression or looking for more studies to add to ESVD could help, but both strategies are labour intensive with uncertain results. A more appropriate alternative is to include samples from similar EFGs for regression, for instance, from the same GET biome or realm.

The result of applying the protocol to the complete ESVD is available in Appendix B and can be used as a preliminary quality assessment of ESVD entries. The software that implements the protocol is open source (DIAS, 2026) and can be straightforwardly adapted to other selection criteria and future versions of ESVD. The results and conclusions may change for other intended regions. Using this protocol for other meta-analytic function development for SEEA-EA may stimulate the use of ESVD, the review of its source studies and entries, as well as the addition of new studies to ESVD.

## **4 META-REGRESSION FOR THE VALUATION OF ECOSYSTEMS SERVICES**

### **4.1 Introduction**

The Brazilian Pantanal wetland is the world's largest continuous tropical wetland. Located at the Upper Paraguay River Basin in the centre of South America, it covers around 150,000 km<sup>2</sup>. The Brazilian Pantanal has 64.5% of its area in the Brazilian Mato Grosso do Sul state (MS) and the remaining in the Mato Grosso state (MT). The Pantanal is a complex of seasonally flooded savannas, seasonally flooded forests, swamps, riparian forests, rivers, lakes, and grasslands. As “one of the main hotspots for ecosystem services worldwide” (1997), providing habitat for threatened species, wintering ground for migratory species and ecosystem services such as the regulation of river flow, provision of native pasture, and fishing resources (TOMAS et al., 2019).

Until 2022, 15% of the pristine natural land vegetation in the Pantanal was replaced, mainly by cultivated pastures, compared to 5% until 1985 (MAPBIOMAS, 2023c). By 2025, a 20.95% accumulated replacement of the pristine natural land vegetation was reported for the Brazilian Pantanal (INPE 2026). Agricultural suitability is low because of poor soil and the annual flooding. Extensive beef cattle production systems on natural grasslands are the main economic activity (90% of Pantanal land) in dynamic equilibrium with the flood and the conservation of Pantanal ecosystems, for two centuries already (BRAZ et al., 2020).

Pantanal conservation and the maintenance of its ecosystem services depend mostly on beef cattle ranchers' good use of the land. Market competition for higher productivity and profitability is now pressuring for intensification of beef cattle land use in the Pantanal, by suppression of natural vegetation for exotic pasture establishment. Land-use zoning specifying areas where natural vegetation suppression, pasture establishment and beef cattle grazing are allowed or forbidden could help.

According to Brazil's Native Vegetation Protection Law (12.651/2012), only the ecologically sustainable exploitation is permitted in the Brazilian Pantanal, provided that the technical recommendations of official research bodies are considered. Furthermore, new suppressions of native vegetation for alternative land use are conditional upon authorization from the state environmental agency. The Pantanal State Law (MATO GROSSO DO SUL, 2023) established the Pantanal Climate Fund, related to the State Policy on Payments for Environmental Services. Thus, the Fund will compensate those who preserve beyond the minimum established by law.

SEEA-EA is the United Nations' standard for ecosystem accounting (UNITED NATIONS STATISTICAL COMMISSION, 2021; UNITED NATIONS et al., 2021). It can be used to measure natural capital to better understand the immense contributions of nature to human well-being and the importance of its protection (UNITED NATIONS et al., 2021). SEEA-EA can foster conservation policies like payment for ecosystem services through the ecosystem service valuation.

To ensure global consistency and comparability, SEEA-EA formally adopted the Global Ecosystem Typology (GET) from the International Union for Conservation of Nature (IUCN) as its reference classification for ecosystem assets (UNITED NATIONS et al., 2021). This hierarchical system, defined by Keith et al. (2020), categorizes ecosystems based on their functional traits and ecological processes rather than simple vegetation structure. By standardizing these definitions, the typology enables countries to map and value diverse ecosystems, from tropical rainforests to urban green spaces, using a unified language that aligns national accounts with global environmental standards. SEEA-EA states that ecosystem accounting should be done at the third level of GET, i.e., Ecosystem Functional Group (EFG) level.

Conducting local primary studies for ecosystem service valuations can be costly and may not pay the precision needed. Primary ecosystem services valuation studies often encounter high costs and long timelines due to the intensive logistical requirements of methodologies like group valuation, which necessitate the organization of stakeholder workshops and potential participant payments.

Furthermore, technical complexity and the need for specialized personnel in fields significantly increase the person-years and financial resources required to achieve higher precision. Finally, researchers frequently face unpredictable data collection hurdles, including a lack of existing baseline data that forces expensive original survey implementation, as well as external environmental constraints like drought that can delay the research process (KUBISZEWSKI et al. 2022). Often, the time required to conduct such primary studies is often incompatible with the need to inform or support public policy. Waiting for these studies to be completed would make timely analysis practically infeasible, highlighting the value of using existing databases to generate reliable estimates.

Value transfer, also known as benefit transfer, uses findings from existing original studies conducted in one or more specific locations, the study sites, to estimate welfare values or similar information for other locations, the policy sites (BRANDER 2013; BURKHARD; MAES, 2017).

The simplest approach for value transfer is using statistics from other studies. In a seminal work, Costanza et al. (1997) applies global mean of unit ecosystem service values to estimate the economic value of 17 ecosystem services from published studies. More precise than global or regional averages, meta-analytic value transfer uses a value function estimated from the results of multiple primary studies to estimate ecosystem service values at policy sites. It allows for controlling differences between study and policy sites, such as population characteristics, area of ecosystem, and abundance of substitutes. Although requiring detailed information on the characteristics of policy sites and being analytically complex, it is practical for consistently valuing large numbers of policy sites (BURKHARD; MAES 2017).

A meta-analytic value transfer (DE GROOT et al., 2012) was the seed for the Ecosystem Valuation Database (ESVD), the largest collection of monetary valuation data on ecosystem services (BRANDER et al., 2025a). Since then, several other studies have used or proposed ESVD for meta-analytic value transfer, all of them using ordinary or generalized least square methods (OLS/GLS) for a log-linear regression model (AMATUCCI et al., 2024; BRANDER

et al., 2012; BRANDER et al., 2022; BRANDER et al., 2024; MAGALHÃES FILHO et al., 2021; VAN 'T HOFF et al., 2022).

A challenge for meta-regression based on ESVD samples using OLS is the large variation and long tails found in ESVD valuation distribution (Chapter 3). OLS is sensitive to outliers and tends to perform poorly in these conditions (DAVISON; HINKLEY, 1997). This problem is exacerbated for log-linear regression models, where the necessary retransformation (exponential function) can introduce significant bias if the error distribution is non-normal or heteroscedastic (MANNING; MULLAHY, 2001).

Although a crosswalk from the ESVD ecosystem typology to GET is feasible (Chapter 3), to our knowledge, no meta-regression using ESVD has yet been developed at EFG level. This may be because SEEA-EA and GET are recent frameworks.

This article presents a method to fit meta-regression models to estimate the total ecosystem service values for a set of EFGs, as well as the impact from marginal changes (1 ha) from one EFG to another. Our method avoids the assumption of homoscedasticity required by OLS regressions and applies other techniques to mitigate problems that can be introduced by the long right tails and outliers found in ESVD, and the retransformation from log-linear regression models. We apply the proposed method to the selected samples from ESVD aiming the EFGs found in the Brazilian Pantanal defined by Dias et al. (2025).

## 4.2 Background

This section presents a brief review of other studies that used ESVD for meta-regression and introduces the main statistical methods used in this article.

- Meta-analytic functions using ESVD

Magalhães Filho et al. (2021) use ESVD to estimate meta-analytic functions for services from 12 biomes<sup>7</sup> and found that meta-analytic transfer performs better

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<sup>7</sup> Using the ESVD definition for biomes.

than unit value transfer, especially when using local explanatory variable values instead of the mean global averages. Brander et al. (2022) discuss how to handle the variety of value concepts (welfare values, exchange values, etc.) in the ESVD for value transfer consistent with SEEA-EA, specifically for the estimation of meta-analytic functions. Van 't Hoff et al. (2022) present four case studies of expected changes in ecosystem service values using value transfer methods based on ESVD. Aziz et al. (2023) compared ecosystem service valuations compiled from ESVD with local and regional derived unit values. Brander et al. (2024) present a synthesis of studies found in ESVD, highlighting the importance of the ESVD as a comprehensive and standardised database for ecosystem service valuation, which can be used to inform policy decisions and support sustainable development. They also discuss the challenges and limitations of using ESVD data for value transfer, including data quality, representativeness, and transferability and emphasize the need for further research to improve the robustness and applicability of value transfer methods in different contexts.

Besides the studies mentioned, ESVD provides a Value Transfer Tool (VTT) with meta-analytic functions, one function per ESVD biome (for instance, Inland wetlands). Each meta-analytic function is obtained by regression using ESVD variables of ESVD entries as well as explanatory variables from other (non-ESVD) public sources. ESVD variables are used for getting data for these explanatory variables from other sources (BRANDER et al., 2025b). A meta-analytic function based on ESVD can accelerate ecosystem service valuation for SEEA-EA. Brander et al. (2012) define a meta-analytic function for valuating ecosystem services from wetlands around the world and is cited by ESVD as “an explanation of the approach” used by VTT (BRANDER et al., 2025b).

- Winsorization

Unusually large observations exert a disproportional impact on the analysis, potentially biasing estimated results (AGUINIS; GOTTFREDSON; JOO, 2013). One important technique to mitigate the instability caused by the long right tail is Winsorization. This technique limits the influence of outliers not by deleting them, but by replacing values beyond extreme percentiles with the nearest values within

the thresholds, thereby preserving the sample size while stabilizing the variance (TUKEY, 1962).

- Quantile Regression

Quantile Regression is a statistical methodology that extends the linear model to estimate the conditional quantiles (such as the median, 10<sup>th</sup>, and 90<sup>th</sup> percentile) of a response variable, providing a more detailed view of the data distribution than OLS, which focuses solely on the conditional mean. Unlike OLS, which assumes constant variance and is sensitive to outliers, Quantile Regression minimizes an asymmetrically weighted sum of absolute errors, making it robust to non-normal errors and suitable for analysing data where the corresponding conditional variation depends on the values of the covariates (KOENKER, 2005, p. 1).

Quantile Regression minimizes an objective function where positive residuals are weighted by ***tau*** and negative residuals by  $1 - \mathbf{tau}$ , where ***tau*** is the target quantile, such as 0.50, for the median, and 0.10 or 0.90, for the tails at 10<sup>th</sup> and 90<sup>th</sup> percentiles. This optimization problem is solved using linear programming algorithms, such as the simplex method or interior point methods. By adjusting ***tau***, the model effectively *tilts* the regression plane to pass through different segments of the data distribution, allowing for the independent estimation of slopes for the lower, median, and upper tails without assuming a specific error distribution (KOENKER, 2005). Quantile Regression is also an alternative method to OLS when heteroscedasticity is found, i.e., when the error terms in a regression model do not have a constant variance (CADE; NOON, 2003), but it usually demands larger sample sizes, particularly for estimating extreme tails (CHERNOZHUKOV, 2005).

- Bootstrapping

This resampling technique approximates the unknown sampling distribution of the estimators by treating the observed sample as a proxy for the population. In non-parametric bootstrapping with replacement,  $N$  independent bootstrap samples are generated by drawing  $n$  observations from the original dataset with replacement, ensuring that each data point has an equal probability ( $1/n$ ) of

appearing in a new sample. By calculating the statistic of interest (e.g., regression coefficients) for each resampled dataset, this method allows for the construction of robust confidence intervals, offering a "direct and simple way to estimate standard errors and confidence intervals for complex parameters" (EFRON, 1979, p. 1), particularly when analytical derivation is intractable or theoretical assumptions are violated (DAVISON; HINKLEY, 1997).

Bootstrapping can help Quantile Regression methods by avoiding the instability of standard asymptotic variance estimators in small-sample regimes (CADE; NOON, 2003), providing more reliable inference for the tail quantiles. Bootstrapping produce more reliable Confidence Intervals (CIs) for the retransformed predictions, because the bootstrap percentile method preserves the correct probability coverage after exponentiation (DAVISON; HINKLEY, 1997).

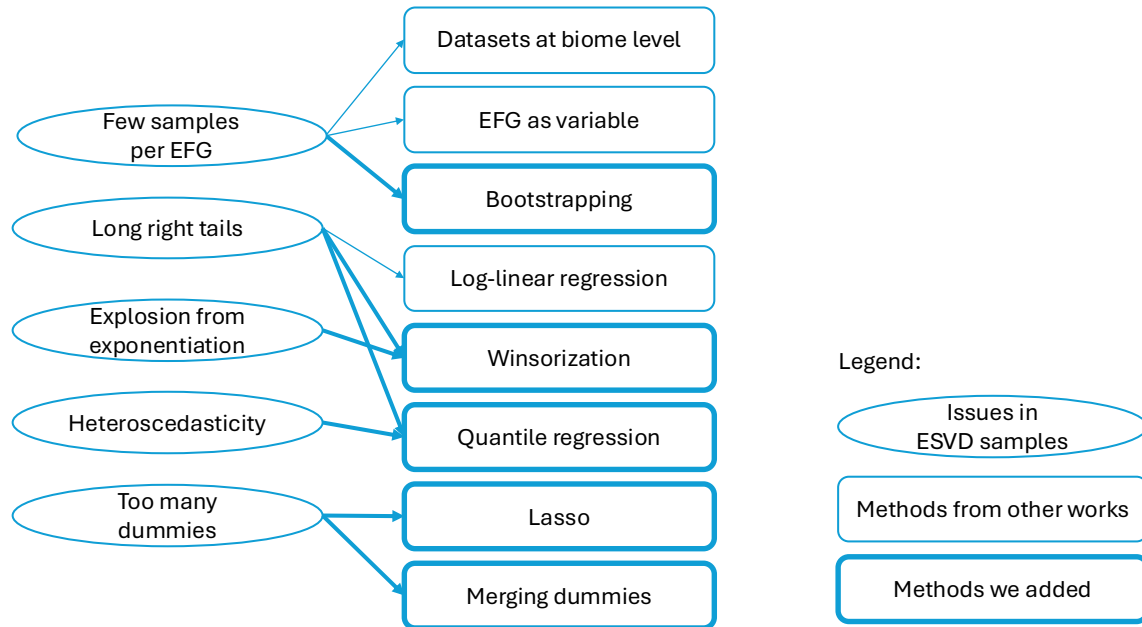
- Lasso

In a standard regression, the model minimizes error by using every variable available, even if some are irrelevant. This often leads to overfitting: the model fits the noise in the training data rather than the actual trend. The Least Absolute Shrinkage and Selection Operator (Lasso) applies a regularization penalty based on the size of the coefficients. This penalty forces the coefficients of weak or redundant variables to become exactly zero thereby performing continuous variable selection and producing sparse models that are easier to interpret than standard regression outputs. To determine the optimal degree of regularization, a resampling procedure randomly partitions the data into subsamples ("folds") to estimate the model's predictive performance. This approach allows for the objective selection of the tuning parameter that minimizes the expected generalization error, effectively balancing the "bias-variance trade-off" inherent in statistical learning (TIBSHIRANI, 1996, p. 268).

### **4.3 Method**

In the Introduction section, we mentioned previous studies that selected and used ESVD samples for meta-analyses in other regions. Figure 4.1 lists the issues found and methods used by those previous studies and ours.

Figure 4.1 - Issues on ESVD samples and methods used.



This flow chart maps the statistical challenges identified in ESVD samples (ellipses) to their respective methodological solutions (rectangles). The arrows illustrate which techniques address specific data issues. Methodological approaches are categorized into those adapted from existing literature (thin-bordered boxes) and the specific enhancements introduced in this thesis (bold-bordered boxes). The issues and methods are described in the text.

Small sample sizes were addressed by including samples from ecosystems outside the policy site that are nevertheless similar, and by using ecosystem and service types as dummy variables in the regression model. To these solutions, we added the use of bootstrapping, which was not utilized in previous works (AMATUCCI et al., 2024; BRANDER et al., 2012; BRANDER et al., 2022; BRANDER et al., 2024; MAGALHÃES FILHO et al., 2021; VAN 'T HOFF et al., 2022). Right-skewed distributions (long tails) were handled by these previous studies using log-linear regression. To cope with this problem, we added Winsorization and Quantile regression. These two new solutions also helped to prevent the "explosion" of results caused by the need to exponentiate values estimated via log-linear regression.

Quantile regression also contributes by not depending on homoscedasticity—a necessary assumption for Ordinary Least Squares (OLS) regression used in all previous studies (AMATUCCI et al., 2024; BRANDER et al., 2012; BRANDER et

al., 2022; BRANDER et al., 2024; MAGALHÃES FILHO et al., 2021; VAN 'T HOFF et al., 2022) but could not be guaranteed for our datasets.

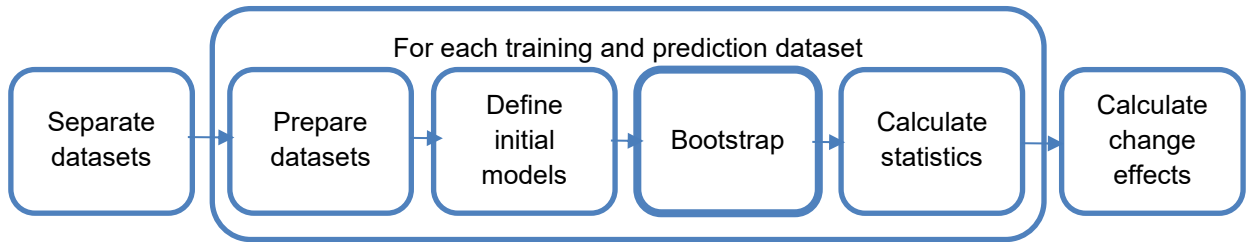
The large number of dummy variables used to represent categorical variables (ecosystems, services, and valuation methods) led us to group valuation methods into three categories based on their frequency and the expectation of similar coefficients, and services into pairs when their coefficients showed similar values.

The Lasso (Least Absolute Shrinkage and Selection Operator) technique, which zeros out coefficients for variables deemed less relevant, was applied in two stages: a preliminary phase and during bootstrapping. To select the regularization penalty that delivers the best model, i.e., the best set of variables and their coefficients, a five-fold cross-validation Lasso process is used. This five-fold process splits the training dataset randomly into 5 equal parts (folds), hides one from the regression, and test the model accuracy on the hidden fold, repeating for each of the five folds. The average error is calculated for the five runs, for each Lasso regularization penalty tested. The regularization penalty that produces the lowest average error in the five cross-validation is declared the winner and used for the final model.

We used the resulting Quantile Regression model for the 50<sup>th</sup> percentile (Q50), to estimate the expected median of total ecosystem service value for EFGs found in the Pantanal, and the impact of changing areas between EFGs. The 80% Prediction Interval (PI) is estimated by the interval between the medians of 10<sup>th</sup> and 90<sup>th</sup> percentiles (Q10 and Q90). We did not use more extreme tails (e.g., 1<sup>st</sup> or 99<sup>th</sup> percentiles) to avoid the variance explosion characteristic of sparse data regions described by Koenker (2005, pp. 77-78). This approach aligns with Cade and Noon (2003, p. 416), who used these quantiles as effective for identifying ecological limiting factors without overfitting to outliers.

The method steps are depicted in Figure 4.2 and described in the text that follows.

Figure 4.2 - The method steps.



## 1 Separate datasets

In this work we follow the recommendations of the System of Environmental-Economic Accounting - Ecosystem Accounting (SEEA-EA), that requires that ecosystem assets are classified using the Global Ecosystem Typology at the Ecosystem Functional Group (EFG) level, at least (UNITED NATIONS, 2021). The method has as inputs the ESVD, a list of EFGs found in the policy site with their respective areas and spatial coordinates, and a specification on how to select training datasets from ESVD for the EFGs found in the policy site.

The number of ESVD samples might be small if they were separated per EFG (Chapter 3), and including samples from similar EFGs may be a feasible alternative. This step associates each entry in ESVD to EFGs and filters those ready for meta-regression at biome or realm level, depending on the number of samples found, using the method described in Chapter 3. Then, it separates the filtered ESVD samples in training datasets with EFGs to include those found in the policy site or that belong to the same GET biome.

To ensure the statistical robustness of both median and boundary estimators, we restricted the analysis to training datasets with a minimum sample size of 100 samples. This sample size is critical for the stability of the Quantile Regression models, particularly for the extreme 10th and 90th percentiles. As noted by Koenker (2005), the variance of a quantile estimator is inversely proportional to the local density of observations; consequently, in small samples ( $N < 100$ ), the sparsity of data in the tails leads to 'variance explosion,' rendering PIs for these outer boundaries unreliable (HAO; NAIMAN, 2007).

This step also prepares a prediction dataset corresponding to each training dataset with EFGs found in the policy site. For each EFG in each prediction dataset, it adds one entry to represent each SEEA service found in the corresponding training dataset, assuming market price as the valuation method to be estimated.

## 2 Test homoscedasticity

After pruning, a diagnostic check for homoscedasticity is applied on each training dataset using the Breusch-Pagan (BP) test on residuals of an OLS model without bootstrapping.

## 3 Prepare datasets

To prepare each training and prediction dataset for the next steps, some transformations need to be done.

### a. Winsorize valuations

This step caps the natural log of the valuations on the training dataset to the 98% quantile. This threshold falls within the standard 1%–5% range recommended to mitigate the effect of spurious outliers (AGUINIS; GOTTFREDSON; JOO, 2013). We did not floor the lower extreme values because of their negligible effect on the log-linear regression model.

### b. Fill numeric variables

In this step we used the spatial coordinates and valuation year of the study site in training dataset and of the policy site in the prediction dataset to get values for numeric variables from sources other than ESVD.

### c. Define baseline and dummies for the categoric variables

For categoric variables, one linear coefficient must be estimated for each possible value (a category) of each variable. This demands that each category of each categoric variable be represented by a dummy variable that has value 1 or zero, except for one value, the baseline category, that is omitted to avoid co-linearity. In this step, the categoric variables EFG, SEEA service, and valuation method are replaced by N-1 dummy variables, where N is the number of categories. Their

respective most frequent values in the training dataset are used as the baseline categories.

The value type we need is the one recommended by SEEA-EA, the exchange value, provided by the market price valuation method, the most frequent in ESVD. Other valuation methods may estimate the welfare value, roughly twice the exchange value. To reduce the number of dummy variables from valuation method category, its most frequent categories are grouped according to value type they most probably estimate, and the less frequent are grouped together as a group of other valuation methods (Table 4.1).

Table 4.1 - Grouping valuation methods according to value type.

Code	Name	Group	Value type	Frequency
MP	Market price	MP	Exchange value	Baseline, most frequent
FI	Net factor income	FI_PF	Mostly exchange value	Many samples
PF	Production function			
CE	Discrete choice experiment	CV_CE_TC	Mostly welfare value	Many samples
CV	Contingent valuation			
TC	Travel cost			
DC	Damage cost avoided	Other	Mixed: exchange value or welfare value	Few samples per valuation method
DE	Defensive expenditure			
GV	Group valuation			
HP	Hedonic pricing			
IO	Input-output modelling			
OC	Opportunity cost			
OT	Other			
PP	Public pricing			
RC	Replacement cost			
RT	Restoration cost			

Valuation methods in the Ecosystem Service Valuation Database (ESVD) grouped according to their probability of representing value types: the exchange value expected by System of Environmental-Economic Accounting - Ecosystem Accounting (SEEA-EA), or welfare value, or an unknown mix of them.

