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Indicator-based natural capital reporting to inform decision-making in the Brazilian Pantanal

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Abstract

The natural capital indicator framework (NCIF) offers an entry-level approach to natural capital reporting using existing data sources and indicators. Here, we test the NCIF for the first time in the megadiverse Pantanal biome in Brazil. We compile publicly available indicators on the cattle, soy, fishing, and nature-based tourism industries alongside indicators on the state of the biome and its ecosystem services. We show that the NCIF is quick to implement using existing environmental and socioeconomic indicators produced by public and NGO statistics communities. However, we identify significant gaps in indicators on the condition and economic value of the biome, the human investment required to derive benefits from the biome, emissions produced by the industries that exploit the biome, and the ecosystem services that maintain the functioning of the biome, such as nutrient cycling and biodiversity. Existing initiatives in Brazil could fill natural capital reporting gaps, including Brazil's experimental natural capital accounts. The NCIF provides a structured approach to highlight gaps in natural capital reporting and guide decision-makers to prioritize investment in filling data and reporting gaps. Systematic, transnational monitoring must fill gaps in natural capital data to inform decision-making in the megadiverse Pantanal biome.

KEYWORDS

beef production, biodiversity monitoring, cattle ranching, ecological condition, ecosystem services, fishing, natural capital accounting, soy agriculture, tourism, wetland

1 | INTRODUCTION

How governments record and report economies needs to consider the diversity of benefits that societies derive from natural capital, both those benefits that can be economically valued and those benefits for which valuation is more challenging (Dasgupta, 2021; Masood, 2022). One way to do this is to take a natural capital approach to reporting on the relationship between countries' economies and the natural environment. Natural capital approaches have been widely criticized, mainly due to the involvement of economic valuation. However, Mace (2019) posits a broader purpose for natural capital approaches, that they should "not be simply a means to

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place a monetary value on the natural environment so that it is taken more seriously in decision-making. Rather, [they] should be the means by which governments, corporations, and individuals can take proper responsibility for the essential components of natural capital that underpin society and a good life (the assets), record the condition of these assets and how this is changing over time, and ensure that provision is made when they fall below critical levels." Natural capital approaches are not simply the monetary valuation of nature and the benefits we derive from it but instead a structured approach for comprehensively understanding nature and our dependence on it in biophysical, social, and economical terms.

There exist a range of approaches to conducting natural capital reporting, including natural capital accounting using the United Nations System for Environmental-Economic Accounting (SEEA-CF) (United Nations, 2012) and Ecosystem Accounting (SEEA-EA) (United Nations, 2021a). In addition, there are now headline indicators (Yun et al., 2017) to complement gross domestic product (GDP) (Ouyang et al., 2020) that include measures of the benefits derived from natural capital (Brandon et al., 2021). Furthermore, natural capital approaches utilize many natural capital data, statistics, and indicators (GGKP, 2020; UNSD, 2021). For example, measures of biophysical flows and economic valuation of ecosystem services (Guerry et al., 2015) and natural assets (Fenichel & Hashida, 2019) and production of environmental statistics (United Nations Statistical Division, 2017). Finally, international indicator initiatives on sustainable development (e.g., sustainable development goals (United Nations, 2021b)), national wealth (e.g., World Bank Changing Wealth of Nations; Lange, 2019), and green growth (e.g., Organization of Economic Co-operation and Development (OECD) Green Growth Indicators; OECD, 2017) catalyze the production of natural capital-relevant indicators.

Many governments are investing in natural capital approaches to economic reporting that give a more complete picture of the dependence of economic growth on nature. More than 100 countries are now compiling natural capital accounts following the UN's SEEA approach (UN SEEA, 2022). Unfortunately, many governments need more capacity to report on natural capital (Brandon et al., 2021). Government statistical agencies often require considerable capacity building to develop natural capital applications and integrate these with existing national environmental statistics. Governments often need help identifying which approaches to natural capital reporting are most appropriate for their needs. The required capacity building can act as a barrier to uptake.

The natural capital indicator framework (NCIF) (Fairbrass et al., 2020) is an entry-level approach to natural capital reporting. It proposes a suite of pre-existing indicators organized within a conceptual framework of natural capital. As such, the NCIF has the potential to be rapidly implemented by statistics experts and to explore policy-relevant questions about natural capital. It connects the indicators of natural assets with biophysical flows of benefits, the human inputs often required to derive benefits from natural capital, and the residuals (e.g., wastes and pollution) produced from these activities. The NCIF brings together the natural capital indicators already produced by a region's statistical activities, such as natural capital accounting activities, national statistics, corporate reporting, NGO, and academic research activities. The NCIF can therefore highlight gaps in natural capital reporting. However, its utility for exploring policy-relevant questions about natural capital is limited by what natural capital indicators are available. The NCIF complements the UN SEEA by aligning with the classification system for natural capital assets used by the SEEA and the typology of ecosystem services from the Common International Classification of Ecosystem Services (CICES).

In this article, we applied the NCIF for the first time in a real-world context in the Brazilian Pantanal biome to understand the utility and feasibility of this entry-level approach to natural capital reporting. We tackled three research questions: (1) To what extent can existing natural capital data and statistics support natural capital reporting on the Brazilian Pantanal biome? (2) How can natural capital data and statistics gaps be filled in the future? (3) Is the NCIF a practical and feasible approach to natural capital reporting in a novel context? Our testing context was the Brazilian Pantanal, a relatively undisturbed biome in Brazil. The Pantanal biome has recently received international attention due to an increase in the extent and frequency of wildfires, the drivers of which are numerous and complex (Libonati et al., 2020). There is interest from the state government, NGOs that work in the region, and academic communities in discussing the possibility of taking a natural capital approach to inform sustainable management in the biome. The NCIF should highlight the underreported goods and benefits hidden from decision-making. Highlighting and filling gaps in the NCIF could lead to more equitable decision-making about the economic activities in the Pantanal biome.

This article presents the methods, including the selection and assessment of indicators for the NCIF and our application of the NCIF to the Brazilian Pantanal biome. First, we focus on the ecosystem assets of the biome and the flow of a representative sample of ecosystem services from these assets, including nature-based tourism. Next,

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we focus on three commodity assets currently produced in the Pantanal: beef cattle, soy, and fish. Cattle ranching and fishing both have a long history of activity in the Pantanal region, while soy agriculture is an emerging industry (Marengo et al., 2021) and poses several unique threats to the Pantanal biome, including increasing soil erosion into the water system, introduction of agrochemicals (Lima et al., 2019), and dredging of waterways for soybean transport (Coelho-Junior et al., 2022). We then present the available indicators for reporting on the ecosystem and commodity assets and highlight the reporting gaps for the biome. Next, we discuss the implications of our results for natural capital reporting in the Brazilian Pantanal biome. Finally, we explore the future utility and feasibility of the NCIF for natural capital reporting, learning from our experience applying the NCIF in the Brazilian Pantanal biome.

