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Review Article

The Cerrado crisis review: highlighting threats and providing future pathways to save Brazil's biodiversity hotspot

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Abstract

This review raises awareness of the Cerrado's value to society and serves as an informative guide for ecology professionals, policymakers, and anyone interested in biodiversity conservation. Herein, we comprehensively and critically address the ongoing degradation process of the Cerrado, highlighting its ecological complexity, biological diversity, and strategic importance for environmental sustainability and climate change mitigation in Brazil. We examine the diversity of ecosystems in the Cerrado, highlighting their specific vulnerabilities and the inadequacy of current legal instruments to guarantee their protection. Our analysis covers the main vectors of pressure on the territory, such as the advance of the agricultural frontier, the predatory use of fire, the silent water crisis, and threats to Indigenous peoples, highlighting how these factors operate in an interconnected manner to disrupt the region's ecosystem services. The limitations of current conservation policies and the invisibility of species and ecosystems in the face of the dominant legal and economic systems are also discussed. Our review proposes ways to mitigate or even reverse this scenario, including increasing the number of Conservation Units and Indigenous lands, valuing regenerative economies, expanding protected areas, and strengthening territorial and climate governance. The defense of the Cerrado is presented here not only as an ecological imperative but as an agenda for environmental justice, water security, and intergenerational responsibility. By integrating data, references, conceptual reflections, and action strategies, we hope to contribute to repositioning the Cerrado at the center of discussions on conservation, climate, and sustainable development.

Key words: Afforestation, conservation, ecological restoration, Forest Code, hydroelectric dams, Indigenous peoples, threatened species, wildfires

"Destroying the rainforest for economic gain is like burning a Renaissance painting to cook a meal."

—Edward O. Wilson, 1990

"*Além de conviver com alguns dos piores solos do Brasil intertropical, a vegetação dos cerrados conseguiu a façanha ecológica de resistir às queimadas, renascendo das próprias cinzas, como uma espécie de fênix dos ecossistemas brasileiros. Não resiste, porém, aos violentos artifícios tecnológicos inventados pelos homens ditos civilizados.*"
("In addition to surviving some of the poorest soils in intertropical Brazil, the vegetation of the Cerrado has achieved the ecological feat of withstanding wildfires, rising from its own ashes like a kind of phoenix among Brazil's ecosystems. It cannot, however, withstand the violent technological artifices invented by so-called civilized men.")

—Aziz Ab'Saber, 2003

This narrative review begins with an urgent premise: the continuous advance of the destruction of the Cerrado and the lack of response proportional to the gravity of what is happening. Some voices have announced, with disconcerting anticipation, the side effects of a logic that insists on exchanging biological diversity for economic convenience. The renowned American biologist Edward O. Wilson and the famous Brazilian geographer Aziz Ab'Sáber, albeit from different territories and perspectives, both pointed to the same structural error: disregarding the inestimable value of nature in the name of immediate gains. This review echoes their warnings, not as a tribute, but as a continuation. What unfolds in the following pages is the result of a concern that arises not only from the accelerated loss of native vegetation, from the invisibility of species, or from disrupted ecological functions, but also from the refusal to accept that this disappearance is natural or inevitable. Although Brasília, Brazil's political capital, is located in the Central Plateau region of the Cerrado in the Federal District, it remains outside the center of political and environmental decision-making, despite being a key element in sustaining the country's ecosystems. Here we examine the scale and effects of this process, articulating data, analyses, and references that reveal the threats on multiple fronts. The degradation of ecosystems, the loss of species, the weakening of protected areas, legal loopholes, territorial conflicts, the marginalization of traditional knowledge, the invasion of exotic species, and the fragmentation of habitats make up the portrait of an ongoing crisis. More than describing this scenario, the article presents possible ways to interrupt and reverse it, with a focus on conservation and restoration, institutional strengthening, and the construction of sustainable alternatives. For clarity, Boxes 1, 2 below provide definitions and context for key terms and concepts used throughout the text.

Box 1. Clarifying confusions about the term "biome".

The term "biome" has been widely adopted in Brazil since 2004 to refer to six large regions—Amazon, Atlantic Forest, Caatinga, Cerrado, Pampa, and Pantanal—delimited by the Brazilian Institute of Geography and Statistics (IBGE) based on their predominant original vegetation. These regions include both enclaves of other plant formations and large areas where native vegetation has been replaced by uses such as agriculture or urbanization. However, the use of this term in Brazil is of a geopolitical nature and, from an ecological point of view, inappropriate, as it encompasses several biomes and ecosystems and is not based on ecological criteria. In ecological science, the term biome refers to large ecological units characterized by predominant climatic patterns and potential vegetation types, regardless of specific species composition (see the 14 biomes proposed by Olson et al. 2001). For example, the savanna biome includes regions of South America, Africa, and Australia that share open vegetation adapted to seasonal rainfall regimes, even though their species composition differs significantly (Olson et al. 2001). We propose here the term "Ecodomain" (from the Greek *oikos* = house, and Latin *dominium* = domain, authority) to designate large ecological units characterized by a relative uniformity of climatic, geomorphological, and biological conditions, encompassing several ecoregions, biomes, and ecosystems. This concept refers to the entire original territorial extent of these large ecological units, irrespective of their current state of conservation. Our concept is similar to that of Morphoclimatic and Phytogeographic Domains proposed by Ab'Saber (1977), who defined these vegetation classes as areas of geographic space with subcontinental dimensions, in which certain similar morphoclimatic characteristics—relief and climate—predominate, in addition to a certain type of vegetation, based on the floristic composition of the plant species present in such an area. It also presents similarities with the concept of "ecoregions" by Dinerstein et al. (2017), although here we adopt a more comprehensive and integrative approach. In the context of the Cerrado, this new term better reflects its ecological complexity than those used in the literature to date, as the Cerrado is made up of different biomes, including grasslands, savannas, and tropical forests, as well as a diversity of related terrestrial ecosystems (Coutinho 2006; Batalha 2011).