To reduce the number of SEEA service dummy variables used by the bootstrapped regressions, we did a quick first log-linear regression model with lower regularization penalty to find pairs of SEEA service dummies with linear coefficients that are less than 5% different. We then merged each pair found into one dummy variable. The SEEA service dummies in the prediction dataset are merged accordingly.

#### d. Prune variables

Flipping between positive and negative values across resampling bootstrap iterations is a primary indicator of multicollinearity, where high correlation among covariates causes coefficient estimates to become erratic and sensitive to minor data fluctuations (DAVISON; HINKLEY, 1997). This step prunes (delete) numeric and dummy variables whose coefficients significantly change signals in their confidence intervals (CI), i.e., lower CI limit  $< -1e-5$  and higher CI limit  $> 1e-5$ , after a first run of 50 bootstrap iterations of a Quantile regression of the median, i.e., Q50 ( $\tau = 0.5$ ). Site area and Income per capita are not pruned regardless of the results, because we wanted to be able to evaluate their influence in all models.

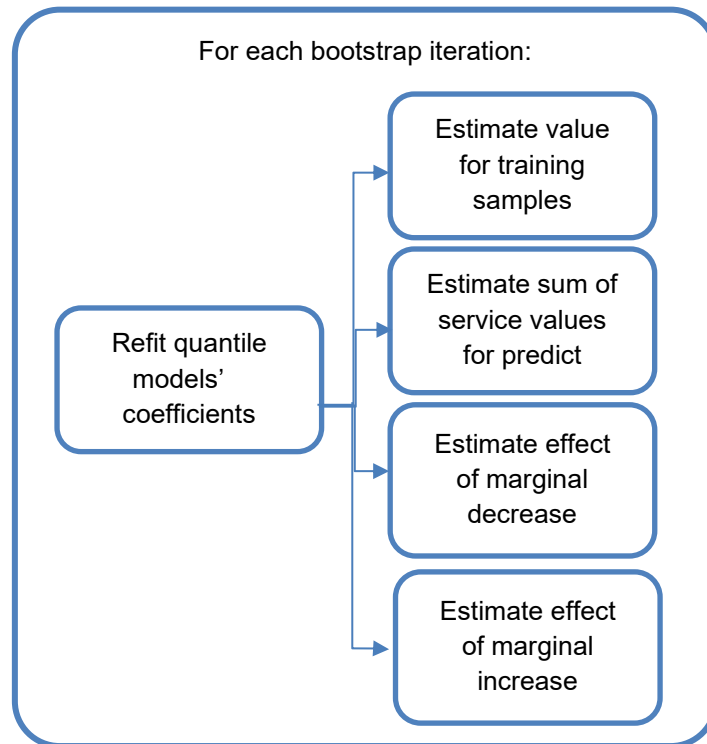
#### e. Standardize variables

To allow a fair effect of Lasso on all variables, their range must be similar. This step standardizes the remaining numeric variables not pruned using Z-score normalization to transform the original log-ized variables into variables with zero average and unit standard variation. Dummy variables are preserved in their original 0/1 format.

### 4 Define initial models

For each prepared training dataset, this step calculates three Quantile Regression models at the quantiles Q10, Q50 and Q90 ( $\tau = 0.1, 0.5$  and  $0.9$ ) and optimizes the regularization penalty for Lasso, testing the following values for the regularization penalty: 0.0001, 0.001, 0.01, 0.05, 0.1, 0.3, 0.5 using a five-fold cross-validation, for each quantile model independently.

Figure 4.3 - The bootstrap step.



## 5 Bootstrap

This step run non-parametric bootstrap iterations with replacement on each training and corresponding prediction dataset to estimate different versions of the Quantile Regression models and use them for estimations described as follows (Figure 4.3).

The bootstrap process is non-parametric, i.e., it makes no assumption on the shape of the distribution of the training data. It works with replacement because, while keeping the total count of samples used, it randomly replaces some of them by copies of others from the same training data set.

In each iteration, the coefficients for the three Quantile Regression models are recalculated using the best regularization penalty found for each of the models on the previous step, for the training dataset resampled for the bootstrap iteration. Then, using these refitted models, this step estimates: 1) ecosystem service values that would correspond to each sample in the training dataset, to assess predictions for ESVD samples; 2) the total ecosystem service value per EFG area found in the prediction dataset; 3) the effect of increasing and 4) decreasing 1 ha

in each EFG area found in the policy site dataset. The results from (3) and (4) are later used to estimate the net effect of changing 1 ha of an area under one EFG to another EFG also found in the Pantanal (for instance, clearing a 1 ha of forest for livestock grazing).

The bootstrap step is initially run with 100 iterations and repeated, doubling the number of iterations until the median and 95% CI of all coefficients change less than 10% between runs. The models and estimations of the final run are the ones used on the next steps.

## 6 Calculate statistics

This step calculates medians, and 95% CI of the coefficients for the bootstrapped Quantile Regression models. It also calculates these statistics for the total ecosystem service value estimations for the EFGs in the prediction datasets, as well the impact of marginal increase and decrease in Site area (1 ha). For more robust aggregation, we used the medians of bootstrap iterations to estimate all values, as proposed by Efron (1979).

The CI defines the range where the median is expected to lie for the set of all possible observations. CI quantifies the uncertainty of the model itself. The PI quantifies the variability of individual observations, defining the much wider range where a single observation is likely to fall. PIs (i.e., the interval between Q10 and Q90) account for both the model's uncertainty and the system's inherent random noise. We then compared the actual values in each training dataset with the 80% PIs estimated for them.

## 7 Calculate change effects

For each pair of EFGs in the prediction datasets, this step calculates the pessimistic, median, and optimistic effects of exchanging 1 ha of area between EFGs. The pessimistic estimation considers the median Q10 of the effect on total ecosystem service value of increasing 1 ha in the ecosystem asset under one EFG, and the corresponding median Q90 of decreasing 1 ha in the ecosystem asset under the EFG that would replace it, and vice-versa for the optimistic estimation. The median effect considers the median of the Q50 for both the initial and final EFGs.

#### 4.4 Policy site, training datasets, variables

Our policy site is the Brazilian Pantanal, so, following our method, we defined datasets that include EFGs that occur in Pantanal (DIAS et al. 2025). Table 4.2 shows the four training datasets of ESVD samples selected for meta-regressions. The dataset  $S_F$  includes all ESVD samples for the Freshwater GET realm. It was necessary to amass all EFGs from this realm to get enough samples that could be used for meta-regression. The sets  $S_{TF1}$  and  $S_{T1}$  includes ESVD samples of all EFGs, regardless they occur in the Pantanal or not) from the GET biomes TF1 Palustrine wetlands and T1 Tropical-subtropical forests, respectively. The set  $S_{T4+}$  includes ESVD samples for all EFGs from the GET biome T4 Savannas and grasslands and the EFG T7.5 Derived semi natural pastures and old fields. We chose to include T7.5 in  $S_{T4+}$  instead of using a separate dataset for T7 GET biome to avoid the bias that would come from intensive land use EFGs samples, like croplands and plantations.

Table 4.2 - EFGs selected per training dataset.

Realm	Biome	EFG	P	#	Dataset
Freshwater	F1 Rivers and streams	F1.1 Permanent upland streams		7	S <sub>F</sub> (118)
		F1.2 Permanent lowland rivers	Y	9	
		F1.3 Freeze thaw rivers and streams		-	
		F1.4 Seasonal upland streams		1	
		F1.5 Seasonal lowland rivers	Y	-	
		F1.6 Episodic arid rivers		-	
		F1.7 Large lowland rivers		24	
	F2 Lakes	F2.1 Large permanent freshwater lakes	B	17	
		F2.2 Small permanent freshwater lakes	Y	6	
		F2.3 Seasonal freshwater lakes	Y	2	
		F2.4 Freeze-thaw freshwater lakes		-	
		F2.5 Ephemeral freshwater lakes		-	
		F2.6 Permanent salt and soda lakes		-	
		F2.7 Ephemeral salt lakes		-	
		F2.8 Artesian springs and oases		1	
		F2.9 Geothermal pools and wetlands		-	
		F2.10 Subglacial lakes		-	
	F3 Artificial wetlands	F3.1 Large reservoirs		9	
		F3.2 Constructed lacustrine wetlands	Y	4	
F3.3 Rice paddies			18		
F3.4 Freshwater aquafarms			-		
F3.5 Canals, ditches, and drains		Y	20		
Terrestrial-Freshwater	TF1 Palustrine wetlands	TF1.1 Tropical flooded forests and peat forests	Y	1	S <sub>TF1</sub> (151)
		TF1.2 Subtropical/temperate forested wetlands		6	
		TF1.3 Permanent marshes	Y	56	
		TF1.4 Seasonal floodplain marshes	Y, B	51	
		TF1.5 Episodic arid floodplains		-	
		TF1.6 Boreal, temperate and montane peat bogs		20	
		TF1.7 Boreal and temperate fens		17	
Terrestrial	T1 Tropical-subtropical forests	T1.1 Tropical and subtropical lowland rainforests	B	347	S <sub>T1</sub> (392)
		T1.2 Tropical subtropical dry forests and thickets	Y	27	
		T1.3 Tropical and subtropical montane rainforests		18	
		T1.4 Tropical heath forests		-	
	T4 Savannas and grasslands	T4.1 Trophic savannas	B	65	S <sub>T4+</sub> (135)
		T4.2 Pyric tussock savannas	Y	4	
		T4.3 Hummock savannas		-	
		T4.4 Temperate woodlands		5	
		T4.5 Temperate subhumid grasslands		43	
	T7 Intensive land use	T7.5 Derived semi natural pastures and old fields	Y	18	Not selected
		T7.1 Annual croplands	n/a	n/a	
		T7.2 Sown pastures and fields	n/a	n/a	
T7.3 Plantations		n/a	n/a		
		T7.4 Urban and industrial ecosystems	n/a	n/a	

Realm, Biome and EFG are the three levels of the Global Ecosystem Typology (GET). P = 'Y' signals that the EFG is found in Pantanal, P = 'B' signals the most frequent EFG, used as the baseline EFG for all regressions. '#' is the number of samples selected per EFG. For each dataset, the total number of samples is between parentheses.

Table 4.3 lists the numeric variables we used and their sources. We used numeric variables similar (but not exactly) those used by the Value Transfer Tool (VTT), a set of meta-analytic functions based on ESVD data (BRANDER et al., 2025b). In its current version, VTT provides one function per ESVD biome, in

aggregations of EFGs similar to GET biomes. The only numeric variables used by VTT whose content comes from ESVD itself is the Site area, all other variables come from public georeferenced datasets. In  $S_{TF1}$  and  $S_{T4}$  datasets, we included the numeric variables that VTT uses for Wetlands and Grasslands, respectively. In  $S_{T1}$  dataset, we included the variables VTT uses for Temperate forests, because the current version of VTT does not offer meta-regression for Tropical forests. In the  $S_F$  dataset, we included the variables VTT uses for Wetlands, except for the percent of water coverage, because the current version of VTT does not offer meta-regression for Tropical forests. Most of the sources of these variables are Google Earth datasets accessed using Google Earth Engine API. The remaining datasets are files downloaded from other sites, in different formats. The documentation available for VTT was incomplete or outdated for some variables, and we searched and chose the most convenient source for some cases.

Table 4.3 - Numeric variables per training dataset.

Variable	S <sub>F</sub>	S <sub>TF1</sub>	S <sub>T1</sub>	S <sub>T4+</sub>	Source	Comment
Site area (ha)	Yes	Yes	Yes	Yes	ESVD	
Income per capita (Int \$ per cap 2020)	Yes	Yes	Yes	Yes	(*1)	Values per year, at country level.
Elevation (m)	Yes	Yes	Yes	Yes	USGS/SRTMGL1_003 (*2)	NASA Shuttle Radar Topography Mission Digital Elevation 30m. This variable is absent in VTT documentation.
Protected Area (%)	Yes	Yes	Yes	Yes	WCMC/WDPA/current /polygons (*2)	VTT documentations says: "World Database of Protected Areas (WDPA)"
Population Density, 30km (persons per km <sup>2</sup> )	Yes	Yes		Yes	CIESIN_GPWv411_GPW_Population_Density (*2)	5 datasets: 2000 - 2005 - 2010 - 2015 - 2020
Population Density, 10km (persons per km <sup>2</sup> )			Yes			
Biodiversity Intactness	Yes	Yes			<a href="http://dx.doi.org/10.5519/0009936">http://dx.doi.org/10.5519/0009936</a>	How much of an area's original biodiversity is still present and functioning compared to its natural state. An ASCII raster file.
Ecosystem Productivity				Yes	MODIS/061/MOD17A3HGF (*2)	The ratio of Net Primary Productivity (NPP) at the ecosystem in the year of analysis, and its historic maximum.
Land cover, water, 30km (%)		Yes			MODIS/061/MCD12Q1 (*2)	Each land cover type.
Land cover, forest, 50km (%)			Yes			
Land cover, grassland, 10 km (%)				Yes		
Road density, 10km (m/km <sup>2</sup> )			Yes		(*3)	Global road density raster files (5 arcminutes) with the Total density, all types combined, available at: <a href="https://www.globio.info/download-grip-dataset">https://www.globio.info/download-grip-dataset</a>
Road density (m/km <sup>2</sup> )				Yes		
Nighttime light (nW/cm <sup>2</sup> /sr)				Yes	NOAA/VIIRS/DNB/MONTHLY_V1 /VCMCFG (*2)	

(\*1) <https://ourworldindata.org/grapher/gdp-per-capita-worldbank>

(\*2) A dataset from Google EarthEngine datasets: <https://developers.google.com/earthengine/datasets/catalog/>

(\*3) [https://dataportaal.pbl.nl/downloads/GRIP4/GRIP4\\_density\\_total.zip](https://dataportaal.pbl.nl/downloads/GRIP4/GRIP4_density_total.zip)

There are some recent and ongoing efforts to map EFG globally, such as GET, that provides a web page with open data and EFG maps (2025a), and the Global Ecosystem Atlas, now in its beta version (GLA, 2025), but for Pantanal these works are not complete, and large areas are unclassified still.

As there is no EFG map that covers the Brazilian Pantanal, we used the ecosystems areas from Bolzan et al. (2021) as proxy. Table 4.4 associates each ecosystem identified by Bolzan et al. (2021) to an EFG in Pantanal defined by Dias et al. (2025). We used 2020 as the valuation year and the geodesic centre of the Pantanal as the spatial coordinates to get the other numeric variables from other sources.

Table 4.4 - Area of Pantanal EFGs.

<b>Pantanal ecosystems</b>	<b>Area (ha)</b>	<b>EFG</b>
Freshwater	612,979	F1.2 Permanent lowland rivers
Wetlands	599,399	TF1.4 Tropical flooded forests and peat forests
Tropical forest	4,766,344	T1.2 Tropical subtropical dry forests and thickets
Woodland	2,143,946	T4.2 Pyric tussock savannas
Grassland	4,309,942	T7.5 Derived semi natural pastures and old fields
Livestock	2,528,129	
<b>Total</b>	<b>14,960,739</b>	

Pantanal ecosystem areas from Bolzan et al. (2021) associated with Ecosystem Functional Groups (EFG) as defined by the Global Ecosystem typology that can be found in Pantanal, according to Dias et al. (2025) and that were considered for meta-regression in this work. Source: Bolzan et al. (2021), with adaptations. Source: Bolzan et al. (2021), with adaptations.

#### **4.5 Results and discussion**

The method was implemented in software using the Python programming language (PYTHON SOFTWARE FOUNDATION, 2026). Computational workflows were managed in Jupyter Notebooks (PROJECT JUPYTER, 2026) and integrated via the Quarto publishing system (POSIT, 2026). The software code and auxiliary files can be found in Dias (2026).

Estimations stabilized after 2000 bootstrap iterations, with changes on coefficients CIs being lower than 10% when the number of iterations was increased to 5000. The results presented here are those obtained after 5000 iterations.

As stated in the Method section, Winsorization was applied to the natural log of the valuations, in training datasets before any meta-regression is made (Table 4.5). After some trials, we chose to cap at 98% as the optimum balance between number of samples affected and the effect on the maximum value. Less than 3% of the samples per training dataset were affected, but with a strong effect: maximum values considered for regression were reduced in 82%, 75%, 99%, and 89% for the datasets defined for the policy site:  $S_F$ ,  $S_{TF1}$ ,  $S_{T1}$  and  $S_{T4+}$ , respectively.

Table 4.5 - The Winsorization effects.

<b>Datasets</b>	<b><math>S_F</math></b>	<b><math>S_{TF1}</math></b>	<b><math>S_{T1}</math></b>	<b><math>S_{T4+}</math></b>
<b>Samples</b>	118	151	392	135
<b>EFGs</b>	12	6	3	5
<b>SEEA Services</b>	15	20	21	21
<b>Min</b>	0.02	0.01	0.01	0.03
<b>Median</b>	358.33	139.47	12.8	40.75
<b>Mean</b>	41,169.63	14,256.61	14,663.10	4,450.14
<b>Max</b>	2,089,021.41	524,404.34	3,277,699.67	281,142.36
<b>Mean after cap</b>	15,884.56	10,059.02	2,192.03	1,305.21
<b>Max after cap</b>	370,614.59	130,947.89	32,268.95	29,847.25
<b>Rows capped</b>	3	4	8	3

Number of samples, number of distinct Ecosystem Functional Groups EFGs as defined by the IUCN Global Ecosystem Typology, and the number of distinct SEEA services as defined by the System of Environmental-Economic Accounting - Ecosystem Accounting (SEEA-EA) associated with them, their minimum, median, mean and maximum valuations in in Int \$/ha/yr. The limit at 98% quantile (Max after cap), the mean after cap and number of samples affected (Rows capped) are also shown. Datasets  $S_F$ ,  $S_{TF1}$ ,  $S_{T1}$ ,  $S_{T4+}$  are described in the Method section.

The ESVD samples that were capped and their source studies deserve further investigation (Table 4.6). For instance, all three valuations capped for  $S_F$  are from the same study. For  $S_{TF1}$ ,  $S_{T1}$  and  $S_{T4+}$ , the valuations came from different studies, two decades of publications and different SEEA services, some are technical reports, but there are also articles published in indexed journals. Half of the valuations for  $S_{TF1}$ ,  $S_{T1}$  and  $S_{T4+}$  are for the SEEA services 4.1 - Ecosystem and species appreciation, indicating that this service maybe a common source of extreme valuations for the GET biomes and EFGs represented by these datasets.

Table 4.6 - ESVD samples capped to 98% quantile.

Dataset	Reference	EFG	Service	Valueld	Int\$ per ha per Year	Capped to
S <sub>F</sub>	Zhao, X., He, Y., Yu, C., Xu, D., & Zou, W. (2019). Assessment of Ecosystem Services Value in a National Park Pilot. <i>Sustainability</i> , 11(23), 6609.	F2.1	1.9	9230004	2,089,021.41	370,614.59
				9230014	1,494,491.50	370,614.59
				9230024	511,969.92	370,614.59
S <sub>TF1</sub>	Kosz, M. (1996). Valuing riverside wetlands: the case of the "Donau-Auen" national park. <i>Ecological Economics</i> , 16(2), 109-127. Chen, Z. M., Chen, G. Q., Chen, B., Zhou, J. B., Yang, Z. F., & Zhou, Y. (2009). Net ecosystem services value of wetland: Environmental economic account. <i>Communications in Nonlinear Science and Numerical Simulation</i> , 14(6), 2837-2843. Valasiuk, S., Giergiczny, M., Zylicz, T., Klimkowska, A., and Angelstam, P. (2018). Conservation of disappearing cultural landscape's biodiversity: are people in Belarus willing to pay for wet grassland restoration?. <i>Wetlands Ecol Manage</i> , 26, 943–960. <a href="https://doi.org/10.1007/s11273-018-9622-y">https://doi.org/10.1007/s11273-018-9622-y</a>	TF1.3	4.1	3680001	524,404.34	130,947.89
		TF1.3	1.9	1510003	261,954.48	130,947.89
		TF1.7	4.1	11150002	240,321.31	130,947.89
S <sub>T1</sub>	Samdin, Z. (2008). Willingness to pay in Taman Negara: A contingent valuation method. <i>International Journal of Economics and Management</i> , 2(1), 81-94. Brander & Yeo (2021). Report on the economic value of ecosystem services from Endau Rompin National Park. Component report of the PA financing Project consultancy project on The Economics of Ecosystems and Biodiversity of Terrestrial Protected Areas in Peninsula Malaysia (TEEB-PA) Ndiaye, M., Ndiaye, S., Modou Sarr, S., & Diouf, M. (2021). Estimation Of The Value Of Goods And Services Produced By Protected Areas: Case Of The Ndock Sare Community Forest In Senegal. <i>European Scientific Journal ESJ</i> , 17(43), 282–292. Awang Noor, A. G., Norini, H., & Khamurudin, M. N. (2007). Valuing the rain forest: The economic values of selected forest goods and services in Ayer Hitam Forest Reserve, Puchong, Selangor. <i>TROPICAL GRICULTURAL SCIENCE</i> , 30(2), 141. Brander & Yeo (2021). Report on the economic value of ecosystem services from Taman Negara National Park Stults, S. (2018). Quantifying Environmental Services: A Spatial Analysis of Northern Guatemala.	T1.1	3.1	13080003	3,277,699.67	32,268.95
		T1.1	4.1	9280037	758,427.67	32,268.95
		T1.2	4.1	13740005	734,717.92	32,268.95
		T1.1	3.1	10970008	205,456.16	32,268.95
		T1.1	4.1	9330037	53,569.84	32,268.95
		T1.1	2.1	12700006	47,602.67	32,268.95
		T1.1	2.1	12700012	36,065.27	32,268.95
T1.1	2.1	12700011	33,275.37	32,268.95		
S <sub>T4+</sub>	Robinson, P., van Schendel, M., Botzen, W., van Beukering, P., van den Heuvel, R., Koetse, M., & Aerts, J. (2022). Economische waardering van natuur en landschap in Zuid-Limburg. Resende, F. M., Fernandes, G. W., & Coelho, M. S. (2013). Economic valuation of plant diversity storage service provided by Brazilian rupestrian grassland ecosystems. <i>Brazilian Journal of Biology</i> , 73(4), 709-716. Farinha, M. J. U. S., Bernardo, L. V. M., Soares Filho, A., Berezuk, A. G., da Silva, L. F., & Ruviano, C. F. (2019). Opportunity cost of a private reserve of natural heritage, Cerrado biome–Brazil. <i>Land use policy</i> , 81, 49-57.	T4.5	4.1	12120031	281,142.36	29,847.25
		T4.2	2.20	9660002	196,993.60	29,847.25
		T4.2	2.1	9610001	35,970.95	29,847.25

Entries from Ecosystem Service Valuation Database (ESVD) whose valuations in Int\$ per ha per year were capped by Winsorization as described in the Method section. Valueld is a unique identification for each valuation. Each valuation is associated with an Ecosystem Functional Group (EFG) as defined by the IUCN Global Ecosystem Typology, and a SEEA service as defined by the System of Environmental-Economic Accounting - Ecosystem Accounting (SEEA-

EA). The new value used for meta-regression after Winsorization is shown. Datasets  $S_F$ ,  $S_{TF1}$ ,  $S_{T1}$ ,  $S_{T4+}$  are described in the Method section. See also Table 4.5.

Only  $S_{T4+}$  dataset has its OLS model passing the global homoscedasticity test ( $p$ -value = 0.2176), so we limited our discussion on Quantile Regression results. All results of homoscedasticity tests are on Appendix C. Appendix C also presents the complete list of variables, the median and mean values and 95% CI for the coefficients of the Quantile Regression models for Q10, Q50 and Q90. We discussed the variables and coefficients found per dataset in the paragraphs that follow.

Table 4.7 - Variables selected.

