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Policy Forums

Legally protected, practically overlooked: The neglect of diffuse seeps in the conservation of Cerrado non-floodplain wetlands

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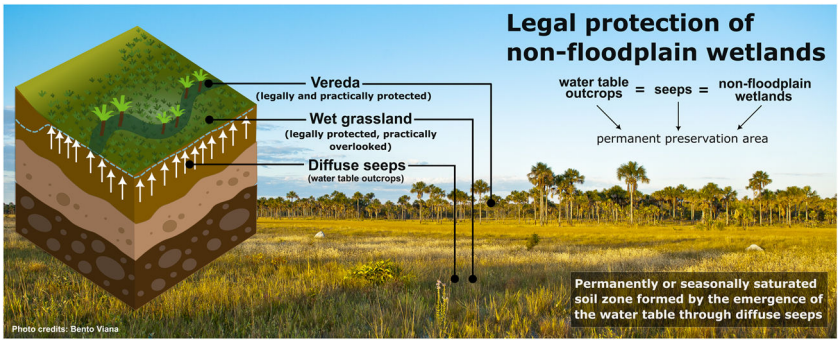
HIGHLIGHTS

- Non-floodplain wetlands form where groundwater emerges to the surface, forming seeps.
- Cerrado's non-floodplain wetlands are key for regional and continental water security.
- Brazil faces challenges to identify and protect diffuse seeps in wetlands.
- Despite existing legal protection, Cerrado diffuse seep wetlands face severe threats.
- Science-policy alignment is key to protecting non-floodplain wetlands effectively.

GRAPHICAL ABSTRACT



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ABSTRACT

Brazil stands out globally for legally protecting seeps (olhos d'água, in Portuguese) — defined as natural outcrops of the water table, even if intermittent — as Permanent Preservation Areas. However, this protection does not extend to non-floodplain wetlands, such as campos úmidos and campos de murundus, which are formed by diffuse seeps and play critical roles in regulating the hydrological cycle and storing carbon. These ecosystems are frequently excluded from conservation efforts due to the lack of clear terminology connecting scientific understanding with legal definitions. In the Cerrado, where diffuse seeps are essential for water security, this disconnect hinders effective protection. Drawing on Brazil's existing legal framework, we argue that recognizing non-floodplain wetlands as seep-formed ecosystems would strengthen conservation and enforcement. We urge scientists, landowners, environmental consultants and government agencies to adopt the term "seeps" when describing these wetlands, ensuring they are recognized as Permanent Preservation Areas under current legislation.

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The role of non-floodplain wetlands in watershed resilience

Wetlands regulate the hydrological cycle, support biodiversity and store substantial amounts of carbon, making their protection essential for climate mitigation and water security (Bridgham et al., 2006; Ghermandi et al., 2010; Palmer, 2024). Despite their significance, wetlands face numerous threats, including artificial drainage, land conversion, invasive species, climate change, and unsustainable water extraction (Calhoun et al., 2017). While floodplain wetlands are relatively well-studied and often integrated into watershed-scale management, non-floodplain wetlands (NFWs) remain largely overlooked (Lane et al., 2023b). NFWs are inland ecosystems situated away from riparian areas, often characterized by their shallow nature and hydrological formation predominantly driven by the emergence of groundwater through seeps (Leibowitz et al., 2023). Despite often lacking surface connectivity with water bodies, NFWs are essential to maintaining the hydrological functioning of watersheds by storing precipitation, recharging groundwater, and gradually releasing it to rivers, sustaining baseflow and enhancing water resilience to climate extremes (McLaughlin et al., 2014; Cohen et al., 2016; Lane et al., 2018; Ameli and Creed, 2019; Lee et al., 2023). Unlike their floodplain counterparts, NFWs are rarely monitored or mapped at local or global scales. This is partly because many NFWs lack a visible surface water layer, which limits both scientific understanding and policy attention (Creed et al., 2017; Lane et al., 2023a). This invisibility contributes to their vulnerability, despite their ecological importance (Chen et al., 2022).

Globally, conservation efforts for these ecosystems have faced significant challenges. In the case of Sackett v. US Environmental Protection Agency, the US Supreme Court removed federal protections for most NFWs, compromising an estimated US$673 billion annually in ecosystem services, including flood mitigation (Sulliván and Gardner, 2023). The ruling relied solely on surface connectivity, ignoring the eco-hydrological functions of NFWs (Gold, 2024). Similarly, in Canada, despite robust legal frameworks, studies reveal widespread wetland degradation due to weak enforcement mechanisms (Poulin et al., 2016). These examples underscore a critical need for aligning scientific understanding with legal mechanisms to safeguard NFWs.