Box 2. Definitions of ecological terms used in this review.

Afforestation: The process of planting trees in areas that historically had no forest cover. It differs from reforestation, which occurs in previously deforested areas.

Área de Proteção Ambiental (APA): Category of sustainable use conservation unit. These are large areas, with a certain degree of human occupation, where the aim is to make the use of natural resources compatible with the conservation of biodiversity. It allows productive activities and residence, as long as specific rules to protect environmental attributes are respected.

Área de Relevante Interesse Ecológico (ARIE): Conservation unit for sustainable use, generally of small extension, with little or no human occupation, which houses rare specimens of fauna or flora, or presents special natural characteristics.

Área de Preservação Permanente (APP): Portion of the territory, protected by law, that performs essential environmental functions, such as the protection of water resources, soil stability, maintenance of biodiversity and climate regulation.

Biome: Large, transcontinental ecological units are characterized primarily by dominant life forms and vegetation structure, rather than by species composition. Biomes group ecoregions sharing similar environmental conditions and major ecological communities, serving as a broad framework for comparing ecosystems worldwide. In Brazil, the term is commonly used officially, but it is a geopolitical simplification and, from an ecological point of view, misleading, since it encompasses several biomes and ecosystems and is not based on ecological criteria.

Campo Limpo: Grassland vegetation ecosystem with less than 5% tree cover, dominated by grasses and herbaceous plants, typically occurring on well-drained, shallow to moderately deep, acidic soils, though they may also develop on poorly drained or waterlogged areas.

Campo Rupestre: Grassland vegetation ecosystem with less than 5% tree cover, featuring plant communities adapted to shallow, acidic, stony soils, typically found on rocky outcrops above 900 meters in altitude.

Campo Sujo: Grassland vegetation ecosystem with less than 5% tree cover, similar to Campo Limpo, but with a sparse presence of shrubs and small trees. These areas typically occur on shallow to deep, acidic soils, which may be well-drained or poorly drained, depending on local conditions.

Carbon sink: Any natural or man-made system capable of absorbing more carbon dioxide (CO_2) from the atmosphere than it emits. Forests, oceans, and soils are examples of natural sinks, as they capture carbon through photosynthesis or by dissolving the gas in water. These sinks play a crucial role in regulating the global climate, helping to mitigate the effects of climate change by reducing the concentration of greenhouse gases (GHG) in the atmosphere.

Carbon source: Any natural or man-made system that releases more CO_2 into the atmosphere than it can absorb. Examples include the burning of fossil fuels, deforestation, wildfires, and soil disturbance, processes that release carbon stored in biomass or soil. These sources contribute to the increase in GHGs in the atmosphere, intensifying global warming and climate change.

Cerradão: Forest vegetation ecosystem with tree cover between 50% and 90%. It presents sclerophyllous and xeromorphic characteristics and is floristically closer to the savannah vegetation ecosystems that make up the Cerrado *sensu stricto*. It normally occurs in deep, well-drained and slightly acidic soils. It is divided into Dystrophic Cerradão in poorer soils, thinner vegetation, and less species diversity, and Mesotrophic Cerradão in soils with greater nutrient richness, presenting a denser canopy and greater species diversity.

Cerrado Denso: Savannah vegetation ecosystem with tree cover between 50% and 70%, formed by taller and irregularly spaced trees, with a smaller presence of grasses. These areas typically occur on deep, well-drained, acidic soils.

Cerrado Ralo: Savannah vegetation ecosystem with tree cover between 5% and 20%, characterized by low and spaced trees, a greater presence of grasses and shrubs, and a more open vegetation structure. These areas typically occur on acidic soils with variable texture, ranging from well-drained to poorly drained.

Cerrado Rupestre: Savannah vegetation ecosystem with tree cover between 5% and 20%, occurring on rocky outcrops, with short trees and a high presence of species adapted to shallow, acidic, stony soils.

Cerrado *sensu stricto*: Complex of savanna vegetation ecosystems of the Cerrado Ecodomain that includes Cerrado Ralo, Cerrado Rupestre, Cerrado Típico, and Cerrado Denso. These ecosystems represent about 70% of the Cerrado Ecodomain and are predominantly grasses and shrubs, with spaced trees adapted to poor soils and strong climatic seasonality.

Cerrado Típico: Savannah vegetation ecosystem with tree cover between 20% and 50%, formed by twisted trees, shrubs, grasses, and herbs, with high structural heterogeneity. These areas typically occur on deep, acidic soils with variable texture and drainage.

Clearing: Removal or suppression of vegetation from an area, regardless of type or successional stage, carried out to prepare the soil for various uses, such as agriculture, pasture, infrastructure or other projects. Clearing can range from the removal of forests to shrubs and grasses, affecting the structure of the habitat, local ecological cycles and the availability of resources for wildlife.

Conservation: Set of practices, policies and actions aimed at protecting ecosystems, species and biological diversity, ensuring the maintenance of ecological processes and natural functions, regardless of their value or usefulness to human beings.

Conservation Units (UCs): Protected area established by law, intended to ensure the preservation and sustainable use of natural resources. In Brazil, it is classified by the National System of Conservation Units (SNUC) into two major groups: Strict Protection Unit, which prioritizes the preservation of ecosystems without direct use of natural resources, and Sustainable Use Unit, which reconciles conservation with the rational use of these resources.