Variables		ESVD training dataset			
		$S_F$	$S_{TF1}$	$S_{T1}$	$S_{T4+}$
<b>EFGs</b>	Initial	11	5	2	4
	Pruned	-	2	2	2
	Q10	-	-	-	-
	Q50	-	2 (1)	-	2
	Q90	8	1 (1)	-	-
<b>SEEA services</b>	Initial	15	20	21	21
	Pruned	-	9	4	12
	Q10	-	-	5(1) + 12 (2)	-
	Q50	-	6 (1) + 4	5 (1) + 12	3 + 6 (2)
	Q90	4 (1) + 4	4 + 4	5 (2) + 12 (6)	-
<b>Valuation method groups</b>	Initial	3	3	3	3
	Pruned	-	2	3	-
	Q10	-	-	-	-
	Q50	1	1	-	3 (1)
	Q90	2 (1)	1	-	-
<b>Numeric variables</b>	Initial	5	6	7	9
	Pruned	-	2	5	6
	Q10	5	3	2 (1)	3
	Q50	5	4 (1)	2 (1)	3 (1)
	Q90	4 (1)	4 (2)	2	-

After 5000 non-parametric bootstrap iterations with replacement. Variables available in each dataset are counted in 'Initial'. Variables pruned before bootstrapping are counted in 'Pruned'. Variables that survived the pruning and were selected by Lasso for each quantile are counted per quantile (Q10, Q50, Q90). Unstable variables (coefficients with positive and negative values in their 95% CI) are represented in '( )'. Variables nullified by Lasso are not counted. Services merged in pairs with similar coefficients are counted after '+'. Baseline categories (Table 4.1) were not counted. Datasets  $S_F$ ,  $S_{TF1}$ ,  $S_{T1}$ ,  $S_{T4+}$  are described in the Method section.

Table 4.7 compares the number of variables effectively used, variables initially available in the training datasets, and variables pruned before bootstrapping. Many

variables were pruned or had their coefficients nullified by Lasso for Quantile Regression.

The rejection of all dummy variables for Q50 model from  $S_F$  dataset means that any estimation of the median for freshwater ecosystem services considers all EFG, SEEA services and valuation methods as indistinguishable from their respective baselines (Table 4.7 and 4.8). Five numeric variables were selected for all quantiles from  $S_F$  dataset, all of them stable, i.e., either positive or negative in their 95% CIs (Table 4.9). The negative coefficient for Site area is explained by the effect of diminishing returns, i.e., when more service is provided, its unit value is reduced, but the Site area coefficient for  $S_F$  (and its effect on ecosystem service value) is the lowest of all datasets. Elevation and biodiversity increase ecosystem service offer, but with negligible effects (median zero). Population density around increases its demand, with a strong positive effect on ecosystem value. A negative coefficient for Income per capita would mean that higher income per capita means lower demand on services, but its median is zero, so its effect is negligible.

The Q50 model for  $S_{TF1}$  have two EFGs selected as variables: TF1.7 (stable) and TF1.2 (unstable), none of them found in Pantanal. TF1.4, the baseline EFG, is found in Pantanal, and the other two EFGs found in Pantanal (TF1.1 and TF1.3) were absorbed by this baseline. TF1.6, not found in Pantanal, was absorbed by the baseline, too, and may bias the estimations for wetlands in Pantanal (Appendix C). Half of the 20 SEEA services found for  $S_{TF1}$  were selected for Q50, one of them with an unstable coefficient, and most of them with zero median, meaning that their estimations are not much different from the baseline (Table 4.8). The negative coefficient for Site area, representing the diminishing return effect, is the highest of all datasets. The coefficient for Income per capita is unstable, with a slightly positive signal, that correspond to the expected, but uncertain, effect. The population density and elevation variables have positive and strong effects (Table 4.9).

Table 4.8 - SEEA services per dataset and their factors.

SEEA service		S <sub>F</sub>		S <sub>TF1</sub>		S <sub>T1</sub>		S <sub>T4+</sub>	
		N	Q50 [95%CI]	N	Q50 [95%CI]	N	Q50 [95%CI]	N	Q50 [95%CI]
1. Provisioning	1.1 Crop	8	1.00	3	1.18 [1.00; 14.53]	14	8.49 [1.52; 70.99]	3	0.26 [0.03; 1.00]
	1.2 Grazed biomass	-	-	1	2.06 [1.00; 69.48]	1	437.94 [35.35; 3,684.24]	3	1.00 [0.15; 1.00]
	1.3 Livestock	-	-	-	-	-	-	1	1.00 [1.00; 53.74]
	1.4 Aquaculture	1	1.00	-	-	-	-	1	1.00
	1.5 Wood	-	-	9	1.00	49	17.34 [7.47; 39.72]	15	1.00
	1.6 Wild fish and other natural aquatic biomass	11	1.00	9	1.00	5	1.00	1	1.00 [1.00; 4.75]
	1.7 Wild animals, plants and other biomass	1	1.00	3	1.00 [0.50; 1.00]	60	1.00	13	1.00
	1.8 Genetic material services	-	-	-	-	5	62.67 [25.62; 223.55]	-	-
	1.9 Water supply	35	<b>(B)</b>	14	0.60 [0.09; 1.00]	9	62.67 [25.62; 223.55]	7	1.00
	1.10 Other provisioning	-	-	3	1.00	64	<b>(B)</b>	12	1.00
2. Regulation	2.1 Global climate	2	1.00	21	1.00	35	6,366.56 [126.30; 21,172.79]	11	1.00
	2.2 Rainfall pattern (at sub continental scale)	-	-	-	-	3	437.94 [35.35; 3,684.24]	-	-
	2.3 Local (micro and meso) climate	8	1.00	1	1.00	-	-	1	1.00 [1.00; 4.75]
	2.4 Air filtration	-	-	6	1.00 [0.44; 2.99]	1	33.03 [1.00; 102.71]	6	0.78 [0.24; 1.03]
	2.5 Soil quality	-	-	6	0.34 [0.02; 1.00]	11	36.25 [8.88; 102.18]	-	-
	2.6 Soil erosion control	1	1.00	1	1.00	15	36.25 [8.88; 102.18]	1	1.00 [0.15; 1.00]
	2.9 Retention and breakdown of nutrients	6	1.00	5	1.00 [1.00; 2.75]	1	43.01 [1.00; 386.73]	-	-
	2.10 Retention and breakdown of other pollutants	1	1.00	-	-	1	43.01 [1.00; 386.73]	1	1.00
	2.11 Baseline flow maintenance	2	1.00	2	1.00 [1.00; 9.07]	5	33.40 [0.38; 788.65]	8	1.00
	2.12 Peak flow mitigation	-	-	1	1.18 [1.00; 14.53]	-	-	-	-

(continue)

Table 4.8 - Conclusion.

SEEA service		S <sub>F</sub>		S <sub>TF1</sub>		S <sub>T1</sub>		S <sub>T4+</sub>	
		N	Q50 [95%CI]	N	Q50 [95%CI]	N	Q50 [95%CI]	N	Q50 [95%CI]
2. Regulation	2.14 River flood mitigation	1	1.00	-	-	-	-	-	-
	2.17 Pollination	-	-	-	-	50	86.98 [18.01; 261.40]	-	-
	2.20 Nursery population and habitat maintenance	-	-	5	1.00	4	8.49 [1.52; 70.99]	3	1.00 [1.00; 266.09]
3. Cultural	3.1 Recreation related	20	1.00	23	<b>(B)</b>	23	86.98 [18.01; 261.40]	10	0.78 [0.24; 1.03]
	3.2 Visual amenity	-	-	6	1.00	-	-	2	1.00
	3.3 Education, scientific and research	1	1.00	2	1.00	2	1.00	4	1.00
	3.4 Spiritual, artistic and symbolic	6	1.00	-	-	-	-	2	1.00
	3.5 Other cultural services	-	-	12	1.00	2	1.00	17	<b>(B)</b>
4. Non-use	4.1 Ecosystem and species appreciation	14	1.00	18	2.06 [1.00; 69.48]	30	44.91 [9.84; 556.48]	13	1.00

Factors were calculated as the exponential of the coefficient found for Q50 and its 95% confidence interval. Services not associated with any ESVD sample from the dataset are signalled as '-'. The baseline service for each dataset is signalled with (B) and has an implicit factor of 1 (the exponential of coefficient 0). Services associated with one or more ESVD samples in the dataset, but whose dummy variables were not selected by Lasso for Q50 are signalled with (1), meaning its estimations will be the same of the baseline service for the dataset, hence, with the same factor 1. Service names were simplified, by removing the suffixes *provisioning*, *regulating*, *services* and their combinations. N is the number of samples for the service. Services associate with no sample were omitted (2.7 Landslide mitigation, 2.8 Solid waste remediation, 2.13 Coastal protection, 2.15 Storm mitigation, 2.16 Noise attenuation, 2.18 Pest control, 2.19 Disease control, 2.21 Other regulating and maintenance).

Table 4.9 - Coefficients of numeric variables for Q50.

Variable	ESVD training dataset			
	S <sub>F</sub>	S <sub>TF1</sub>	S <sub>T1</sub>	S <sub>T4+</sub>
Site area (ha)	-0.0865 [-0.2290; 0]	-0.5388 [-0.7442; -0.3570]	-0.3681 [-0.4998; -0.1907]	-0.1743 [-0.4461; 0.0353]
Income per capita (Int \$ per cap 2020)	0 [-0.7158; 0]	0.1190 [-0.3230; 0.6185]	0.0072 [-0.5147; 0.3768]	1.1279 [0; 2.1463]
Elevation (m)	0 [0; 0.2988]	0.5922 [0.0581; 1.0921]	P	P
Biodiversity Intactness	0 [0; 1.5669]	P	n/a	n/a
Protected Area (%)	n/a	n/a	P	-0.1515 [-0.3074; 0]
Population Density, 30km (persons per km <sup>2</sup> )	0.4726 [0.1746; 0.6069]	0.3093 [0; 0.7187]	n/a	P
Population Density, 10km (persons per km <sup>2</sup> )	n/a	n/a	P	n/a
Ecosystem Productivity	n/a	n/a	n/a	P
Land cover, water, 30km (%)	n/a	P	n/a	n/a
Land cover, forest, 50km (%)	n/a	n/a	P	n/a
Land cover, grassland, 10 km (%)	n/a	n/a	n/a	P
Road density, 10km (m/km <sup>2</sup> )	n/a	n/a	P	n/a
Road density (m/km <sup>2</sup> )	n/a	n/a	n/a	P
Night-time light (nW/cm <sup>2</sup> /sr)	n/a	n/a	n/a	P
CV_CE_TC	0 [-0.1541; 0]	1.4060 [0.1244; 2.5599]	P	1.5037 [0; 3.4537]
FI_PF	0	P	P	0 [0; 2.1978]
Other	0	P	P	0 [-1.6909; 0.6935]

Medians of coefficients for Q50 quantile and 95% confidence interval from 5000 non-parametric bootstrap iterations with replacement for numeric variables and valuation method group dummies (last three rows). All numeric variables are used in regression model as their natural logs, except for Biodiversity index. Some numeric variables were not tested for the dataset (n/a) or were pruned in a first step (P). See Table 4.3 for the sources and description of numeric variables. See Table 4.1 for the description of dummy variables for valuation method group. Datasets S<sub>F</sub>, S<sub>TF1</sub>, S<sub>T1</sub>, S<sub>T4+</sub> are described in the Method section.

No EFG was selected by Lasso for any model of S<sub>T1</sub>, meaning that any estimation from this model applies to any EFG of the T1 biome, reducing all models for S<sub>T1</sub> to

the biome it represents (Table 4.7). The deletion of all EFG dummies may be explained by the fact that  $S_{T1}$  samples have only three EFGs, and the most frequent, chosen as baseline, represents 87% of the samples (Table 2.1). The Q50 model for the dataset  $S_{T1}$  presents a mix of effects from many SEEA services (17, one unstable) and just two numeric variables: Site area, with the expected negative sign on its coefficient and a relevant effect, and Income per capita, unstable, with negligible median coefficient (Table 4.7 and 4.9). All but one SEEA service variable have positive coefficients, meaning that all these services are found to be more valuable than the baseline SEEA service 1.10 - Other provisioning services (Table 4.8). Differently from the other datasets, the coefficients for SEEA service in  $S_{T1}$  vary a lot, making the expected median estimation for the SEEA global climate regulating services to represent more than six thousand times the estimations for the baseline, other provisioning services. The grazed biomass provisioning service and rainfall pattern regulating services (at sub continental scale) are the second most valuable, more than four hundred times the baseline service.

Two EFGs were selected for the Q50 model of the dataset  $S_{T4+}$ , one of them, EFG T7.5, is found in Pantanal and has a relevant negative coefficient (Appendix C). Other two EFGs were absorbed by the baseline T4.1, not found in Pantanal. One of the EFGs not selected and absorbed by the baseline is T4.2, that is found in Pantanal, so the estimations for this EFG may be biased by the baseline and the other EFG absorbed (T4.3). Most of the coefficients for SEEA services for  $S_{T4+}$  have median zero (representing a multiplicative factor of 1), with some outliers to the left and to the right, meaning that services do not differentiate estimations for this dataset, significantly (Table 4.9). The coefficient for Site area is unstable, although mostly negative. The coefficient for Income per capita is positive, as expected, and the highest of all datasets. The coefficient for the variable that measures the percentage of protected area in the 30 km neighbourhood is negative and relevant, meaning that protected areas have a negative impact on ecosystem service value or supply, which is counterintuitive. One possible explanation is the absorption by

this variable of the effect of the population density variable that was pruned, but this hypothesis needs further investigation.

Only one valuation method group was selected with non-zero median for Q50, and only for  $S_{TF1}$  and  $S_{T4+}$ . The coefficients found for this dummy variable deserves further investigation: the multiplicative factors<sup>8</sup> that correspond to the Q50 median is 4.08 for  $S_{TF1}$  and 4.5 for  $S_{T4+}$ . As this dummy variable represents a group of valuations methods usually used to estimate welfare value, the expected factor for this variable should be around 2 for any dataset, as welfare value is around twice the market price, the baseline category.

Figure 4.4 shows the estimated values defined by the median of Q50 and the PI defined by the medians of Q10 and Q90 for each sample using the Quantile Regression models fitted to each training dataset.

For the dataset  $S_F$ , PI covers 83.9% of sample values. The expected median from bootstrapped Q50 for  $S_F$  seem to be distributed in two bands, one band below 10\$/ha/yr and one band above 10\$/ha/yr. Although this phenomenon is typical of categorical variables, no categoric variable remained in Q50 model for  $S_F$ . What may explain this stratification is the few numeric variables that survived, with only Site area and population density with relevant effects, i.e., with median values distant from zero (Table 4.7).

The PI estimated for  $S_{TF1}$  covers 80.8% of its sample values, but failed to cover extreme low values, below \$1 per ha and year. Q50 median predicts only part of the growth of the actual sample values, alternative variables might explain remaining growth.

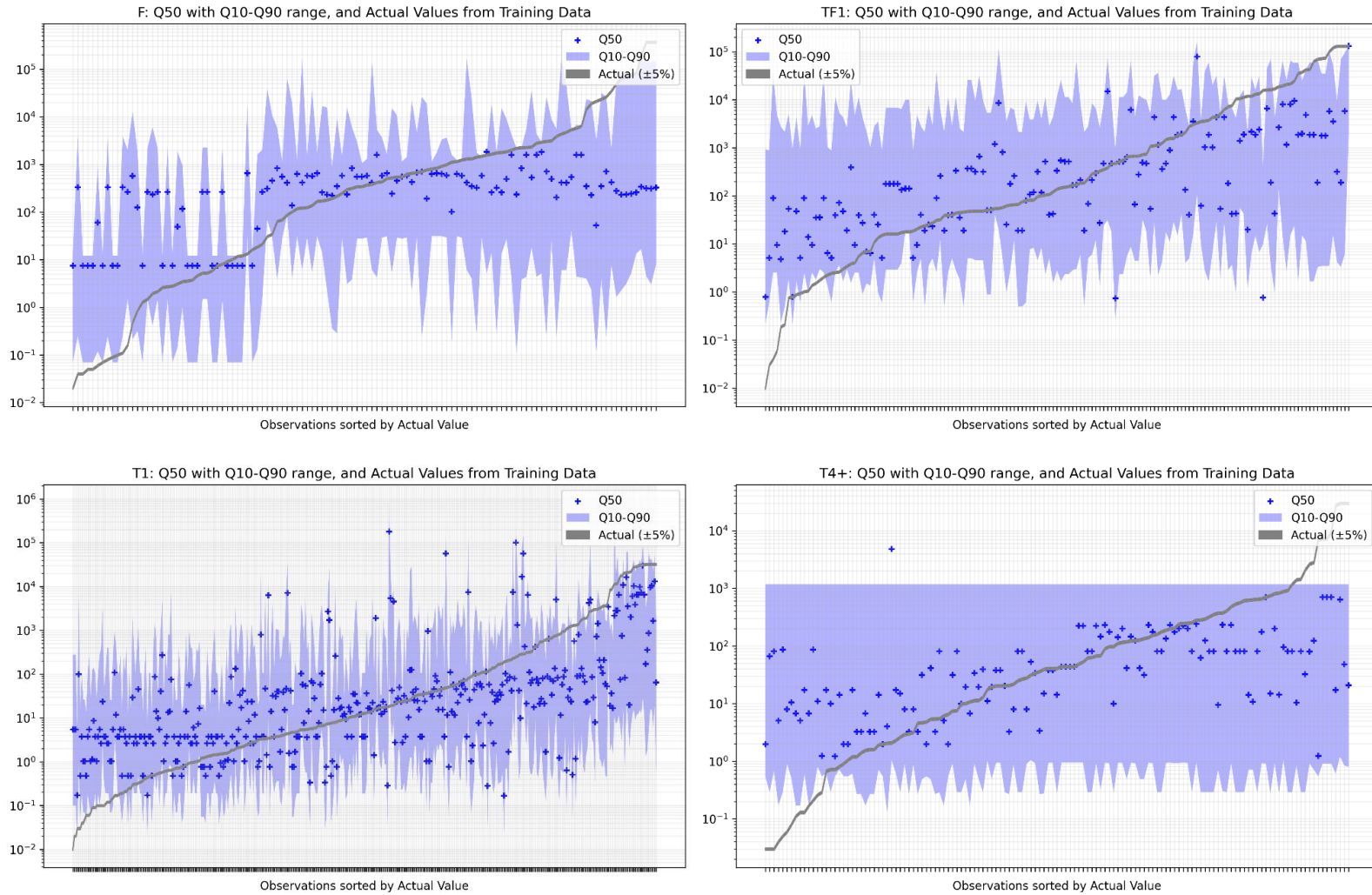
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<sup>8</sup> I.e., the exponential of the coefficient of the dummy variable found for the log-linear regression model. It represents a factor to be multiplied to the value that would be estimated for the baseline category, *ceteris paribus*.

The PI for  $S_{T1}$  covers 80.4% of the sample values. The spikier chart for  $S_{T1}$  is partially justified by the larger number of samples available, almost the sum of the other three training dataset sample numbers. Like  $S_F$ ,  $S_{T1}$  presents bands for the expected mean and median, mostly for the left half of actual sample values. Like  $S_F$ ,  $S_{T1}$  has few numeric variables that survived pruning and selection by Lasso, but differently from  $S_F$ ,  $S_{T1}$  has many dummy variables, mostly SEEA services (Table 4.7).

The ceiling for the PI for  $S_{T4+}$  is the result of the collapse of the Q90 model, where Lasso could not select any relevant variable (Table 4.7). The actual values above \$1,000 per ha and year are beyond this ceiling. Regardless of this, Q10-Q90 covers 80.7% of  $S_{T4+}$  sample values.  $S_{T4+}$  also presents bands for the expected mean and median, as  $S_F$  and  $S_{T1}$ , now more distinguishable at the right half of sample values. More investigation on sample values is needed to explain these phenomena. This investigation may suggest alternative numeric variables.

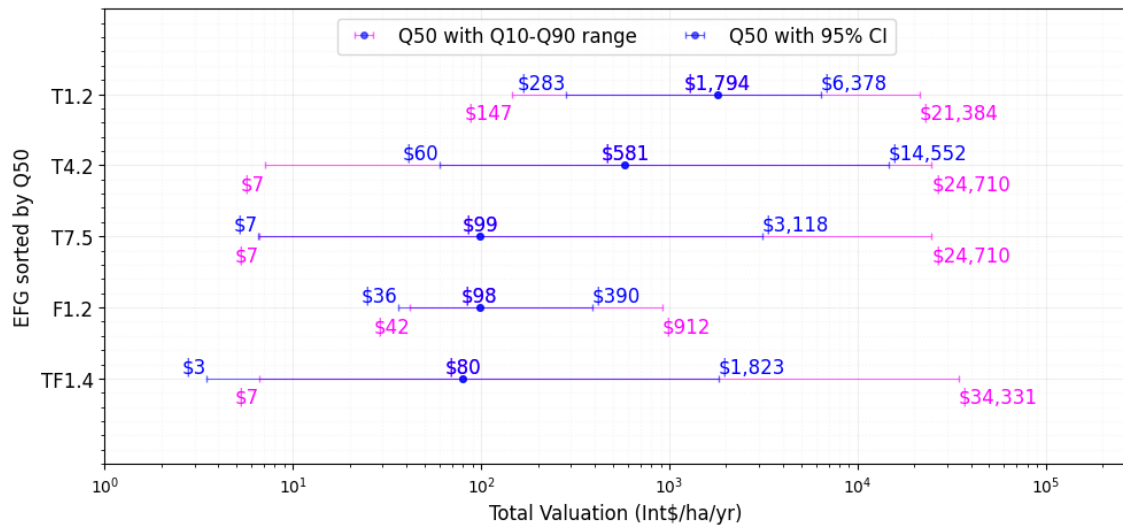
Figure 4.4 - Estimations and prediction intervals for Quantile Regression.



Estimations from 5000 non-parametric bootstrap iterations with replacement.

The models fitted by the bootstrap iterations were used to estimate the total ecosystem service value for the EFGs in the Brazilian Pantanal defined by the prediction datasets (Figure 4.5).

Figure 4.5 - Total ecosystem service value for Pantanal EFGs.



Sum of service values per ha and year estimated by meta-regression for each EFG, standardised by purchasing power parity in dollars for 2020. Results found after 5000 non-parametric bootstrap iterations with replacement. The estimated median is the median of the bootstrapped sum of Q50 regressions for all services of each Ecosystem Functional Group (EFG), as defined by the IUCN Global Ecosystem Typology. The 95% confidence interval is defined by the 2.5 and 97.5 percentiles for these bootstrapped estimations. The 80% PI is defined by the medians of the bootstrapped sum of Q10 and Q90 estimations for all EFGs services. The PI defined by Q10 to Q90 does not contain the corresponding 95% CI for the expected median (Q50) for F1.2 and TF1.4 at the lower bounds because of the different probability levels used: 80% for PIs, 95% for CIs.

Table 4.10 compares our estimations for Pantanal EFG with those from Bolzan et al. (2021) for the corresponding ecosystem areas defines by them, and their estimations multiplying these areas by De Groot et al. (2012) global average unit values. The 95% confidence interval of median our estimated medias contain the estimations from Bolzan et al. (2021), except for the Freshwater and Wetlands ecosystems, with their estimations higher than our medians. This may be explained by the long right tails of ecosystem services valuation estimations.

