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REVIEW

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Ten relevant questions for applying biodiversity offsetting in the Pantanal wetland

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Abstract

In Brazil, biodiversity offsetting operates in an ad hoc manner while biodiversity equivalence has mainly been overlooked by public policies. Despite being mandatory since 1965s Forest Code (Law 4.771), we fail to have a robust offsetting framework. The revision of the forest code in 2012 (*i.e.*, Native Vegetation Protection Law—NVPL—Law n° 12,651/2012), maintained the obligation for landowners to set aside a biome-specific percentage of their native vegetation for preservation. Known as Legal Reserves, these set-asides are a precondition for compliance with NVPL's regularization procedure called CAR (Rural Environmental Cadaster). Despite enthusiasm about biodiversity offsetting opportunities following the NVPL enactment in 2012, uncertainties around its implementation remains. Here, we formulated 10 questions that discuss and

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illustrate how offsetting can be applied to maintain wetland integrity, economic fairness and biodiversity conservation in the Pantanal and Upper Paraguay River basin (UPRB). The aim is to stimulate robust public policies and stimulate wetland offsetting research opportunities. We provided examples of implementation opportunities of the NVPL in integrating the floodplain and highland in Pantanal at UPRB, analyze spatial compliance deficits, and illustrate opportunities that require harmonized legislation and policies between Mato Grosso and Mato Grosso do Sul states in Brazil.

KEYWORDS

biodiversity, Brazil Pantanal, Forest-code, Native Vegetation Protection Law—NVPL, offsetting, wetlands

1 | INTRODUCTION

Biodiversity offsetting is a system for placing a value on a habitat, plant or animal, meaning the "credit" or "unit" can be bought or sold to "offset" damage being done, thereby creating a financial incentive to conserve natural assets elsewhere (OECD, 2016). This is a potential tool for counteracting biodiversity losses from habitat conversion and development. However, wetlands, such as the Brazilian Pantanal, have temporal hydrological dynamics (i.e., the hydrological signature) that impose several challenges for a robust offsetting baseline reference. Furthermore, the compensation system can be controversial. Part of the controversy relates to operational issues on how to counterbalance biodiversity losses in one place by generating equivalent biodiversity benefits elsewhere. Recently, Maron et al. (2016) raised two key questions about offsetting programs from around the world: (1) is offsetting good, bad, or at least better than the status quo for biodiversity conservation outcomes? and (2) what information is required to support offsetting decision making? To answer these questions, ethical, social, and technical challenges must be addressed, in order to achieve consensual decisions. In developing countries, offsetting programs are becoming part of environmental policies, and therefore should be systematically evaluated.

In Brazil, biodiversity offsetting was embedded in the first Forest Code (FC) enacted in 1965. A broad review of the FC by the Brazilian Congress in 2012 resulted in the enactment of the Native Vegetation Protection Law (NVPL), law n° 12,651/2012. The NVPL, also known as the "new Forest Code," which maintained the regulations where private landowners needed to maintain Legal Reserves (LR—biome-specific percentage set-asides). One innovation of the NVPL was that landholders were required to undergo a licensing procedure called the Rural Environmental Cadaster (Cadastro Ambiental Rural—CAR). CAR is a self-declaratory electronic regulatory procedure in which landowners need to submit a spatially explicit land-use compliance report, providing data on native vegetation in terms of NVPL requirements (Brasil., 2012). This process presented multiple opportunities for large-scale offsetting to occur in Brazil. In fact, efforts to comply with the NVPL are expected to mobilize billions of dollars and involve millions of hectares over the next few decades (Soares-Filho et al., 2014), contributing to Brazil's ambitious commitments to restore 12 Mha of native vegetation as a contribution to the global target of the Bonn Challenge, which aims to promote the restoration of 350 Mha of degraded/deforested land by 2030 (www.bonnchallenge.org), and also to comply with other agreements, such as the Paris Climate Agreement and the National Policy of Native Vegetation Recovery (aiming the recovery of 12 million hectares of native vegetation until 2030). Estimated progress on restoration goals can be followed on the Observatory of restoration and reforestation, which gathers field information with satellite data to provide an overview of the reforestation and restoration situation in all Brazilian biomes, mapped, until 2024, 153.14 thousands hectares of restoration and 18.58 millions hectares in secondary vegetation (https://observatoriodarestauracao.org.br/home).

Despite some enthusiasm regarding biodiversity-offsetting opportunities, there are still many uncertainties regarding the criteria and the practicality of its implementation, including market potential. Many questions are still unresolved, including: delays on deadlines for CAR registrations, priority areas definitions for offsetting of Environmental Reserve Quotas (Cotas de Reserva Ambiental—CRA), which are native vegetation areas registered for offsetting, and whether negotiable CRAs could be traded between states, watersheds, and biomes (da Cruz et al., 2020).

Historically, some of the earliest ecosystem-based offsetting studies promoted by the 1972 Clean Water Act in the United States were focused primarily on temperate wetlands. These early initiatives on wetland offsetting in the United States and other countries served as the basis for offsetting proposals in tropical regions (Gonçalves et al., 2015). However, applying these methods to tropical offsetting had its limitations, due to differences in ecosystem complexity, biodiversity and measures for economic valuation and fungibility (Ten Kate et al., 2004).

The objective of this article is to present 10 fundamental questions about biodiversity offsetting in the Pantanal wetland. The Pantanal is a vast tropical wetland located mostly in Brazil, but also extending into Bolivia and Paraguay. It is the world's largest tropical wetland area, covering an estimated 140,000 km^2. The Pantanal is located in the Upper Paraguay River Basin (UPRB), which is formed by the floodplain (the Pantanal biome) and the surrounding highlands (Cerrado and Amazon—by IBGE map) (Figure 1), and enclaves of Atlantic Forest according to the Atlantic Forest law (#11,428/2006), where the headwaters of the main rivers that form the biome are located.

In a workshop attended by a selected nature conservation experts and Pantanal wetland experts (see details in Methods), we thoroughly discussed the primary challenges and deficiencies within current wetland conservation initiatives in the region. Simultaneously, we explored the potential presented by the NVPL. Drawing insights from scenarios outlined by Maron et al. (2016) and issues emphasized by Ten Kate et al. (2004), we crafted 10 pivotal questions. These questions require immediate consideration as we work toward developing a robust offsetting framework tailored to the unique features of the region, characterized by its dynamic nature as a wetland significantly influenced by flood pulses and avulsive processes.