Degradation: Process of progressive deterioration of the structure and ecological functions of an ecosystem, without necessarily total removal of vegetation. It can be caused by selective logging, burning, habitat fragmentation or illegal activities, resulting in loss of biodiversity and ecosystem services.

Ecodomain: From the Greek *oikos* (“house”) and the Latin *dominium* (“domain, authority”). Term proposed in this article to designate large ecological units characterized by a relative uniformity of climatic, geomorphological, and biological conditions that encompass multiple ecoregions, biomes, and ecosystems. In this context, we refer to the entire original territorial extent of these large ecological units, irrespective of their current state of conservation.

Ecoregion: Large-scale ecological units defined as distinct biodiversity assemblages whose boundaries include the spatial extent necessary to sustain key ecological processes. These units draw on natural delineations, group biogeographically similar habitats within broader biomes, and serve as foundational basemaps for conservation planning due to their ecological coherence and biodiversity representativeness.

Ecosystem: A system composed of living organisms (biological community) and the physical environment (abiotic factors) in interaction, functioning as an ecological unit through energy flow and nutrient cycling.

Ecotone: A transition zone between ecosystems, characterized by the gradual or abrupt overlap of species and environmental conditions. This zone presents high ecological heterogeneity, may harbor unique species, and plays a fundamental role in landscape connectivity.

Estação Ecológica: Strictly protected conservation unit designed for the preservation of nature and the development of scientific research, with restricted public access to avoid environmental impacts.

***Ex situ* conservation:** Conservation of components of biodiversity outside their natural habitat, in controlled or semi-controlled environments. Its objective is to protect endangered species, conserve genetic material or support reintroduction programs.

Floresta Nacional (FLONA): Sustainable use conservation unit intended for the rational use of forest resources and scientific research, established at the federal level. Similar areas under state management are known as State Forests, which fulfill an equivalent function at the regional level.

Forest Code: Set of rules that regulate the use and protection of native vegetation in Brazilian territory. The current legislation is Law No. 12,651/2012, which establishes rules for Permanent Preservation Areas (APPs), Legal Reserves, land use and recovery of degraded areas. The code seeks to reconcile agricultural production with environmental conservation, and is one of the main legal instruments for territorial planning and biodiversity protection in Brazil.

***In situ* conservation:** This is the conservation of components of biodiversity in their natural environment, allowing ecological and evolutionary processes to continue to operate. It involves the protection of habitats, protected areas and natural landscapes where species occur naturally.

Invasive species: Organisms introduced outside their natural range that have the capacity to spread rapidly, compete with native species, disrupt ecosystem balance, and cause harm to biodiversity, the economy, and human health. In Brazil, the terms “exotic species” and “alien species” are often used for species originating from other countries, while “native species” refers to those that occur naturally within the country. However, some native species may become invasive when introduced to regions outside their original geographic range or ecosystem.

Mata Ciliar: Forest vegetation ecosystem along watercourses, with tree cover between 50% and 90%, formed by tall trees and dense, semi-deciduous vegetation. These areas typically occur on deep, acidic, and often waterlogged soils, depending on the topography and hydrological regime.

Mata de Galeria: Forest vegetation ecosystem that follows small rivers and streams, forming forest tunnels with treetops touching above the watercourse, with tree cover between 70% and 95%. This is an evergreen forest, with vegetation that remains green throughout the year. These areas typically occur on deep, acidic, and often waterlogged soils.

Mata Seca: Forest vegetation ecosystem adapted to long periods of drought. It is a deciduous dry forest, with tree cover ranging from 15% to 90%, composed of trees that lose their leaves during the dry season, which significantly reduces canopy density during this period. These areas generally occur on acidic soils, which may be shallow or deep, and are typically well-drained, experiencing seasonal water stress, especially when developed on limestone outcrops. Some authors consider variations of Mata Seca, including seasonal semideciduous forests and evergreen forests, but we consider these ecosystems as part of the Atlantic Forest Ecodomain.

Monumento Natural: Strictly protected conservation unit designed to protect rare, unique natural elements or those of scenic, geological, or cultural value, ensuring the conservation of these characteristics in generally small areas.

Morphoclimatic and Phytogeographic Domain: Concept created by Aziz Ab’Sáber to designate large geographic areas with a certain homogeneity of relief (morphology), climate and types of vegetation (phytogeography), encompassing different biomes and ecosystems.

Palmeiral: Savannah vegetation ecosystem dominated by palm trees, often associated with humid areas or paths, with tree cover between 30% and 80% (depending on the dominant palm species) and herbaceous and shrubby understory. These areas typically occur on acidic soils, which may be well-drained or waterlogged, depending on the palm species and local topography.

Parque: Strictly protected conservation unit designed to preserve natural ecosystems of great ecological relevance and scenic beauty, which may be established at the federal (National Park), state (State Park), or municipal (Municipal Natural Park) levels. It allows controlled public use for recreational, educational, and tourist purposes, ensuring environmental integrity.

Parque de Cerrado: Savannah vegetation ecosystem characterized by continuous grass cover and groups of trees forming small vegetation islands or isolated individuals, with tree cover between 5% and 20%. The soil is acidic and poorly drained, favoring vegetation growth only on murundus (elevated mounds), which have better drainage. This configuration creates a mosaic of microhabitats.