2 | METHODS

2.1 | Case study: The natural capital context of the Brazilian Pantanal

The Pantanal biome is the largest continuous tropical wetland in the world and straddles three countries: Brazil (78%), Bolivia (18%), and Paraguay (4%) (Tomas et al., 2019). The Brazilian section of the biome overlaps 16 municipalities in the states of Mato Grosso (MT) and Mato Grosso do Sul (MS). The Pantanal's flooding regime makes year-long access difficult, restricting the economic activities that can occur. Nevertheless, the biome is experiencing increasing economic activity, including cattle ranching, fishing, nature-based tourism, agriculture, mining, and infrastructure development (Tomas et al., 2019), alongside an increasing extent and frequency of wildfires (Libonati et al., 2020).

Despite these growing threats, the Pantanal is Brazil's least disturbed biome (IBGE, 2020b; Overbeck et al., 2015). It is one of the most critical areas in the world for conserving terrestrial biodiversity, carbon, and water (Jung et al., 2021). It is a vital ecosystem service hotspot (Tomas et al., 2019), supporting water supply and disturbance regulation (Seidl & Moraes, 2000), fish and wild plants for local communities, and growing recreational fishing and nature-based tourism industries (Bolzan et al., 2021). Ecosystem service valuation work highlights that economic markets undervalue the biome when valuation is based solely on the commercial products produced in the region such as cattle (Bolzan et al., 2021; Seidl & Moraes, 2000). The regional government, NGOs, and research communities are attempting to remedy this by including ecosystem services in the Pantanal policy agenda, such as payments for ecosystem services at the national and regional scale (Federal Law #14.119/2021 and Law #5235/2018 from Mato Grosso do Sul state), and the bioeconomy program (Regulatory act #121/2019 from Ministry of Agriculture, Livestock and Supply). National and state laws related to sustainable agricultural and livestock production include the National Policy on Agroecology and Organic Production (Pnapo, Decree #7794/2012) and the state of Mato Grosso do Sul Law on agroecological and organic production initiatives (Law #5279/2018). The Pantanal State Program for Sustainable and Organic Beef in MS provides a fiscal incentive for organic beef production, which is increasing the use of livestock practices that advance the conservation of the Pantanal. Most recently, the state of Mato Grosso do Sul published Law No. 6160/2023, which provides for the conservation, protection, restoration, and ecologically sustainable exploitation of the Pantanal Plain Restricted Use Area (AUR-Pantanal) and creates the State Fund for the Sustainable Development of the Pantanal biome. Finally, the research community is also investigating the development of new markets for ecosystem goods that are currently not traded in the formal economy (Bortolotto et al., 2017).

2.2 | The NCIF is an entry-level approach to reporting on natural capital

For this case study application of the NCIF, we focused on applying the NCIF to the dominant and emerging environment-dependent economic activities in the region: cattle ranching in the lowland, agricultural production of soy in the plateau and encroachment on the periphery of the Pantanal plain, fishing, and nature-based tourism. We aimed to produce the four aligned frameworks of natural capital indicators for the ecosystem assets of the Brazilian Pantanal biome, which includes nature-based tourism, and the three commodity assets of cattle ranching, soy agriculture, and fishing (Table 1 and Figure 1).

2.3 | Assessing the availability of natural capital indicators

We sought to find 80 unique indicators across the four frameworks, of which 29 comprised the ecosystem asset framework, while the three commodity asset frameworks comprised 17 indicators each. The ecosystem asset framework comprises more indicators than each commodity asset because we assume that multiple ecosystem services flow from the ecosystem asset and that only a single provisioning ecosystem service flows from each commodity asset. Therefore, we limited our ecosystem asset

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TABLE 1 Descriptions of the types of indicators to populate each component of the NCIF and examples of appropriate indicators relevant to the Brazilian Pantanal case study.

Component	Indicator type	Indicator description	Examples
Ecosystem assets	Extent	The quantity of the asset type measured by volume or area.	Area of wetland ecosystem assets (ha)
	Condition	An index of biodiversity measures the condition of the ecosystem asset.	Biodiversity Intactness Index for wetland ecosystem assets
	Economic	The net present value of the asset type.	Net present value of wetland ecosystem assets (R$)
Commodity assets	Extent	The quantity of the asset type measured by volume or area.	Area of pasture (ha)
	Condition	The condition of the asset type.	Pasture conservation status indicator (Santos et al., 2017)
	Economic	The net present value of the asset type.	Net present value of cattle stock (R$)
Flows from ecosystem assets	Biophysical	Ecosystem assets support multiple flows of ecosystem services. The biophysical flows of ecosystem services are measured by volume, area, or an index of biodiversity.	P: volume of wild fruits extracted (tonnes); R&M: volume of carbon sequestered by the ecosystem assets (tonnes); C: species diversity of the ecosystem assets
Flows from commodity assets	Biophysical	Commodity assets support a single provisioning ecosystem service flow. The biophysical flow is measured by quantity.	Heads of cattle sold (*n*)
Human inputs to derive goods/benefits from ecosystem assets	Economic	Investment in protection, management, and restoration is the financial cost of deriving benefits from ecosystem assets via ecosystem services.	Cost of conservation management of wetland ecosystem assets (R$)
	Social	The human capital required to derive benefits from ecosystem assets via ecosystem services is measured by employment in protection, management, and restoration.	Population employed in the nature conservation sector (%)
Human inputs to derive goods/benefits from commodity assets	Economic	Investment in cultivating, managing, and extracting natural resources is the financial cost of deriving benefits from commodity assets via ecosystem services.	Cost of harvesting cattle (R$)
	Social	The human capital required to derive benefits from ecosystem assets via ecosystem services is measured by employment in cultivating, managing, and extracting natural resources.	Population employed in the beef industry (%)
Benefits flowing from ecosystem assets	Economic	The financial benefits are derived from ecosystem assets via flows of ecosystem services. However, ecosystem asset benefits are predominantly not traded in markets and are challenging to value monetarily.	P: income from fishing for traditional communities (R$); R&M: value of carbon credits for carbon sequestered by the ecosystem assets (R$); C: value of jaguar tourism (R$)
	Social	The social benefits are derived from ecosystem assets via flows of ecosystem services. Social benefits are measured by access to natural resources, impacts of natural disasters, exposure to	P: proportion of fish protein in diets in traditional communities (%); R&M: percentage of population affected by water-related events (%); C: nature-based tourists (*n*)

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TABLE 1 (Continued)