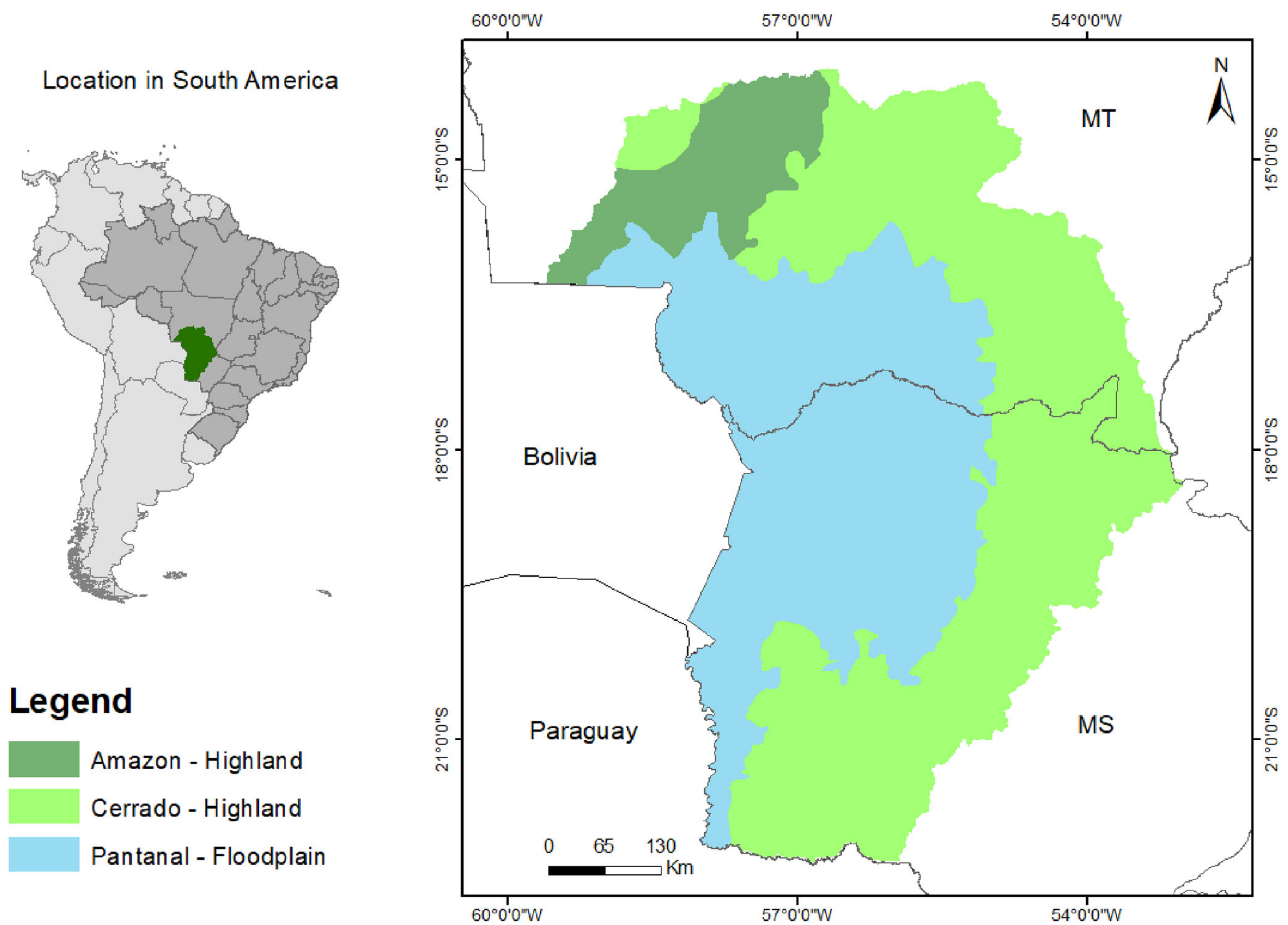

FIGURE 1 Location of the Upper Paraguay River Basin (UPRB). Brazilian states: MS—Mato Grosso do Sul, MT—Mato Grosso. The highlands of the Upper River Paraguay Basin (UPRB) are covered by the Cerrado and Amazon biotas (by IBGE map), while the Floodplain constitutes the Pantanal biome.

The 10 questions addressed are:

1. What concepts used in offsetting strategies are missing in the Brazilian NVPL legislation and implementation initiatives?
2. Which biodiversity dimensions should be considered in offsetting?
3. How can the spatial allocation of offsets promote best biodiversity conservation outcomes (on-site versus off-site)?
4. How do UPRB hydrology and the Pantanal's flood pulse affect offsetting scenarios?
5. Are there habitat equivalences between UPRB highland and lowland ecosystems, for offsetting purposes?
6. How can different types of environments in the UPRB highlands be restored, and what is their value in Pantanal offsetting?
7. Should native grasslands be a target for biodiversity offsetting when managed for sustainable cattle production in the Pantanal?
8. Is off-site offsetting a strategic alternative to achieve conservation in the Pantanal?
9. How can the effectiveness of wetland governance be improved for biodiversity offsetting?
10. How can these technical questions be communicated, so that they capture the interest of the general public?

Although we are aware that offsetting is comprised of many types of compensation requirements (*e.g.*, Environmental Impact Assessments for industrial development, dams, and other large projects), we focused our analysis on requirements for rural properties in the Upper Paraguay River basin, where the Pantanal wetland is located.

Here, we aim to explore potential offsetting scenarios from the NVPL framework, and considering, regional conditions we developed and proposed practical alternatives for viable offsetting scenarios, in the Pantanal and bordering highlands of the UPRB rooted in the NVPL. Together the questions and scenarios provide a robust and fair-minded pathway to regional offsetting.

2 | METHODS AND RESULTS

2.1 | Study area

The Pantanal is a vast tropical wetland located mostly in Brazil, but also extending into Bolivia and Paraguay, covering an estimated 160,000 km^2 (Keddy et al., 2009). The Pantanal is located in the UPRB, which is formed by the floodplain and the highlands (Cerrado and Amazon) (Figure 1), where the sources of the main rivers that form the biome are located.

The socioenvironmental context of the Pantanal is shaped by a complex interplay of ecological, economic, and cultural factors.

The biome is renowned for its exceptional biodiversity, hosting a wide variety of plant and animal species (Junk et al. 2011). It is home to numerous endemic and endangered species, including jaguars, capybaras, caimans, and a rich array of bird species. The wetland ecosystem provides essential ecosystem services, such as water filtration, flood control, and habitat for wildlife. These services are crucial for the sustenance of both the environment and human communities.

Local communities in and around the Pantanal have developed traditional livelihoods that are closely linked to the wetland ecosystem. Fishing, agriculture, and cattle ranching are common economic activities. The sustainable use of natural resources is crucial for the livelihoods of many local residents. However, this balance is often challenged by external factors such as climate change, land-use changes, and infrastructure development.

The Pantanal has become a popular destination for ecotourism, attracting visitors interested in its unique flora and fauna (Almeida-Gomes et al., 2022). Tourism can bring economic benefits to the region, but it also raises concerns about the potential for environmental degradation and disruption to local communities. However, the biome faces several environmental threats, including deforestation (better referred to as native vegetation suppression since Pantanal also has savannas and grassland formations), wildfires, hydrological pattern changes (*e.g.*, by dams and hidrovia), pollution (by herbicides and other pesticides), introduction of exotic alien grasses for pasture, and climate change (Garcia et al., 2021; Guerra, de Oliveira, et al., 2020; Guerra, Reis, et al., 2020; Guerra, Roque, et al., 2020; Ikeda-Castrillon et al., 2022; Marengo et al., 2016; Marengo et al., 2021; Tomas et al., 2019; Viana et al., 2023; Wantzen et al., 2024). These challenges can upset the delicate balance of the wetland ecosystem and impact the region's biodiversity.

2.2 | Workshop dynamic and co-writing process

First, supported by Nature and Culture International and the Fundação de Apoio à Pesquisa de Mato Grosso do Sul (Fundect) and Neotropica Foundation, a steering team composed by four academics from Universidade Federal de Mato Grosso do Sul and Humboldt Institute

(Colômbia) which selected and invited researchers who published papers about offsetting from different Brazilian states and/or countries which faced similar challenges. In total, we invited 27 researchers. We received positive feedback from 25 people in which we aligned their agendas for a 3 days workshop in person in Bonito, Mato Grosso do Sul 4–7 October 2015. This group was composed by 18 researchers from Brazil (6 states), 3 from Australia, 1 Colombia, 2 from France, and 1 from Italy.

The first day of the workshop was to ensure a common language of terms and core principles. We had two speakers: Mato Grosso do Sul's Public Prosecutor Dr. Luciano Loubet and Prof. Hugh P. Possingham. Along 2 days, participants were immersed in the methodological phases of: phase (i) visioning and general approach development through a participatory dynamics (whole team); phase (ii) discussion with local stakeholders to address gaps in visions; phase (iii) formulation of key questions and knowledge gaps by the expert groups; phase (iv) consolidation and ranking of questions and potential issues to be explored by scientific papers. After the event, the team started a co-writing process of the manuscript using the google-docs tools. The Brazilian steering team was responsible to consolidate the paper, including anchoring it in particularities about the Pantanal and the broader Brazilian legislation.

3 | METHODS

We summarized the total area and number of properties of the UPRB in Table 1, as well as the status of properties in terms of compliance with the NVPL and percent native habitat cover. To calculate the Legal Reserve surplus/deficit for native remnants of vegetation, we first surveyed the rural properties perimeters using data from the collections of the National Institute for Colonization and Agrarian Reform (INCRA) in the Land Management System (SIGEF) database (INCRA, 2021). We have opted to utilize land tenure data over the original Rural Environmental Registry (CAR) data, as land tenure data presents fewer issues related to property overlap and geometric errors, thereby reducing the number of exclusions during our analyses.

The limits of the Legal Amazon, Pantanal floodplain and the UPRB were accessed from the databases of the Brazilian Institute of Geography and Statistics (IBGE, 2021). For the Legal Reserve percentages required by the NVPL, we used the Soares-Filho et al. (2014), database for main vegetation types at 1:5,000,000 scale (Figure 2). We use the remnants of native vegetation land use and land cover data from MapBiomas Platform Collection 6 (MapBiomas, 2021).

The data processing was conducted in QGIS version 3.16.11—Hannover, using the zonal and intersection statistics algorithms to quantify native vegetation remnants, for each rural property. Only the properties that were totally within the limits of the UPRB were selected, accounting for 31,790. However, to quantify the Legal Reserve surplus/deficit (*i.e.*, amount of remaining native vegetation existing on properties) it was necessary to divide the rural properties either by two biomes or by the limits of the Legal Amazon, accounting for 33,552 non-overlapping features at the end, encompassing highlands and the floodplain, covering 36.2 million hectares. This division was necessary because when considering the remnants of native vegetation on a property that is located in two biomes, the percentage required by the NVPL will be a function of the location of the remnants, and may even be in one or more biomes.