Phytophysiognomy: Refers to the appearance of vegetation. It is the set of structural and functional characteristics of vegetation in an area, such as shape, height and density of plants, regardless of the species present. The term is often used as a synonym for ecosystem, but this approach is mistaken because phytophysiognomy does not address abiotic factors or interactions between organisms and the environment, focusing exclusively on the physiognomic and structural aspects of vegetation cover.

Refúgio de Vida Silvestre: Strictly protected conservation unit aimed at protecting natural environments that ensure conditions for the survival or reproduction of species or communities of local fauna, with regulated public visitation.

Reserva Biológica (REBIO): Strictly protected conservation unit aimed at fully preserving the biota and other natural attributes within its boundaries, without direct human interference, except for management actions necessary to restore altered ecosystems and for authorized scientific research.

Reserva de Desenvolvimento Sustentável (RDS): Sustainable use conservation unit that seeks to reconcile nature conservation with improving the quality of life of traditional populations living within its boundaries, ensuring the sustainable use of natural resources.

Reserva Extrativista (RESEX): Sustainable use conservation unit aimed at the sustainable exploitation of natural resources by traditional populations, ensuring their culture, subsistence, and the conservation of these resources.

Reserva Legal: Area located within a rural property that must be maintained with native vegetation, as determined by the Brazilian Forest Code, with the aim of conserving biodiversity.

Reserva Particular do Patrimônio Natural (RPPN): Sustainable use conservation unit established by the landowner's initiative, which designates the area for the preservation of biological diversity, without changing ownership or preventing land use for activities that do not harm conservation.

Restoration: Process of restoring degraded or destroyed ecosystems, with the aim of reestablishing their original structure, functioning and biodiversity. It may involve planting native species, soil management and controlling invasive species, among other actions.

Tons of carbon: Represents the total amount of all GHGs, not just CO_2, converted into a common unit based on the global warming potential of each gas. It is synonymous with a metric ton of carbon dioxide equivalent (CO_2e).

Transition zone: A contact zone between two or more ecodomains, where environmental gradients and species mixing occur. It presents high biological diversity and intermediate characteristics. In Brazil, examples include areas between the Cerrado and the Amazon, between the Caatinga and the Amazon, or between the Caatinga and the Atlantic Forest.

Vegetation enclave: A restricted area containing ecosystems from a distinct Ecodomain, inserted in a different dominant matrix, originated by specific local conditions. It acts as an "ecological island", with contrasting communities. In Brazil, examples include Cerrado ecosystems in the Atlantic Forest or vice versa, reflecting the environmental and historical complexity of the landscape.

Vereda: Savannah vegetation ecosystem typical of humid areas, with tree cover between 20% and 50%, characterized by hydromorphic soils, herbaceous and shrubby vegetation, with the predominance of indicator species such as buriti palms (*Mauritia flexuosa* L.f.) and xiriri palms (*Mauritiella armata* (Mart.) Burret). These areas typically occur on hydromorphic, acidic soils, which are poorly drained and often waterlogged, especially in flat or gently sloping terrain.

Cerrado on high alert: rampant clearing

The Cerrado is the second largest Ecodomain in South America, after the Amazon, with an original area of approximately 2,000,000 km^2 (Fig. 1A, see Boxes 1, 2 for definitions). Most of this area is located in Brazil, which accounts for approximately 98% of the total coverage, while small portions also extend into Bolivia and Paraguay. In Brazilian territory, the Cerrado occupies approximately 23% of the national surface (Klink and Machado 2005) (Fig. 1B). Recognized as a global biodiversity hotspot (Myers et al. 2000), the Ecodomain is home to thousands of endemic species and plays a crucial role in maintaining the main Brazilian river basins (Klink and Machado 2005). Despite its enormous importance, the Cerrado has been suffering increasingly intense pressures, mainly due to urban and agricultural expansion, recurrent fires, mining, and land speculation. It is estimated that more than 55% of its native vegetation has already been destroyed, totaling more than 1,000,000 km^2, converted into pastures, monocultures, and urban areas, especially in the last five decades (Machado et al. 2024). This process intensified from the 1980s onwards, marking the beginning of an accelerated phase of anthropogenic conversion. According to data from MapBiomas (2024), between 1985 and 2023, the Cerrado lost approximately 380,000 km^2 of native vegetation, equivalent to 19% of its original coverage in this period (Fig. 2). The devastation was especially concentrated in the MATOPIBA region (comprising the Brazilian States of Maranhão, Tocantins, Piauí, and Bahia), which has become the main axis of expansion of the national agricultural frontier in recent years, although other regions of the Cerrado experienced higher deforestation rates during the mid-1980s (Machado et al. 2024).

Based on data from INPE's PRODES system (INPE 2025), the history of devastation in the Cerrado reveals an alarming trajectory of native vegetation loss