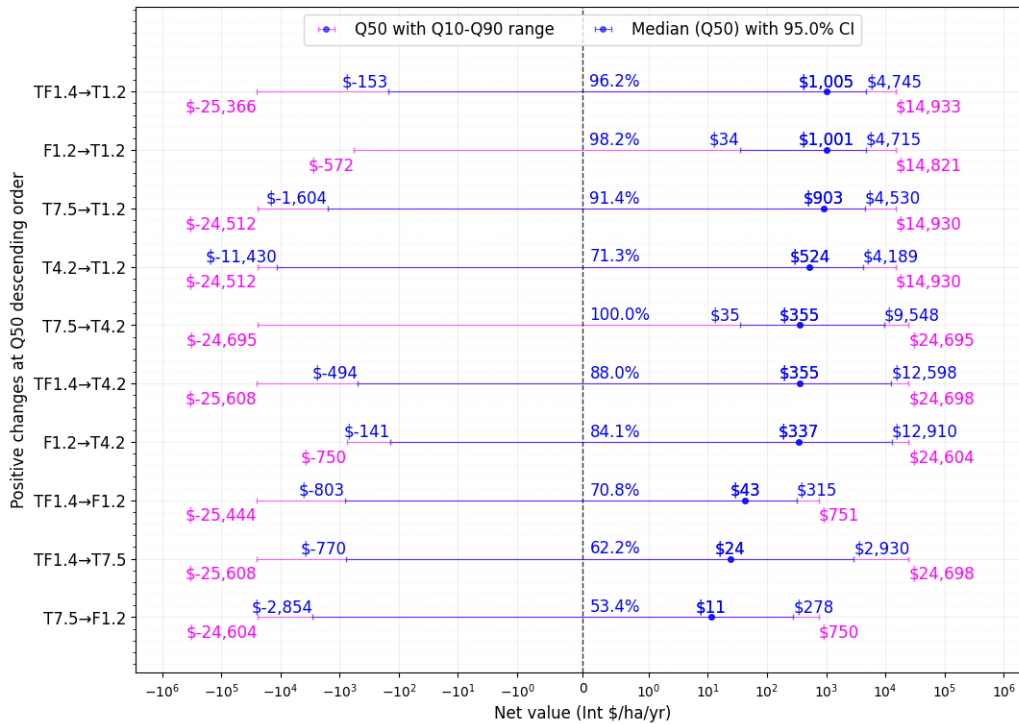
Table 4.10 - Comparing total ecosystem service value estimations.

<b>Pantanal ecosystems</b>	<b>Area (ha)</b>	<b>Bolzan et al. 2021 (Int \$/ha/year)</b>	<b>Median [95% CI] (Int \$/ha/year)</b>
Freshwater	612,979	5,244	98 [36; 390]
Wetlands	599,399	31,563	80 [3; 1,823]
Tropical forest	4,766,344	6,470	1,794 [283; 6,378]
Woodland	2,143,946	1,952	581 [60; 14,552]
Grassland	4,309,942	3,528	99
Livestock	2,528,129	25	[7; 3,118]
<b>Total</b>	<b>14,960,739</b>	<b>4,841</b>	<b>691</b> <b>[102; 5,104]</b>
		<b>72.42 B\$/year</b>	<b>10.53 B\$/year</b> <b>[1.53; 76.37]</b>

First three columns come from Bolzan et al. (2021). Unit values used by Bolzan et al. 2021 come from global averages in De Groot et al. (2012), originally in international dollars for 2007, adjusted to 2020, used by ESVD and our work, for comparison. Last column with our estimated median for unit value multiplied by the area estimated by Bolzan et al. (2021). Grand total in the last rows in billions of Int \$/year for 2020.

We also estimated the impact of changing 1 ha of each area from its EFG to another and the probability of each change having a positive impact (Figure 4.6).

Figure 4.6 - Impact of changing Pantanal EFGs.



Change X → Y represent the combined effect of diminishing 1 ha of the EFG X and increasing 1 ha in EFG Y. Only positive impacts are shown, reverse changes have negative impacts of the same amount. See also Figure 4.5.

The median values found for positive impacts in Figure 4.6 indicates an order slightly different from the order implied from the Figure 4.5, from the most valued to the least valued EFG:

- 1) T1.2 Tropical subtropical dry forests and thickets
- 2) T4.2 Pyric tussock savannas
- 3) F1.2 Permanent lowland rivers
- 4) T7.5 Derived semi natural pastures and old fields
- 5) TF1.4 Seasonal floodplain marshes

There is lower certainty on the preference for transitions between the first two EFGs, with a probability of 71.3% for T1.2 having more valuable ecosystem services in total than T4.2; and between the last three EFGs (F1.2, T7.5, TF1.4), with even lower probabilities. All other probabilities are higher than 80%, 100% for the transition T7.5 to T4.2.

Figure 4.6 is presented in such a way that only positive results are shown. Reversing the EFGs on any change will have the same magnitude with negative sign. The way the chart is presented does not mean that these changes are actual land cover conversions, or even that they are physically and biologically possible or practical. They show the positive impact of reducing one ha of an EFG X and increasing one ha of the EFG Y. Each positive impact can be interpreted as the avoided negative impact of the reverse change. In fact, this interpretation can be much more useful for policy-making. For example, the impact of replacing T1.2 or T4.2 by T7.5 is negative with more than 90% probability, with estimated median of Int \$903 and Int \$355 per ha per year, respectively. For comparison, Payment for Environmental Services mechanism for the Pantanal biome of the Brazilian state of Mato Grosso do Sul offers financial compensation of approximately R\$ 55.47 per ha per year to rural landowners in 2025, or Int \$17.50 in 2020, considering Brazilian inflation rates and purchasing power parity. This financial compensation was estimated from the average profit per ha and year from cow-calf farms in the Pantanal (ARMÔA, 2025). The large difference between the estimated median for total ecosystem service that is preserved and the compensation paid for the average profit lost indicates that the investment on ecosystem service conservation is worthwhile. The variations now estimated might support policy makers to do more informed decisions about the risk related to the undervaluation or overvaluation of specific sites and land cover changes.

For most transitions, the high percentages on expected median values suggest a very high probability that the expected median transition yields a positive value, but the PIs, representing the range where 80% individual sites would fall, almost always cross zero. This means that although we have strong confidence on median positive impacts for the changes in Figure 4.6, there is a significant risk of losing ecosystem service value on these changes for specific sites. Conversion from wetlands (TF1.4) to savannas and grasslands (T4.2) and semi-natural

pastures<sup>9</sup> (T7.5) have positive medians, but also the largest prediction interval on the negative side, and policy decisions most consider this risk.

#### **4.6 Final remarks**

Finding meta-regression models that explain the variation of the valuations found in ESVD is not an easy task, considering the few samples that fulfils the requirements for meta-regression (Chapter 3), the number of potential dummy variables needed for representing EFGs, SEEA services and valuation methods, the very large variation of the valuations themselves, that come from all over the world, the long right tail.

Quantile Regression allowed us to account for some of the large variations of ecosystem service valuations in ESVD without the homoscedasticity assumption needed for OLS. Non-parametric bootstrapping with replacement helped Q10, Q50 and Q90 models to converge. Lasso helped to reduce the large number of potential variables to those more relevant. We were able to find consistent effects on some numeric variables proposed: Site area, Income per capita, population. Quantile Regression allowed for different models (different coefficients, even different variables) that fitted better the lowest and highest values.

We tested a set of numeric variables like those used by VTT for similar GET biomes selected for our training datasets, but many of these variables were considered unstable and were pruned or had their coefficients nullified by the Lasso step. Adding or replacing variables used may reduce the remaining variations, e.g., livestock population on grasslands and savannas. Alternatively, new sources for the same variables may be used, for instance, more detailed sources for land cover percentage of forest, water and grasslands. We did not investigate alternative variables.

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<sup>9</sup> GET define EFG T7.5 as “[e]xtensive ‘semi-natural’ grasslands and open shrublands” that exists “where woody components of vegetation have been removed or greatly modified” and “[r]emaining vegetation includes a substantial component of local indigenous species, as well as an introduced exotic element”, used mainly for livestock grazing.

Part of the large variation found in ESVD data that could not be explained by the developed meta-regression models come from the inherent uncertainties on the primary studies that provided the valuations, and on the process of standardizing valuations to Int \$ per ha and year for 2020. These uncertainties are not represented as ESVD data and so could not be considered by the method used.

As a direct result of the use of Lasso to select the most relevant variables for regression, the models fitted to the training datasets do not differentiate many EFGs. Meta-regressions for  $S_{TF1}$  estimate the same ecosystem service values for the three Pantanal EFGs and for TF1.6 (Boreal, temperate and montane peat bogs), *ceteris paribus*. Meta-regressions for  $S_{T4}$  estimate the same for T4.2 (Pyric tussock savannas, found in Pantanal) and T4.1 and T4.3 (Trophic savannas and Hummock savannas, not found in Pantanal). Although  $S_{T1}$  has more samples than the other models, estimations for Tropical and subtropical forests are not differentiated by their EFGs, but by other variables. All EFGs and SEEA services get the same valuation for  $S_F$  (Freshwater realm): rivers, lakes and artificial streams. Estimations for them vary based on the values for Site area and Population density, with minor effects from Income per capita, Elevation, Biodiversity Intactness and Protected Area. A possible explanation is the combination of few samples with a great diversity of ecosystems and services represented.

The residual estimated per sample and the coefficients' CIs presented in this work can be used to prioritize source studies to be reviewed or to be added to ESVD, e.g., for the same EFG and SEEA service of an outlier, complementing the Chapter 3 proposals. Other techniques were tested, with unsatisfactory results, for instance: adding the product of SEEA Service dummies and Income per capita as interaction variables; turning pruning on and off, or constraining its effects on some, not all, variables or datasets; applying Winsorization to the numeric variables and calculated values, considering biophysical limitations. Other techniques and their combinations may be tried, but from the results we found until now, increasing the number of samples and looking for alternative numeric variables seem more promising.

Quantifying the uncertainties on total ecosystem service value and for transitions from one EFG to another prevents the risk of over-valuation, when compared to standard mean-based models, providing a scientifically defensible roadmap for ecosystem service payment and restoration. The expected median of value per EFG change and its probability of being greater than zero can be used to define preferences for payment for ecosystem services. The CIs can be used to set limits for payment, and the medians, to balance the policy application.

## **5 CONCLUSION**

This thesis estimated ecosystem services for the Brazilian Pantanal using innovative meta-regression techniques for value transfer based on selected ESVD entries. To fulfil this objective, we answered the research questions presented in the Introduction through chapters written as articles dedicated to each question.

### **5.1 Answering the research questions**

In Chapter 2 we answered how ecosystems of the Pantanal can be classified according to the IUCN Global Ecosystem Typology (GET). We identified the EFG found in Pantanal through crosswalking GET with national vegetation and macrohabitats typologies used for Pantanal found in the literature. We also found out that there is no map for EFGs that cover the Pantanal satisfactorily, although there are promising opportunities for that based on the two classification systems found (we come back to this later in this Conclusion).

In Chapter 3 we answered how can ESVD entries be systematically selected to support region-specific meta-regression, in the Brazilian Pantanal, by defining and applying a protocol that associates one or more EFG from GET to each ESVD entry and select those that could be used to support region-specific meta-regression defined by any set of EFGs. We applied the protocol to the Pantanal EFGs found in Chapter 2 and we found out that too few ESVD samples would be selected if only these EFGs were used.

In Chapter 4 we answered what are the estimated total ecosystem service value provided by Pantanal ecosystems and the estimated loss (or gain) in ecosystem service value associated with marginal land use and cover conversion in the Pantanal. For that, we used the protocol defined in Chapter 3 to select ESVD samples relevant for meta-regression applied to EFGs found in the Brazilian Pantanal defined by Chapter 2. The need for a minimum number of ESVD samples led to the parametrization of the protocol defined in Chapter 3 for the inclusion of EFGs not found in the Brazilian Pantanal, but that are similar to them, using the GET hierarchy to define what EFGs are similar, i.e., from the same GET biome or realm, according to GET hierarchy. We used this criterion also to define

which services each EFG provides, considering that all EFGs found in a dataset provide all services found in the same dataset. We then obtained the value for additional numeric variables not available in ESVD from public geo-referenced data sources, fitted meta-regression models to these samples, and applied these models to ecosystems found in the Brazilian Pantanal. We chose Quantile Regression over OLS because only one of the four datasets of ESVD samples satisfied the homoscedasticity assumption needed for OLS. Bootstrapping was used to cope with the instability that comes from few samples, and Lasso was used to reduce the number of variables considered, especially dummy variables from the many different EFGs and SEEA services.

More ESVD samples might reduce the remaining variation not explained by the EFGs, services and the other variables used, if the diversity in ecosystems and services grows slower than the number of samples added, although this cannot be guaranteed beforehand. Around 30% of ESVD entries could not be used for meta-regression, as per the protocol requirements in Chapter 3. One of the requirements is the association of each sample with a single EFG, the level required by SEEA-EA. A compromise solution would be allowing for samples associated with multiple EFGs of the same GET biome, but maybe engaging on new primary local studies would be a more effective and efficient way to have ecosystem service valuations calibrated for Pantanal for Freshwater EFGs.

## **5.2 Limitations**

The limitations of this work can be attributed to the methods used by each chapter and their inputs (see Thesis Development Plan in Chapter 1). Our crosswalking from GET to the two national classification systems found in Chapter 2 successfully defined the EFG list used by Chapters 3 and 4, but an EFG map for the Pantanal could not be derived from these national classification systems because no map exist for one of them, and the crosswalking to the other already mapped does not allow for a one-to-many relationship from GET to it.

The crosswalking from GET and ESVD ecosystem typology in Chapter 3 also looked for a one-to-many relationship. Although these two typologies are very similar, many ESVD entries were associated with multiple EFGs after the

crosswalking, mostly because they were already associated with many ESVD ecosystems in ESVD typology. These multiple associations prevented these valuations to be selected by our protocol, reducing the number of samples for meta-regression. A method that allowed associations with various EFGs would also increase the sample size. Since sample size is a primary limitation, this could help to improve the results, especially for Freshwater EFGs (Chapter 4).

Each dataset of ESVD samples defined in Chapter 4 amassed ESVD valuations associated with EFGs from Pantanal or with EFGs assumed to be similar enough to avoid biasing the meta-regression to valuations extremely different from those expected for the Brazilian Pantanal. The adopted criteria of similarity is the same used by previous works: belonging to the same upper level of classification, in our case, the GET biome, with an exception for EFG T7.5, that we included in a dataset with savanna and grasslands EFGs (GET biome T4), to avoid bias from Intensive agriculture EFGs (GET biome T7). For Freshwater, we needed to extend the scope of the dataset to the realm, including valuation for any river or lake found in ESVD samples selected by the protocol from Chapter 3. This approach might have added bias to some estimations from valuations associated to EFGs not found in the Pantanal that are not as similar as expected.

The inputs used by the methodologies presented in thesis also have their own limitations:

**ESVD:** Each ESVD entry hides unknown uncertainties introduced by its source study and by the process used to compile its standardized value and other attributes (Appendix B).

**Location and Areas:** As there is no EFG map available for the Brazilian Pantanal, we used an ecosystem classification from the literature (Bolzan et al., 2021) that could be translated to GET to define the areas of the Pantanal EFGs.

**Other sources:** We used the same numeric variables and respective sources used by the Value Transfer Tool (VTT) provided by ESVD, and many were rejected by the Lasso method used to select relevant variables.

### 5.3 Future work

The process developed by this these can help to overcome the limitations found in future studies. The results from Chapter 3 can help to prioritize primary studies to be added to ESVD. Exploring the ESVD valuations used for meta-regression in Chapter 4 and their estimations errors (for instance, looking for outliers) may also help, and we leave this investigation on individual ESVD samples and their source studies for future work.

Despite its limitations, the systematization and data curation provided by ESVD has eased the application of meta-analysis enormously. We were able to confirm and dimension the influence of important variables on the total ecosystem service value per EFG, and to support policies to avoid the conversion of terrestrial ecosystems. We believe ESVD can keep improving and growing by adopting the *modus operandi*, tools and environments used by the free and open-source software community: who uses it, improves it. Protocols for selection and meta-regression as ours can explore ESVD content for different policy sites under different EFGs and georeferenced variables. The results could drive source study review and the addition of new studies. Both the data and processes could be hosted in open collaborative version control environments on the web. The software code for the protocol (Chapter 3) and for the meta-regression (Chapter 4) are available to stimulate the adoption of this scenario (DIAS, 2026). Although we aim valuations for the Brazilian Pantanal, the methods developed in this thesis and the software code that implements it can be adapted to other regions of the world.

Ecosystem service valuation from primary studies or value transfer are important steps for SEEA-EA. Another essential step beyond the scope of this thesis is the monitoring changes on ecosystem assets, i.e., geo-referenced continuous areas uniformly classified using GET at EFG level. As far as we know, none of the undergoing efforts to map global ecosystems using GET covers the Brazilian Pantanal satisfactorily yet. Many of these efforts are based on cross-walking GET to regional, national and local classification systems already mapped, as recommended by GET. For the Brazilian Pantanal, Chapter 2 presents two

national classification systems that are promising: One more compatible to GET, developed specifically for the Pantanal (CUNHA et al., 2021), but not mapped yet, and another, that is the base for almost all national vegetation mapping (IBGE, 2012), but that does not represent the complexity of Pantanal ecosystems that come from the interaction of its vegetation and its hydrology, i.e., the Freshwater and transitional Terrestrial-Freshwater EFGs. We need some sort of combination of the two classification systems identified by Chapter 2, oriented by GET. Some work has been started already on this direction (IBGE, 2021b; GLOBAL ECOSYSTEMS ATLAS, 2025). We understand that local knowledge of Pantanal hydrology and macrohabitats will be fundamental for mapping Freshwater and transitional Terrestrial-Freshwater EFGs. As mentioned in Chapter 3, Keith et al. (2025) proposed an approach for attributing percentages for many-to-many relationships between typologies that can be also helpful.

Terrestrial EFGs could be split into lower levels of GET typology using this local knowledge, for instance, to discriminate the ecosystem services from different macrohabitats (CUNHA et al, 2021) and vegetation classes (IBGE, 2012) that fit T4.2 definition, or to differentiate cultivated pasture and native pasture, both under T7.5, in our work. This specialization is very important for Pantanal conservation, as it could not be captured through meta-analysis using ESVD. This specialization would be useful for future primary studies and policies at farm level.

The methods of Chapters 2, 3 and 4, and their software implementations, can be used to estimate the value of environmental services for other regions in Brazil and worldwide, helping to reach the goals of the Convention On Biological Diversity (CBD) through the Kunming-Montreal Global Biodiversity Framework (GBF), most specifically the indicator B1, “Services provided by ecosystems”, supported by SEEA-EA.

In the future, these methods can evolve to software tools for estimating environmental services in Brazilian rural landscapes to support National Policy on Payment for Environmental Services (BRASIL, 2021c), Brazilian Biodiversity Strategies and Action Plans (BRASIL, 2025b) implementation or other public policies or economic incentives for sustainable use of Brazilian biomes. These

software tools could be also adopted by Mato Grosso do Sul state to validate its policy on payments for ecosystem services on a scientific basis, with 63% of the Pantanal are occupying 25% of the state territory. It also can complement the Sustainable Pantanal Farm (*Fazenda Pantaneira Sustentável* - FPS) program of the Mato Grosso State (the remaining 37% of Pantanal, 7% of the state territory) with the inclusion of the valuation of ecosystem services conserved through sustainable practices in the certification label being developed by Embrapa and its partners.

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## GLOSSARY

**Convention on Biological Diversity (CBD)** - An international treaty adopted at the 1992 Earth Summit in Rio de Janeiro, designed to protect the Earth's natural resources and ensure a sustainable future.

**Kunming-Montreal Global Biodiversity Framework (GBF)** - An international agreement adopted in December 2022 during the 15th Conference of the Parties (COP15) to the Convention on Biological Diversity (CBD).

**ecosystem services** - The diverse benefits that humans derive from nature, specifically categorized into provisioning (e.g., food/water), regulating (e.g., climate regulation), cultural (e.g., quality of life), and supporting services.

**Ecosystem Functional Group (EFG)** - A classification level (Level 3) within the IUCN Global Ecosystem Typology that identifies groups of related ecosystems sharing common ecological drivers.

**Embrapa** - The Brazilian Agricultural Research Corporation is a state-owned research institution under the Ministry of Agriculture and Livestock. Founded in 1973, its primary mission is to develop technologies, knowledge, and technical-scientific information for Brazilian agriculture and livestock.

**Embrapa Pantanal** - A decentralized research unit of the Brazilian Agricultural Research Corporation (Embrapa), headquartered in Corumbá, Mato Grosso do Sul. Established in 1975, it is dedicated to the scientific technological development of the Pantanal biome, focusing on the balance between economic production and environmental conservation.

**Ecosystem Service Valuation Database (ESVD)** - A comprehensive collection of monetary valuation data derived from scientific publications and technical reports, intended to standardize ecosystem service values globally.

**Global Ecosystem Typology (GET)** - A multi-level, function-based typology for Earth's ecosystems developed by the IUCN and adopted by the United Nations as a standard for ecosystem accounting.

**Instituto Nacional de Pesquisas Espaciais (INPE)** - The National Institute for Space Research in Brazil, which operates under the Ministério da Ciência, Tecnologia e Inovações.

**International Union for Conservation of Nature (IUCN)**: A global membership union composed of both government and civil society organizations. Created in 1948, it is the world's largest and most diverse environmental network and serves as the global authority on the status of the natural world and the measures needed to safeguard it.

**Lasso (Least Absolute Shrinkage and Selection Operator)** - A statistical regularization method used in regressions to prevent overfitting by penalizing the size of coefficients and forcing weak variables to exactly zero.

**log-linear regression model** - A regression model where the dependent variable transformed by the natural logarithm is estimated as a linear of the independent variables, that may or may not be transformed using the natural logarithm, too. This model is primarily used when the relationship between variables is exponential.

**meta-analysis** - A statistical procedure that integrates and synthesizes the quantitative results of multiple independent studies addressing the same research question. This method typically involves calculating a weighted average, where studies with larger sample sizes or lower variance are given more weight in the final calculation.

**meta-analytic value transfer** - A functional category of value transfer that utilizes a meta-regression model to estimate the economic value of ecosystem services at a specific "policy site" (where data is missing) using a synthesized database of "study sites" (where data already exists).

**meta-analytic function** - The function defined by the regression model obtained from the application of a meta-analytic value transfer.

**meta-regression** - An extension of meta-analysis that employs regression-based techniques to investigate and explain heterogeneity among the effect sizes of multiple primary studies. While a standard meta-analysis calculates a weighted

average effect, meta-regression uses study-level characteristics (moderators)—such as sample size, geographic location, or methodological quality—as independent variables to determine their statistical influence on the observed outcomes.

**Ordinary Least Squares (OLS)** - A standard regression method that focuses on estimating the conditional mean of a response variable by minimizing the sum of squared residuals. OLS relies on the assumption of homoscedasticity (constant variance of error terms) and can perform poorly or produce biased results when data contains outliers or long-tailed distributions. In the context of the sources, OLS is noted for its sensitivity to the large variations often found in ecosystem service valuation data.

**Pantanal** - The world's largest continuous tropical wetland, characterized as a complex mosaic of flooded savannas, forests, and grasslands in the centre of South America.

**Quantile Regression** - A statistical methodology that extends the linear model to estimate the conditional quantiles of a response variable, such as the median (50th percentile) or the 10th and 90th percentiles. Unlike methods that focus solely on the mean, Quantile Regression minimizes an asymmetrically weighted sum of absolute residuals, making it robust to non-normal errors and useful for analysing data where variation depends on the values of covariates. It is particularly effective at revealing complex relationships in the long tails of a distribution that mean-based models might fail to capture and serves as an alternative when heteroscedasticity is present.