Disruption of the natural flood pulse on the Pantanal floodplain is directly related to agriculture-related developments and land-use intensification on the UPRB highlands, which according to our analysis, 56.7% of the properties in the floodplain data does not comply with the NVPL. Vegetation loss within the UPRB highlands over the last 50 years (Table 1) has reached alarming levels (Roque et al., 2016), and vegetation deficits of non-compliant properties at the database in highlands exceeds 100,000 km^2 (Figure 3 and Table 1), a great offsetting opportunity, for the watershed, since the Pantanal floodplain is still largely undisturbed with 78% of properties

TABLE 1 Total area, number, compliance status with NVPL and percent cover of native vegetation remnants on properties in the Upper Paraguay River Basin (UPRB).

UPRB stratification	TA (km^2)	TAP (km^2)	PC (%)	N°P	N°P COMP	COMP (%)
Pantanal floodplain (PF)	150,961	71,257	47.2%	3111	2428	78.0%
UPRB highlands (UPRBH)	210,552	117,226	55.7%	30,441	13,174	43.3%
UPRB (PF + UPRBH)	361,513	188,483	52.1%	33,552	15,602	46.5%

Note: Property variables are listed separately for the Pantanal floodplain, the highlands bordering the Pantanal and the entire UPRB.
Abbreviations: COMP, level of compliance in percent; N°P, number of rural properties; N°P COMP, number of compliant rural properties; PC, percentage of compliant rural properties; TA, total area; TAP, total area covered by properties.
Source: SIGEF Database 2022.

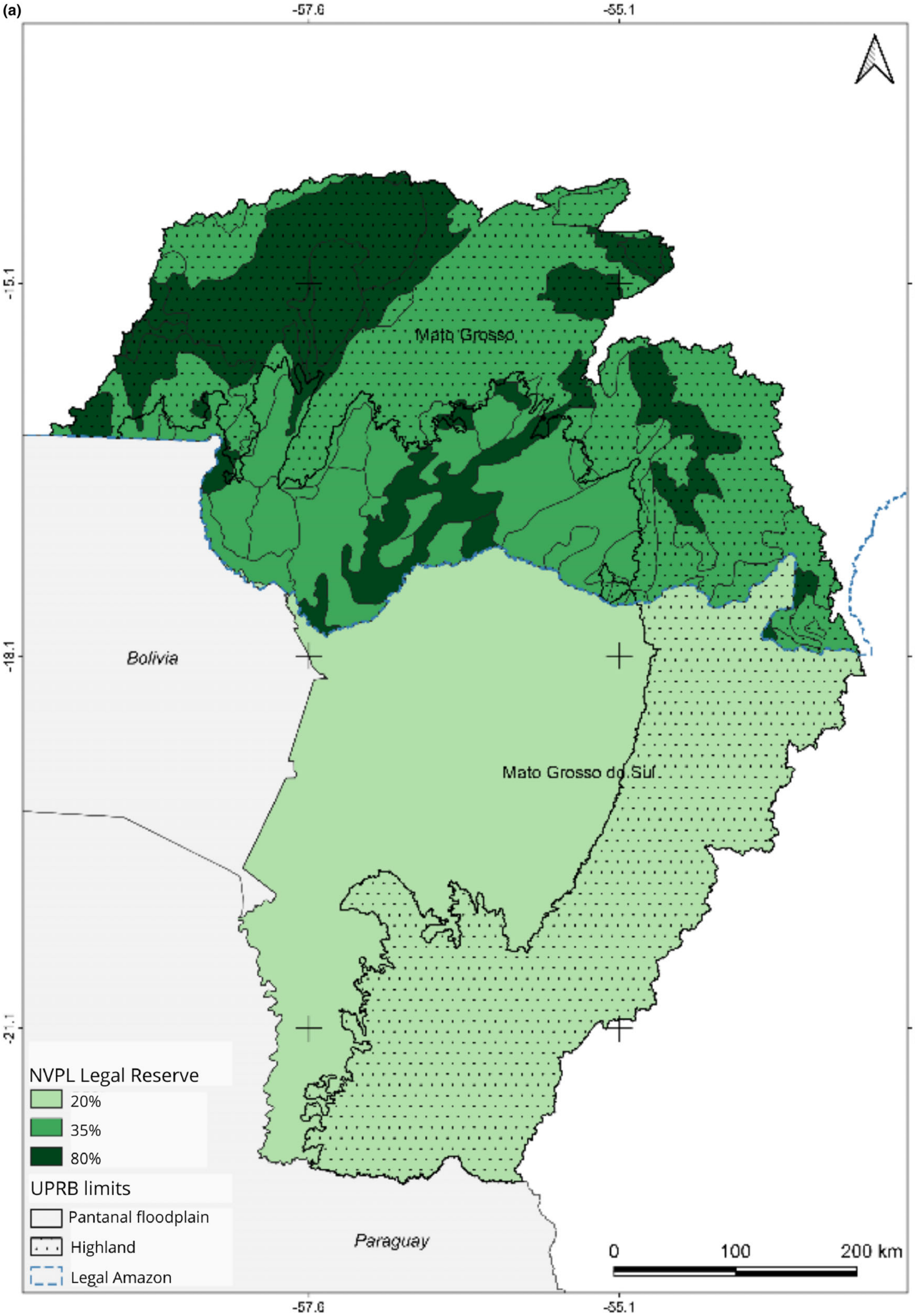

FIGURE 2 Regulatory percentages for legal reserves (LR) at the Upper Paraguay River Basin (UPRB) where the Pantanal floodplain is in compact greens, and the UPRB highlands are shown in dashed greens. The dotted blue line is the limit between Mato Grosso, which follows the Legal Amazon requirements for LRs, and Mato Grosso do Sul, which follows the Cerrado/Pantanal NVPL requirement for each rural property applying for Rural Environmental Cadaster (CAR).

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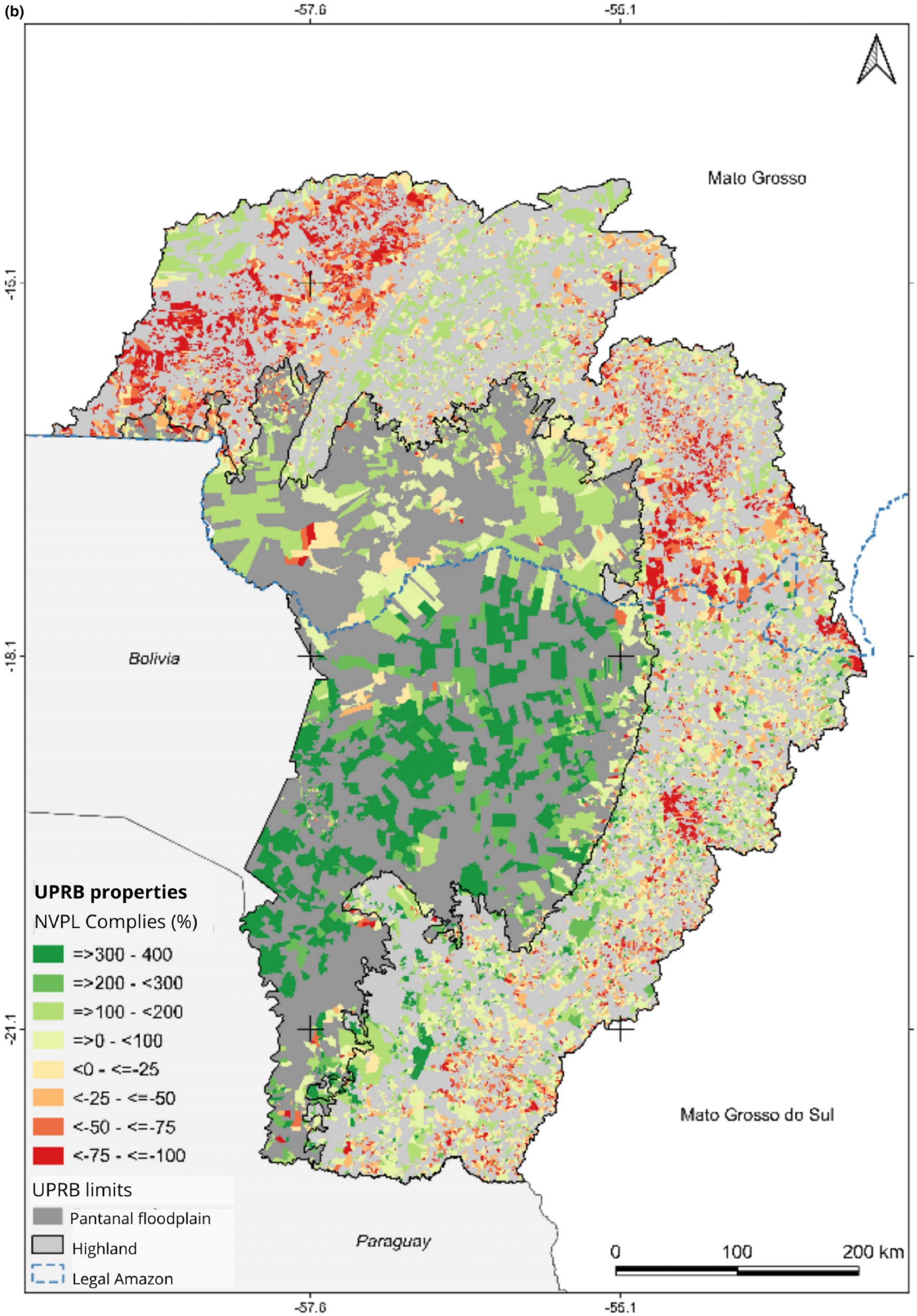