Amidst these global challenges, Brazil stands out with its Law No. 12,651/2012 (Native Vegetation Protection Law - NVPL), which explicitly protects seeps and diffuse seeps (olhos d'água and olhos d'água difusos, in Portuguese), defined as natural outcrops of the water table, as Permanent Preservation Areas. While this eco-hydrological approach provides a promising legal framework for NFWs conservation, its implementation has been undermined by the failure of scientists, policymakers, government agencies and environmental consultants to explicitly link NFWs with seeps, particularly diffuse seeps. This disconnect — across scientific literature, policy frameworks, governance and public awareness — prevents the law from being effectively applied to safeguard these critical ecosystems. By focusing on the Cerrado biome — where NFWs play a critical role in water security for Brazil and South America — we underscore the urgency of recognizing NFWs as seep-formed ecosystems already protected by law. Doing so would support the legal protection of ecosystems currently neglected in practice and offer a clearer basis for actors such as scientists, environmental authorities, landowners, licensing professionals, and enforcement agents to consistently identify and classify NFWs as Permanent Preservation Areas, advancing national conservation strategies for water security and contributing to global best practices for NFW conservation.

Legal provisions for seeps and their application for Cerrado non-floodplain wetlands

The Brazilian Native Vegetation Protection Law (NVPL) defines zones critical for water resources, such as riparian zones, lakeshores, springs and seeps as Permanent Preservation Areas (PPAs). The NVPL mandates that PPAs protect "areas surrounding perennial springs and seeps", where springs are defined as "natural outcrops of the water table that give rise to a watercourse", and seeps as "natural outcrops of the water table". Although initially limited to perennial springs and seeps only, the Brazilian Supreme Court (in the case ADI 4903/2019) extended protection to areas around intermittent springs and seeps. While challenges such as low compliance hinder the effectiveness of protected areas in general (Brancalion et al., 2016; Soares-Filho et al., 2014; Soterroni et al., 2018), a key issue for seeps is the failure to apply this nomenclature due to lack of association with NFWs. Often treated as synonymous with springs and rarely addressed in wetland scientific literature in Brazil (Junk et al., 2015; Queiroz, 2015), seep areas are often overlooked in Brazil, limiting their full legal protection. For instance, the Rural Environmental Registry (Cadastro Ambiental Rural - CAR) — a government software for land-use monitoring — combines springs and seeps into a single category (SICAR, 2024). As the platform does not distinguish between these hydrologically distinct features, landowners tend to recognize only springs, while seeps (particularly diffuse seeps) are frequently disregarded altogether. This design reinforces the mistaken perception that seeps and springs are equivalent, contributing to the institutional invisibility of NFWs and undermining the implementation of existing legal protections for these ecosystems.

While definitions of springs and seeps vary widely, often leading to imprecise terminology (Williams, 2016), the most widely accepted perspective is that both are areas where the water table naturally reaches the surface (Springer and Stevens, 2009). The water table is the limit between the water-saturated soil below (groundwater) and unsaturated soil above (vadose zone), often following topographic gradients (Fan, 2015; Baird and Low, 2022). The key difference is that springs are point-source discharges that may give rise to streams (Fig. 1A) (Everdingen, 1991), while seeps are areas of slower groundwater discharge, either as a point-source but often diffusively, that typically do not form watercourses (Fig. 1B and C) (Ollis et al., 2013; O'Driscoll et al., 2019). Diffuse seeps, in particular, are often invisible without saturated surface water and thus remain undetected by a quick visual identification alone.

Groundwater emergence occurs due to the rise of the regional or perched water table (Ashley et al., 2013), both vital to the hydrological cycle (Baird and Low, 2022). A regional water table is generally associated with a larger geographical area and can be influenced by various sources of recharge, such as precipitation (Winter et al., 1998). A perched water table has a smaller spatial scale, forming where infiltrating water encounters an impeding layer (i.e., a layer of lower permeability), resulting in a localized lens of saturated soil above the regional water table (Júnior et al., 2004; Augustin et al., 2009; Woessner and Poeter, 2020). Additionally, springs and seeps can be either perennial or intermittent, depending on the seasonal fluctuations of the water table and local climatic conditions (Ketchum et al., 2000; Snyder, 2008).