Component	Indicator type	Indicator description	Examples
		pollution, or engagement with natural capital.	
Benefits flowing from commodity assets	Economic	The financial benefits are derived from commodity assets via flows of commodity resources.	Gross value added in the National Accounts associated with cattle resources (R$)
	Social	The social benefits derived from commodity assets via flows of the commodity resources.	People relying on fish as a protein source (*n*)
Residuals produced during the exploitation of ecosystem and commodity assets	Economic	The economic costs of waste and pollution that are produced through deriving benefits from natural capital. Costs are measured by expenditure on waste disposal and pollution treatment, and damages.	Cost of solid waste treatment (R$); damages from stratospheric ozone depletion (R$)
	Social	The social impacts of residuals are produced through deriving benefits from natural capital. Impacts are measured by employment in related industries and the health impacts of residuals.	Percentage of the population employed in the wastewater industry (%); percentage of the population exposed to water pollution (%)
	Environmental	The environmental impact of residuals produced through deriving benefits from natural capital. Impacts are measured by the amount of residuals produced, managed, and emitted into the environment.	Volume of waste managed by management type (tonnes); GHG emissions (tonnes)

Note: CICES classifies ecosystem services as provisioning (P), regulation and maintenance (R&M), or cultural (C).

framework to include a representative sample of five ecosystem services, including two provisioning ecosystem services (one biotic and one abiotic), two regulation and maintenance ecosystem services (one biotic and one abiotic), and one cultural ecosystem service, as defined by CICES. We did not differentiate between biotic and abiotic cultural ecosystem services, as it was not feasible to delimit them to this classification level.

We selected a representative sample of ecosystem services by identifying the available indicators and selecting those representing the most critical ecosystem services in the Brazilian Pantanal. Our representative sample of ecosystem services flowing from the ecosystem asset included the following:

1. Provisioning (abiotic): Abstraction of water from the ecosystem for human consumption.
2. Provisioning (biotic): Extracting wild plants from the ecosystem for human consumption. We used the list of wild food plants harvested in the Pantanal (Bortolotto et al., 2017) as our guide to find indicators of relevant plant species for this ecosystem service.
3. Regulation and maintenance (abiotic): Regulation of physical, chemical, and biological conditions that mitigate the human and economic impacts of floods. We focus on flooding for the abiotic component of this ecosystem service because of the abiotic nature of water and its predominant role in flooding.
4. Regulation and maintenance (biotic): Regulation of atmospheric composition and conditions by the ecosystem that mitigates the human and economic impacts of wildfires. We focus on wildfires for the biotic component of this ecosystem service because of the biotic nature of forests and other natural terrestrial land cover and the predominant role that these types of vegetation play in wildfires.
5. Cultural (abiotic and biotic): Direct, in-situ, and outdoor interactions with living systems that depend on presence in the environmental setting. We focus on the diversity of the Pantanal's wildlife and its link to nature-based tourism for this ecosystem service.

Various actors in Brazil produce natural capital data, information, and indicators. For example, the national

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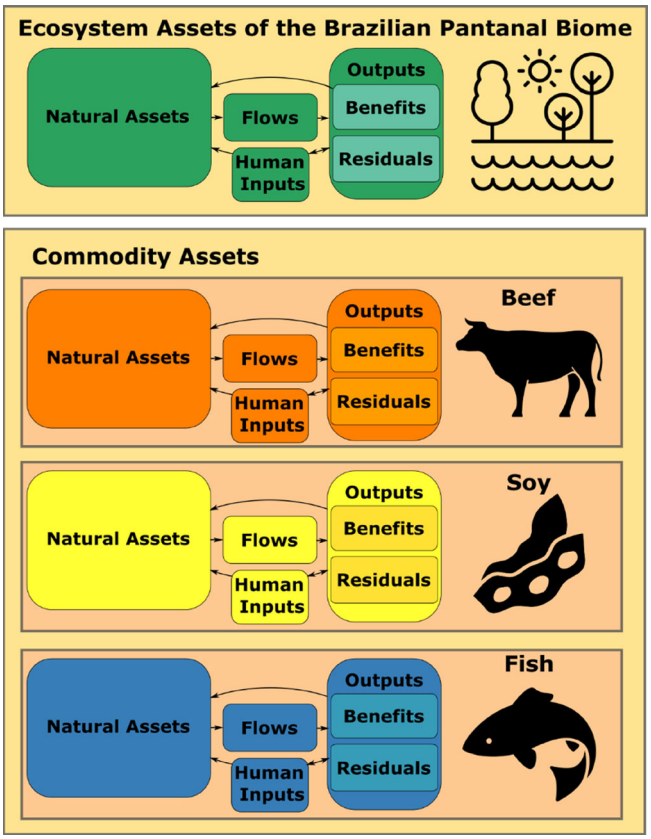

FIGURE 1 The study focused on producing four aligned natural capital indicator frameworks for the Brazilian Pantanal biome's ecosystem assets, which includes nature-based tourism as a cultural ecosystem service flowing from the ecosystem asset, and commodity assets of beef cattle, soy, and fish. Images: https://thenounproject.com/.

statistics department Instituto Brasileiro de Geografia e Estatística (IBGE) reports statistics on economic activities that exploit natural capital, including livestock, agriculture, fishing, and mining. Since 2020, IBGE has produced national experimental ecosystem accounts on ecosystem extent, use, and change (IBGE, 2020b), endangered species (IBGE, 2020a), and water resources (IBGE, 2020c) following the UN's SEEA-EA. IBGE is also developing experimental accounts on non-timber forest products (IBGE, 2021a) and water resources (IBGE, 2021b, 2021c). In addition, an active community of universities and international organizations use big data and online reporting platforms to increase the transparency of drivers of environmental change in Brazil. Examples include deforestation (e.g., MapBiomas, www.mapbiomas.org), livestock/agricultural production (e.g., Trase, www.trase.earth), and wildfires (e.g., ALARMES, www.lasa.ufrj.br). In the Brazilian Pantanal, a research infrastructure network supports collecting environmental data operated by public, private, academic, and NGO stakeholders (Tomas et al., 2019).

We searched for relevant indicators for our frameworks in the official statistics databases of the state governments of MT and MS and the online databases of relevant Brazilian federal government ministries, research institutes, and indicator reporting initiatives. We also searched the online databases of academic and non-governmental data and indicator reporting initiatives such as MapBiomas, Trase, and ALARMES. One UK-based researcher (AF) and two Brazil-based research assistants (VM and EQ) conducted the search stage of the study. In addition, we liaised with experts to identify sources of indicators, search databases, and extract relevant datasets. We organized the indicators in a database (Fairbrass et al., 2024). Finally, we mapped the available indicators onto the NCIF to assess the feasibility of conducting natural capital reporting for the Brazilian Pantanal using existing sources of indicators. See the Supplementary Methods for more detail on the data sources.