FIGURE 3 Spatial distribution of properties in the UPRB according to their level of compliance for native vegetation cover, related to NVPL requirements. The map displays on-property vegetation surpluses (green scale) and deficits (red scale) for Legal Reserves regulations. The dark line defines the limits between the UPRB highlands and the Pantanal floodplain, and the gray background areas are non-registered properties. *Source*: https://mapbiomas.org/.

complying with NVPL and with CRA surpluses. Current trends, however, show an increasingly rapid rate of replacement of native rangelands by cultivated exotic grass species (Tomas et al., 2019), and wildfire acceleration in the Floodplain (Garcia et al., 2021). Meanwhile the watershed compliance for the entire UPRB, is 46.5%, weakening Brazil's position and commitments to the Convention on Biological Diversity (CBD) Aichi Biodiversity Targets, the Ramsar Convention on Wetlands, and the constitutional status of the Pantanal as a National Heritage Ecosystem (Brasil, 1988).

4 | DISCUSSION

We framed our 10 questions during our expert workshop discussions. These questions operationalize and clarify practical situations and everyday problems that managers and stakeholders will face when implementing NVPL offsetting in the Pantanal following the opportunities presented by alternative scenarios of the NVPL illustrated in Figure 4 from (a) as the business as usual scenario to (e) as a land value based offsetting. 1:1, elucidating the challenges in comparing and trading completely different vegetation/biodiversity assemblages and land values (non-fungible currencies) between the Cerrado highlands and Pantanal wetlands.

5 | WHAT CONCEPTS USED IN OFFSETTING STRATEGIES ARE MISSING IN THE BRAZILIAN NVPL LEGISLATION AND INITIATIVES?

Biodiversity offsetting is intended to be a compensatory measure that targets neglected impacts from a specific project, that is, due to avoidance, minimization, and/or mitigation actions, and enforces accountable biodiversity conservation outcomes. Any gains accruing from conservation actions need to be quantified in the same tradable currencies as the losses, and they must be comparable and fungible over the period that the conservation action is implemented (Costanza, 2000; Lourival et al., 2008; Sklar et al., 2005). Fungibility means that environmental options are truly and mutually interchangeable, based on measures of biodiversity values (targets). Offset compensation goals vary from "no net loss" to "net gain" in biodiversity (Bull et al., 2013; Zedler, 2004). By "no net loss," we mean an outcome of biodiversity offsetting in which the target level of biodiversity is not less than an expected level of original biodiversity, in contrast to a level determined by a counterfactual scenario (Bull et al., 2013). "Net gain" is an outcome that aims to quantify ecological impacts and create additional biodiversity components (Bull et al., 2013). In Brazil, the mechanisms associated with the NVPL can be considered as "no net loss" cases, since they determine biome-specific percentages for "no net loss" on all private properties, represented by Legal Reserves (LR) (Soares-Filho et al., 2014). Although size (minimum percentage of native vegetation cover) is a critical element for LR compensations, an adequate system should go beyond size, whereby the hectares missing in compliance should be compensated by other hectare in the same biome Considering the landscape complexity of the UPRB and the Pantanal, an adequate framework would include possibilities for: (1) weighting distinct vegetation types based on surrogacy, (2) creating reference baselines to allow evaluations of ecological equivalencies, currency values, and fungibility and (3) developing a set of parameters to direct selection of target locations based on priorities, monitoring indicators, and so on. Despite the capacity of Brazilian experts to assist with offsetting, decisions continue to be ad-hoc, that is, defined by the local authorities in charge and/or conducted on a case-by-case basis, without objective metrics or frameworks. In fact, the NVPL 1:1 compensation ratio based solely on area is used (Figure 4a), lacking robustness and fairness for the protection of native ecosystems. The NVPL completely neglects economics when dealing with compliance deficits and surpluses for offsetting, creating inter-regional inequalities by allowing deforestation leakages (Lourival et al., 2008).

6 | WHICH BIODIVERSITY DIMENSIONS SHOULD BE CONSIDERED IN OFFSETTING?

Different biodiversity dimensions can be used in offsetting (*e.g.*, presence of threatened/endemic species, species richness). Unfortunately, science-based biodiversity equivalence, with specific and transparent objectives, is neglected by the NVPL, while in the earlier forest code the ratios varied from state to state up to 1:4 in Mato Grosso and Pará, for example. Instead, offsetting equivalence has often been determined by local governments or the courts, responding to issues for non-compliant companies/landowners. Recently, however, using mapping of post-fire degradation (Martins et al., 2022; Martins et al., 2024), the Mato Grosso do Sul Public Prosecutor office used scientific information to designate where are the need for restoration and fire management actions in the Pantanal and highland. Although measuring and quantifying biodiversity is a contentious, time-consuming, complex, multiscale and expensive task, there is an emerging consensus in the literature that no single metric