The legal definition in the current legislation in Brazil ensure that any natural outcrop of the water table (i.e., diffuse seeps) qualifies as PPAs, with implications for NFWs across all biomes. We underscore the particular importance of enforcing seep protection in the Cerrado, the most strategic biome for water security in Brazil. As the largest Neotropical savanna, covering approximately 22% of Brazilian territory, Cerrado serves as the headwaters for most of the country's river basins (Lima and Silva, 2007). Known as the "Brazilian water tank" (Lima, 2011), the Cerrado plays a crucial role in hydrological dynamics, feeding the Amazon and other major river systems in Brazil and South America (Oliveira et al., 2014; Rodrigues et al., 2021). It also hosts the headwaters that form the Pantanal, the world's largest tropical wetland (Ivory et al., 2019; Santos et al., 2024). Located in central Brazil, the Cerrado is rich in both water recharge and discharge zones (Oliveira et al., 2017). The hydrological role of seeps in sustaining these dynamics is central to regional water security, yet they are increasingly degraded through drainage and groundwater extraction for irrigation (Salmona

et al., 2023).

Most Cerrado NFWs are formed by seeps, originating from shallow water tables that outcrop at the surface. This contrasts with Pantanal or Amazon floodplain wetlands, which are mainly flood-driven (Silva et al., 2000; Pott and Pott, 2004; Junk et al., 2015, 2018; Durigan et al., 2022). In the Cerrado, groundwater emerges both at specific points (Fig. 1B) and diffusely, with the diffuse mode being more prevalent (Fig. 1C). Seep discharge varies seasonally: in the rainy season, rising water tables bring groundwater to the surface; in dry periods, seep saturation may recede to deeper soil layers or disappear entirely, as in hyperseasonal wetlands (Batalha et al., 2005; Cianciaruso et al., 2005; Souza et al., 2019). These seep-driven processes help maintain river base flows through extended droughts, highlighting the role of NFWs in hydrological resilience and regional water security (Leibowitz et al., 2023). Vegetation types associated with Cerrado NFWs are mostly wet grasslands and palm swamps. In Brazil, various terms are used to describe vegetation in these areas, such as campo limpo úmido, campo sujo úmido, campo de murundus and vereda (Ribeiro and Walter, 1998; Durigan et al., 2022). Despite variation in terminology, all of these areas share one common feature: they are formed by groundwater emergence