2.4 | Assessing the suitability of natural capital indicators

The suitability of available indicators for natural capital reporting was then assessed according to the following five criteria (Table 2):

1. *Coverage*: We prioritized indicators reported for all 16 municipalities that overlapped with the footprint of the Brazilian Pantanal over indicators only reported for a subset of the 16 municipalities. We excluded indicators not reported for any of the 16 municipalities in the study.
2. *Scale*: We only selected indicators reported at the municipality scale. Indicators reported at a coarser scale, such as at the state or national scale, were excluded from the study.
3. *The number of repeats*: It is helpful to be able to investigate changes in indicators over time. Therefore, we prioritized indicators reported for multiple years over those only available for a single year.
4. *Frequency*: To align with the standard frequency of national statistics reporting in Brazil, we prioritized indicators that are reported at least annually over those reported less frequently.
5. *Producer*: To maximize the relevance of this study for policymakers and public actors, we prioritized indicators produced by federal or state government agencies over indicators produced by non-government

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TABLE 2 Indicator suitability assessment criteria for natural capital reporting in the Brazilian Pantanal.

	Suitability for natural capital reporting		
Criteria	**Less**	→	**More**
Coverage	A single municipality within the footprint of the Brazilian Pantanal	Some but not all of the 16 municipalities that overlap with the footprint of the Brazilian Pantanal	All 16 municipalities that overlap with the footprint of the Brazilian Pantanal
Scale	Municipality		
Number of repeats	1	2	3+
Frequency	No repeats	Less than annual	At least annual
Producer	Non-government agencies, e.g., universities, NGOs, and private companies		Federal or state government agency

institutions, such as university researchers, NGOs, and private companies.

To include an indicator in our study, it had to meet our lowest suitability criteria, that is, an indicator produced by a non-government agency that is available for at least 1 year for at least one of the municipalities overlapping the footprint of the Brazilian Pantanal. When we found more than one potential indicator for a component in our framework, we used our suitability criteria to select the most suitable indicator.

2.5 | Exploring the available natural capital indicators

We plotted the available indicators using univariate plots to explore temporal and spatial trends in the indicators and relationships between indicators across the different components of the overall framework. In addition, we explored relationships between indicators within and across the four frameworks to investigate the relationship between the state of the environment, the flows of goods, and benefits from natural capital, human inputs, and residuals concerning the Pantanal ecosystem, the beef, soy, fishing, and nature-based tourism industries.

3 | RESULTS

3.1 | Availability of natural capital indicators and filling reporting gaps

We found 14 out of 29 indicators for the ecosystem framework, 10 out of 17 for the beef commodity framework, 10 out of 17 for the soy commodity framework, and 6 out of 17 for the fish commodity framework (Figure 2). We sourced most indicators from the online official government statistics, including employment statistics, production volumes, and values, area of agricultural production, and organic agricultural and livestock production statistics from the IBGE. In addition, we sourced health statistics from the Ministry of Health's DataSus platform, water production and use statistics from the National Sanitation Information System (SNIS), and fishing and nature-based tourism statistics from the National Water and Sanitation Agency (ANA). In general, government statistics were reported annually at the municipality scale for all 16 municipalities in the Pantanal, typically from the early 2000s till the study date. However, government statistics produced less regularly were the indicators of organic livestock and agriculture production, which were only available in 2017, and fishing and tourism statistics, which were only available for 2018.

We found non-government sources of indicators on pasture, agriculture, and natural land cover from MapBiomas, burned land area from LASA, air emissions and carbon storage from SEEG, the HDI/Gini Index, and some health statistics from the Atlas Brasil platform. The indicators reported by MapBiomas, LASA, and SEEG were available at the municipality scale and updated annually from 1985, 2001, and 2000, respectively, to 2021. In addition, Brazil's decadal national census produces the HDI and Gini Index, which were available every 10 years from 1991 to 2010. However, the indicator on hospitalizations for diseases related to inadequate environmental sanitation was only available for 2013–2017 on the Atlas Brasil platform. Therefore, we could not find a more up-to-date source for this indicator. In the long term, limiting natural capital reporting to government-only data sources and indicators may be desirable as public

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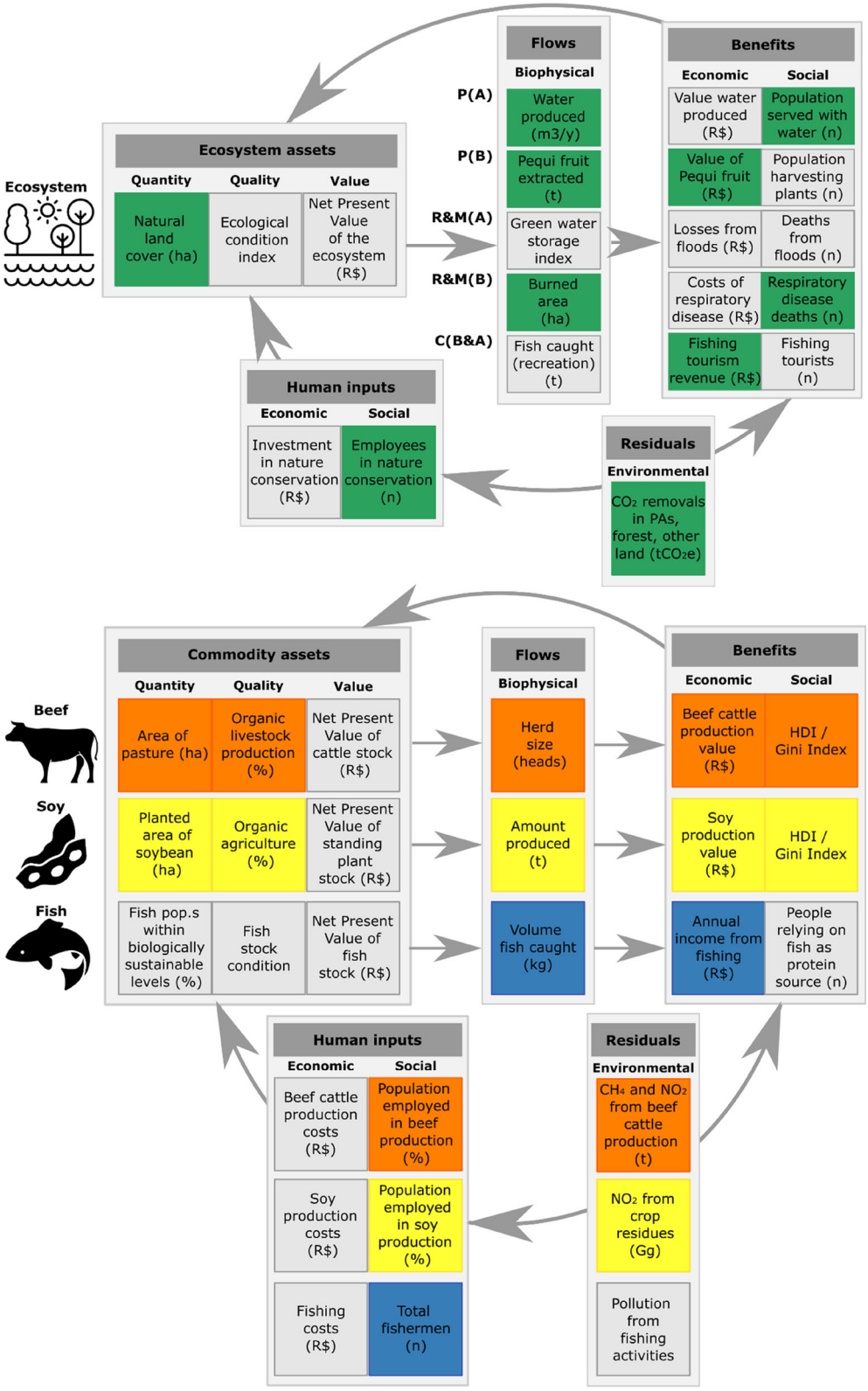