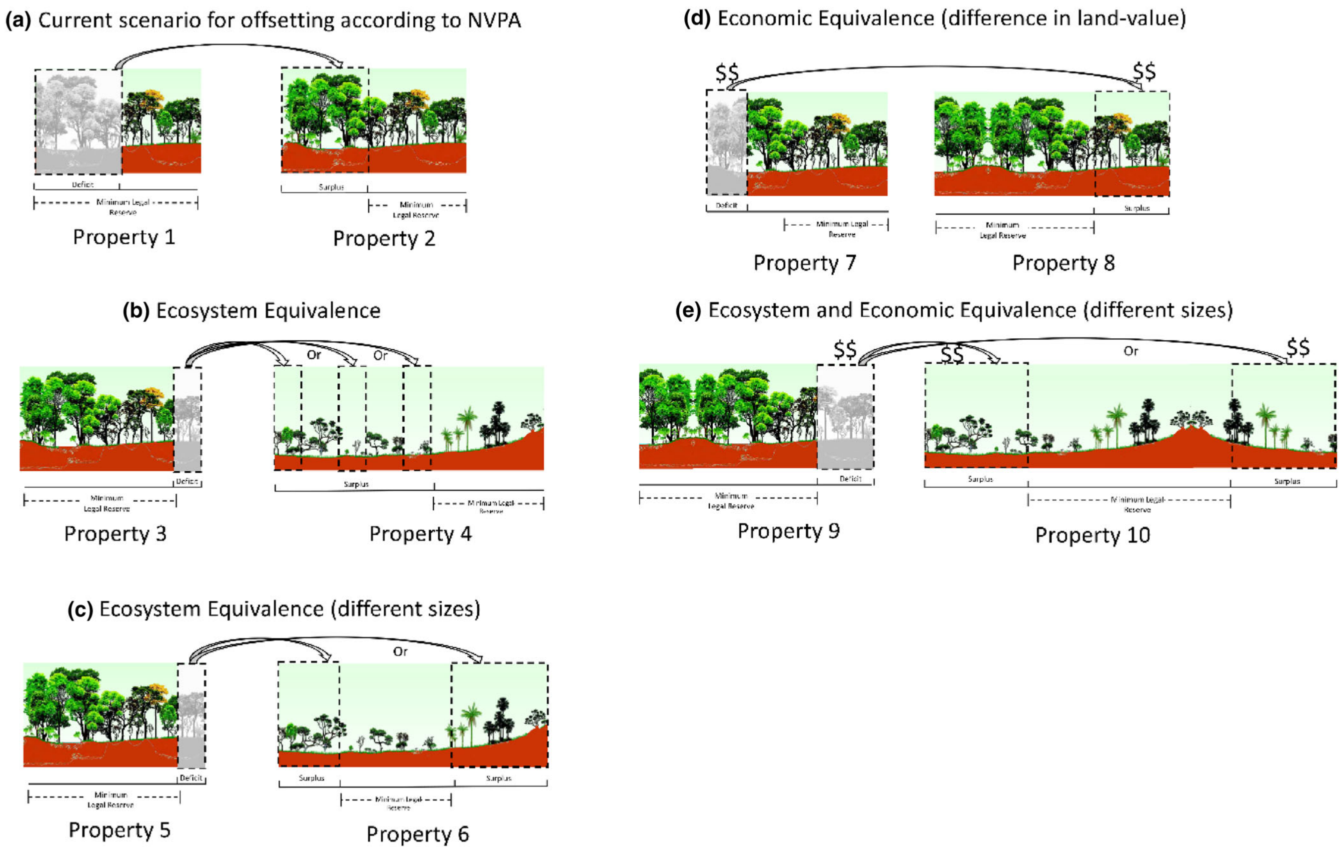

FIGURE 4 Seven opportunity scenarios for offsetting, considering the native vegetation protection act (NVPL) on the Trade of Environmental Reserve Quotas (CRAs). These scenarios could support State legislation and play a major role in biodiversity conservation for properties with legal reserves (LR), compliance surpluses, and/or deficits of CRAs. In (a), which reflects the current NVPL status, a 1 to 1 ratio is used for trading, that is, 1 ha of deficit is offset in-kind by 1 ha of surplus habitat between property (1) and property (2). In (b), ecosystem equivalence is calculated between properties (3) in deficit and (4) with surplus, that is, an amount of lost native vegetation (deficit) is compensated for off-site at a 1 to 1 ratio of a different type of ecosystem in the same biome. In (c), there is recognition that 1 ha lost needs to be compensated at a ratio greater than 1 to 1, due to uneven equivalence between habitats, therefore offsetting is done off-site between properties (5) and (6) through an ecosystem equivalence habitat calculator. In (d), offsetting policy is based on land value, where the deficit was generated (on property 7), enabling substantial area increase of standing native vegetation on an off-site location (property 8) considering its lower land value (*e.g.*, highland x Pantanal). Finally, in (e), the most desired scenario, a calculator factors both ecosystem equivalence and land value conditions between properties (9) and (10) and establishes optimal trading ratios.

adequately represents the numerous dimensions of biodiversity (from genes to ecosystems) (Pereira et al., 2012). Depending on the dimension under consideration, there are idiosyncratic biodiversity responses to anthropogenic impacts (Westgate et al., 2014), and complex mechanisms can affect biodiversity effects on ecosystem functioning (Caliman et al., 2013). Brazil's NVPL, considers area and biomes when dealing with biodiversity equivalence. Hence, legal reserve deficits and surpluses, when compensated in a 1:1 ratio, are insufficient to prevent biodiversity loss.

Biodiversity surrogates can be useful to solve the problem of biodiversity multidimensionality and the idiosyncratic responses of different dimensions to anthropogenic impacts. Characterizing the relationships between large animals (*e.g.*, big cats—*Panthera onca* and *Puma concolor*, peccaries—*Pecari tajacu*, tapir—*Tapirus terrestris*, migratory fish—*Salminus brasiliensis*, *Pseudoplatystoma corruscans*) and landscape metrics (e.g., patch heterogeneity and cohesion, flood patterns, and habitat suitability) has the potential for developing effective biodiversity surrogates that are representative of the Pantanal's biodiversity during dry and wet phases (Drechsler et al., 2009; Lourival, Drechsler, et al., 2011). However, biodiversity surrogacy remains poorly understood in the Pantanal, because few studies on the congruence patterns of multiple taxa have been conducted. The adoption of proper strategies to select biodiversity surrogates that are robust across multiple dimensions (Figure 4b) would help produce better offsetting outcomes and environmental policies (Lawrence & Robinson, 2014; Lourival et al., 2009).

7 | HOW CAN THE SPATIAL ALLOCATION OF OFFSETS PROMOTE BEST BIODIVERSITY OUTCOMES (ON-SITE VERSUS OFF-SITE)?

On-site/off-site offset compensation is a multiscale problem and, as in most environmental classification systems, it involves some conceptual and some operational challenges. Historically, the term Pantanal referred only to the floodplains, but not the highlands of the UPRB. This geographic exclusion of the highlands has complicated development of environmental policies that protects watershed integrity of the Pantanal. There are several legal implications when the Brazilian Government considers the floodplains as the official boundary of the biome. One of the practical effects of this definition was that the headwater of the catchments that drain the surrounding highlands into the Pantanal (*e.g*., the Amolar, Bodoquena, Maracaju, Urucum, Parecis, and Araras mountain ranges and plateaus) were treated as if they were not intrinsically linked to floodplain dynamics. The result was that the UPRB highlands were excluded from legal and functional offsetting efforts, threatening the protection and integrity of this National Heritage Ecosystem.

Recently, however, a greater understanding has been achieved about the interdependencies between UPRB plateaus and the floodplain (Bergier, 2013), indicating that a broader geographic definition that includes the entire UPRB should be used as a management unit for sustainable development (*e.g*., for resolving conflicts related to water resource use, control of erosion and pollution and, perhaps, offsetting schemes) (Figure 4). We believe this broader definition of the Pantanal biome, including both the floodplains and the highlands should be used for offsetting, because the hydrologic regime of the highlands is intrinsically linked to the flood pulse in the Pantanal, creating a huge spatially and temporally heterogeneous environment (Junk et al., 2014; Lourival, Drechsler, et al., 2011; Lourival, Watts, et al., 2011) (Figure 4c).

The UPRB, is located within two Brazilian states, Mato Grosso and Mato Grosso do Sul, and are shared by Bolivia and Paraguay. This imposes another level of complexity for offsetting, since current legal frameworks are not consistent across states nor countries (OAS, 2005). The NVPL allows offsetting throughout the same "biome," whose official borders are established by the Brazilian Institute of Geography and Statistics—IBGE (Figure 2).

Land tenure is another important spatial aspect of the Pantanal that adds to the complexity of offsetting. Currently landowners have formal ownership over their titled farms, nevertheless, in some cases, a layer of "ownership" by "ribeirinhos," traditional angler communities, who constructed their settlements along river embankments, is also recognized. The lack of clarity regarding land tenure may cause conflicts over the use of riverside areas and may jeopardize offsetting practices in some parts of the floodplain (Chiaravalloti, 2017).

Another regional scale difficulty for offsetting arises due to the existence and classification of Pantanal subregions (Hamilton et al., 1996; Silva & Abdon, 1998), the most recent attempt to classify the Pantanal into sub regional units was proposed by Assine et al. (2015) based on hydrology and the long-term geomorphologic landscape dynamics of the UPRB. Even within sub-regions, areas cannot be considered homogeneous ecological units for offsetting purposes, because hydrologic and vegetation patterns are highly heterogeneous.

As a rule of thumb, habitat offsetting is preferable if it is conducted near the impacted area (*i.e*., on-site) (IUCN, 2012). However, the NVPL framework also allows off-site offsetting, and that can cause spatial inequalities in terms of biodiversity equivalence and unfairness in terms of land values, particularly if the offsetting is based solely on a 1:1 area ratio (Figures 2, 3). Considering that land value varies dramatically between states and municipalities in the UPRB, a potential offsetting scenario could include damage-mitigation from high-value land that is offset by low-value land hectare-equivalents far away from the "source," reducing the potential offsetting benefits received by low-value land markets (Figure 4d). Within the UPRB, we believe that offsets should be located as close as possible to the non-compliant territorial unit (*i.e*., property and habitat). This would increase the chances that offsetting contributes to the conservation and integrity of the same ecosystems that included the impacted area, and that the needs of local people are met and that compliant neighbor are benefitting.

Pragmatic and scientifically robust methods for simultaneously solving ecological and social justice issues will be very useful to promote objective and transparent offsetting for both "in-kind" and "on-site" scenarios (Schulz et al., 2015). In the workshop, with all participants, we explored through opportunities associated with payments for ecosystem services (PES) using the entire UPRB as an offsetting unit (environmental payments in highlands and floodplain). In Figure 4 we present initial suggestions for models that take into account the environmental and economic aspects of land equivalence, as well as compensation schemes for the UPRB.