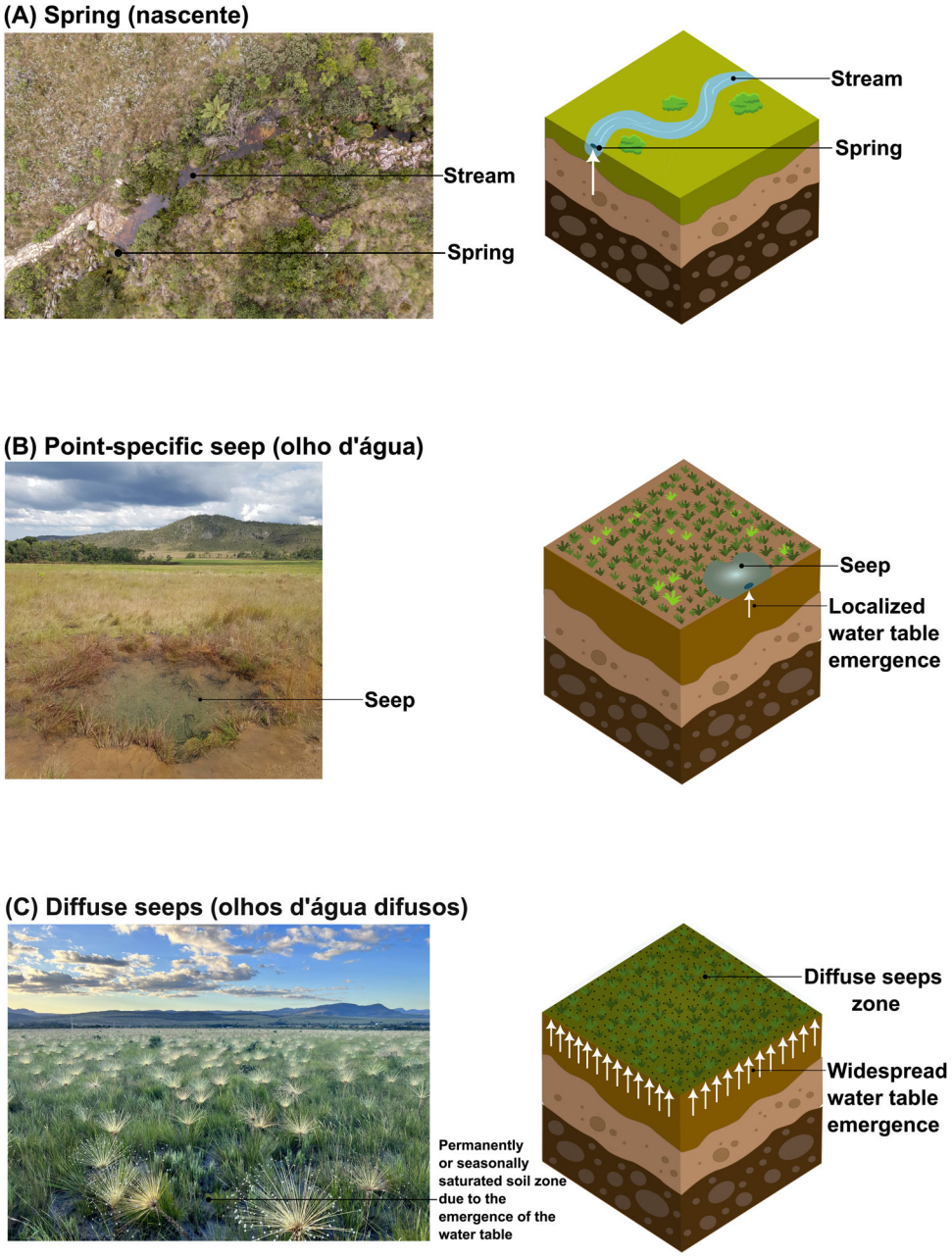

Fig. 1. Types of water table emergence in the Cerrado: (A) Spring (nascente) – concentrated groundwater discharge that may give rise to a watercourse; (B) Point-specific seep (olho d'água) – localized, seasonal or permanent outcrop of the water table, with flow insufficient to form a watercourse; (C) Diffuse seeps (olhos d'água difusos) – widespread water table outcrops forming seasonally or permanently saturated soils, without visible surface water or watercourse formation. Note also the presence of diffuse seep-fed wet grassland in the background of Fig. 1B. Although all three types of ecosystems, where water table emerges in the surface, are legally recognized as PPAs under Brazilian law, their practical protection is uneven: springs are widely acknowledged and enforced; point-specific seeps are more likely to be protected in practice due to the presence of visible surface water; and diffuse seeps — despite sustaining NFWs such as campos úmidos and campos de murundus, and functioning as critical ecosystems for river discharge regulation — are systematically excluded. This gap results from both the mistaken assumption that seeps (olhos d'água) are synonymous with springs (nascentes), and a prevailing bias toward protecting features with visible surface water, which hinders the recognition of seep-dependent saturated soil zones. Photo credits: (A) Adriano Kirihara; (B) Armando Moraes da Silva; (C) Rafael Oliveira. Illustrations: by the authors.

and qualify legally as seeps, and therefore must be protected as PPAs under existing law.

Present law, absent protection: the importance of scientific consensus on seeps for legal safeguarding of NFWs ecosystems

The scientific literature acknowledges that many types of NFWs occur where groundwater emerges, as noted in the Brazilian Wetland Inventory (Junk, 2024). However, the term 'seeps' is rarely used, revealing a persistent disconnect between eco-hydrological understanding and legal terminology. This is also true in the Cerrado: although many NFWs are described as groundwater-fed (Ribeiro and Walter, 1998), they are rarely labeled as seeps (olhos d'água), even when they meet that definition. As a result, ecosystems formed by diffuse seeps (like wet grasslands) are typically not recognized as legally protected areas. The only exception is the vereda, a type of palm swamp explicitly listed as a PPA under Brazilian law. This singular mention results in selective protection, while other seep-fed NFWs with similar hydrological characteristics remain overlooked in conservation policies (Fig. 2).