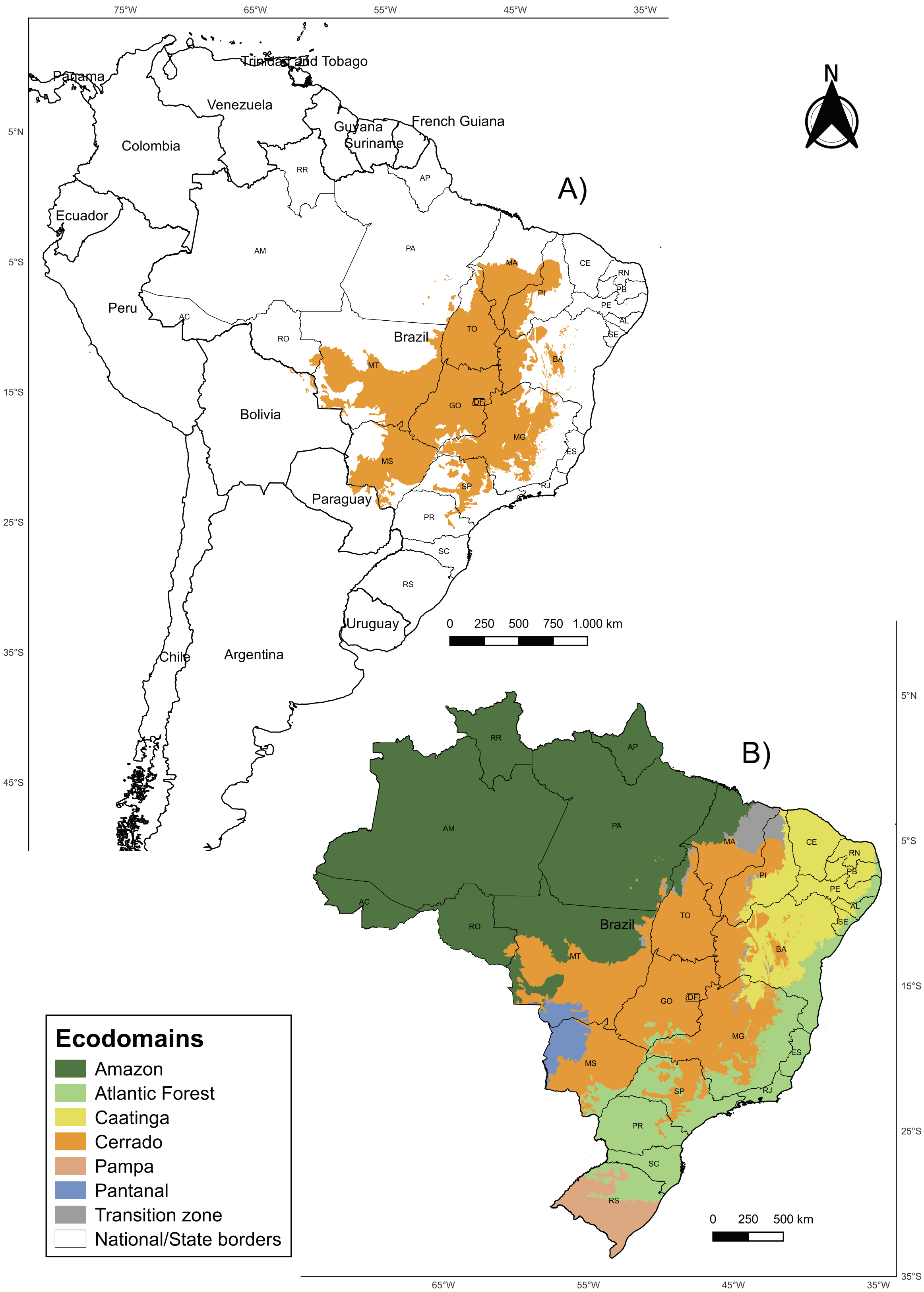

Figure 1. Original extension of the Cerrado Ecodomain, with approximately 2,000,000 km^2, covering mainly Brazil (98% of its area) and small portions of Bolivia and Paraguay (**A**); and the Brazilian Cerrado inserted between the other Ecodomains of the country (**B**). These maps were made using the Cerrado shapefile developed by Cássio Cardoso Pereira, which incorporates refined boundaries of the Ecodomain, along with an adaptation of the ecoregion shapefiles from Dinerstein et al. (2017). Figure design: Cássio Cardoso Pereira.

in recent decades. Since systematic monitoring began in 2001, the Cerrado has lost more than 326,000 km^2 of native vegetation cover—an area equivalent to almost the entire territory of Italy (Fig. 3). Between 2001 and 2012, annual clearing rates ranged from 8,976.17 to 28,766.81 km^2. The first two years recorded 26,933.02 km^2 of clearing, followed by peaks of 28,766.81 km^2 in 2003 and 2004. From 2005 onwards, there was a sustained downward trend, with a reduction of 41.27% until 2010: from 16,878.78 km^2 to 9,910.35 km^2. In the following two years, 2011 and 2012, clearing reached the lowest level of the decade, with 8,976.17 km^2. However, from 2019 onwards, a new escalation was observed: in 2020, 7,905.16 km^2 were cleared; in 2021, 8,531.44 km^2; in 2022, 10,688.73 km^2; and, in 2023, the recent peak of 11,011.69 km^2. Only in 2024 was a reduction of 25.77% observed, with 8,174.17 km^2 cleared, still one of the highest rates in the historical series. In 2025, deforestation fell to 7,235.27 km^2, representing an 11.49% reduction compared to the previous year, signaling a possible slowdown in devastation (Fig. 3). Although annual clearing rates have been decreasing recently, it is important to remember that each new area cleared increases the total accumulated environmental loss. This means that the Cerrado continues to shrink, albeit at a slower pace. Therefore, the ideal goal should be to eliminate clearing completely.

These numbers indicate that the Cerrado has lost more native vegetation in recent years than any other Brazilian Ecodomain, including the Amazon in terms of annual area converted (INPE 2025). Although the PRODES system only records clear-cutting of vegetation, complementary studies suggest that degradation by fire, selective extraction, exotic species invasion, and intensive land use significantly increase environmental impacts (da Silva Arruda et al. 2024). The advancement of this process compromises not only the Ecodomain's biodiversity and ecosystem services, but also the climate and water resilience of vast regions of the country. This scenario reinforces the urgency of specific public policies for the Cerrado, focusing on conservation, restoration, and sustainable land use.