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8 | HOW DOES UPRB HYDROLOGY AND THE PANTANAL'S FLOOD PULSE AFFECT OFFSETTING SCHEMES?

The Pantanal is larger than Greece and is comprised of a continuum of permanently to seasonally flooded wetlands, with rivers and rarely flooded portions. During seasonal rain cycles and the annual flood pulse, many regions shift from terrestrial to aquatic habitats and back again (Drechsler et al., 2009). In the Pantanal, the Paraguay River and its main tributaries continuously transport sandy sediment that originates mostly from the northern and the eastern Central Brazilian plateau. Multiannual cycles of higher floods or droughts can cause dramatic shifts in forest patch dynamics with retraction of woody vegetation from low lying areas during higher flood periods or encroachment of woody vegetation into low lying areas during drier periods (*e.g.*, *Vochisia divergens*, Pohl, *Licania parvifolia*, Huber, *Curatella americana* Lineu, *Byrsonima orgbigniana*, A. Juss). Such dynamics, including long-term changes in forest cover, can be modeled and should be accounted for in the biodiversity calculations of no-net-loss offsetting (Lourival, Drechsler, et al., 2011). Climate change, in synergy with anthropogenic factors, may strongly impact Pantanal macro-ecosystem dynamics (da Cunha et al., 2015). Further investigation on the potential impacts caused by development projects, such as hydroelectric dams, is essential, as they can induce harsher transitions between flood pulse stages (Alho & Sabino, 2011; Lourival, Drechsler, et al., 2011; Tomas et al., 2019). Dantas et al., 2016 demonstrated, using niche overlap analysis, that disturbances are pivotal for maintaining or shifting between the multiple stable states of a biome. Although we still lack an experimental evaluation of flood-pulse effects on the Pantanal's alternative stable states, landscape-scale evidence indicates that there is an interaction between flood history and altitudinal gradient that determines patch dynamics and the distributions of community assemblages (Drechsler et al., 2009).

The synergy between human-induced changes and climate impacts (Marengo et al., 2016; Trenberth, 2009) may result in an increased likelihood of extreme floods and droughts, dramatically altering the Pantanal's hydrology (Hamilton, 2002), fire regime (Leal Filho et al., 2021) productivity, species diversity and abundance (*e.g.*, Desbiez et al., 2010), species distributions (*e.g.*, Tomas et al., 2001), alien species invasion (Luz et al., 2024), and cattle ranching economics (Seidl et al., 2001).

It is our perception that offsetting in dynamic ecosystems such as the UPRB requires an approach that facilitates stakeholder understanding of natural dynamics in both the highlands and at the floodplain. Mato Grosso do Sul state legislation requires NVPL non-compliant landowners to offset within state boundaries but allows it among biomes (Articles 10, 11 of the Stadual Law 6,160/2023 and the Article 12 of the Decree 16,388/2024), while in the Mato Grosso it is allowed only in the same biome (Article 18, 33, 44 of the Decree 1,491/2018) as same as the federal law (Articles 45, § 2°, IV of the Law 12,651/2012).

9 | ARE THERE HABITAT EQUIVALENCES BETWEEN UPRB HIGHLANDS AND LOWLAND ECOSYSTEMS FOR OFFSETTING PURPOSES?

Offsetting requires equivalence of currencies, which is often derived from scientifically defensible surrogates for calculating fungibility or for comparisons between areas and habitats (Gonçalves et al., 2015). In cases, where habitats are fungible, prioritization of sites and habitats has important ecological implications in offsetting, and is intrinsically dependent on site and habitat fungibility potential (Figure 4d,e) and the choice of currency (Fairbairn, 2015; Lourival et al., 2008; Quétier & Lavorel, 2011).

In the UPRB, the challenges of habitat/vegetation classification and equivalence are complicated by NVPL limitations (Tomas et al., 2018). Vegetation classifications in the Pantanal are inherently complex because of phytogeography and the influence of flood pulse history on the spatial distribution and species composition of habitats throughout the floodplain. Inter-annual differences in rainfall and flooding result in a highly dynamic and complex gradient of habitat types when compared to the UPRB highlands (*e.g.*, da Cunha et al., 2015). Highland areas outside the floodplain lack pronounced seasonal floods and differ enormously in terms of edaphic characteristics. Therefore, vegetation, habitat and landscape or biodiversity signature comparisons between the UPRB highlands and the Pantanal floodplain will require clearly defined ecological criteria to determine equivalence. Some recent studies have shed light on how to consider habitat equivalence in situations where ecological data is lacking (Doncaster, 2009; Joubert & Samways, 2014; Quétier & Lavorel, 2011). These studies suggest a simple currency trading equivalence system for the UPRB and the Pantanal wetland. According to Lourival, Drechsler, et al. (2011), landowners clearly understand value-based equivalence methods for compensation between highland and floodplain properties, and it is a practical method that can help halt habitat conversion.

Appropriate equivalence ratios can balance the impact of land use changes on land value, avoiding inter-regional compensation leakage and proving their value for "off-site" offsetting. In addition, the land value differences between the highlands and the floodplain may create offsetting scenarios where the value of standing vegetation is increased, or larger plots are guaranteed for protection in the floodplain. Since highland and floodplain phyto-phisiognomies are not directly comparable for the purposes of determining ecological equivalence at the scale of the UPRB, therefore land value can be used as trade currency (see Felfili et al., 1992; Ratter et al., 2003; Tomas et al., 2018).

A potential avenue worth exploring in an "offsetting calculator" that measures the functional equivalence of UPRB habitats, since areas of aquifer discharge and recharge, springs, riparian vegetation, wetlands, meanders, and oxbow lakes are all key components of the hydrologic system and contribute to UPRB ecosystem functionality. We see an evaluation of ecosystem functions, processes and services in the UPRB as an important area of study for the future of offsetting, clarifying fungibility issues across highland-floodplain gradients and allowing in-kind offsetting with tradable currencies (Figure 4c–e).

10 | HOW CAN DIFFERENT TYPES OF ENVIRONMENTS IN THE UPRB BE RESTORED, AND WHAT IS THEIR VALUE IN PANTANAL OFFSETTING?

Recent studies have explored ways to include restoration, uncertainty, and time lags in offset calculators (Burgin, 2008; Maron et al., 2012). Offsetting typically involves trading relatively certain and immediate losses (*e.g.*, due to natural habitat conversion) for less certain and potentially delayed gains (*e.g.*, from constructed wetlands or vegetation restoration projects). However, these calculations rely on regional knowledge of restoration processes. Caution is needed when defining what restoration is able to achieve, particularly in biodiverse wealthy regions, where ecosystem services and/or biodiversity are not fully understood.

Most restoration studies in the Neotropics focus on forested ecosystems. Meanwhile, native grasslands and wetlands are increasingly at risk due to conversion to cultivated grass species for cattle grazing and crops (Veldman et al., 2015; Zaloumis & Bond, 2011). Only recently, restoration methods were developed for savanna ecosystems (Guglieri-Caporal et al., 2011; Vieira et al., 2006) and there is a lack of information for Pantanal (Garcia et al., 2022; Guerra, de Oliveira, et al., 2020; Guerra, Reis, et al., 2020; Guerra, Roque, et al., 2020). Moreover, recently the discussion on the use of fire management as a restoration tool has been supported by the latest results for the Pantanal (Martins et al., 2022; Ribeiro & Pereira, 2023; Martins et al., 2024).

Most of the current native Pantanal vegetation has been managed/disturbed by humans due to two centuries of cattle ranching and the use of fire for pasture clearing and renewal (Prance & Schaller, 1982). Therefore, the Pantanal has been described as a cultural landscape (Schmitz, 2002). Although a significant proportion of the Pantanal is dominated by natural savanna grasslands (*i.e.*, rangelands), 18% has been converted to cultivated pastureland (Souza et al., 2020). In the floodplain, the aggressively invasive *Urochloa* species has historically been used to substitute natural vegetation with the aim of providing more productive pasture for cattle (Harris et al., 2005; Tomas et al., 2009; Alho, 2011). Evidence shows that fencing and floods are highly effective tools for passive restoration in the Pantanal, particularly for keystone plant species, and threatened fauna (Johnson et al., 1997). Isolation from cattle prevents indiscriminate grazing on native seedlings (Eaton et al., 2011; Johnson et al., 1997; Junk & Nunes da Cunha, 2012; Santos Jr et al., 2013). While saplings viability and recruitment, can be facilitated by the native assemblage of seed-dispersers and predators (Eaton et al., 2017). Conversely, the unsustainable management of local timber for fencing, may result in increasing degradation of woodland habitats, as highlighted by Prance and Schaller (1982). Hence, to avoid this impact during restoration, an alternative cost-effective method to protect seedlings (particularly transplanted seedlings) against herbivory that works quite well with in Pantanal is the individual fencing (protective wire mesh seedling cages with 1 m high) to protect against the most common mammals (*e.g.*, capybara and tapir that are shorter than 1 m) (Reis et al., 2021).