This invisibility stems from both scientific neglect in adopting the term "seeps" and its systematic misuse as a synonym for springs by governmental agencies, environmental consultants and landowners. It is further reinforced by a prevailing bias toward visible surface water: in the absence of an apparent surface water layer, seep-formed wetlands (primarily defined by saturated soils rather than visible water) are frequently neglected in conservation efforts. This contributes to weak enforcement and legally questionable authorizations, including native vegetation suppression, drainage, and the use of groundwater for agricultural irrigation in areas that should be protected under NVPL (Latrubesse et al., 2019; Silva et al., 2021; Maia, 2024). These authorizations, although formally issued, often violate existing legislation. Environmental licensing processes frequently rely on generalized vegetation maps and field assessments that overlook eco-hydrological

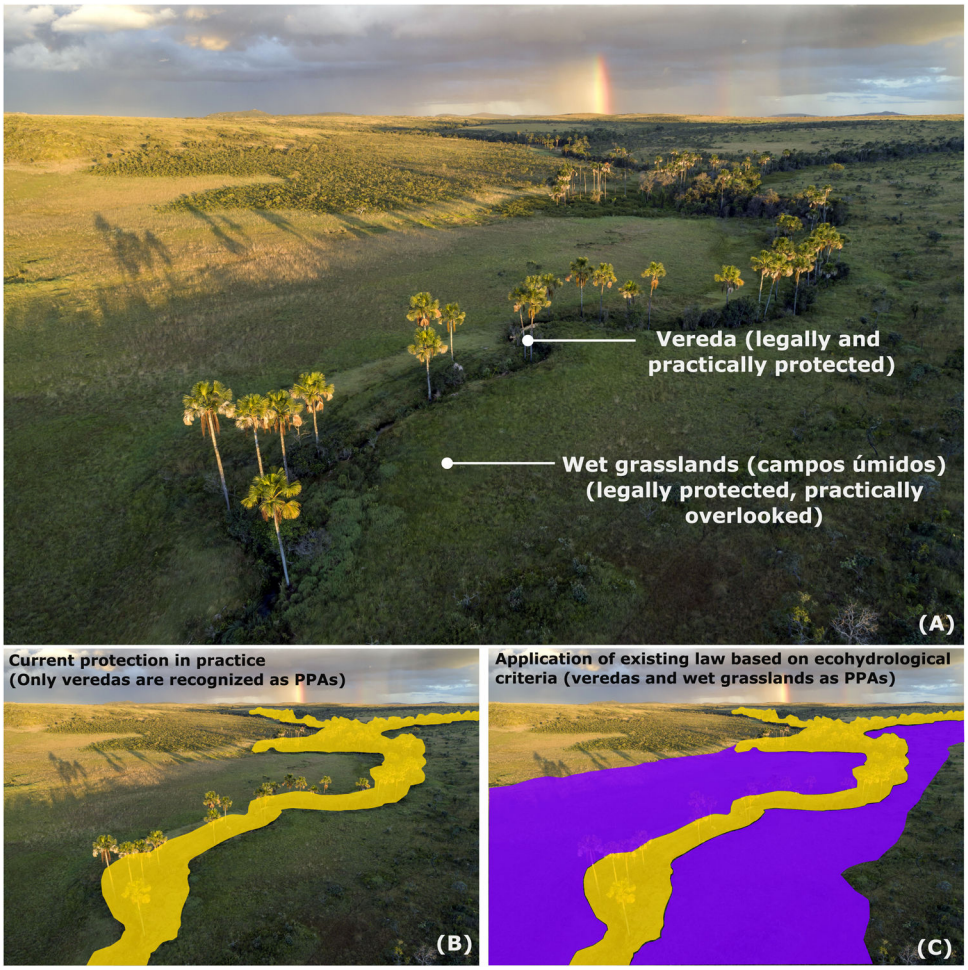

Fig. 2. Non-floodplain wetland (NFW) in the Cerrado. This example shows a case where a vereda occurs alongside adjacent wet grasslands (campos úmidos), although such co-occurrence is not always present. (A) Aerial image showing a vereda, characterized by scattered palm trees (*Mauritia flexuosa*) over a permanently or seasonally waterlogged area, and adjacent wet grasslands, which present a species-rich herbaceous cover without trees or shrubs, associated with permanently or seasonally saturated soils due to the water table rising close to the surface (diffuse seeps); (B) Current application of the law in practice, where only veredas (marked in yellow) are protected as Permanent Preservation Areas (PPAs), based on a specific provision in Brazilian law that explicitly lists veredas as PPAs; (C) Legally consistent — but not adopted — application of the law, recognizing all seep-fed NFWs as PPAs (marked in yellow and purple). According to Article 3, item XVIII of Law 12,651/2012, seeps (olhos d'água) are defined as permanent or seasonal outcrops of the water table. Article 4, item IV further establishes that seeps (olhos d'água), whether perennial or intermittent, are legally protected as PPAs. Therefore, NFWs with saturated soils from water table emergence (diffuse seeps) meet the legal criteria for protection. To identify the extent of wet grasslands (marked in purple) in the field, one must verify the presence of soils saturated by the water table and vegetation adapted to these conditions. A practical method to delineate the spatial extent of wet grasslands is to dig 30 cm into the soil at the peak of the rainy season; if water is present at that depth, it typically indicates a shallow water table and confirms that the area is fed by a seep, forming a wetland. Where water is absent at that depth, the area is likely outside the wetland boundary. Photo: André Dib. Illustration and visual overlay: by the authors (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