**regression model** - A statistical framework used to estimate the strength and direction of the relationship between a dependent variable (often called the outcome or response variable) and one or more independent variables (predictors or covariates), by fitting a mathematical function to observed data.

**SEEA-EA (System of Environmental-Economic Accounting – Ecosystem Accounting)** - The official United Nations standard for ecosystem accounting, used to measure natural capital and the contributions of nature to human well-being.

**value transfer** - Also referred to as *benefit transfer*, this is a cost-effective method of using results from previous *study sites* to estimate environmental values for other *policy sites*.

**Winsorization** - A statistical technique used to manage the instability of long-tailed distributions in ESVD data by capping valuations at a specific quantile (e.g., 98%) to mitigate the impact of outliers.

## **APPENDIX A - SUPPLEMENTARY MATERIAL FOR CHAPTER 2**

The Appendix A is Supplementary Material for the paper published from the text in Chapter 2.

This Supplementary Material includes the detailed results of matching EFG to the four typologies evaluated:

- Table A.1: Matching Ecosystem Functional Groups (EFGs) to the Brazilian Pantanal macrohabitats.
- Table A.2: Matching Ecosystem Functional Groups (EFGs) to the IBGE vegetation classes found in the Brazilian Pantanal.
- Table A.3: Matching Ecosystem Functional Groups (EFGs) to the land use and cover typology used by Mapbiomas.
- Table A.4: Matching Ecosystem Functional Groups (EFGs) to the land use and cover typology used by the Fourth National Communication of Brazil to the United Nations Framework Convention on Climate Change.

The auxiliary tables below were added here to help to understand IUCN Global Ecosystem structure and Cunha et al. 2021, 2023 structure:

- Table A.5: Number of Ecosystem Functional Groups (EFGs) per Real and Biome in the IUCN Global Ecosystem version 2.1.
- Table A.6: Number of Pantanal Macrohabitats per Functional unit and Subclass.

Table A.1 - Matching Ecosystem Functional Groups (EFGs) to the Brazilian Pantanal macrohabitats.

Code	Macrohabitat name	EFG	EFG name	Note
1.1.1	Central parts of river channels	F1.5	Seasonal lowland rivers	
1.1.2	River shores	F1.5	Seasonal lowland rivers	
1.1.3	Rapids, waterfalls, barriers, rocky terrain	F1.2	Permanent lowland rivers	
1.2.1	Large lakes and bays in recesses of mountain ranges on the edge of Pantanal	F2.2	Small permanent freshwater lakes	
1.2.2	Lakes in abandoned canals and meanders (Oxbow lakes)	F2.2	Small permanent freshwater lakes	
1.2.3	Depression lakes within Pantanal	F2.2	Small permanent freshwater lakes	
1.2.4	Meandering inner lakes (Umlaufseen)	F2.2	Small permanent freshwater lakes	
1.2.5	Lakes enclosed by marginal dikes (Dammuferseen)	F2.2	Small permanent freshwater lakes	
1.2.6	Brackish water lakes, with margins dominated by emergent aquatic macrophytes, such as <i>Typha</i> spp. (cattail)	F2.3	Seasonal freshwater lakes	
1.2.7	"Salinas": lakes with high salinity, without aquatic macrophytes	F2.3	Seasonal freshwater lakes	
2.1.1	"Furos", "paraná", "bocas"	F1.5	Seasonal lowland rivers	
2.1.2	"Corixos"	TF1.4	Seasonal floodplain marshes	
2.1.3	"Vazantes" (covered with herbaceous vegetation)	TF1.4	Seasonal floodplain marshes	
2.1.4	"Landis" (covered with polyspecific forests described in macrohabitat – see 3.5.4)	TF1.1	Tropical flooded forests and peat forests	
2.2.1	Open water areas	TF1.3	Permanent marshes	
2.2.2	Areas covered with floating and rooted emerging aquatic macrophytes	TF1.3	Permanent marshes	
2.2.3	Areas covered with monodominant rooted aquatic macrophytes ( <i>Oryza alta</i> and <i>Oryza glumaepatula</i> ) paddy fields, in addition to <i>Hymenachne amplexicaulis</i> and <i>Leersia hexandra</i>	TF1.4	Seasonal floodplain marshes	
2.2.4	Areas of temporary lowlands (depression) (false lagoons), with amphibious aquatic macrophytes and predominance of the "Mimosinho" grass ( <i>Reimarochloa brasiliensis</i> ), in addition to <i>Steinchisma laxum</i> , <i>Setaria parviflora</i> and <i>Digitaria fuscescens</i>	TF1.4	Seasonal floodplain marshes	
3.1.1	Sandy beaches	TF1.4	Seasonal floodplain marshes	

(continue)

Table A.1 - Continuation.

Code	Macrohabitat name	EFG	EFG name	Note
3.1.2	Rocky outcrops	F1.5	Seasonal lowland rivers	
3.1.3	Steep shores	TF1.4	Seasonal floodplain marshes	
3.2.1	Non-flooding areas, soaked by rainwater, for a short period of time during major floods dominated by <i>Elionurus muticus</i> (carona grass) (see macrohabitat 5.1.1)	TF1.4	Seasonal floodplain marshes	
3.2.2	Flooded for less than three months, meadow with predominance of <i>Mesosetum chaseae</i> ("cerrado" grass) (see macrohabitat 5.1.2)	TF1.4	Seasonal floodplain marshes	
3.2.3	Flooded for about three months, field of <i>Axonopus leptostachyus</i> (hard grass), field of <i>Andropogon hypogynus</i> (red grass)	TF1.4	Seasonal floodplain marshes	
3.2.4	Flooded for about six months, a field of <i>Axonopus purpusii</i> (mimoso), <i>Reimarochloa</i> spp. (treat) and others	TF1.4	Seasonal floodplain marshes	
3.2.5	Herbaceous communities flooded for about six months in sedimentary areas along the river, <i>Paspalum wrightii</i> field	TF1.4	Seasonal floodplain marshes	
3.3.1	Flooded for a few weeks, areas with murunduns (murundun fields, with <i>Curatella americana</i> litter)	TF1.4	Seasonal floodplain marshes	
3.3.2	Flooded for up to three months (dirty field of canjiqueira <i>Byrsonima cydoniifolia</i> and of rubbish <i>Curatella americana</i> )	TF1.4	Seasonal floodplain marshes	
3.3.3	Flooded up to six months (dirty field of pigeon <i>Combretum laxum</i> and <i>Combretum lanceolatum</i> )	TF1.4	Seasonal floodplain marshes	
3.3.4	Flooded areas from weeks to months with small land elevations ( <i>Tacurus</i> )	TF1.4	Seasonal floodplain marshes	
3.4.1	Shrub flooded for up to three months (canjiqueira, dominated by <i>Byrsonima cydoniifolia</i> )	TF1.4	Seasonal floodplain marshes	
3.4.2	Shrub flooded four to six months (thorny, dominated by <i>Mimosa</i> spp., <i>Bytneria</i> spp.)	TF1.4	Seasonal floodplain marshes	
3.4.3	Shrub flooded up to six months (dovecote, dominated by <i>Combretum lanceolatum</i> and <i>Combretum laxum</i> )	TF1.4	Seasonal floodplain marshes	
3.4.4	Barreiro or barrier – area flooded during the rainy season (trees and bushes of Barreiro-preto, <i>Prosopis rubriflora</i> , <i>Mimosa hexandra</i> and/or <i>Machaerium hirtum</i> )	TF1.4	Seasonal floodplain marshes	
3.5.1	Forests flooded for three to six months, for example in the lower reaches along river channels	TF1.1	Tropical flooded forests and peat forests	
3.5.2	Shrubs and pioneer forests flooded for six months by proximity to river channels	TF1.1	Tropical flooded forests and peat forests	
3.5.3	Forests flooded for a few weeks, for example on edges of capon and ridges and higher riverine forests	TF1.1	Tropical flooded forests and peat forests	
3.5.4	"Landis", evergreen forests flooded during the flood and inserted into the natural drainage channel	TF1.1	Tropical flooded forests and peat forests	

(continue)

Table A.1 - Continuation.

Code	Macrohabitat name	EFG	EFG name	Note
3.5.5	Chaco floodplain forest	TF1.1	Tropical flooded forests and peat forests	
3.5.6	Deciduous forest soaked for two months	TF1.1	Tropical flooded forests and peat forests	
3.6.1	Forests dominated by <i>Licania parvifolia</i> (pepper), flooded for up to six months	TF1.1	Tropical flooded forests and peat forests	
3.6.2	Forests dominated by <i>Vochysia divergens</i> (cambarazal), flooded for up to eight months	TF1.1	Tropical flooded forests and peat forests	
3.6.3	Forests dominated by <i>Erythrina fusca</i> (squash), flooded for up to eight months	TF1.1	Tropical flooded forests and peat forests	
3.6.4	"Paratidal", park savanna dominated by <i>Tabebuia aurea</i> , flooded four to eight months	TF1.4	Seasonal floodplain marshes	
3.6.5	Open "Carandazal", savanna dominated by <i>Copernicia alba</i> , flooded up to three months	TF1.4	Seasonal floodplain marshes	
3.6.6	Dense "Carandazal", savanna dominated by <i>Copernicia alba</i> , flooded up to eight months	TF1.4	Seasonal floodplain marshes	
3.6.7	Six to eight month flooded savannas dominated by <i>Couepia uiti</i> ("pateiral")	TF1.4	Seasonal floodplain marshes	
3.6.8	Partially flooded savanna with <i>Curatella americana</i> ("lixerial")	TF1.4	Seasonal floodplain marshes	
4.1.1	Swamps dominated by <i>Cyperus giganteus</i> ("pirizal")	TF1.3	Permanent marshes	
4.1.2	Swamps dominated by <i>Thalia geniculata</i> ("caeté")	TF1.3	Permanent marshes	
4.1.3	Swamps dominated by <i>Canna glauca</i> ("cana do brejo")	TF1.3	Permanent marshes	
4.1.4	Multispecific swamps	TF1.3	Permanent marshes	
4.1.5	Floating swamps ("baceiros" or "batumes")	TF1.3	Permanent marshes	
4.2.1	"Biritizais", standing water, dominated by <i>Mauritia flexuosa</i>	TF1.1	Tropical flooded forests and peat forests	
4.2.2	"Veredas" (footpaths), areas that in some stretches form marshes of running water, dominated by <i>Mauritia flexuosa</i> or not and herbaceous and subshrub species.	TF1.1	Tropical flooded forests and peat forests	
5.1.1	Clear field of "caronal", dominated by <i>Elionurus muticus</i> (see macrohabitat 3.2.1)	T4.2	Pyric tussock savannas	
5.1.2	Clear field dominated by <i>Mesosetum chaseae</i> ("cerrado" grass), <i>Aristida</i> spp. (goat's beard), <i>Paspalum lineare</i> ("fura-bucho", "goat's beard") and others (see macrohabitat 3.2.2)	T4.2	Pyric tussock savannas	

(continue)

Table A.1 - Conclusion.

Code	Macrohabitat name	EFG	EFG name	Note
5.1.3	Dense forested savanna	T4.2	Pyric tussock savannas	
5.1.4	Savanna stricto sensu free from flooding	T1.2	Tropical/subtropical dry forests and thickets	
5.1.5	Semideciduous forest	T1.2	Tropical/subtropical dry forests and thickets	
5.1.6	"Acurizal", monodominant formations of acuri palm <i>Attalea phalerata</i>	T1.2	Tropical/subtropical dry forests and thickets	1
5.1.7	"Babaçual", monodominant formation of babassu palm <i>Attalea speciosa</i>	T1.2	Tropical/subtropical dry forests and thickets	1
5.2.1	Deciduous forest	T1.2	Tropical/subtropical dry forests and thickets	
5.2.2	Rocky savanna	T4.2	Pyric tussock savannas	
5.2.3	Rocky grassland	T4.2	Pyric tussock savannas	
6.1.1	Landfill mound	T1.2	Tropical/subtropical dry forests and thickets	1
6.2.1	Reservoirs (tanks and watering troughs)	F3.2	Constructed lacustrine wetlands	
6.2.2	Borrow pits	F3.2	Constructed lacustrine wetlands	
6.2.3	Artificial channels	F3.5	Canals, ditches, and drains	
6.2.4	Roads and dikes	T7.4	Cities, villages and infrastructure	
6.2.5	Subsistence farming (small farms)	T7.5	Derived semi-natural pastures and old fields	
6.2.6	Exotic grazing lands	T7.5	Derived semi-natural pastures and old fields	
6.2.7	Drained areas for agricultural use	T7.1	Short rotation croplands	
6.2.8	Drained areas without agricultural use	T7.5	Derived semi-natural pastures and old fields	

Matching EFG (Keith et al. 2022) to the macrohabitats proposed by Cunha et al. (2021, 2023) for Pantanal. The macrohabitat name in English is a translation of the macrohabitat name in Portuguese as cited in Cunha et al. (2023). Functional Unit and Subclass of each macrohabitat and IUCN Global Ecosystem Typology Realm and Biome of each EFG were omitted for conciseness (see Tables S1.2 and S1.3). The last column has references to notes right after the table.

Note 1: There are only palm trees and no (or very few) arboreous trees. These macrohabitats are degraded forests.

Table A.2 - Matching Ecosystem Functional Groups (EFGs) to IBGE vegetation classes found in the Brazilian Pantanal.

N	IBGE type	IBGE Code	EFG(s)	# of EFGs	Note
1	Riparian Vegetation, Alluvial (Arboreal, Bush, Herbaceous) - along rivers	Fa	TF1.1, TF1.3, TF1.4	3	1
2	Semi-deciduous Seasonal Forest, Submontane (Woods)	Fs	T1.2	1	
3	Deciduous Seasonal Forest, Lowlands (Woods, Dry Forest)	Cb	T1.2	1	
4	Deciduous Seasonal Forest, Submontane (Woods, Dry Forest, Limestone Forest)	Cs	T1.2	1	
5	Savanna (Cerrado), Woodland (Cerradão)	Sd	T4.2	1	
6	Savanna (Cerrado), Wooded (Campo Cerrado, Cerrado, Cerrado Aberto), Without Riparian Vegetation	Sas	T4.2	1	
7	Savanna (Cerrado), Wooded (Campo Cerrado, Cerrado, Cerrado Aberto), With Riparian Vegetation	Saf	TF1.1	1	
8	Savanna (Cerrado), Park Savanna without Riparian Vegetation	Sps	T4.2	1	
9	Savanna (Cerrado), Grassy-woody (Campo, Campo Limpo, Campo Sujo, Caronal and Campo Alagado), Without Riparian Vegetation	Sgs	T4.2	1	
10	Savanna (Cerrado), Grassy-woody (Campo, Campo Limpo, Campo Sujo, Caronal and Campo Alagado), With Riparian Vegetation	Sgf	TF1.1	1	
11	Savanna (Cerrado), Woodland + Wooded	Sd+Sa	T4.2	1	
12	Savanna (Cerrado), Woodland + Grassy-woody	Sd+Sg	T4.2	1	
13	Savanna (Cerrado), Wooded + Woodland	Sa+Sd	T4.2	1	
14	Savanna (Cerrado), Grassy-woody + Woodland	Sg+Sd	T4.2	1	
15	Savanna (Cerrado), Wooded + Grassy-woody	Sa+Sg	T4.2	1	
16	Savanna (Cerrado), Grassy-Woody + Wooded	Sg+Sa	T4.2	1	
17	Steppic Savanna (Chaco), Wooded (Chaco), Without Riparian Vegetation	Tas	T4.2	1	
18	Steppic Savanna (Chaco), Wooded (Chaco), With Riparian Vegetation	Taf	TF1.1	1	
19	Steppic Savanna (Chaco), Park (Carandazal, Campina de Carandá, Paratudal), Without Riparian Vegetation	Tps	T4.2	1	
20	Steppic Savanna (Chaco), Park (Carandazal, Campina de Carandá, Paratudal), With Riparian Vegetation	Tpf	TF1.1	1	
21	Steppic Savanna (Chaco), Grassy-woody (Campo, Campo Limpo, Campo Sujo, Campina and Campo Alagado), Without Riparian Vegetation	Tgs	T4.2	1	
22	Steppic Savanna (Chaco), Grassy-woody (Campo, Campo Limpo, Campo Sujo, Campina and Campo Alagado), With Riparian Vegetation	Tgf	TF1.1	1	
23	Steppic Savanna (Chaco), Forested + Wooded	Td+Ta			0
24	Steppic Savanna (Chaco), Wooded + Forested	Ta+Td	T4.2	1	
25	Steppic Savanna (Chaco), Wooded + Grassy-woody	Ta+Tg	T4.2	1	
26	Steppic Savanna (Chaco), Grassy-woody + Wooded	Tg+Ta	T4.2	1	
27	Pioneer Formations, Vegetation with fluvial and/or lacustrine-arboreal (Cambarazal), Bush (Espinheiral, Saranzeiro, Macega, Pateiral, Pimenteiral), Herbaceous (Pirizal, Caetezal, Brejo and Bacero) influence.	Pa	TF1.3, TF1.4	2	1
28	Areas of Ecological tension or Floristic Contacts, Ecotone, Savanna / Deciduous Seasonal Forest (Woods)	SNt(Sct)			0
29	Areas of Ecological tension or Floristic Contacts, Ecotone, Savanna / Semi-deciduous Seasonal Forest (Woods)	SNt(Sft)			2
30	Areas of Ecological tension or Floristic Contacts, Ecotone, Semi-deciduous Seasonal Forest / Pioneer Formations (Woods)	NPT(F+Pa)			2

(continue)

Table A.2 - Conclusion.

N	IBGE type	IBGE Code	EFG(s)	# of EFGs	Note
31	Areas of Ecological tension or Floristic Contacts, Ecotone, Savanna / Pioneer Formations (Cerrado, Campo Sujo, Cambarazal)	SPt(S+Pa)			2
32	Areas of Ecological tension or Floristic Contacts, Ecotone, Steppic Savanna / Pioneer Formations (Chaco, Campo Sujo)	TPt(T+Pa)			2
33	Areas of Ecological tension or Floristic Contacts, Ecotone, Savanna / Wooded Steppic Savanna	STt(Ta+Sa)			2
34	Areas of Ecological tension or Floristic Contacts, Enclave, Savanna / Submontane Deciduous Seasonal Forest (Woods)	SNc/(Sd+Cs)			0
35	Areas of Ecological tension or Floristic Contacts, Enclave, Savanna / Submontane Semi-deciduous Seasonal Forest (Woods)	SNc/(Sd+Fs)			2
36	Areas of Ecological tension or Floristic Contacts, Enclave, Steppic Savanna / Lowlands Deciduous Seasonal Forest (Woods)	TNc/(Td+Cb)			2
37	Vegetation Refuges (Relics Communities), Herbaceous montane refuge (Campo)	rmh	T4.2	1	
38	Anthropogenic Areas, Secondary Vegetation, of Savanna	Vs.S			
39	Anthropogenic Areas, Secondary Vegetation, of Lowlands Deciduous Seasonal Forest	Vs.Cb			
40	Anthropogenic Areas, Secondary Vegetation, of Submontane Deciduous Seasonal Forest	Vs.Cs	T7.5	1	3
41	Anthropogenic Areas, Secondary Vegetation, of Submontane Semi-deciduous Seasonal Forest	Vs.Fs			
42	Anthropogenic Areas, Secondary Vegetation, of Forested Steppic Savanna	Vs.Td			
43	Anthropogenic Areas, Secondary Vegetation, of Park Steppic Savanna	Vs.Tp			0
44	Anthropogenic Areas, Annual Agriculture, in Submontane Deciduous Seasonal Forest region	Ac.Cs			
45	Anthropogenic Areas, Annual Agriculture, in Savanna region	Ac.S	T7.1	1	3
46	Anthropogenic Areas, Annual Agriculture, in Indian lands	Ac ti			
47	Anthropogenic Areas, Livestock and Agriculture, Small holdings	Ag			0
48	Anthropogenic Areas, Livestock and Agriculture, Rural settlements	Ag ar	T7.5	1	
49	Anthropogenic Areas, Annual Agriculture, Sugar cane	Cana			0
50	Anthropogenic Areas, Annual Agriculture, Forestry Reforestation (Eucalyptus)	R			0
51	Anthropogenic Areas, Livestock (Planted pasture), in Lowlands Deciduous Seasonal Forest region	Ap.Cb			
52	Anthropogenic Areas, Livestock (Planted pasture), in Submontane Deciduous Seasonal Forest region	Ap.Cs			
53	Anthropogenic Areas, Livestock (Planted pasture), in Alluvial Semi-deciduous Seasonal Forest region	Ap.Fa			
54	Anthropogenic Areas, Livestock (Planted pasture), in Submontane Semi-deciduous Seasonal Forest region	Ap.Fs	T7.5	1	3
55	Anthropogenic Areas, Livestock (Planted pasture), in Savanna region	Ap.S			
56	Anthropogenic Areas, Livestock (Planted pasture), in Steppic Savanna region	Ap.T			
57	Anthropogenic Areas, Livestock (Planted pasture), in Indian lands	Ap ti			
58	Anthropogenic Areas, Livestock (Planted pasture), Rural settlements	Ap ar	T7.5	1	
59	Anthropogenic Areas, Other Anthropogenic Areas, Urban Influence	lu	T7.5	1	
60	Anthropogenic Areas, Other Anthropogenic Areas, Areas degraded by mining	lm	T7.4	1	
61	Anthropogenic Areas, Other Anthropogenic Areas, Occupied floodplains	Fa Ag			0
62	Other, Water masses (dams, reservoirs, rivers, streams, saline marshes)	Agua	Freshwater Realm	18	4

Matching EFG (Keith et al. 2022) to the IBGE (1992) vegetation classes mapped to the Upper Paraguay River Basin in the Brazilian Mato Grosso do Sul state by Carlini and Silva (2014, 2015), covering 66% of the Brazilian Pantanal. Only the lowest level types are listed. The names of the types in English are those in Carlini and Silva (2015) with minor adaptations to reduce the table width. The last column has references to notes right after the table.

Note 0: This type was found by Carlini and Silva (2015) in the plateau of the Upper Paraguay River Basin of the Mato Grosso do Sul Brazilian state but not found in the Pantanal inside this region and is not considered for EFG matching.

Note 1: The definition of this type satisfies (i.e., does not contradict) the definition of more than one EFG.

Note 2: Ecotone and enclave types were not matched to any EFGs because their vegetation is already considered for matching to an EFG.

Note 3: Types that represent anthropogenic land use areas associated with their pristine vegetation regions were considered as one single type representing their final land use.

Note 4: IBGE has only one type for water bodies.

Table A.3 - Matching Ecosystem Functional Groups (EFGs) to the land use and cover typology used by Mapbiomas.

<b>Mapbiomas types</b>	<b>Corresponding IBGE types</b>	<b>EFG(s)</b>
1. Forest		
1.1. Forest Formation	Ca, Cb, Cm, Cs, Fa, Fb, Fs, P, Pa, Pm, SN, Sd, Td	T2.2, T1.2
1.2. Savanna Formation	Sa, Sp, Sg, Td, Ta, Tp	T4.1
2. Non-forest Natural Formation		
2.1. Wetland	Tg, Sp, Pa, Tp	TF1.4
2.2. Grassland	Sg, Sp, Ta, Tg	T4.5
3. Farming		
3.1. Pasture	AP, PE, PS	T7.2, T7.5
3.2 (Other) Temporary Crop	AMc	T7.1
4. Non-vegetated Area		
4.1 Urban Area		T7.4
5. Water		
5.1 River, Lake		F1.1, F1.2, F2.1, F2.2, F3.1, F3.2, F3.5,

Matching EFG (Keith et al. 2022) to Mapbiomas natural vegetation types through the corresponding Mapbiomas classes (Mapbiomas 2023a).