The highlands of the UPRB have lost more than 60% of its natural vegetation cover, despite regulatory protections provided in the NVPL, key landscapes such as: gallery forests, springs, *veredas*, steep slopes (*i.e.*, >45°), and mountaintops (*i.e.*, considered Permanent Preservation Areas—APPs), had these ecosystem components converted by noncompliant landowners. On-site APP restoration is non-negotiable for off-site offsetting and critical for maintaining ecosystem integrity, resilience, and functionality, both in the UPRB highlands and on the floodplain according to the NVPL. Although landowner's compliance with APP regulations remains highly variable among properties. These systems are siltation control agents that consequently protect aquatic habitats biodiversity (Guerra, de Oliveira, et al., 2020; Guerra, Reis, et al., 2020; Guerra, Roque, et al., 2020). Applying restoration strategies during offsetting is one of the alternatives provided by the NVPL framework. Increasing compliance with the NVPL could be accomplished through substantial intensification of enforcement by environmental agencies that are responsible for monitoring creating market opportunity for non-compliant landowners. In addition to ensuring mandatory protection and restoration of APPs, the agencies should also be involved in finding best-case alternative solutions for dealing with LR and APP deficits on rural properties.

Unfortunately, the dismantling of federal, state, and municipal enforcement agencies and regulations in Brazil are a deliberate delay on the implementation of the NVPL (da Silva et al., 2015; Kehoe et al., 2019; Resende et al., 2019; Walker et al., 2009). Despite since 2017 Brazil has law for implement the National Plan for Native Vegetation Recovery (PLANAVEG) by the Ministry of the Environment for the recovery of 12 million hectares of native vegetation until 2030 (PROVEG; Brasil, 2017), after 2016, political scenario that increased agribusiness influence and the rise of a more conservative agenda, enhanced deforestation, particularly in Cerrado (Luiz & Steinke, 2022). The current government policy aims for zero deforestation and return of PLANAVEG actions, and has been implementing The Action Plans for Prevention and Control of Deforestation and Wildfire in several biomes, including Pantanal.

11 | SHOULD NATIVE GRASSLANDS BE A TARGET FOR BIODIVERSITY OFFSETTING WHEN MANAGED FOR SUSTAINABLE CATTLE PRODUCTION IN THE PANTANAL?

In contrast, intensification and substitution of native grass species by introduced and invasive grasses are causing major transformations on the floodplain. Many studies document the impact of intensive grazing on forest understory plants, forest structure, and species occupancy (*e.g.*, da Cunha et al., 2015; Johnson et al., 1997; Schmitz, 2002; Tomas et al., 2009). Even in less intense cattle grazing scenarios, where forested areas were exposed to high cattle use, losses of fruiting tree and wildlife species were documented (Eaton et al., 2017).

The development of cattle certification schemes that are based on sustainable ranching, nature-based tourism and other market-based conservation incentives can enhance the national and global economic competitiveness of the Pantanal without increasing the current human footprint. Such initiatives contribute to the value of floodplain properties and the viability of offsetting programs aimed at conserving the Pantanal wetlands. One good example of such "toolkit" is the Sustainable Pantanal Ranch (SPR) program developed by EMBRAPA Pantanal, which determines property values based on a set of environmental, social, and economic indicators (Santos et al., 2017).

The Pantanal ranching tradition that protects and spares 2 ha of rangeland wetlands while using 1 ha of grasslands makes the biome a natural case of "triple bottom line" sustainability in offsetting (*i.e.*, when the economy, environment, and culture of the region are protected). Facilitating the sustainable coexistence of cattle ranching with healthy populations of several endangered species (Cavalcanti et al., 2012; Desbiez et al., 2010; Harris et al., 2005; Tomas et al., 2010, 2015, 2019). Therefore, it requires special treatment during efforts to develop offsetting policies. Unfairness in the pejorative treatment of the effective role of traditional farmers as less productive farms, riverine, and indigenous communities as invisible to public policies, gives them a sense of inequality that does not reflect their role as protectors of this national treasure.

12 | IS OFF-SITE OFFSETTING A STRATEGIC ALTERNATIVE TO ACHIEVING CONSERVATION IN PANTANAL?

This question is a follow up on arguments posed in question 3 and aims to discuss the use of additionality in compensation mechanisms. Additionality refers to the conservation benefit produced by the delivery of an offset that does not exist in the absence of the compensation action (Bull et al., 2017). The measure of additional conservation benefit generated by an offset is the difference between the outcome of a biodiversity-offset action relative to the outcome when the offset has not been implemented. Although the most common form of guaranteeing "additionality" is through habitat creation and restoration, additionality can also be achieved by allowing protection of areas under imminent or projected threat of biodiversity loss, for example, protecting native forest in an area where a landowner has the "legal right" (through the NVPL) to convert it to pasture or crops. According to the NVPL, a variable percentage (from 20 to 80% depending on the biome) of legal deforestation/conversion is acceptable on rural properties in Brazil except in the Atlantic Forest where there is a specific regulatory framework—Law No. 11,428 of 2006 (Brasil, 2006).

The cost of a "forgone deforestation opportunity" is considered as a "landowner's right" and is embedded in the NVPL as well as in the 1965's Forest Code. This "right" is exercised by some landowners to convert all of their legally convertible land to agriculture. This clause of the NVPL legislation carries a potential threat to native vegetation through time, particularly for on-site offsetting. However, some landowners decide not to exercise these rights, and protect their land beyond NVPL compliance requirements, for example, by creating private reserves (RPPNs). These landowners should qualify to be compensated, for example, for maintaining ecosystem services and biodiversity, because this type of protection can be considered an "additionality" under the offsetting policies.

The literature on systematic conservation planning suggests that, in certain circumstances, greater environmental benefits result when offsets can be aligned with landscape or regional conservation goals, which may involve "out-of-kind" and "off-site" offsetting examples (McKenney & Kiesecker, 2010). The benefits of off-site offsets could also extend to securing protection of non-statutory sites due to their local biodiversity importance, relevance to population dynamics or threatened species. However, it will be important to separate protected-area outcomes achieved through offsets from those achieved through other means (Chauvenet et al., 2017).

Over the last three decades, the Pantanal has been the focus of several priority setting initiatives (Brasil., 2007; Lourival et al., 2009). Only recently, however, spatial biodiversity prioritization using systematic conservation planning was applied to tackle the challenge of providing more robust conservation outcomes in the Pantanal. Examples of such an approach are the 2016 prioritization led by the Brazilian Ministry for the Environment (MMA, 2018) and Ecological-Economic Zoning conducted by the state of Mato Grosso do Sul (ZEE-MS, 2015). Although these initiatives lacked comprehensive socioeconomic spatially explicit data (Lourival, Watts, et al., 2011), we believe that they are fundamental for achieving the objectives of biodiversity conservation, collaborating with regional and national planning processes. More importantly, they provide the cornerstones for establishing no-go zones, or places where risk levels associated with native habitat conversion are unacceptable, regardless of their potential to be offset (*e.g.*, we cannot afford to lose area in the Atlantic Forest where less than 17% of its original range survives). In the Pantanal, biodiversity conservation strategies should include increasing formal protected areas in priority regions, since only 5% of the floodplain is protected in no-take reserves (Tomas et al., 2019). Currently, protected areas in the Pantanal are insufficiently representative of the full range of landscape configurations, flood regimes, endangered species distributions, and unique and fragile ecosystems, such as the brackish-water lagoons of the Nhecolândia region (*i.e.*, *Salinas*) (Tomas et al., 2019). It is important to stress that the prioritization of no-take reserves should incorporate the CARE concept, that is, comprehensiveness, adequacy, representation, and efficiency (Lourival, Drechsler, et al., 2011; Possingham et al., 2001). Such principles and knowledge improve the quality of protected area networks, connectivity, and enhance ecosystem stability and help meet the Aichi target of 17% representation of continental ecosystems (11 goal; CBD, 2020) (Lourival et al., 2009; Tomas et al., 2019).