FIGURE 2 Overview of the available (colored boxes) and missing (gray boxes) indicators for the ecosystem, beef, soy, and fish natural capital indicator frameworks for the Brazilian Pantanal. We denote ecosystem services as abiotic (A) or biotic (B) provisioning (P), regulation and maintenance (R&M), and cultural (C) following the CICES classification system. HDI denotes the human development index. For simplicity, we have omitted some indicators of residuals from the figure. Images: https://thenounproject.com/.

decision-makers are more likely to be accepting of government-produced statistics. However, the non-government data/indicator sources that we identified offer a beneficial temporary solution to fill natural capital reporting gaps. Future work should investigate how to integrate non-governmental data/indicators into governmental statistical reporting to provide decision-makers with quality assurance on indicators used in natural capital reporting. We present the details of all the available indicators in the Supplementary Results.

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3.2 | Exploring the available natural capital indicators

We identified a reasonable number of indicators of human uses of the environment that have a market value, for example, soy agriculture, cattle ranching, fishing, and tourism. These indicators illustrate how such activities differ across municipalities and over time. However, gaps in the availability of natural capital indicators across all the components of the ecosystem and the commodity asset frameworks mean that our ability to demonstrate the full potential of the NCIF for answering policy-relevant questions about natural capital in the Brazilian Pantanal is limited. However, our study does reveal essential gaps in the data and indicators, which, if filled, would reveal novel insights into relationships between the economy and the environment in the Brazilian Pantanal.

3.3 | Cattle ranching

Most municipalities have experienced an increase in pasture area over the past 30 years, mirrored by an increase in the population employed in the cattle industry in each municipality (Figure 3). Interestingly, emissions from beef production stayed relatively stable over two decades in most municipalities, suggesting that the cattle industry may have become more productive without increasing emissions. A small proportion of establishments are practicing organic livestock production, which offers opportunities to increase the sustainability of the Pantanal cattle ranching industry if more establishments adopt sustainable production practices. Since 2001, the Pantaneira Association of Organic and Sustainable Livestock (ABPO, abpopantanalorganico.com.br) has promoted the adoption of sustainable and organic cattle production practices in the Pantanal, of which the MS state government

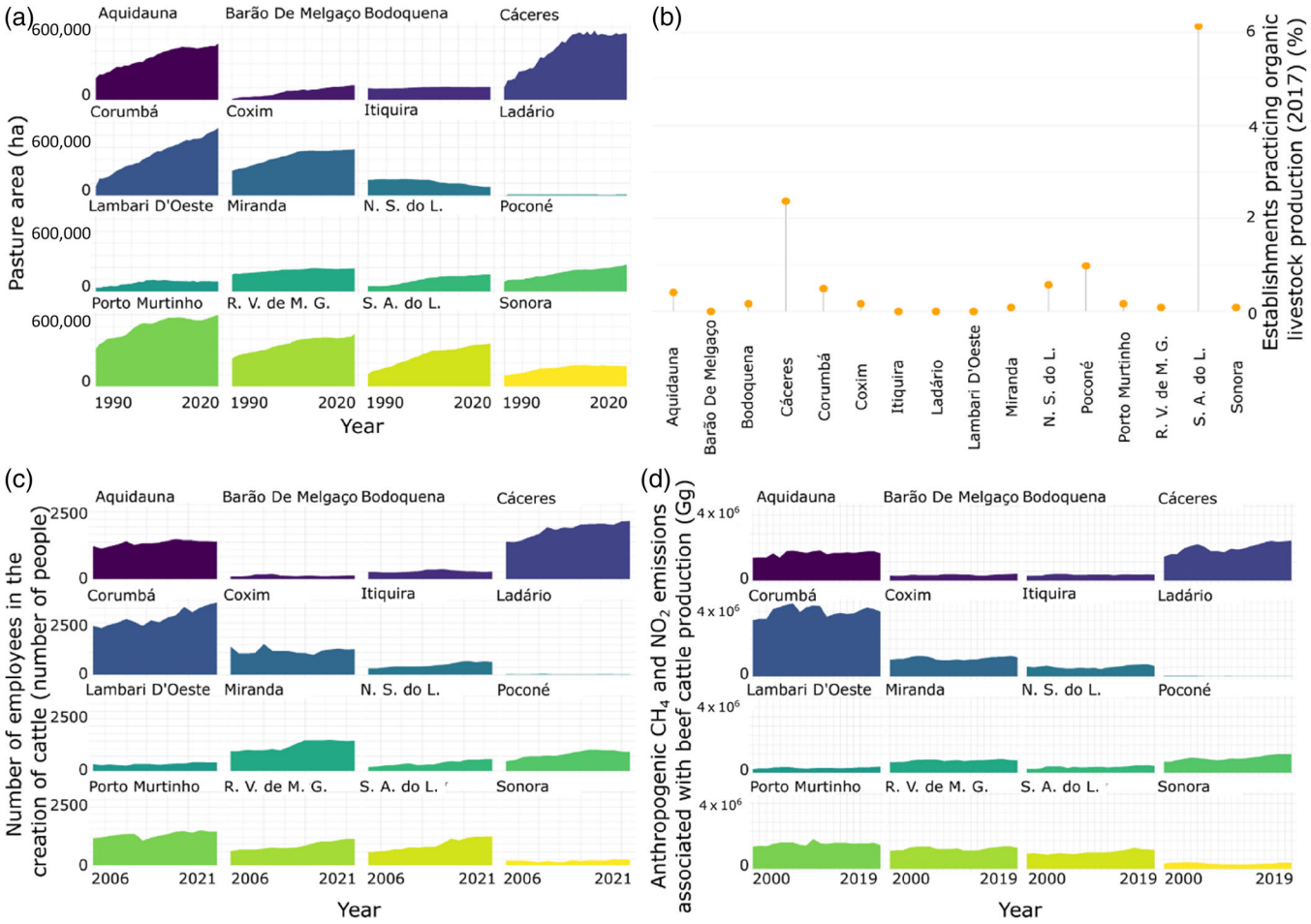

FIGURE 3 Natural asset and human input indicators for the 16 municipalities in the Brazilian Pantanal, including (a) pasture area (ha) during 1990–2020; (b) establishments practicing organic livestock production in 2017 (%); (c) number of people employed in the creation of cattle (number of people) during 2006–2021; and (d) non-anthropogenic CH_4 and NO_2 emissions associated with beef cattle production (Gg) during 2000–2019. Data for (a) are from MapBiomas (MapBiomas, 2020), for (b) are from IBGE's Agricultural Census (IBGE, 2021a), for (c) are from the national employment register, CAGED (IBGE, 2021b), and for (d) are from the Greenhouse Gas Emission and Removal Estimating System, SEEG (SEEG, 2019).