Grasslands, savannas, and forests: for a complete and coherent protection of the Cerrado Ecodomain

The Cerrado as an Ecodomain comprises one of the most complex and paradoxically neglected ecological landscapes on the planet. Although commonly labeled as a "tropical savanna", this framing is conceptually inaccurate and politically reductionist, as it ignores the real structural diversity of the region (Coutinho 2006; Batalha 2011; Silveira 2025). The Cerrado is home to different types of biomes: grasslands, savannas, and tropical forests, that function as distinct ecosystems in terms of structure, ecological processes, and vulnerability (Coutinho 2006; Ribeiro and Walter 2008; Batalha 2011). These ecosystems, known in Brazil as phytophysiognomies (Ribeiro and Walter 2008), are not continuously distributed, but rather in highly dynamic and interdependent mosaics, which imposes additional challenges to their conservation, monitoring, and management (Ribeiro and Walter 2008). Savannas predominate in area and comprise 70% of the vegetation throughout the Ecodomain (Ribeiro and Walter 2008). Even so, this numerical predominance does not justify generalization. The use of the term "Cer-

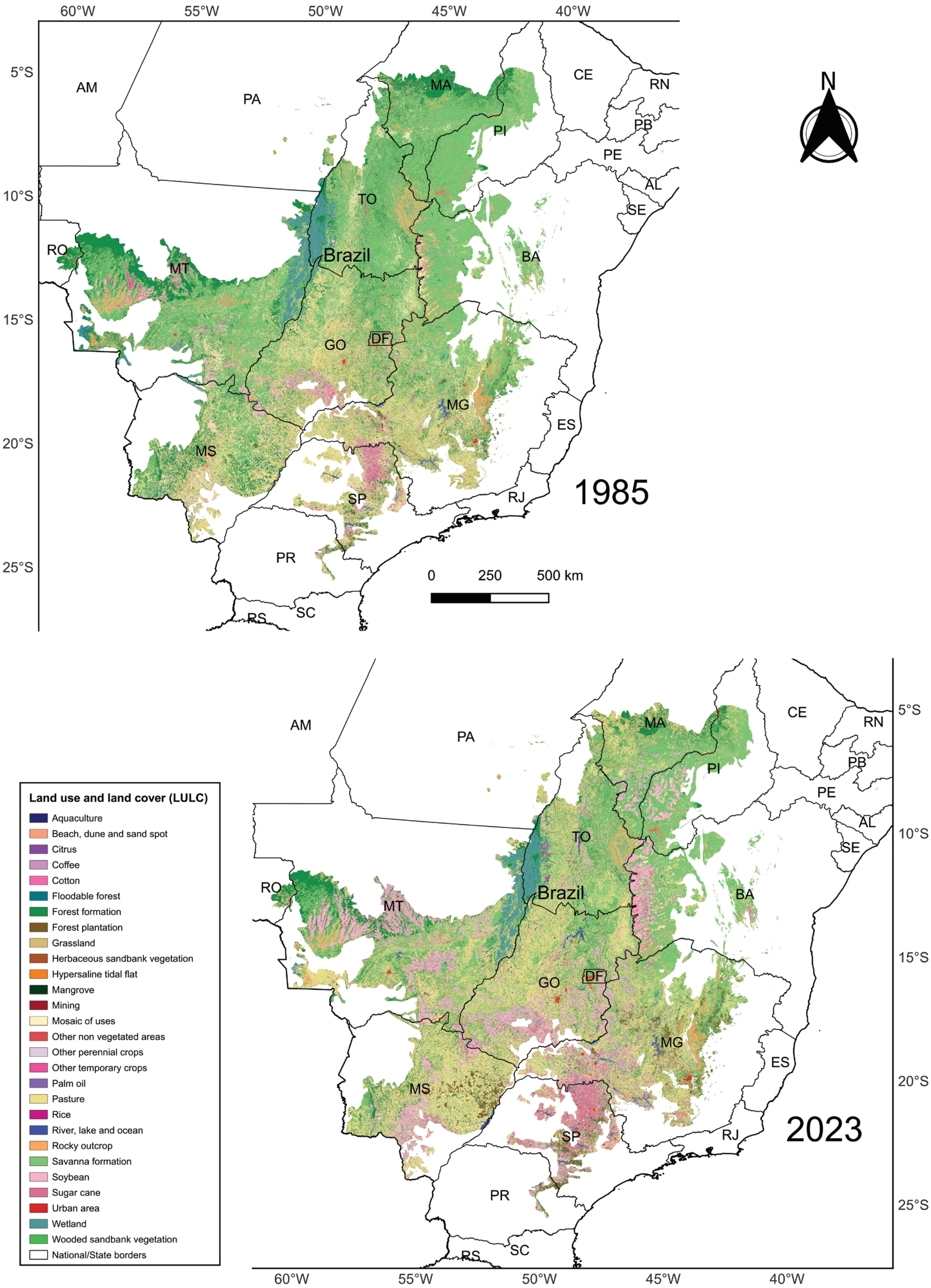

Figure 2. Land use and land cover (LULC) in the Cerrado Ecodomain in 1985 and 2023, revealing significant changes in the spatial structure of the territory. An intensification of human activities can be observed, with emphasis on agricultural expansion, which resulted in the significant replacement of native vegetation by alternative uses. This process represents an accelerated landscape transformation over the last four decades. These maps were made using the Cerrado shapefile developed by Cássio Cardoso Pereira, with LULC data available from MapBiomas (2024). Figure design: Cássio Cardoso Pereira.

rado biome", in the singular, has operated as a political simplification that makes the equally structural grassland and forest formations invisible (Box 1). As Batalha (2011) proposes, this definition is incompatible with international ecological literature, which recognizes biomes as physiognomic and functional units, and not merely floristic ones. From this more refined perspective, the Cerrado does not constitute a single biome, but rather a set of biomes arranged in interdependent ecosystems, the understanding of which requires abandoning simplifying categories and recognizing heterogeneity as a central element.