Table A.4 - Matching Ecosystem Functional Groups (EFGs) to the NC4 types.

IPCC Categories	NC4 types	Type codes	# EFG(s)	EFG(s)
Forest land	Managed Forest	FM	3	TF1.1, TF1.3, TF1.4
Forest land	Unmanaged Forest	FNM	2	T1.2, T4.2
Forest land	Secondary Forest	FSec	5	T1.2, T4.2, TF1.1, TF1.3, TF1.4
Forest land	Reforestation	Ref	1	T7.3
Forest land	Selective Logging	CS	1	T7.3
Grasslands	Managed Grasslands	GM	1	T7.5
Grasslands	Unmanaged Grasslands	GNM	3	TF1.1, TF1.3, TF1.4
Grasslands	Secondary Grasslands	GSec	5	T4.2, TF1.1, TF1.3, TF1.4, T7.5
Grasslands	Other Managed Woody Formations	OFLM	4	TF1.1, TF1.3, TF1.4, T7.5
Grasslands	Other Unmanaged Woody Formations	OFLNM	3	TF1.1, TF1.3, TF1.4
Grasslands	Other Secondary Woody Formations	OFLSec	5	T4.2, TF1.1, TF1.3, TF1.4, T7.5
Grasslands	Pasture	Ap	1	T7.5
Grasslands	Degraded Pasture	APD	1	T7.5
Cropland	Annual agriculture	Ac	1	T7.1
Cropland	Perennial crops	PER	1	T7.3
Cropland	Semi-perennial crops	CANA	1	T7.3
Settlements	Settlements	S	1	T7.4
Other land	Managed Dunes	DnM	1	T3.4?
Other land	Unmanaged Dunes	DnNM	1	T3.4?
Other land	Managed Rocky Outcrop	ArM	1	T3.4?
Other land	Unmanaged Rocky Outcrop	ArnM	1	T3.4
Other land	Mining	Min	1	T3.4?
Other land	Exposed Soil	SE	1	T3.4
Wetlands	Rivers and Lakes	A	14	F1.x, F2.x, F3.5
Wetlands	Reservoirs	RES	4	F3.1, F3.2, F3.3, F3.4
Not Observed	Not Observed	NO	n/a	n/a

Matching Ecosystem Functional Groups (EFGs) to the land use and cover typology used by the Fourth National Communication of Brazil to the United Nations Framework Convention on Climate Change.

Table A.5 - Number of Ecosystem Functional Groups (EFGs) per Realm and Biome in the IUCN Global Ecosystem version 2.1.

<b>Realm / Biome</b>	<b>Number of EFG</b>
<b>Freshwater</b>	<b>22</b>
F1 Rivers and streams	7
F2 Lakes	10
F3 Artificial fresh waters	5
<b>Freshwater-Marine</b>	<b>3</b>
FM1 Semi-confined transitional waters	3
<b>Freshwater-Terrestrial</b>	<b>7</b>
TF1 Palustrine wetlands	7
<b>Marine</b>	<b>24</b>
M1 Marine shelves	10
M2 Pelagic ocean waters	5
M3 Deep sea floors	7
M4 Anthropogenic marine systems	2
<b>Marine-Freshwater-Terrestrial</b>	<b>3</b>
MFT1 Brackish tidal systems	3
<b>Marine-Terrestrial</b>	<b>7</b>
MT1 Shoreline systems	4
MT2 Supralittoral coastal systems	2
MT3 Anthropogenic shorelines	1
<b>Subterranean</b>	<b>3</b>
S1 Subterranean lithic systems	2
S2 Anthropogenic subterranean voids	1
<b>Subterranean-Freshwater</b>	<b>4</b>
SF1 Subterranean freshwaters	2
SF2 Anthropogenic subterranean freshwaters	2
<b>Subterranean-Marine</b>	<b>3</b>
SM1 Tidal subterranean systems	3
<b>Terrestrial</b>	<b>34</b>
T1 Tropical-subtropical forests	4
T2 Temperate-boreal forests & woodlands	6
T3 Shrublands & shrubby woodlands	4
T4 Savannas and grasslands	5
T5 Deserts and semi-deserts	5
T6 Polar-alpine	5
T7 Intensive land-use systems	5
<b>General Total</b>	<b>110</b>

Source: Adapted from Keith et al. (2022).

Table A.6 - Number of Pantanal Macrohabitats per Functional unit and Subclass.

<b>Functional unit / Subclass</b>	<b>Number of Macrohabitats</b>
<b>1. Permanently aquatic areas</b>	<b>10</b>
1.1. River Channels	3
1.2. Lakes	7
<b>2. Predominantly Aquatic Areas</b>	<b>8</b>
2.1. Areas with Periodically Flowing Water	4
2.2. Areas Periodically Covered by Standing Water	4
<b>3. Predominantly Terrestrial Areas</b>	<b>30</b>
3.1. Areas Without or With Sparse Vegetation Cover	3
3.2. Areas Covered with Grasses and Herbaceous Plants	5
3.3. Areas Covered by Herbaceous Plants, Shrubs, and Small Groups of Trees	4
3.4. Areas Covered by Shrublands	4
3.5. Areas Covered by Polyspecific Forests	6
3.6. Areas Covered by Monodominant Stands	8
<b>4. Swampy Areas</b>	<b>7</b>
4.1. Swamps Covered by Herbaceous Plants	5
4.2. Swamps Covered by Herbaceous Plants and Palms	2
<b>5. Permanently Terrestrial Areas</b>	<b>10</b>
5.1. Paleo-Deltas, Alluvial Terraces, and Paleo-Levees	7
5.2. Inselbergs	3
<b>6. Anthropogenic Areas</b>	<b>9</b>
6.1. Paleo-Anthropogenic Areas	1
6.2. Areas of Recent Anthropogenic Activities	8
<b>General Total</b>	<b>74</b>

Source: Adapted from Cunha et al. (2021).

## APPENDIX B - SUPPLEMENTARY MATERIALS FOR CHAPTER 3

This appendix is a Supplementary Material for the paper to be published from the text in Chapter 3.

### B.1 ESVD variables

Most of the ESVD variables were not used. Here we present all of them with an example of content, if and how they were used by the protocol to select ESVD entries for meta-analytic function development or for suggesting ESVD entries and source studies for review, and why not (Table B.1).

Table B.1 - ESVD attributes (columns) and their use by the proposed protocol.

Field	Example	Used?	How (if used) or why (if not used)
Valuelid	5790001	Yes	ESVD unique ID for entries, used to count and identify them.
StudyId	579	Yes	Used to detect possible duplication of source studies.
ESVD2.0_Biome	Inland wetlands, Rivers, and lakes	No	Expected to be calculated from "ESVD2.0 Ecosystem Codes"
ESVD2.0_Biome_Codes	3; 4	Yes	Mapped to GET, when filled and ESVD2.0_Ecozone_Codes and ESVD2.0_Ecosystem_Codes is not filled.
ESVD2.0_Biome_1 to ESVD2.0_Biome_8	Inland wetlands	No	Expected to be a split from "ESVD2.0_Biome".
ESVD2.0_Ecozones	Seasonal floodplain marshes; Rivers and streams; Freshwater lakes; Peatlands	No	Expected to be calculated from "ESVD2.0_Ecosystem_Codes"
ESVD2.0_Ecozone_Codes	3.3; 4.1; 4.2; 3.1	Yes	Mapped to GET, when filled and ESVD2.0_Ecosystem_Codes is not filled.
ESVD2.0_Ecozone_1 to ESVD2.0_Ecozone_13	Seasonal floodplain marshes	No	Expected to be a split from "ESVD2.0_Ecozones".

(continue)

Table B.1 - Continuation.

Field	Example	Used?	How (if used) or why (if not used)
ESVD2.0_Ecosystems	Subtropical-temperate forested peatlands	No	Expected to be calculated from "ESVD2.0_Ecosystem_Codes"
ESVD2.0_Ecosystem_Codes	3.1.2	Yes	Mapped to GET, when filled.
ESVD2.0_Ecosystem_1 to ESVD2.0_Ecosystem_7	Subtropical-temperate forested peatlands	No	Expected to be a split from "ESVD2.0_Ecosystems".
Ecosystem Text		No	Expected to have been classified into "ESVD2.0_Ecosystem_Codes"
ES_Text	Recreational fishing	No	Expected to have been classified into "SEEA".
TEEB_ES	1; 19	No	Used "SEEA" instead.
TEEB_SubES		No	Used "SEEA" instead.
ES_1 to ES_14	Food	No	Used "SEEA" instead.
CICES		Yes	Used to review and fix "SEEA" for some cases only.
SEEA	Biomass provisioning services	Yes	Ecosystem service name according to SEEA-EA.
Countries	Brazil, Federative Republic of	No	Expected to be calculated from "Country_Codes".
Country_Codes	BRA	Yes	Country codes. Used to suggest ESVD entries to review, only. If necessary for meta-analytic function, will be obtained from Latitude and Longitude.
Country_Code_1 to Country_Code_17	BRA	No	Expected to be a split from "Country_Codes".
Country_1 to Country_17	Brazil, Federative Republic of	No	Expected to be a split from "Countries".
Continent	South America	No	Expected to be calculated from "Country_Codes".
Scale Of Site	Local	Yes	Used to investigate issues with standardised values.
Study Location	Pantanal	No	Used "Latitude" and "Longitude" instead.
Protection Status	Protected	No	Too many empty entries.
Site Area	13800000	Yes	Used to investigate issues with standardised values only.
Site Area Unit	Ha	Yes	Used to investigate issues with standardised values only.
Site Area In Hectares	13800000	Yes	Needed for meta-analytic function development. Used to investigate issues with standardised values, too.
Site Length		Yes	Used to investigate issues with standardised value only.
Site Length Unit		Yes	Used to investigate issues with standardised value only.

(continue)

Table B.1 - Continuation.

Field	Example	Used?	How (if used) or why (if not used)
Site Length Km		Yes	Used to investigate issues with standardised value only.
Site Condition		No	Expected to be classified in "Ecosystem condition".
Ecosystem Condition		No	Too many empty entries.
Latitude	-17.65	Yes	Site spatial coordinate.
Longitude	-57.42	Yes	Site spatial coordinate.
Valuation Methods	TC	Yes	Issue when empty or including "VT" (value transfer).
Valued Change		No	No clear use for our protocol.
Original Value	35059424	Yes	Used to investigate issues with standardised values only.
Currency	United States Dollar	No	Expected to be reflected in the standardised value.
Value Year	1994	Yes	Year of the valuation
Spatial Unit	total area	Yes	Used to investigate issues with standardised values only.
Temporal Unit	Year	Yes	Used to investigate issues with standardised values only.
Present Value Year		No	Expected to be reflected in the standardised value.
Present Value Discount Rate		No	Expected to be reflected in the standardised value.
Beneficiary Unit	Total	Yes	Used to investigate issues with standardised values only.
Number Of Beneficiaries		Yes	Used to investigate issues with standardised value only.
Type Of Beneficiary		No	Expected to be classified in "Beneficiary Unit".
Int\$ Per Hectare Per Year	47551	Yes	Valuation standardised by purchasing parity power for \$ in 2020. Nicknamed as "standardised value".
Authors	Shrestha et al.	Yes	Used to review if the source study is duplicated only.
Title	Value of recreational fishing in the Brazilian Pantanal: a travel cost analysis using count data models.	Yes	Used to detect possible duplication of source studies.
Reference	Shrestha, R. K., Seidl, A. F., & Moraes, A. S. (2002). Value of recreational fishing in the Brazilian Pantanal: a travel cost analysis using count data models. Ecological economics, 42(1-2), 289-299.	Yes	Used to review if the source study is duplicated only.
Year pub	2002	Yes	Used to review if the source study is duplicated only.

(continue)

Table B.1 - Conclusion.

<b>Field</b>	<b>Example</b>	<b>Used?</b>	<b>How (if used) or why (if not used)</b>
Notes	Need to add in population density, GDP per capita data, and compute value in USD 1995.	No	Too specific, does not allow automatic classification.
Secondary Data Sources		No	No clear use for our protocol.
Reviewed		No	No clear use for our protocol.

## B.2 Crosswalk from ESVD to GET

The `esvd_get.csv` file contains the crosswalk of ESVD Biomes, Ecozones, and Ecosystems to Global Ecosystem Typology (GET) Realms, Biomes, and Ecosystem Functional Groups (EFG). This file can be found at <https://github.com/fernandortdias/MyPhD/tree/master/ESVD%20for%20Pantana>. Contributions are welcome. An extract from it is shown in Table B.2:

Table B.2 - Translating ESVD biome, ecozone and ecosystem types into Global Ecosystem Typology (GET), some examples.

#	ESVD_Biome	ESVD_Ecozone	ESVD_Ecosystem	GET_Realm	GET_Biome	GET_EFG
1	1			M		
2	1	1.1		M	M1	
3	1	1.1	1.1.1	M	M1	M1.1
4	1	1.1	1.1.2	M	M1	M1.2
5	1	1.1	1.1.3	M	M1	M1.3
...	...	...	...	...	...	...
212	15	15.2		T	T7	T7.4
213	15	15.2	15.2.1	T	T7	T7.4
214	15	15.2	15.2.2	T	T7	T7.4
215	15	15.3		T	T7	T7.4
216	15	15.3	15.3.1	T	T7	T7.4

Empty cells in each ESVD entry of `esvd_get.csv` should be read like this:

- An empty cell for an ESVD variable matches ESVD entries where the respective variable is empty too.
- An empty cell for a GET variable means that the corresponding information cannot be defined from the ESVD variables, so all EFGs that satisfy the non-empty GET variables to the left are associated with the ESVD entries that match the values of the corresponding ESVD variables.

### B.3 Source studies about the Pantanal

Four studies mention Pantanal in their title. These studies are the source of 53 ESVD entries valuating 18 SEEA ecosystem services, but none are associated with a Pantanal EFG with no issue (Table B.3).

Table B.3 - Source studies in ESVD that mention Pantanal in their title.

StudyId	Reference	EFGs	Issues	#
579	Shrestha, R. K., Seidl, A. F., & Moraes, A. S. (2002). Value of recreational fishing in the Brazilian Pantanal: a travel cost analysis using count data models. <i>Ecological economics</i> , 42(1-2), 289-299.	F1.4; F1.5; F2.3; TF1.2; TF1.4	Multiple EFGs Multiple service types	1
952	Seidl, A. F., & Moraes, A. S. (2000). Global valuation of ecosystem services: application to the Pantanal da Nhecolandia, Brazil. <i>Ecological economics</i> , 33(1), 1-6.	F1.5; F2.3; T1.1; T4.1; TF1.2; TF1.3; TF1.4	Multiple EFGs Multiple service types Valuation methods include VT	4
			Multiple EFGs Valuation methods include VT	13
953	Massaroli, B. A. R., Araújo, J. M., Ortega, J. C., Valle Nunes, A., Mateus, L., Silva, S. E., & Penha, J. (2021). Temporal dynamics and economic valuation of recreational fisheries of the lower Cuiabá River, Brazilian Pantanal. <i>Fisheries Management and Ecology</i> , e12479.	F1.7	No standardised value No study site area	2
956	Seidl, A., De Salis, S., Moraes, A.S. & Araujo Crispim S.M. (2000). SUSTAINABILITY OF TIMBER EXPLOITATION IN THE BRAZILIAN PANTANAL, MS. III Symposio sobre Recurso Naturais e Socio-economicos do Pantanal Os Desafios do Novo Milenio.	TF1.4	No study site area	33

## B.4 Empty standardised values

Empty or non-positive standardised values is the second most frequent issue found. This Supplementary Material explores possible explanations for ESVD entries with this issue and suggests source studies to review for Pantanal EFGs, although some of these ESVD entries may have other issues.

### B.4.1 Non-positive standardised value

While 513 entries have empty standardised values for some Pantanal EFGs, there are 74 entries with standardised values reported as zero, and none have negative standardised values (Table B.4).

Table B.4 - ESVD entries for Pantanal EFGs with zero or negative standardised value, some of them with other issues.

StudyId	Reference	EFG	Other issues	#
161	Christie et al (2011) Economic Valuation of the Benefits of Ecosystem Services delivered by the UK Biodiversity Action Plan	T7.5		29
			Multiple service types	24
		TF1.3		4
			Multiple service types	3
1326	Grossmann, M. (2012). Economic value of the nutrient retention function of restored floodplain wetlands in the Elbe River basin. <i>Ecological Economics</i> , 83, 108-117.	TF1.4	Multiple service types	16
			Multiple service types No site area	1
575	Seyam, I. M., Hoekstra, A. Y., Ngabirano, G. S., & Savenije, H. H. G. (2001). The value of freshwater wetlands in the Zambezi basin. <i>Value of water research report series</i> , 7.	TF1.4	Valuation methods include VT	1
640	Turpie, J. K. (2000). The use and value of natural resources of the Rufiji floodplain and delta, Tanzania. Unpublished report to IUCN (EARO).	TF1.4	From a duplicated study	1
1263	Fernández, M., Rivas, F., & Durán, M. (2006). Valoración económica ambiental del bosque experimental "El Caimital", Municipio Obispos estado Barinas. <i>Revista Forestal Latinoamericana</i> , 40, 29-45.	T1.2		1

### B.4.2 Explaining issues with the standardised value

The standardised value is calculated as “International \$” per ha and year from an original value in another currency, possibly not spatially or temporally distributed in the source study. Two conditions seem to explain most of the issues on standardised value: Empty or zero Original Value variable and Spatial Unit variable is empty, or it represents a total, and Site Area In Hectares is empty or zero (Table B.5).

Table B.5 - Conditions for most of the issues on standardised value for Pantanal EFGs.

		No standardised value	False	True
No original value	No spatial distribution			
True	False		0	61
False	True		1	304
	False		860	222

ESVD entries with Original Value variable empty or non-positive are opportunities for source study review (Table B.6).

Table B.6 - Source studies with no original value in a ESVD entry for Pantanal EFGs.

StudyId	Reference	EFG	Other issues	#
161	Christie et al (2011) Economic Valuation of the Benefits of Ecosystem Services delivered by the UK Biodiversity Action Plan	T7.5		29
			Multiple service types	24
		TF1.3		5
			Multiple service types	3

### B.4.3 Reviewing ESVD entries with no site area

Among the ESVD entries for Pantanal EFGs with empty standardised value explained by empty or zero site area, some have site length data, maybe because the valuation site is linear (e.g., a river). For these, maybe a site area could be estimated if there is enough information for site width along this length. It has probably been done already for other ESVD entries, as there are ESVD entries associated with EFGs that represent rivers with positive site area and standardised value (Table B7).

Table B.7 - Studies with no value for Pantanal EFGs with known original value, unknown site area, but known site length.

StudyId	Reference	EFG	Other issues	#
521	Rayment et al (2014) Estimating the Impact on Public Benefits from Changes in Investment in the Environment Agency Waterways	F1.2		8
1445	Sander, H. A., & Haight, R. G. (2012). Estimating the economic value of cultural ecosystem services in an urbanizing area using hedonic pricing. <i>Journal of environmental management</i> , 113, 194-205.	T7.4		5
1400	MacDonald, D. H., Morrison, M. D., Rose, J. M., & Boyle, K. J. (2011). Valuing a multistate river: the case of the River Murray. <i>Australian Journal of Agricultural and Resource Economics</i> , 55(3), 374-392.	F1.5		4
159	Christie, M., & Rayment, M. (2012). An economic assessment of the ecosystem service benefits derived from the SSSI biodiversity conservation policy in England and Wales. <i>Ecosystem Services</i> , 1(1), 70-84.	F3.5		4
853	Doss, C. R., & Taff, S. J. (1996). The influence of wetland type and wetland proximity on residential property values. <i>Journal of agricultural and resource economics</i> , 120-129.	TF1.3	From a duplicated study	3
1453	Loomis, J. (2002). Quantifying recreation use values from removing dams and restoring free-flowing rivers: A contingent behavior travel cost demand model for the Lower Snake River. <i>Water Resources Research</i> , 38(6), 2-1.	F1.2		2
179	Dallimer, M., Tinch, D., Hanley, N., Irvine, K. N., Rouquette, J. R., Warren, P. H., ... & Armsworth, P. R. (2014). Quantifying preferences for the natural world using monetary and nonmonetary assessments of value. <i>Conservation Biology</i> , 28(2), 404-413.	T7.4		2
490	Peirson, G., Tingley, D., Spurgeon, J., & Radford, A. (2001). Economic evaluation of inland fisheries in England and Wales. <i>Fisheries Management and Ecology</i> , 8(4?5), 415-424.	T7.4		2
298	Hanley et al (2003) Aggregating the benefits of environmental improvements- distance-decay functions for use and non-use values	F1.2	Multiple service types	1
413	MacMillan and Ferrier (1994) A Bioeconomic Model for Estimating the Benefits of Acid Rain Abatement to Salmon Fishing- A case Study in South West Scotland	F1.2		1

### B.4.5 Reviewing ESVD entries with unknown beneficiaries

Most of the remaining cases of issues on standardised value seem to be explained by the absence of information of the Number Of Beneficiaries when this information is requested by the Beneficiary Unit variable (Table B8).

Table B.8 - Explaining the remaining issues on the standardised value for Pantanal EFGs.

		<b>No standardised value</b>		<b>False</b>	<b>True</b>
<b>No original value</b>	<b>No spatial distribution</b>	<b>Unknown beneficiaries</b>			
<b>True</b>	<b>False</b>	<b>False</b>	<b>True</b>	0	61
	<b>True</b>	<b>False</b>	<b>True</b>	0	115
<b>False</b>	<b>True</b>	<b>False</b>	<b>True</b>	1	189
	<b>False</b>	<b>False</b>	<b>True</b>	9	137
	<b>False</b>	<b>False</b>	<b>False</b>	851	85

Most of these remaining cases concentrate on two types of beneficiaries: household and person. A possible explanation: the original value was estimated per beneficiary, and the number of beneficiaries was not informed, so it cannot be distributed spatially (Table B.9).

Table B.9 - Source studies with issues on standardised value for Pantanal EFGs, with original value and spatial distribution known, type of beneficiaries specified but the number of beneficiaries is not informed.

StudyId	Reference	EFG	Beneficiary Unit	Other issues	#
1365	Brouwer, R., Bliem, M., Flachner, Z., Getzner, M., Kerekes, S., Milton, S., ... & Wagtendonk, A. (2009, June). Ecosystem service valuation from floodplain restoration in the Danube River Basin: An international choice experiment application. In Annual Conference of the Association of Environmental and Resource Economists, Amsterdam.	TF1.4	household	Multiple service types	21
1449	Pattison, J., Boxall, P. C., & Adamowicz, W. L. (2011). The economic benefits of wetland retention and restoration in Manitoba. <i>Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie</i> , 59(2), 223-244.	TF1.3	household		10
910	Calleja, A., Díaz-Balteiro, L., Iglesias-Merchan, C., & Soliño, M. (2017). Acoustic and economic valuation of soundscape: An application to the 'Retiro' Urban Forest Park. <i>Urban forestry &amp; urban greening</i> , 27, 272-278.	T7.4	person		10
771	Behera, M. C., & Nath, M. R. (2012). Financial valuation of non-timber forest products flow from tropical dry deciduous forests in Boudh district, Orissa. <i>International Journal of farm sciences</i> , 2(2), 83-94.	T1.2	household	Multiple service types	8 3
1428	Trenholm, R., Haider, W., Lantz, V., Knowler, D., & Haegeli, P. (2017). Landowner preferences for wetlands conservation programs in two Southern Ontario watersheds. <i>Journal of Environmental Management</i> , 200, 6-21.	TF1.3	person		8
851	Baral, S., Basnyat, B., Khanal, R., & Gauli, K. (2016). A total economic valuation of wetland ecosystem services: an evidence from Jagadishpur Ramsar site, Nepal. <i>The Scientific World Journal</i> , 2016.	F3.2	household	From a duplicated study Multiple service types From a duplicated study	7 3
114	Brouwer (1999) Public Right of Access, overcrowding and the value of peace and quiet: the validity of contingent valuation as an information tool	TF1.3	household	Multiple service types	6
632	Turner et al (2003) Towards an integrated environmental assessment for wetland and catchment management	TF1.3	person	Multiple service types	6

(continue)

Table B.9 - Continuation.