As discussed earlier, around 18% of the Pantanal has been converted to cultivated non-native grasslands, so the number of non-compliant properties is relatively small (Figure 4b), while most of the threats to floodplain integrity and functionality originate in the UPRB highlands. For instance, most of river springs of the Pantanal's main rivers are located on the highlands and many are degradeted and in need of restoration. Therefore, under the current NVPL framework that does not recognize the importance of highland-floodplain interdependency while it restricts offsetting sites within the same biome, therefore it becomes impossible to address the needs for watershed protection across the UPRB using only on-site and in-kind offsetting. In this context, only a concerted state-level, rather than federal-level legislation can solve these issues by designating the UPRB as an "offsetting unit" that encompassing highland-floodplain off site offsetting at state level (MS-MT).

13 | HOW CAN THE EFFECTIVENESS OF WETLAND GOVERNANCE BE IMPROVED FOR BIODIVERSITY OFFSETTING?

Currently, there are several levels of disarticulated and competing governance agendas relevant to sustainable development of the Pantanal and the UPRB. The complexity of operating in three countries, two Brazilian states, and over 90 municipalities that share the region's environmental challenges, requires broad approaches. On top of ineffective official coordination, the private sector, ranchers, anglers, agribusiness corporations, road administration agencies, river transportation enterprises, mining companies, the hydroelectric power sector, and tourism operators, are all seeking to gain economically from the Pantanal's ecosystem services, biodiversity, and natural resources. Additionally, Indigenous Lands, public protected areas, urban areas, rural, and riverine community-use territories are all competing for space without any integrative/effective forum that aims to promote dialog, coexistence, knowledge sharing, and collaborative initiatives for integrated planning. Although the unpredictable dynamics of the Pantanal determine a limited exploitation of resources, as is the case of fishermen, due to the temporal and spatial unpredictability of the distribution of fish (Chiaravalloti et al., 2021), it is important to create rules that limit the extraction of resources for ecological sustainability. Despite the urgent need for such a dialog being unquestionable, collaborative opportunities have been rare and restricted to Academia, NGOs, and the National Water Agency-ANA.

Adequate governance is a key to effectiveness of legal frameworks. If public policies and institutions are aligned, their concerted efforts can guide the implementation of robust offsetting strategies. In our view, there are two forums qualified for such discussions, the Watershed Committees (WSC) and the Pantanal Biosphere Reserve (PBR), both of which are more active in the Brazilian portion of the UPRB. The WSCs are representative, consultative committees formally established to advocate for major watersheds in Brazil through discussions, planning and watershed management. Although the WSC are organized by state via the National Water Agency (ANA) and are composed of stakeholders from a variety of organizations in the watersheds, they are funded by a water-use-based fee (user paying fee) charged to the economic sectors involved. The Biosphere Reserve, on the other hand, in spite lacking resources has a much more democratic governance model with international recognition by the United Nations Education Scientific and Cultural Organization (UNESCO) and the Brazilian government also aggregates RAMSAR and World Heritage sites. The supra-national recognition presents advantages when dealing with trilateral interests and may help to articulate Brazil, Bolivia and Paraguay actions on broader issues concerning conservation and sustainability goals for the UPRB. Perhaps, a hybrid model that combines governance aspects of the WSCs and the Biosphere Reserve could help resolve watershed-scale issues and develop effective offsetting strategies for both Mato Grosso and Mato Grosso do Sul.

The example of People's Biodiversity Register (PBR) committees as instance that encourage greater power sharing, including all sectors of society with a commitment to biodiversity conservation and the provision of ecosystem services (Hooper et al., 2005). For offsetting purposes, the main responsibilities of such governance boards would be to: (1) approve general goals and offsetting plans for biodiversity conservation, (2) establish economic mechanisms for biodiversity offsetting, with prioritization of offset strategies, species, and ecosystem services, (3) arbitrate conflicts concerning different offsetting scenarios, (4) establish a common regulatory framework for states and countries regarding enforcement and offsetting rules that ensure the desired scenario outcomes for a given set of objectives and finally (5) promote coordination among entities and strategies within the PBR framework.

14 | HOW CAN THESE TECHNICAL QUESTIONS BE PRESENTED, SO THAT THEY CAPTURE THE INTEREST OF THE GENERAL PUBLIC?

Offsetting is a subject that is generally not recognized or discussed by the general public. This is true not only for the Pantanal and the UPRB. Traditionally in Brazil, these processes are tackled as part of compensation mechanisms resulting from Environmental Impact Assessments (EIA) without considering quantitative biodiversity approaches and “no-net-loss” outcomes. Only a limited number of environmentalists, members of the licensing sector and developers work with the challenges and opportunities involved in offsetting. Achieving a better understanding of the potential interactions between the existing compensation programs and offsetting associated with a CRA market is necessary (da Cruz et al., 2020).

There is increasing awareness about the value of biodiversity, however, we believe that public understanding of offsetting should be improved, so that proper solutions to Maron et al. (2016) challenges are approached and solved. Offsetting provides an opportunity to develop solutions that include a combination of technical, social, economic, and ethical elements characteristic of complex conservation-related problems, and strategic steps should be taken to conserve and use biodiversity sustainably.

We believe that developing strategic communication programs that engage governments, academic institutions, non-governmental organizations, private organizations, political parties, as well as the broader public, is key to implementation of successful offsetting strategies. However, the outreach materials explaining offsetting mechanisms need to be easily understood and easy to apply in on-the-ground real-life situations.

For the UPRB and the Pantanal, the Taquari river siltation case caused by highland native habitat conversion (see Galdino, 2006; Lourival et al., 2008; Louzada et al., 2021) is a classic example of that complexity, is still unresolved. Developing a more effective communication program that promotes integrated watershed management from the highlands to the floodplain seems to be the most suitable solution in the case of the Taquari River, with spillover effects to several other UPRB watersheds, where habitat conversion is altering sediment dynamics and river flows on the floodplain.

To illustrate offsetting to rural communities, a currency-based hectare multiplier could be derived from economic land value, and used to develop a spatially explicit offsetting calculator that illustrates spatial solutions for recovery from erosion and siltation impacts to downstream floodplain landowners and communities (Assine, 2005; Galdino, 2006; Godoy et al., 2002; Lourival et al., 2008). Developing offsetting procedures for the Taquari River basin would provide a relevant experimental case study that shows the applicability of offsetting compensation for impacts on biodiversity, ecosystem services, and fisheries, and is replicable in other watersheds of the UPRB.

15 | CONCLUSION

From a watershed management perspective, using the UPRB in Brazil as the offsetting unit for the Brazilian Pantanal would achieve better conservation and management outcomes than restricting offsetting to areas within the floodplain. We recommend adopting a scientifically sound classification system similar to Assine et al. (2015) that encompasses the entire UPRB, to frame offsetting solutions. Such system could be used to determine biodiversity equivalence and then couple the biodiversity equivalence measures with economic parameters, such as land value, to enhance fairness (Figure 4d). Aligning biodiversity and land values (Lourival et al., 2008) to calculate equivalence could bring greater clarity and efficiency (Figure 4e) to offsetting in the Pantanal.

A "compensation calculator", which combines biodiversity and land value measures, would be required to achieve effective and efficient social–ecological equivalence (Bull et al., 2013, 2017) between the floodplain and the bordering highlands in the UPRB. The best offsetting results occur when equivalence consists of "in-kind" habitat quality and the offsetting location is "on-site." However, off-site and in-kind, or surrogate-based offsets as illustrated in Figure 4 could be used if the process was transparent, scientifically robust and explicitly built into relevant offsetting policy. These methods of delivering offsets would provide additional options for achieving no-net-loss outcomes.

Simultaneously resolving the issues of asymmetric land prices, common in "distance-from-source" (offsite) offsetting, and "source-sink" biodiversity differences often inherent in watersheds (i.e., highland to floodplain), contexts is a challenge that encompasses all 10 of the proposed questions for Pantanal and UPRB offsetting.

In addition, a structured and well-designed communication and public awareness campaign is needed in order to educate the public about the limitations of offsetting within the NVPL framework and present more effective offsetting options. Other communication activities should include the production and distribution of educational materials, such as reference manuals, teaching aids, and public notices. Workshops, presentations, lectures, symposia, conferences, and exhibits are needed to share research findings and disseminate conservation messages are essential to enable stakeholders, so that they make better and more informed decisions regarding the sustainable use of natural resources.

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CONFLICT OF INTEREST STATEMENT

The authors would like to declare that this chapter was produced as an outcome of a Workshop held in Bonito—Mato Grosso do Sul, Brazil, and it is a result of collective work. The workshop was attended by 30 Pantanal conservation experts from four countries (Brazil, Australia, USA, and Italy). All the ideas expressed in the text are original, but based on the array of literature consulted and reviewed. Therefore, we would like to state that no conflict of interest exists that would prevent this article from being published.

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