Grassland ecosystems—characterized by a dominant herbaceous-shrub layer and tree cover of less than 5%—include Campo Limpo, Campo Sujo, and Campo Rupestre, and occur preferably on shallower, well-drained soils with low fertility (Box 2, Fig. 4) (Ribeiro and Walter 2008). The Cerrado grasslands are increasingly and rapidly being pressured by urban expansion, fragmenting habitats and compromising their ecological integrity. Certain variants face even greater threats due to their geological characteristics, which make them prime targets for mineral extraction, such as Campo Rupestre, which develops in extreme hilltop environments with rocky outcrops (Silveira et al. 2016). These altitudinal and lithic contexts also include the Cerrado Rupestre, a unique savanna ecosystem that combines grassland and savanna elements on quartzite and ferruginous substrates, where endemism and adaptive specialization reach extraordinary levels (Pereira and Fernandes 2022a). Together, the Campo Rupestre and Cerrado Rupestre occupy around 7% of the total area of the Cerrado, highlighting their rarity and strategic importance for the conservation of biodiversity, especially because they coexist in the same environment, represent less than 2% of the national territory, are home to around a third of the Brazilian flora, and serve as the cradle of the country's waters (Reatto et al. 1998; Pereira and Fernandes 2022a). Despite their ecological significance, these areas have been particularly targeted by mining, given their proximity to deposits of iron, niobium, gold, and quartz (Silveira et al. 2016; Fernandes et al. 2020). The destruction of outcrops, the suppression of rare vegetation, and the compromise of local microclimates generate irreversible ecological losses, especially given the lack of legal recognition of these ecosystems, which are often not even identified as priorities in technical reports (Fernandes et al. 2020; Pereira and Fernandes 2022a). Furthermore, the increased frequency and intensity of fires caused by the invasion of exotic species is threatening fire-sensitive species that previously survived isolated on outcrops, protected by the scarcity of natural fuel on hilltops (Neves and Conceição 2010). This cycle of fires, facilitated by invasive grass species, accelerates the homogenization of the landscape and puts endemic species that depend on fragile microhabitats at definitive risk (Fig. 4). Finally, invasive species can also indirectly increase the risk of infectious and zoonotic diseases by creating favorable conditions for the proliferation of vectors, such as ticks, which endangers animal populations, their interactions with plant species, and also poses risks to human health (Flory et al. 2025).

Savanna ecosystems—characterised by a discontinuous tree-shrub stratum over a dominant herbaceous understory, with tree cover varying between 5% and 50%—encompasses a diversity of ecosystems: Cerrado Denso, Cerra-

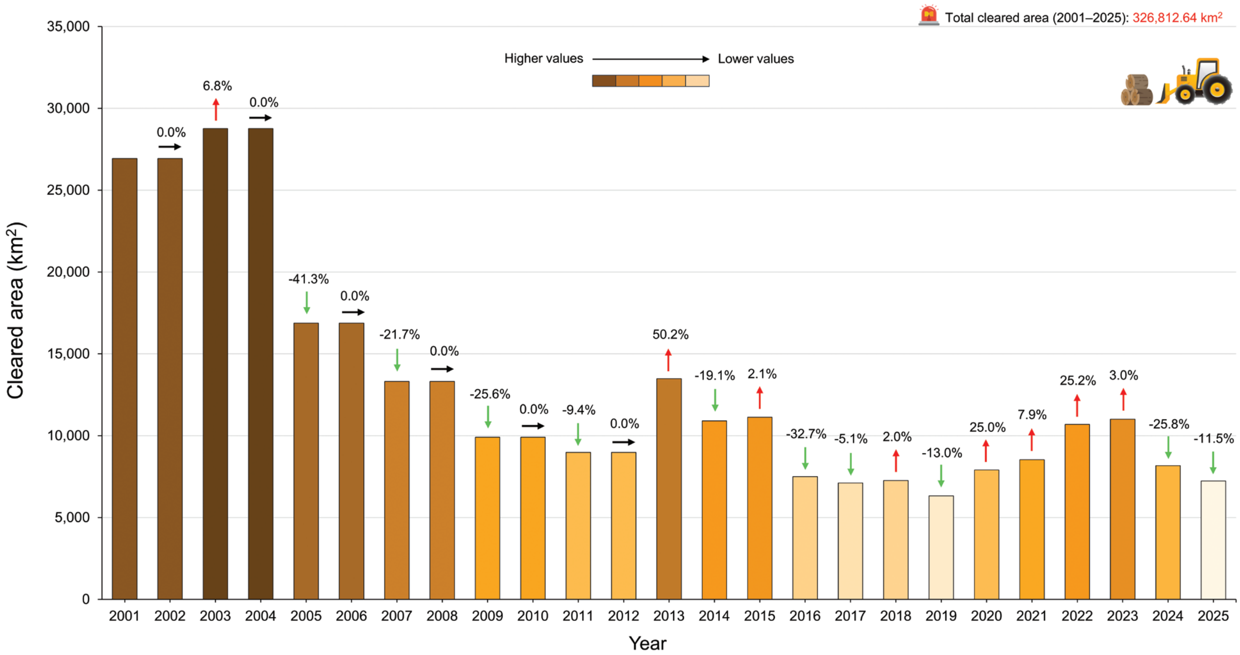

Figure 3. Annual clearing in the Cerrado (2001–2025) according to PRODES (INPE 2025). Bars represent the total area cleared each year (km²), with colors ranging from dark orange (highest values) to light orange (lowest values), indicating relative variation in intensity. Arrows indicate the percentage change compared to the previous year: increases (↑, red), decreases (↓, green), and stability (→, black, 0.0%). PRODES (INPE 2025) estimates annual clearing of native vegetation using Landsat-class satellite images with 20–30 m spatial resolution and a revisit interval of 16 days, analyzing changes between consecutive "reference years" (August–July). These data do not detect degradation, only complete removal of natural vegetation. The icons used in this figure are from Wikimedia licensed under CC BY-SA 4.0. Figure design: Cássio Cardoso Pereira.