StudyId	Reference	EFG	Beneficiary Unit	Other issues	#
511	Ragkos, A., Psychoudakis, A., Christofi, A., & Theodoridis, A. (2006). Using a functional approach to wetland valuation: the case of Zazari–Cheimaditida. <i>Regional Environmental Change</i> , 6(4), 193-200.	F2.2	person	Multiple service types	3
72	Bateman et al (2006) Decoy effects in choice experiments and contingent valuation, asymmetric dominance	F2.2	household		4
822	Willemens, L., Hein, L. & Verburg, P. H. (2010). Evaluating the impact of regional development policies on future landscape services	T7.4	Person	Valuation methods include VT	4
101	Blomquist, G. C., & Whitehead, J. C. (1998). Resource quality information and validity of willingness to pay in contingent valuation. <i>Resource and Energy Economics</i> , 20(2), 179-196.	TF1.3	household	Multiple service types	4
909	Bernath, K., & Roschewitz, A. (2008). Recreational benefits of urban forests: Explaining visitors' willingness to pay in the context of the theory of planned behavior. <i>Journal of environmental management</i> , 89(3), 155-166.	T7.4	Person		4
1361	Borzykowski, N., Baranzini, A., & Maradan, D. (2017). A travel cost assessment of the demand for recreation in Swiss forests. <i>Review of Agricultural, Food and Environmental Studies</i> , 98(3), 149–171. <a href="https://doi.org/10.1007/s41130-017-0047-4">https://doi.org/10.1007/s41130-017-0047-4</a>	T7.4	person		3
316	Hunter, P. D., Hanley, N., Czajkowski, M., Meams, K., Tyler, A. N., Carvalho, L., & Codd, G. A. (2012). The effect of risk perception on public preferences and willingness to pay for reductions in the health risks posed by toxic cyanobacterial blooms. <i>Science of the total environment</i> , 426, 32-44.	F2.2	household	Multiple service types	2
28	Amare, D., Mekuria, W., T/wold, T., Belay, B., Teshome, A., Yitafaru, B., ... & Tegegn, B. (2016). Perception of local community and the willingness to pay to restore church forests: The case of Dera district, northwestern Ethiopia. <i>Forests, Trees and Livelihoods</i> , 25(3), 173-186.	T1.2	household	Multiple service types	2
904	Majumdar, S., Deng, J., Zhang, Y., & Pierskalla, C. (2011). Using contingent valuation to estimate the willingness of tourists to pay for urban forests: A study in Savannah, Georgia. <i>Urban Forestry &amp; Urban Greening</i> , 10(4), 275-280.	T7.4	Person		1
784	Tibesigwa, B., Ntuli, H., & Lokina, R. (2020). Valuing recreational ecosystem services in developing cities: The case of urban parks in Dar es Salaam, Tanzania. <i>Cities</i> , 106, 102853.	T7.4	household	Multiple service types	2
					1

(continue)

Table B.9 - Continuation.

StudyId	Reference	EFG	Beneficiary Unit	Other issues	#
1450	Yu, J. (2010). An economic analysis of landowners' willingness to adopt wetland riparian conservation management: a Saskatchewan case study (Doctoral dissertation).	TF1.3	household		2
				No site area	1
368	Kosz, M. (1996). Valuing riverside wetlands: the case of the "Donau-Auen" national park. <i>Ecological Economics</i> , 16(2), 109-127.	TF1.3	person		2
903	Kleiber, O. (2001). Valuation of recreational benefits and visitor conflicts in an urban forest. In Fifth International Conference of the International Society for Ecological Economics (ISEE), Moscow, Russia.	T7.4	person		1
504	Powe, N. A., Garrod, G. D., & Willis, K. G. (1995). Valuation of urban amenities using an hedonic price model. <i>Journal of Property Research</i> , 12(2), 137-147.	T7.4	person		2
1299	Behjou, F. K., Esfahan, E. Z., Ramezani, M., Hashemian, A., & Amirahmadi, N. (2014). Estimating the outdoor recreational value of Shorabil lake based on Contingent Valuation Method (CVM). <i>European Journal of Experimental Biology</i> , 4(2), 282-285.	F2.2	person		1
940	Mohamed, N., Shamsudin, M. N., Ghani, A. N. A., Radam, A., Kaffashi, S., Rahim, N. N. R. N. A., & Hassin, N. B. (2012). Willingness to pay for watershed conservation at Hulu Langat, Selangor. <i>Journal of Applied Sciences(Faisalabad)</i> , 12(17), 1859-1864.	TF1.1	person		1
379	Langford, I. H., Bateman, I. J., & Langford, H. D. (1996). A multilevel modelling approach to triple-bounded dichotomous choice contingent valuation. <i>Environmental and Resource Economics</i> , 7(3), 197-211.	TF1.3	person	Multiple service types	1
296	Hanley, N., MacMillan, D., Wright, R. E., Bullock, C., Simpson, I., Parsisson, D., & Crabtree, B. (1998). Contingent valuation versus choice experiments: estimating the benefits of environmentally sensitive areas in Scotland. <i>Journal of agricultural economics</i> , 49(1), 1-15.	TF1.3	household	Multiple service types	1
253	Garrod, G. D., Willis, K. G., & Saunders, C. M. (1994). The benefits and costs of the Somerset Levels and Moors ESA. <i>Journal of rural studies</i> , 10(2), 131-145.	TF1.4	household		1
444	Moncur, J. E. T. (1973). The value of recreation areas on Oahu. Report prepared for the Center for Governmental Development, University of Hawaii.	T1.2	person		1
1313	Bastidas, J. A. O., Sánchez, M. T. C., & Montenegro, A. F. (2016). Valoración económica del recurso natural agua del humedal Coroncoro de Villavicencio. <i>Lámpsakos</i> , (16), 33-43.	T7.4	person		1
911	López-Mosquera, N., & Sánchez, M. (2012). Theory of Planned Behavior and the Value-Belief-Norm Theory explaining willingness to pay for a suburban park. <i>Journal of environmental management</i> , 113, 251-262.	T7.4	person		1

(continue)

Table B.9 - Conclusion.

<b>StudyId</b>	<b>Reference</b>	<b>EFG</b>	<b>Beneficiary Unit</b>	<b>Other issues</b>	<b>#</b>
478	ONS (2019). Valuing green spaces in urban areas: a hedonic price approach using machine learning techniques. Office for National Statistics	T7.4	household	Multiple service types	1
1409	Tapsuwan, Sorada & Ingram, Gordon & Brennan, Donna C., 2007. "Valuing Urban Wetlands of the Gngangara Mound: A Hedonic Property Price Approach in Western Australia," 2007 Conference (51st), February 13-16, 2007, Queenstown, New Zealand 10418, Australian Agricultural and Resource Economics Society.	T7.4	household	Multiple service types	1
1408	Pandit, R., Polyakov, M., Tapsuwan, S., & Moran, T. (2013). The effect of street trees on property value in perth, western australia. Landscape and Urban Planning, 110(1), 134–142. <a href="https://doi.org/10.1016/j.landurbplan.2012.11.001">https://doi.org/10.1016/j.landurbplan.2012.11.001</a>	T7.4	household		1
1400	MacDonald, D. H., Morrison, M. D., Rose, J. M., & Boyle, K. J. (2011). Valuing a multistate river: the case of the River Murray. Australian Journal of Agricultural and Resource Economics, 55(3), 374-392.	F1.5	household		1
1247	Meyerhoff, J., Dehnhardt, A., & Hartje, V. (2010). Take your swimsuit along: the value of improving urban bathing sites in the metropolitan area of Berlin. Journal of environmental planning and management, 53(1), 107-124.	T7.4	person		1

## **B.5 Suggested ESVD entries and source studies to review**

This supplementary Material proposes criteria to select ESVD entries and source studies found with issues for Pantanal EFGs to be reviewed, as they are easier to review or are more likely to increase ESVD entries available for meta-analytic function development for Pantanal.

### **B.5.1 Source studies on selected Pantanal EFGs**

It is more efficient to review studies that are source for ESVD entries with issues associated with Pantanal EFGs with fewer ESVD entries with no issue, e.g., selected freshwater and terrestrial EFGs found in Pantanal (Table B.10).

Table B.10 - Studies on Pantanal freshwater and terrestrial EFGs with the most ESVD entries with issues (top ten).

StudyId	Reference	EFG	Issues per entry	#
161	Christie, M., Hyde, A., Cooper, R., Fazey, I., Dennis, P., Warren, J. M., ... & Hanley, N. (2011). Economic Valuation of the Benefits of Ecosystem Services Delivered by the UK Biodiversity Action Plan (Defra Project SFFSD 0702).	T7.5	No standardized value	29
			Multiple service types	24
772	Mahapatra, A. K., & Tewari, D. D. (2005). Importance of non-timber forest products in the economic valuation of dry deciduous forests of India. <i>Forest Policy and Economics</i> , 7(3), 455-467.	T1.2	No standardised value No study site area	33
1410	Carson, R. T., Hanemann, W. M., & Wegge, T. C. (2009). A nested logit model of recreational fishing demand in Alaska. <i>Marine Resource Economics</i> , 24(2), 101-129.	F1.2	No standardised value No study site area	19
831	Schaafsma, M., Brouwer, R. & Rose, J. (2012) Directional heterogeneity in WTP models for environmental valuation	F2.2	Multiple service types No standardised value No study site area	13
275	Green and Tunstall (1992) The Amenity and Environmental Value of River Corridors in Britain	F1.2	Multiple service types No standardised value No study site area	12
770	Purushothaman, S., Viswanath, S., & Kunhikannan, C. (2000). Economic valuation of extractive conservation in a tropical deciduous forest in Madhya Pradesh, India. <i>Tropical ecology</i> , 41(1), 61-72.	T1.2	Multiple service types	10
1300	Bekoe, J., Balana, B. B., & Nimoh, F. (2021). Social cost-benefit analysis of investment in rehabilitation of multipurpose small reservoirs in northern Ghana using an ecosystem services-based approach. <i>Ecosystem Services</i> , 50.	F3.5	Multiple service types	9
			Multiple service types No standardised value	1
1137	Sidibé, Y., Myint, M., & Westerberg, V. (2014). An economic valuation of agroforestry and land restoration in the Kelka Forest, Mali. Assessing the socio-economic and environmental dimensions of land degradation. Report for the Economics of Land Degradation Initiative, by International Union for Conservation of Nature, Nairobi, Kenya. Available from: <a href="http://www.eld-initiative.org">www.eld-initiative.org</a>	T1.2	Multiple service types	9
771	Behera, M. C., & Nath, M. R. (2012). Financial valuation of non-timber forest products flow from tropical dry deciduous forests in Boudh district, Orissa. <i>International Journal of farm sciences</i> , 2(2), 83-94.	T1.2	Multiple service types No standardised value	8
640	Turpie, J. K. (2000). The use and value of natural resources of the Rufiji floodplain and delta, Tanzania. Unpublished report to IUCN (EARO).	T1.2	From a duplicated study	8
521	Rayment et al (2014) Estimating the Impact on Public Benefits from Changes in Investment in the Environment Agency Waterways	F1.2	No standardised value No study site area	8

## B.5.2 Splitting ESVD entries per EFG

ESVD entries associated with multiple EFGs may have their ecosystems reclassified or split per EFG after source study review to add ESVD entries for some Pantanal EFGs with few entries with no issue, e.g., freshwater EFGs (Table B.11).

Table B.11 - Source studies of ESVD entries associated with multiple freshwater EFGs and at least one Pantanal EFG.

StudyId	Reference	EFGs	#
116	Brouwer, R., Bliem, M., Getzner, M., Kerekes, S., Milton, S., Palarie, T., ... & Wagtendonk, A. (2016). Valuation and transferability of the non-market benefits of river restoration in the Danube river basin using a choice experiment. <i>Ecological Engineering</i> , 87, 20-29.	F1.2; F1.7	15
256	Garrod and Willis (1996) Angling and recreational values of low-flow alleviation in rivers	F1.1; F1.2	14
159	Christie and Rayment (2012) An Economic Assessment of the Ecosystem Service Benefits Derived from the SSSI Biodiversity Conservation Policy in England and Wales	F1.1; F1.2	7
		F2.1; F2.2; F2.3; F2.4; F2.5; F2.8; F2.9	7
1437	Miller, S., Tait, P., & Saunders, C. (2015). Estimating indigenous cultural values of freshwater: A choice experiment approach to Māori values in New Zealand. <i>Ecological Economics</i> , 118, 207-214.	F1.1; F1.2; F1.3; F1.4; F1.5; F1.6; F1.7; F1.1; F1.2; F1.3; F1.4; F1.5; F1.6; F1.7	10
1392	Hill, B. H., Kolka, R. K., McCormick, F. H., & Starry, M. A. (2014). A synoptic survey of ecosystem services from headwater catchments in the United States. <i>Ecosystem Services</i> , 7, 106-115.	F1.1; F1.2; F1.3; F1.4; F1.5; F1.6; F1.7; F1.1; F1.2; F1.3; F1.4; F1.5; F1.6; F1.7	9
56	AHLHEIM, M., O. FRÖR and N. SINPHURMSUKSKUL (2006): The role of participation in CVM survey design: evidence from a tap waater improvement program in northern Thailand. In Proceedings of the Third World congress of Environmental and Resource Economists, Kyotot, Japan, July 2006. In: <a href="http://www.webmeets.com/files/papers/ERE/WC3/551/Participation_Paper.pdf">http://www.webmeets.com/files/papers/ERE/WC3/551/Participation_Paper.pdf</a> .	F1.1; F1.2	8

(continue)

Table B.11 - Continuation.

StudyId	Reference	EFGs	#
1385	Van Houtven, G., Mansfield, C., Phaneuf, D., Von Haefen, R., Milstead, B., Kenney, M., & Reckhow, K. (2014). Combining expert elicitation and stated preference methods to value ecosystem services from improved lake water quality. <i>Ecological Economics</i> , 99, 40-52. doi:10.1016/j.ecolecon.2013.12.018	F2.1; F2.10; F2.2; F2.3; F2.4; F2.5; F2.8; F2.9; F2.1; F2.2; F2.3; F2.4; F2.5; F2.8; F2.9; F2.10; F2.6; F2.7	7
650	Verma, M., Bakshi, N., & Nair, R. P. K. (2001). Economic valuation of Bhoj Wetland for sustainable use. Unpublished project report for World Bank assistance to Government of India, Environmental Management Capacity-Building. Bhopal: Indian Institute of Forest Management, 35.	F2.1; F2.2; F2.3; F2.8	6
1132	Nedkov, S. (2009). Analyzing spatial dimensions of ecosystem services and their valuation using GIS: A case study in Smolyan municipality. <i>Problems of Geography</i> , 4, 53-61.	F2.1; F2.2	4
13	Ahlheim (2006) Economic valuation of environmental benefits in developing and emerging countries: theoretical considerations and practical evidence from Thailand and the Philippines, <i>Quarterly Journal of International Agriculture</i> 45 (2006), No. 4: 397-419	F1.1; F1.2	4
184	Davis and O'Neil (1992) Discrete Choice Valuation of Recreational Angling in Northern Ireland	F1.1; F1.2	3
1442	Hjerpe, E. E., & Hussain, A. (2016). Willingness to pay for ecosystem conservation in Alaska's Tongass National Forest: A choice modeling study. <i>Ecology and Society</i> , 21(2).	F1.1; F1.2; F1.3; F1.4; F1.5; F1.6; F1.7; F1.1; F1.2; F1.3; F1.4; F1.5; F1.6; F1.7	2
1460	Clayton, C., & Mendelsohn, R. (1993). The value of watchable wildlife: A case study of McNeil River. <i>Journal of Environmental Management</i> , 39(2), 101-106.	F1.1; F1.2; F1.3; F1.4; F1.5; F1.6; F1.7; F1.1; F1.2; F1.3; F1.4; F1.5; F1.6; F1.7	2
21	Alam (2006) Valuing the environment in developing countries: Problems and potentials, <i>Asia Pacific Journal on Environment and Development</i> 13 (1 & 2), 27-44.	F1.1; F1.2	2
816	Horlings, E., Schenau, S., Hein, L., Lof, M., de Jongh, L., & Polder, M. (2019, October). Experimental monetary valuation of ecosystem services and assets in the Netherlands. In A paper for the 25th meeting of the London Group on environmental accounting Melbourne (pp. 7-10).	F1.1; F1.2 F2.1; F2.2	1 1
1222	Edens, B., & Graveland, C. (2014). Experimental valuation of Dutch water resources according to SNA and SEEA.	F2.1; F2.2	1

(continue)

Table B.11 - Conclusion.

StudyId	Reference	EFGs	#
1290	Ramírez García, A. G., Escalante, I. C. C., Miranda, D. D., & Hernández, A. A. P. (2023). Valoración económica y disponibilidad a pagar por el agua en comunidades rurales. <i>Económicas CUC</i> , 44(1), 83-102.	F1.1; F1.2	1
1451	Magat, W. A., Huber, J., Viscusi, W. K., & Bell, J. (2000). An iterative choice approach to valuing clean lakes, rivers, and streams. <i>Journal of Risk and Uncertainty</i> , 21(1), 7-43.	F1.1; F1.2; F1.3; F1.4; F1.5; F1.6; F1.7; F1.1; F1.2; F1.3; F1.4; F1.5; F1.6; F1.7	1
		F2.1; F2.10; F2.2; F2.3; F2.4; F2.5; F2.8; F2.9; F2.1; F2.2; F2.3; F2.4; F2.5; F2.8; F2.9; F2.10; F2.6; F2.7	1

### B.5.3 Duplicated studies

There are ESVD entries that come from source studies with different StudyId but similar titles, when converted to lower case, no diacritics, stop words, or punctuation. Our protocol rejected them all. Some of these studies have the same titles, references, authors and publication years; others are slightly different in one or more of these variables. Some of them are sources for ESVD entries of different EFGs, and some simplified titles occur for source studies with no ESVD entry associated with a Pantanal EFG. Reviewing these source studies will clarify if their ESVD entries are duplicates, and if and which of them could be rejected and which could be accepted. For this article, we rejected them all (Table B.12).

Table B.12: - Duplicated source studies.

Simplified title	Title	StudyId	Reference	Authors	Year pub	Other issues	#
environmental functions economic value natural ecosystems	Environmental functions and the economic value of natural ecosystems	279	de Groot, R. S. (1994). Environmental functions and the economic value of natural ecosystems. In A. Jansson (Ed.), Investing in natural capital: the ecological economics approach to sustainability (pp. 151-168)	Groot	1992	Multiple EFG	0
						Multiple EFG Multiple service types	0
		280	de Groot, R. S. (1994). Environmental functions and the economic value of natural ecosystems. In A. Jansson (Ed.), Investing in natural capital: the ecological economics approach to sustainability (pp. 151-168)	Groot	1993		2
						Multiple service types	1

(continue)

Table B.12: - Continuation.

Simplified title	Title	StudyId	Reference	Authors	Year pub	Other issues	#
green infrastructure urban climate adaptation residents views climate impacts green infrastructure shape adaptation preferences	Green infrastructure for urban climate adaptation- How do residents' views on climate impacts and green infrastructure shape adaptation preferences	1230	Derkzen, M. L., van Teeffelen, A. J., & Verburg, P. H. (2017). Green infrastructure for urban climate adaptation: How do residents' views on climate impacts and green infrastructure shape adaptation preferences?. <i>Landscape and urban planning</i> , 157, 106-130.	Derkzen et al	2017	Multiple service types	1
	Green infrastructure for urban climate adaptation: How do residents' views on climate impacts and green infrastructure shape adaptation preferences?	828	Derkzen, M. L., van Teeffelen, A. J., & Verburg, P. H. (2017). Green infrastructure for urban climate adaptation: How do residents' views on climate impacts and green infrastructure shape adaptation preferences?. <i>Landscape and urban planning</i> , 157, 106-130.	Derkzen, M. L., van Teeffelen, A. J., & Verburg, P. H.	2017	Multiple service types No standardised value No study site area	3
influence wetland type wetland proximity residential property values	The Influence of Wetland Type and Wetland Proximity on Residential Property Values	853	Doss, C. R., & Taff, S. J. (1996). The influence of wetland type and wetland proximity on residential property values. <i>Journal of agricultural and resource economics</i> , 120-129.	Doss and Taff	1996	No standardised value No study site area	3
	The influence of wetland type and wetland proximity on residential property values.	206	Doss, C. R., & Taff, S. J. (1996). The influence of wetland type and wetland proximity on residential property values. <i>Journal of agricultural and resource economics</i> , 120-129.	Doss and Taff	1996	No standardised value	1
sustainable flood defence case washlands		229	English Nature. (2001) Sustainable flood defence The case for washlands	English	1996		0
	Sustainable flood defence The case for washlands	230	English Nature (2001) Sustainable flood defence The case for washlands	English Nature	2001	Multiple service types Multiple service types No standardised value No study site area	2 0

(continue)

Table B.12: - Continuation.

Simplified title	Title	StudyId	Reference	Authors	Year pub	Other issues	#
							0
		51	Baral, S., Basnyat, B., Khanal, R., & Gauli, K. (2016). A total economic valuation of wetland ecosystem services: an evidence from Jagadishpur Ramsar site, Nepal. The Scientific World Journal, 2016.	Baral et al	2016	Multiple service types	0
						Valuation methods include VT	0
total economic valuation wetland ecosystem services evidence jagadishpur ramsar site Nepal	A Total Economic Valuation of Wetland Ecosystem Services: An Evidence from Jagadishpur Ramsar Site, Nepal						4
		851	Baral, S., Basnyat, B., Khanal, R., & Gauli, K. (2016). A total economic valuation of wetland ecosystem services: an evidence from Jagadishpur Ramsar site, Nepal. The Scientific World Journal, 2016.	Baral et al	2016	No standardised value	8
						Multiple service types	1
						No standardised value	3
						Multiple service types	0
		636	Turpie, J. K. (2000). The use and value of natural resources of the Rufiji floodplain and delta, Tanzania. Unpublished report to IUCN (EARO).	Turpie	2000	Multiple service types	0
use value natural resources rufiji floodplain delta tanzania	The Use and Value of Natural Resources of the Rufiji Floodplain and Delta, Tanzania						10
		640	Turpie, J. K. (2000). The use and value of natural resources of the Rufiji floodplain and delta, Tanzania. Unpublished report to IUCN (EARO).	Turpie	2000	No standardised value	1
						Multiple EFG	0
						Multiple service types	0

(continue)

Table B.12: - Conclusion.