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is supportive (MS Rural, 2018). By filling gaps in the indicators on economic inputs into cattle production, policymakers could ask questions about the efficiency of the cattle ranching industry and the impact of livestock production practices on the economic and social benefits of beef production in the municipalities that overlap the footprint of the Pantanal.

3.4 | Soy agriculture

Soybean agriculture is expanding into the Pantanal region, though it is currently limited to a few municipalities within the biome. Over the past two decades, both the quantity and value of soybeans produced in these municipalities have grown (Figure 4a,b). Similar to data on beef cattle, we found yearly indicators for all 16 municipalities in our study spanning multiple years. One noticeable omission is the net present value (NPV) of standing soy crops. EMBRAPA reports the NPV of soybean crops for certain regions and time periods. For example, in the 2017/18 period, soybeans in the South-Western Amazon had an NPV of R$ 1287.27 per hectare (Quintino et al., 2018). However, the production of NPV statistics is typically project-specific, meaning they are not consistently produced over time or for the municipalities in our research.

3.5 | Nature-based tourism

Nature-based tourism extends beyond fishing in the Pantanal biome, characterized by its megadiversity. The region's rich fauna has fostered a significant wildlife observation industry, particularly on jaguars. To

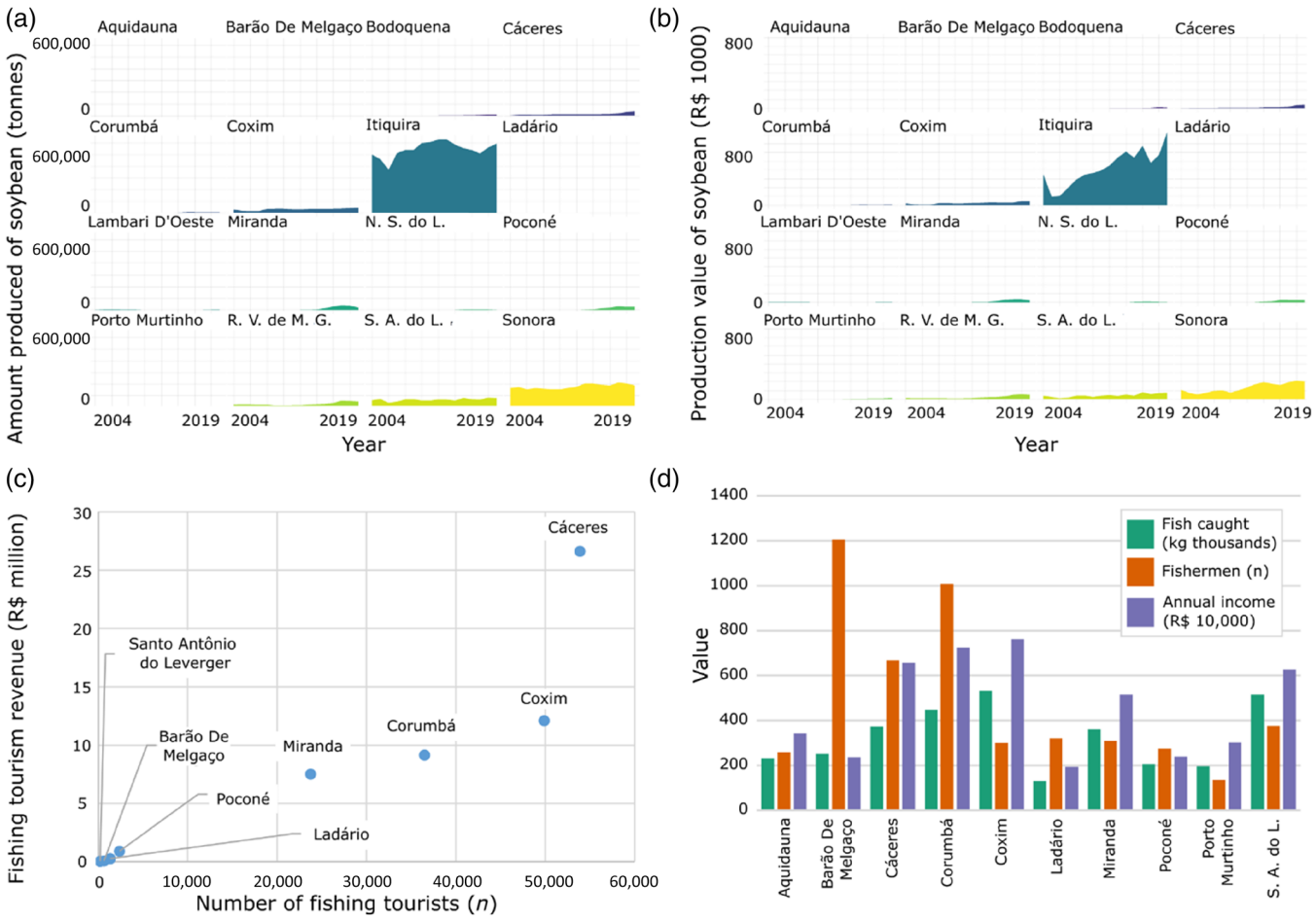

FIGURE 4 (a) Amount of soybeans produced (tonnes) during 2004–2019 for the 16 municipalities in the Brazilian Pantanal. (b) Production value of soybeans (R$ 1000) during 2004–2019. (c) Value of fishing tourism and the number of fishing tourists in 2018 for eight municipalities in the Pantanal region. (d) Volume of fish caught, estimate of total professional artisanal fishermen, and annual income for professional artisanal fishermen in 2018 for 10 municipalities in the Pantanal region. Data for (a) and (b) are from the Brazilian Institute of Geography and Statistics (IBGE, 2021d) and for (c) and (d) are from the Brazilian National Water Agency (Agência Nacional de Águas, 2020b).