indicators of seep-fed wetlands. Mapping products used by government agencies and consultants tend to focus on visible features, such as surface water, riparian forests and palm swamps (veredas), failing to identify saturated soils formed by diffuse seeps. As a result, legally protected wetlands are routinely misclassified — often as degraded pastures — and cleared or drained with official approval. This systemic flaw in environmental assessments highlights the urgent need to improve scientific and technical tools to ensure legal compliance and effective conservation outcomes. Cerrado wetlands have already lost over 580,000 hectares of native vegetation between 1985 and 2020, with 61% of these wetland losses attributed to agricultural and livestock (MapBiomas Project, 2023). As a consequence, water shortages and streamflow reduction are already being observed, trends that are likely to worsen under continued water overuse and climate change (Silva et al., 2021). This situation is reducing both groundwater flow and aquifer recharge, compromising water supplies for urban use, local communities, and agriculture, and reducing availability across entire basins (Leite-Filho et al., 2024; Martins et al., 2024).

Science plays a key role in strengthening environmental governance and ensuring that existing laws are effectively implemented (Lopes et al., 2023). We propose two priority actions to advance protection of NFWs under the NVPL: first, it is essential that all actors — scientists, environmental consultants, landowners and public agencies — consistently adopt the terms "seeps" and "diffuse seeps" to describe ecosystems where the water table naturally outcrops. This eco-hydrological vocabulary must be embedded in research, technical reports, and environmental licensing procedures to ensure alignment with existing legal definitions. Equally important is the recognition that seeps occur in multiple forms, particularly diffuse seeps, which are often invisible due to the absence of surface water (see Fig. 1C). In the Cerrado, vegetation types such as campo úmido and campo de murundus can serve as key indicators of groundwater emergence. Using these ecological cues to identify and classify seep-formed landscapes is critical for applying legal protections under the NVPL and promoting the need of restoration where degradation has occurred. Second, we recommend the development of high-resolution maps that distinguish between riparian and non-riparian wetlands (NFWs) based on their hydrological formation mechanisms. Although the technical capacity for such mapping already exists — including remote sensing, hydromorphic soil identification, and seasonal monitoring with piezometers — no official initiative currently delineates wetlands using eco-hydrological criteria. We propose that scientists lead the creation of meter-scale, seasonally informed maps, supported by field validation of hydrological features. These maps should be institutionalized by government agencies to inform licensing decisions, environmental enforcement, and restoration planning.

In addition, we encourage the development and dissemination of simple, field-based indicators, such as testing for shallow water table presence by digging approximately 30 cm into the soil at the peak of the rainy season. Water accumulation at that depth typically indicates soil saturation due to groundwater emergence, helping to delineate the extent of seep-fed wetlands. In the Cerrado, certain plants are also reliable ecological indicators of diffuse seeps, including some species of *Bulbostylis*, *Cyperus*, *Rhynchospora* (Cyperaceae), *Paepalanthus*, *Syngonanthus* (Eriocaulaceae), the presence of any species of *Utricularia* (Lentibulariaceae) and *Drosera* (Droseraceae), *Andropogon virgatus*, *Trichanthecium parvifolium* (Poaceae), and species of *Xyris* (Xyridaceae) (Durigan et al., 2022). These species, genera and families are typically found in areas with seasonally saturated soils, particularly in landscapes where visual cues are subtle or absent.

Given the current political context in Brazil, where laws protecting native vegetation are under threat (Vale et al., 2021; Overbeck et al., 2024), fully enforcing existing legislation is an urgent step to safeguard the provision of water resources. Supported by robust science, this approach can secure the protection that NFWs are already entitled to under Brazilian law. The Cerrado exemplifies this urgency: its diffuse seep-fed wetlands are essential to water security and carbon storage (Souza et al., 2025), but remain largely neglected in practice. In a world increasingly threatened by water scarcity and climate change, Brazil's legal framework offers a rare opportunity to align science and policy, ensuring protection of these ecosystems and offering a model for global NFW conservation.

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Declaration of competing interest

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

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