Simplified title	Title	Studyld	Reference	Authors	Year pub	Other issues	#
using economic valuation techniques inform water resources management survey critical appraisal available techniques application	Using economic valuation techniques to inform water resources management: A survey and critical appraisal of available techniques and an application.	1129	Birol, E., Karousakis, K., & Koundouri, P. (2006). Using economic valuation techniques to inform water resources management: A survey and critical appraisal of available techniques and an application. <i>Science of the total environment</i> , 365(1-3), 105-122.	Birol, E., Karousakis, K., & Koundouri, P.	2006	Multiple EFG No standardised value No study site area	0
	Using economic valuation techniques to inform water resources management: a survey and critical appraisal of available techniques and an application	94	Birol, Karousakis and Koundouri (2006) Using economic valuation techniques to inform water resources management: a survey and critical appraisal of available techniques and an application, <i>Science of the Total Environment</i> , The 365 (2006) 105-122	Birol et al	2006		1
willingness pay environmental services provided trees core fringe areas benin city nigeria	Willingness-to-pay for Environmental Services Provided By Trees in Core and Fringe Areas of Benin City, Nigeria	1184	Arabomen, O. J., Chirwa, P. W., & Babalola, F. D. (2019). Willingness-to-pay for Environmental Services Provided By Trees in Core and Fringe Areas of Benin City, Nigeria 1. <i>International Forestry Review</i> , 21(1), 23-36.	Arabomen, O. J., Chirwa, P. W., & Babalola, F. D.	2019	Multiple service types	1
		1321	Arabomen, O. J., Chirwa, P. W., & Babalola, F. D. (2019). Willingness-to-pay for Environmental Services Provided By Trees in Core and Fringe Areas of Benin City, Nigeria 1. <i>International Forestry Review</i> , 21(1), 23-36.	Arabomen et al.	2019	No standardised value No study site area	1

Source studies with similar titles and the other issues found for ESVD entries associated with each Studyld. “#” is the number of entries found for Pantanal EFGs for each title.

## B.6 Protocol results and code

The file “protocol\_results.csv” has the results of applying the protocol to the complete ESVD file. This file can be found at:

[https://github.com/fernandortdias/MyPhD/tree/master/ESVD%20for%20Pantana I.](https://github.com/fernandortdias/MyPhD/tree/master/ESVD%20for%20Pantana%20I)

The first ESVD entry of the “protocol\_results.csv” file is the heading with the name of the issue represented by each variable:

- Valued: Copy of the “Valued” variable in ESVD.
- GET\_Realm, GET\_Biome, GET\_EFG: The codes of the corresponding levels at Global Ecosystem Typology (GET) that could be inferred from the value of ESVD variables “ESVD2.0\_Ecosystem\_Codes”, “ESVD2.0\_Ecozone\_Codes” and “ESVD2.0\_Biome\_Codes” as described in the article. Empty if no GET type could be inferred for each level. A list of codes separated by ‘;’ if more than one could be inferred for each level.
- service\_codes: The code of the SEEA service type whose name could be found in ESVD variable “SEEA”. Empty if no name of a valid SEEA service type code could be found. A list of codes separated by ‘;’ if more than one SEEA service type could be found.
- service\_supertypes: The name of the SEEA service supertypes corresponding to the service\_codes. Empty if no SEEA service type could be found. A list of codes separated by ‘;’ if SEEA service types of more than one supertype were found.
- service\_categories: The name of the SEEA service category corresponding to the service\_codes. Empty if no SEEA service type could be found. A list of codes separated by ‘;’ if SEEA service types of more than one category were found.
- simplified\_title: The content of the ESVD variable “Title” converted to a string with low caps only, no stopwords, punctuation, diacritics or repeated spaces. “<None>”, if a the “Title” variable is empty or a simplified title could not be obtained.
- no\_EFG: “True” if GET\_EFG variable is empty. “False”, otherwise.

- no\_GET\_biome: “True” if GET\_Biome variable is empty. “False”, otherwise.
- no\_GET\_realm: “True” if GET\_Realm variable is empty. “False”, otherwise.
- multiple\_EFG: “True” if GET\_EFG value is a list separated by ‘;’. “False”, otherwise.
- multiple\_GET\_biome: “True” if GET\_Biome value is a list separated by ‘;’. “False”, otherwise.
- multiple\_GET\_realm: “True” if GET\_Realm value is a list separated by ‘;’. “False”, otherwise.
- no\_service: “True” if service\_codes variable is empty. “False”, otherwise.
- multiple\_service\_types: “True” if service\_codes value is a list separated by ‘;’. “False”, otherwise.
- multiple\_service\_supertypes: “True” if service\_supertypes value is a list separated by ‘;’. “False”, otherwise.
- multiple\_service\_categories: “True” if service\_categories value is a list separated by ‘;’. “False”, otherwise.
- no\_standardised\_value: “True” if ESVD variable “Int\$ Per Hectare Per Year” variable is empty, is not a number, is zero or negative. “False”, otherwise.
- no\_year: “True” if ESVD variable “Value Year” is empty, could not be read as a integer or is < 1970 or higher > 2024. “False”, otherwise.
- no\_coordinates: “True” if ESVD variable “Latitude” is empty, could not be read as a number, is < -90 or > 90 or if ESVD variable “Longitude” variable is empty, could not be read as a number, or is < -180 or > 180. “False”, otherwise.
- no\_country: “True” if ESVD variable “Country\_Codes” is empty. “False”, otherwise.
- multiple\_countries: “True” if ESVD variable “Country\_Codes” is a list of two or more values. “False”, otherwise.
- no\_valuation\_method: “True” if ESVD variable “Valuation Methods” is empty. “False”, otherwise.

- valuation\_method\_is\_VT: “True” if ESVD variable “Valuation Methods” value is “VT”. “False”, otherwise.
- valuation\_methods\_include\_VT: “True” if ESVD variable “Valuation Methods” value is a list of two or more values and “VT” is one of them. “False”, otherwise.
- from\_duplicated\_study: “True” if Simplified title has the same value for two or more ESVD entries of different “StudyId”. “False”, otherwise.
- from\_unidentified\_study: “True” if Simplified title is “<None>”. “False”, otherwise.
- no\_site\_area: “True” if Site Area In Hectares is empty, zero or negative. “False”, otherwise.

## APPENDIX C - SUPPLEMENTARY MATERIALS FOR CHAPTER 4

The Appendix C has Supplementary Material for the paper to be published from the text in Chapter 4.

### C.1 Homoscedasticity tests

This Tables C.1 to C.4 list the results of a Breusch-Pagan homoscedasticity test on residuals of an Ordinary Least Square (OLS) model without bootstrapping on the variables selected for each training dataset.

For all tables:

- $S_F$ ,  $S_{TF1}$ ,  $S_{T1}$ , and  $S_{T4+}$  are the training datasets of ESVD samples selected for meta-regression, associated with ecosystems as defined but the Global Ecosystem Typology, respectively, from the Freshwater (F) realm, from the Palustrine wetlands biome (TF1), from the Tropical and subtropical forests (T1), and from the Savanna and grasslands biome (T4), this last one accrued by the T7.5 Derived semi natural pastures and old fields.
- The dummy variables are those with prefixes “EFG\_”, “SEEA\_” and “VM\_”, all other are numeric continuous variables.

Table C.1 - Homoscedasticity test for the SF dataset.

<b>Scope</b>	<b>Variable</b>	<b>p-value</b>	<b>Verdict</b>
GLOBAL MODEL	All Selected	0.038	FAIL (Heteroscedastic)
Individual	EFG_F1_1	0.5696	Stable
Individual	EFG_F1_2	0.2772	Stable
Individual	EFG_F1_4	0.505	Stable
Individual	EFG_F1_7	0.192	Stable
Individual	EFG_F2_2	0.654	Stable
Individual	EFG_F2_3	0.3433	Stable
Individual	EFG_F2_8	0.505	Stable
Individual	EFG_F3_1	0.1047	Stable
Individual	EFG_F3_2	0.2332	Stable
Individual	EFG_F3_3	0.146	Stable
Individual	EFG_F3_5	0.0424	VOLATILE SOURCE
Individual	Elevation_Mean_In	0.8383	Stable
Individual	income_per_capita_In	0.0441	VOLATILE SOURCE
Individual	LBII_0m	0.0396	VOLATILE SOURCE
Individual	Pop_Mean_30_In	0.3645	Stable
Individual	SEEA_1_4_U_2_14	0.3523	Stable
Individual	SEEA_1_6	0.6319	Stable
Individual	SEEA_1_7_U_1_1	0.7794	Stable
Individual	SEEA_2_10_U_3_3	0.3748	Stable
Individual	SEEA_2_11_U_2_1	0.2403	Stable
Individual	SEEA_2_3	0.0846	Stable
Individual	SEEA_2_6	0.505	Stable
Individual	SEEA_2_9	0.1254	Stable
Individual	SEEA_3_4_U_3_1	0.017	VOLATILE SOURCE
Individual	SEEA_4_1	0.9345	Stable
Individual	Site Area In Hectares_In	0.0614	Stable
Individual	VM_CV_CE_TC	0.609	Stable
Individual	VM_FI_PF	0.7045	Stable
Individual	VM_Other	0.4999	Stable

Table C.2 - Homoscedasticity test for the S<sub>TF1</sub> dataset.

Scope	Variable	p-value	Verdict
GLOBAL MODEL	All Selected	0.0203	FAIL (Heteroscedastic)
Individual	EFG_TF1_1	0.5208	Stable
Individual	EFG_TF1_2	0.1322	Stable
Individual	EFG_TF1_7	0.0018	VOLATILE SOURCE
Individual	Elevation_Mean_In	0.1223	Stable
Individual	income_per_capita_In	0.7718	Stable
Individual	Pop_Mean_30_In	0.1682	Stable
Individual	SEEA_1_7	0.7778	Stable
Individual	SEEA_1_9	0.4877	Stable
Individual	SEEA_2_11	0.4667	Stable
Individual	SEEA_2_12_U_1_1	0.9378	Stable
Individual	SEEA_2_3	0.5208	Stable
Individual	SEEA_2_4	0.8552	Stable
Individual	SEEA_2_5	0.3974	Stable
Individual	SEEA_2_9	0.3379	Stable
Individual	SEEA_4_1_U_1_2	0.0011	VOLATILE SOURCE
Individual	Site Area In Hectares_In	0.2393	Stable
Individual	VM_CV_CE_TC	0.1109	Stable

Table C.3 - Homoscedasticity test for the S<sub>T1</sub> dataset.

Scope	Variable	p-value	Verdict
GLOBAL MODEL	All Selected	0.0157	FAIL (Heteroscedastic)
Individual	income_per_capita_In	0.0986	Stable
Individual	SEEA_1_5	0.8424	Stable
Individual	SEEA_1_8_U_1_9	0.2866	Stable
Individual	SEEA_2_1	0.0234	VOLATILE SOURCE
Individual	SEEA_2_10_U_2_9	0.3236	Stable
Individual	SEEA_2_11	0.902	Stable
Individual	SEEA_2_17_U_3_1	0.0388	VOLATILE SOURCE
Individual	SEEA_2_2_U_1_2	0.204	Stable
Individual	SEEA_2_20_U_1_1	0.2967	Stable
Individual	SEEA_2_4	0.4482	Stable
Individual	SEEA_2_5_U_2_6	0.0667	Stable
Individual	SEEA_4_1	0.2761	Stable
Individual	Site Area In Hectares_In	0.6776	Stable

Table C.4 - Homoscedasticity test for the  $S_{T4+}$  dataset.

Scope	Variable	p-value	Verdict
GLOBAL MODEL	All Selected	0.2176	Pass (Homoscedastic)
Individual	EFG_T4_4	0.0818	Stable
Individual	EFG_T4_6	0.0403	VOLATILE SOURCE
Individual	income_per_capita_In	0.2374	Stable
Individual	PA_Perc_30_In	0.2977	Stable
Individual	SEEA_1_1	0.3734	Stable
Individual	SEEA_1_3	0.6062	Stable
Individual	SEEA_1_6_U_2_3	0.4724	Stable
Individual	SEEA_2_20	0.1011	Stable
Individual	SEEA_2_6_U_1_2	0.7568	Stable
Individual	SEEA_3_1_U_2_4	0.2114	Stable
Individual	Site Area In Hectares_In	0.3514	Stable
Individual	VM_CV_CE_TC	0.3325	Stable
Individual	VM_FI_PF	0.6062	Stable
Individual	VM_Other	0.076	Stable

Results of a Breusch-Pagan homoscedasticity test on residuals of an Ordinary Least Square (OLS) model without bootstrapping and with a light alpha (0.01) of the variables selected for the  $S_{T4+}$  training dataset.

## C.2 Variables and coefficients

The Tables C.5 to C.8 list the variable selected for Quantile Regression for the quantiles 0.1, 0.5 and 0.9, and, for the coefficients found, the medians and 95% confidence intervals and the probability of each coefficient being positive (Prob >0) from the non-parametric bootstrapped iterations with replacement.

For all tables:

- $S_F$ ,  $S_{TF1}$ ,  $S_{T1}$ , and  $S_{T4+}$  are the training datasets of ESVD samples selected for meta-regression, associated with ecosystems as defined but the Global Ecosystem Typology, respectively, from the Freshwater (F) realm, from the Palustrine wetlands biome (TF1), from the Tropical and subtropical forests (T1), and from the Savanna and grasslands biome (T4), this last one accrued by the T7.5 Derived semi natural pastures and old fields.
- The dummy variables are those with prefixes “EFG\_”, “SEEA\_” and “VM\_”, all other are numeric continuous variables.

Table C.5 - Medians and 95% confidence intervals and the probability of each coefficient being positive (Prob >0) for the S<sub>F</sub> dataset.

Variable	Quantile	Lower CI	Median	Upper CI	Prob >0
Const	0.1	-0.2481	0.8359	2.0489	0.87
Const	0.5	4.5855	5.2681	5.8034	1
Const	0.9	7.4084	9.2606	10.4642	1
EFG_F1_1	0.9	-0.1956	-	-	-
EFG_F1_2	0.9	-1.9130	-	-	-
EFG_F2_2	0.9	-	-	0.0955	0.03
EFG_F2_3	0.9	-	-	0.7750	0.09
EFG_F3_1	0.9	-0.2080	-	-	0.01
EFG_F3_2	0.9	-	-	0.4842	0.07
EFG_F3_3	0.9	-3.2132	-1.2113	-	-
EFG_F3_5	0.9	-5.9486	-3.1626	-	-
Elevation_Mean_In	0.1	-	-	0.2520	0.08
Elevation_Mean_In	0.5	-	-	0.2988	0.30
Elevation_Mean_In	0.9	-	0.4825	0.9734	0.90
income_per_capita_In	0.1	-3.1770	-1.8407	-	-
income_per_capita_In	0.5	-0.7158	-	-	-
income_per_capita_In	0.9	-0.9384	-	1.2014	0.31
LBII_0m	0.1	-	-	4.7993	0.12
LBII_0m	0.5	-	-	1.5669	0.16
LBII_0m	0.9	1.0913	5.4926	8.7492	0.99
Pop_Mean_30_In	0.1	-	0.0895	0.4654	0.69
Pop_Mean_30_In	0.5	0.1746	0.4726	0.6069	1
Pop_Mean_30_In	0.9	0.0641	0.4733	0.7103	0.99
SEEA_1_6	0.9	-1.2560	-	-	-
SEEA_1_7_U_1_1	0.9	-2.0766	-	-	-
SEEA_2_3	0.9	-	-	1.7820	0.44
SEEA_2_9	0.9	-	-	0.0426	0.03
SEEA_3_4_U_3_1	0.9	-	-	0.5370	0.15
SEEA_4_1	0.9	-0.4428	-	2.3752	0.11
Site Area In Hectares_In	0.1	-0.4112	-0.0468	-	-
Site Area In Hectares_In	0.5	-0.2290	-0.0865	-	-
Site Area In Hectares_In	0.9	-0.4891	-0.1757	-	-
VM_CV_CE_TC	0.5	-0.1541	-	-	-
VM_CV_CE_TC	0.9	-3.2040	-0.9776	-	-
VM_Other	0.9	-0.9018	-	0.9798	0.10

Table C.6 - Medians and 95% confidence intervals and the probability of each coefficient being positive (Prob >0) for the S<sub>TF1</sub> dataset.

Variable	Quantile	Lower CI	Median	Upper CI	Prob >0
const	0.1	0.7720	1.3025	2.1434	1
const	0.5	4.0330	4.6980	5.3732	1
const	0.9	6.8649	8.5776	9.6170	1
EFG_TF1_2	0.5	-0.2466	-	0.9721	0.12
EFG_TF1_7	0.5	-4.4253	-2.2730	-	-
EFG_TF1_7	0.9	-0.9495	-	0.3420	0.06
Elevation_Mean_In	0.5	0.0581	0.5922	1.0921	0.98
Elevation_Mean_In	0.9	0.0060	0.3125	1.0215	0.99
income_per_capita_In	0.1	-0.2719	-	-	-
income_per_capita_In	0.5	-0.3230	0.1190	0.6185	0.65
income_per_capita_In	0.9	-0.4989	-	0.5618	0.22
Pop_Mean_30_In	0.1	-	0.1459	0.5430	0.67
Pop_Mean_30_In	0.5	-	0.3093	0.7187	0.94
Pop_Mean_30_In	0.9	-0.2331	0.0466	0.6450	0.55
SEEA_1_7	0.5	-0.6965	-	-	0.01
SEEA_1_9	0.5	-2.4485	-0.5156	-	-
SEEA_1_9	0.9	-2.2012	-	-	-
SEEA_2_11	0.5	-	-	2.2053	0.14
SEEA_2_11	0.9	-	-	0.7555	0.07
SEEA_2_12_U_1_1	0.5	-	0.1647	2.6761	0.52
SEEA_2_12_U_1_1	0.9	-	-	0.2846	0.04
SEEA_2_4	0.5	-0.8198	-	1.0944	0.08
SEEA_2_5	0.5	-3.9802	-1.0653	-	-
SEEA_2_5	0.9	-	-	0.0873	0.03
SEEA_2_9	0.5	-	-	1.0103	0.23
SEEA_2_9	0.9	-	-	0.7428	0.07
SEEA_4_1_U_1_2	0.5	-	0.7233	4.2410	0.65
SEEA_4_1_U_1_2	0.9	-	1.0869	2.4235	0.93
Site Area In Hectares_In	0.1	-0.7040	-0.4329	-0.1099	-
Site Area In Hectares_In	0.5	-0.7442	-0.5388	-0.3570	-
Site Area In Hectares_In	0.9	-0.6040	-0.2620	-0.0312	-
VM_CV_CE_TC	0.5	0.1244	1.4060	2.5599	0.98
VM_CV_CE_TC	0.9	-	0.9166	2.8449	0.84

Table C.7 - Medians and 95% confidence intervals and the probability of each coefficient being positive (Prob >0) for the S<sub>T1</sub> dataset.

Variable	Quantile	Lower CI	Median	Upper CI	Prob >0
const	0.1	-2.8818	-2.4430	-1.9444	-
const	0.5	-0.3965	0.1847	0.7499	0.70
const	0.9	3.2211	4.1503	5.1439	1
income_per_capita_In	0.1	-0.6643	-0.2020	0.2220	0.20
income_per_capita_In	0.5	-0.6770	-0.0808	0.3266	0.35
income_per_capita_In	0.9	-1.5723	-0.9532	-0.2861	0.01
SEEA_1_5	0.1	1.2992	3.0560	3.7549	1
SEEA_1_5	0.5	2.0104	2.8532	3.6818	1
SEEA_1_5	0.9	1.0092	3.1773	5.5272	1
SEEA_1_8_U_1_9	0.1	-0.1003	3.4572	6.6997	0.95
SEEA_1_8_U_1_9	0.5	3.2433	4.1379	5.4096	1
SEEA_1_8_U_1_9	0.9	0.2182	1.6358	3.1964	0.99
SEEA_2_1	0.1	3.5274	4.9994	6.4916	1
SEEA_2_1	0.5	4.8387	8.7588	9.9605	1
SEEA_2_1	0.9	5.2070	6.2236	7.2696	1
SEEA_2_10_U_2_9	0.1	-	6.1367	9.2502	0.87
SEEA_2_10_U_2_9	0.5	-	3.7615	5.9577	0.87
SEEA_2_10_U_2_9	0.9	-0.2381	1.2455	3.5361	0.82
SEEA_2_11	0.1	-0.1173	1.2894	7.4642	0.95
SEEA_2_11	0.5	-0.9587	3.5086	6.6703	0.88
SEEA_2_11	0.9	-2.9775	0.4295	2.5040	0.62
SEEA_2_17_U_3_1	0.1	0.6746	2.1624	3.6379	0.99
SEEA_2_17_U_3_1	0.5	2.8907	4.4657	5.5661	1
SEEA_2_17_U_3_1	0.9	2.5497	4.0357	5.4394	1
SEEA_2_2_U_1_2	0.1	5.4997	7.2103	10.0515	0.98
SEEA_2_2_U_1_2	0.5	3.5653	6.0821	8.2118	0.98
SEEA_2_2_U_1_2	0.9	-	2.9163	4.6885	0.97
SEEA_2_20_U_1_1	0.1	0.5108	2.0673	3.6229	1
SEEA_2_20_U_1_1	0.5	0.4209	2.1392	4.2625	0.99
SEEA_2_20_U_1_1	0.9	-0.1772	1.2279	2.4682	0.96
SEEA_2_4	0.1	-	5.9389	7.0448	0.64
SEEA_2_4	0.5	-	3.4974	4.6319	0.64
SEEA_2_4	0.9	-0.1382	0.4147	1.8350	0.59
SEEA_2_5_U_2_6	0.1	1.5938	3.1054	5.4801	1
SEEA_2_5_U_2_6	0.5	2.1833	3.5905	4.6267	1
SEEA_2_5_U_2_6	0.9	-0.3754	1.6010	3.5385	0.95
SEEA_4_1	0.1	1.1964	1.9700	4.0914	1
SEEA_4_1	0.5	2.2863	3.8046	6.3216	1
SEEA_4_1	0.9	2.5373	3.7433	5.9302	1
Site Area In Hectares_In	0.1	-0.4190	-0.2587	-0.1312	-
Site Area In Hectares_In	0.5	-0.4988	-0.3681	-0.1907	-
Site Area In Hectares_In	0.9	-0.4460	-0.2973	-0.1351	-

Table C.8 - Medians and 95% confidence intervals and the probability of each coefficient being positive (Prob >0) for the S<sub>T4+</sub> dataset.

Variable	Quantile	Lower CI	Median	Upper CI	Prob >0
const	0.1	-2.1274	-0.3857	0.4618	0.14
const	0.5	1.6014	2.9209	4.0522	1
const	0.9	6.4724	7.0704	8.8535	1
EFG_T4_4	0.5	-	1.8706	5.1776	0.59
EFG_T4_6	0.5	-2.4100	-1.4874	-0.6304	-
income_per_capita_In	0.1	-	0.4323	1.6379	0.60
income_per_capita_In	0.5	-	1.1279	2.1463	0.97
PA_Perc_30_In	0.1	-0.0721	-	-	0.01
PA_Perc_30_In	0.5	-0.3074	-0.1515	-	-
SEEA_1_1	0.5	-3.5883	-1.3504	-	-
SEEA_1_3	0.5	-	-	5.0353	0.08
SEEA_1_6_U_2_3	0.5	-	-	1.5583	0.18
SEEA_2_20	0.5	-	-	5.5838	0.18
SEEA_2_6_U_1_2	0.5	-1.9034	-	-	0.01
SEEA_3_1_U_2_4	0.5	-1.4188	-0.2484	0.0311	0.03
Site Area In Hectares_In	0.1	-0.1732	-	-	-
Site Area In Hectares_In	0.5	-0.4461	-0.1743	0.0353	0.05
VM_CV_CE_TC	0.5	-	1.5037	3.4537	0.96
VM_FI_PF	0.5	-	-	2.1978	0.06
VM_Other	0.5	-1.6909	-	0.6935	0.08

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Corresponding Author: Fernando Rodrigues Teixeira Dias

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