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illustrate, the economic valuation of jaguar-centric tourism in the Pantanal biome approached nearly US$ 7 million in 2015 (Tortato et al., 2017). However, at the municipality level, we could not find a comprehensive assessment of nature-based tourism. Although broad tourism data exists at the municipal level, there is a dearth of statistics discerning which portion is directly influenced by the region's natural capital, outside of fishing tourism. Consequently, for our study, we have confined our examination to fishing tourism as a representative metric for the cultural ecosystem services of the Pantanal biome. Fishing tourism depends directly on the exploitation of the Pantanal biome in the form of catching and harvesting wild fish species. With information on eight municipalities for a single year (Agência Nacional de Águas, 2020b), we can see a clear relationship between the value of fishing tourism and the number of visitors (Figure 4c). By filling the indicator gaps on the condition of the ecosystem and the volume of fish caught by fishing tourists, policymakers could ask questions about how environmental degradation may be impacting the economic and social benefits derived from the fishing tourism industry in the Pantanal.

3.6 | Fishing

The Brazilian National Water Agency (ANA) conducted an in-depth analysis of fishing activities in the Pantanal. This study provided a wealth of data relevant to our work, covering fishing statistics in 10 municipalities in our study (Agência Nacional de Águas, 2020a). Our analysis revealed significant variances across municipalities (Figure 4d). Some municipalities, despite having many fishermen, do not report significant fish catches or income from fishing. In contrast, other municipalities with fewer fishermen record substantially higher fish catches and related incomes. Additional metrics, such as "fishing effort" (available in the ANA report) and "fishing costs" (an indicator we could not locate), could potentially illuminate the reasons for these differences. The ANA's study is pivotal for understanding fishing in the Pantanal due to its detailed data. Its comprehensive approach to data gathering, handling, and analysis serves as a model for future studies. Regular updates to this study would offer a more in-depth view of the benefits derived from fishing in the Pantanal.

However, there are notable gaps in the current data landscape. Key missing indicators, such as the fish stock's status and NPV, warrant attention in subsequent studies. By addressing these indicators, future research could provide a clearer picture of the fish stock's health and the socio-economic benefits people derive from fishing. Such insights would be instrumental in shaping policies and strategies to ensure the sustainable and beneficial coexistence of the Pantanal's communities with their rich aquatic resources.

4 | DISCUSSION

In this study, we applied the NCIF, a "light-touch" approach to natural capital reporting, for the first time in a real-world context to the Brazilian Pantanal biome. Using the structure of the NCIF, we compiled indicators from a range of sources to investigate the relationship between the natural capital of the Pantanal biome and four industries in the region: cattle ranching, soy cultivation, fishing, and nature-based tourism. Our work revealed considerable reporting gaps, particularly concerning the condition of the biome's ecosystem assets and the biome's many goods and benefits that do not have a market value, such as wild foods and the freshwater on which agriculture and people depend. However, we did identify data and modeling initiatives that could fill natural capital reporting gaps in the future, such as the development of Brazil's experimental ecosystem accounts and global natural capital models and data. Our study demonstrates that the NCIF is a practical "entry-level" approach to natural capital reporting to scope available data and indicators and identify reporting gaps, which decision-makers can use to prioritize investment in natural capital reporting.

4.1 | Opportunities and future research for filling natural capital reporting gaps in the Brazilian Pantanal

The NCIF highlights the gaps in data and indicators where effort and investment should be focused to understand the sustainable use of natural capital. The economic dimension of sustainability dominates statistical reporting in Brazil, which must be challenged to properly account for the vital contributions that natural capital makes to society. The government reports statistics on the benefits of provisioning ecosystem services, such as beef, soy, wild fruits, and water, and to a lesser extent, some cultural ecosystem services in the form of fishing tourism. The benefits from provisioning and cultural services are directly observable and reflected in market prices. Nevertheless, their long-term sustainability depends on silent and invisible regulation and maintenance services, such as waste remediation, sediment retention, carbon storage, disaster mitigation, pest regulation, and pollination. These services are vital for local

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and global human health and well-being, and it is expensive to provide engineered replacements. There are opportunities to fill reporting gaps on some regulation and maintenance services in the Pantanal region using biophysical modeling of remote-sensing and in situ data (United Nations, 2022). Global maps of critical natural capital (Chaplin-Kramer et al., 2022) provide information on nitrogen and sediment retention, pollination, flood regulation, ecosystem carbon storage, and atmospheric moisture recycling. In addition, there is activity in Brazil to develop environmental-economic physical land accounts (IBGE, 2022a), as well as ecosystem accounts for water, energy, forests (wood and non-wood resources), biodiversity, ecosystem extent, and ecosystem condition (IBGE, 2022b), which should fill natural capital reporting gaps in the future. Government statisticians could also collaborate with the academic research community in the Pantanal to develop official statistics using these geospatial datasets data from field surveys to fill reporting gaps. Systematic reporting on ecosystem services could feed into the existing financial mechanisms in the region such as the Programa Estadual de Pagamento por Serviços Ambientais (State Payment Program for Environmental Services, PSA) in Mato Grosso do Sul.

Reporting on trade in the informal economy is challenging. However, it would make the value of the numerous ecosystem goods that benefit local communities visible to decision-makers. For example, there needs to be more reporting on the foods and materials, such as wild fruits and seeds, that are not traded in the formal economy in the Pantanal. Of the 18 wild fruits and seeds (Bortolotto et al., 2017) identified as suitable for valorization in the Pantanal, IBGE only reports on a single species, the Pequi fruit (*Caryocar brasiliense*). We recommend that the IBGE expand its ecosystem accounts to include a wide range of non-timber forest products, such as those detailed by Bortolotto et al. (2017), thus allowing decision-makers to understand the volumes and value of the wild foods and materials used by local communities in the Pantanal.

Maintenance of ecosystems in good condition is paramount to delivering ecosystem services in perpetuity, so the Brazilian government must move beyond statistics on ecosystem extent to include the condition of ecosystems. Government reporting of Brazil's ecosystem statistics is experimental and limited to the extent of land cover/use and threatened species statistics (IBGE, 2020a, 2022a). The government must coordinate the effort to identify and fill gaps in the data to quantify ecosystem condition, such as ecosystem functions, and functional species groups, such as pollinators and pest regulators. There are many opportunities to fill gaps using global maps and locally produced datasets about the ecosystem assets in the Pantanal. Brazil has a dedicated online platform for biodiversity data, the Brazilian Biodiversity Information System (Sistema de Informação sobre a Biodiversidade Brasileira, www.sibbr.gov.br), which facilitates online access to the wealth of biodiversity data collected in the country. However, there needs to be a systematic approach to data collection that prioritizes spatial and temporal consistencies. For data on biodiversity, a systematic approach to monitoring Brazil's biodiversity could be informed by the IBGE's "Mapping of Biodiversity Records in Brazil" initiative that aims to indicate areas in the country where there are sufficient records and those that need more collection (Sarti, 2021).

It may also be desirable for decision-makers to estimate the economic value of the Pantanal biome using metrics such as the NPV (Yun et al., 2017) or the gross ecosystem product (GEP) (Ouyang et al., 2020). The NPV and the GEP are the headline indicators analogous and complimentary to GDP; they convey a measure of the economic value of nature that can inform decision-making. However, the NPV and GEP approaches rely on the valuation of ecosystem services, so they are based only on the ecosystem services determined by our preferences at the time of valuation and omit services that are only appreciated in the future when social or environmental conditions have changed (Mace, 2019). Therefore, the economic valuation of the Pantanal biome should be conducted with the knowledge that essential ecosystem services are likely to be missed and accompanied by the caveat that, for this reason, any valuation is an underestimate.

The difference between administrative and environmental boundaries presents a challenge for monitoring and reporting on natural capital. This challenge in the Brazilian Pantanal plays out in three specific ways that our work here highlights. First, many municipalities that overlap the footprint of the Pantanal contain two biome types: the Pantanal wetland and the grassland of the Cerrado biome. This complicates natural capital reporting, as when using governmental statistics reported for administrative units, it is impossible to delineate statistics for the Pantanal and Cerrado biomes. To remedy this problem, we recommend that the government report statistics using administrative and environmental units, as done by both the MapBiomas and SEEG platforms. Second, the Pantanal biome overlaps two Brazilian states, and both have their environmental and socioeconomic monitoring and reporting approaches. Therefore, the state governments should harmonize their approaches to monitoring so that there is a complete picture of the state of the Brazilian Pantanal. Third, and along the same vein, the Pantanal biome spans three countries, including Brazil, Paraguay, and Bolivia. The NGO community

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recognizes the need for transnational monitoring of the Pantanal through the Pantanal Observatory (Observatorio Pantanal, www.observatoriopantanal.org), a group of 36 organizations that coordinate monitoring across the three countries. The relevant national and state governments should embrace this coordinated international effort to support biome-scale monitoring that gives a complete picture of the state of the biome than is currently available through the individual efforts of the relevant administrative agencies.

4.2 | Lessons learned from the first real-world application of the NCIF

In 6 months, we implemented the NCIF for the ecosystem and three commodity assets in the Brazilian Pantanal with a team of academic researchers. A team of experts embedded in the government could conduct this task more rapidly and comprehensively. Regarding the approach's utility, the NCIF has highlighted what is already available and the gaps in natural capital reporting in the Brazilian Pantanal. Furthermore, the NCIF clarifies the gaps in reporting that the federal and state governments may want to fill by investing in systematic data collection in the biome. Decision-makers must use the NCIF transparently, led by politically independent parties, to ensure that indicators are not selectively chosen to tell or hide particular stories about the relationship between economic activities and the environment.

There are several exciting avenues of future research for the NCIF and natural capital reporting in the Brazilian Pantanal:

- *Explore indicators of relational and intrinsic values*: The NCIF is currently limited to indicators of instrumental values of nature. The work on values for nature from the IPBES (IPBES, 2022) defines the relational and intrinsic values for nature and offers examples of appropriate indicators. The Brazilian Pantanal research community has already identified a gap in the consideration of non-instrumental values for nature in decision-making (Almeida-Gomes et al., 2022; Chiaravalloti et al., 2022). Future work should explore how these values can be represented in the NCIF and the appropriate indicators to do this.
- *Convene transdisciplinary teams to select indicators*: Transdisciplinary teams of policymakers, practitioners, and scientists should collaboratively assess appropriate indicators for natural capital reporting in the Brazilian Pantanal.
- *Investigate and develop social benefit indicators*: Identify available indicators and develop novel indicators representing the social benefits of specific ecosystem services. Indicators must be more specific than generic human development and inequality indicators, such as the HDI and Gini coefficient. In addition, they must be non-financial and specific to individual ecosystem services.
- *Investigate natural capital reporting for a more comprehensive range of commodity assets*: The scope of our study is limited to a small number of commodity assets to provide a proof of concept of the NCIF in the Pantanal. However, several other commodity assets are produced in the biome, such as energy from hydroelectric dams (Tomas et al., 2019). Future work could investigate natural capital reporting for other commodity assets in the Pantanal biome.
- *Expand the commodity asset NCIF to include a wide range of ecosystem services*: In this work, we limited the commodity assets to the provisioning of beef, soy, and fish only. However, livestock production and fishing support a wide range of ecosystem services, such as the cultural identity that people derive from working and living in agricultural and fishing communities and the positive impact of livestock grazing on the potential for soil to sequester carbon (Merida et al., 2022). Future work should investigate how to balance the complexity of reporting on the wide range of ecosystem services flowing from commodity assets with the simplicity that decision-makers desire from a few indicators.
- *Combine government statistics with biophysical modeling to fill reporting gaps*: A range of data and modeling platforms produce biophysical and sometimes monetary estimates of natural capital to support natural capital accounting (United Nations, 2022). Future research should explore the data and models to fill natural capital reporting gaps using biophysical modeling alongside the existing data for the Brazilian Pantanal.

5 | CONCLUSIONS

Pressure is growing on countries to move toward reporting on the wide range of benefits that flow to local, regional, and global communities from natural capital (Masood, 2022). Our application of the NCIF, an entry-level approach to natural capital reporting, in the Brazilian Pantanal highlights that many goods and benefits that flow from the Pantanal biome need to be monitored systematically and reported by the government. Brazil has considerable activity and capacity to fill natural capital reporting gaps, including by developing experimental ecosystem accounts by IBGE, the national statistics agency. IBGE should expand this work to include the condition of Brazil's ecosystem assets and

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non-provisioning ecosystem services, such as regulation of the hydrological cycle, the economic value of which is becoming increasingly apparent (Leite-Filho et al., 2021). We have shown here that the NCIF provides a structured approach to bringing together natural capital information to explore policy questions about the dependence of humans and the economy on the environment. This first real-world test of the NCIF demonstrates that it can be applied rapidly and easily using pre-existing indicators produced by the government, academic, and NGO sectors.

AUTHOR CONTRIBUTIONS

Alison Fairbrass, Julia Tomei, Celma Ribeiro, and Claudio Oller conceived the study and acquired the funding. Elvander Quaresma, Victor Moretti, and Fabio de Oliveira Roque supported Alison Fairbrass in data acquisition, while Alison Fairbrass performed the analysis and led the writing of the manuscript. All authors were involved in reviewing the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to disclose.

DATA AVAILABILITY STATEMENT

The data on which this article is based are available in Fairbrass et al. (2024).

ETHICS STATEMENT

The research did not involve people or sensitive issues, so no ethics approval was required.

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