do Ralo, Cerrado Rupestre, Cerrado Típico, Palmeiral, Parque de Cerrado, and Vereda (Box 2, Fig. 4) (Ribeiro and Walter 2008). These ecosystems generally develop on deep, acidic soils with low fertility, often shaped by seasonal rainfall and fire regimes (Ribeiro and Walter 2008). The Cerrado Denso, in turn, approaches the forest threshold, with an almost continuous canopy and larger trees, which defies simplistic classifications and demands recognition of its position as a transitional ecosystem. Although they dominate the Cerrado Ecodomain territorially, savannas have been intensively converted into agricultural monocultures driven by mechanization and the intensive use of chemical fertilizers and amendments, as well as exotic pastures and commercial forestry, especially *Eucalyptus* spp. L'Hér. (Klink and Machado 2005; Strassburg et al. 2017). The degradation of these ecosystems compromises their functional integrity: native species are suppressed, the natural fire regime is altered, and the remaining areas lose their ecological identity, hindering restoration efforts and blurring the boundaries between open and secondary formations. In this context, Vereda, a unique, humid ecosystem, is particularly threatened by agricultural expansion, the lowering of the water table, and the misuse of springs, which compromises their ecological function and the survival of the Buriti Palm (*Mauritia flexuosa* L.f.), and the Xiriri Palms (*Mauritiella armata* (Mart.) Burret; Nunes et al. 2022) (Fig. 4).

Forest ecosystems—with tree cover greater than 50%—include Cerradão, Mata Ciliar, Mata de Galeria, and Mata Seca (Box 2, Fig. 4) (Ribeiro and Walter

2008), and have been systematically degraded by selective deforestation, irrigated agriculture, intensive livestock farming, logging, urban expansion, and mining (Beuchle et al. 2015). The opening of new areas for planting and agricultural activities has caused a significant reduction in the Cerradão, a process that also puts strong pressure on water resources. Notably, the growing demand for water for agricultural irrigation and livestock watering has considerably reduced the flow of springs and streams (Latrubesse et al. 2019), directly impacting the Mata Ciliar and Mata de Galeria. Urban expansion, in turn, advances into riparian areas, driven by the real estate appreciation of land near watercourses. Urbanization intensifies silting, soil impermeability, and forest fragmentation. The Mata Seca, especially in limestone areas, is also affected by mining limestone, dolomite, and phosphate, which destroys the rocky substrate and makes ecological regeneration impossible. The lack of specific legal recognition for these formations worsens their vulnerability, allowing them to be treated as areas of "low environmental value" in licensing processes. The loss of these forests compromise associated biodiversity, disrupt ecological corridors, and weaken the ecosystem services that support the hydrological and climatic resilience of the Ecodomain (Fig. 4). It is important to emphasize that the major land-use changes observed in the Cerrado's grasslands, savannas, and forests are facilitated by the opening of new roads (Fig. 4). Road construction acts as the primary driver of ecosystem transformation, a gateway for occupation and exploitation, allowing access to previously preserved areas, paving the way for clearing, fires, invasive species, crop farming, livestock, monocultures, mining, and urbanization (Fig. 4). This sequence of transformations is a common feature throughout the Cerrado Ecodomain, intensifying the fragmentation and degradation of its diverse ecosystems.

Some recent conservation strategies have resorted to reclassifying Cerrado ecosystems as belonging to other Ecodomains, with the aim of ensuring greater legal protection. An emblematic example is the attempt to classify the Campo Rupestre as part of the Atlantic Forest, under the argument that they occur in transition areas or share certain floristic taxa (Miola et al. 2019). However, this association is ecologically imprecise: these are ecosystems adapted to lithic soils, extreme climates, and high altitudes, with a very high degree of endemism and specialization, whose identity is deeply rooted in the Cerrado Ecodomain and the Espinhaço Range, a mountain chain in eastern Brazil extending through Minas Gerais and Bahia, and not in the Atlantic Forest and its Campos de Altitude (Vasconcelos 2011). Another frequent example of reclassification aimed at benefiting from stricter legal protection under the Atlantic Forest law is the inclusion of dry forests (including the Mata Seca ecosystem of the Cerrado) as part of this Ecodomain (Espírito-Santo et al. 2011). These attempts at "biogeographic translocation" reveal not only institutional weaknesses but also a symbolic dependence on tropical forests as a conservation paradigm. The same is true of the Forest Code (Law no. 12,651, of 05/25/2012, see Presidência da República 2012), which requires the protection of 35% of native vegetation in Cerrado areas within the Legal Amazon, but only 20% in the rest of the Ecodomain, an asymmetry that ignores the real vulnerability and ecological importance of the territory (Metzger et al. 2019). Instead of trying to include Cerrado ecosystems under the legal umbrella of the Atlantic Forest or the Amazon, the most coherent and fair path would be to definitively recognize

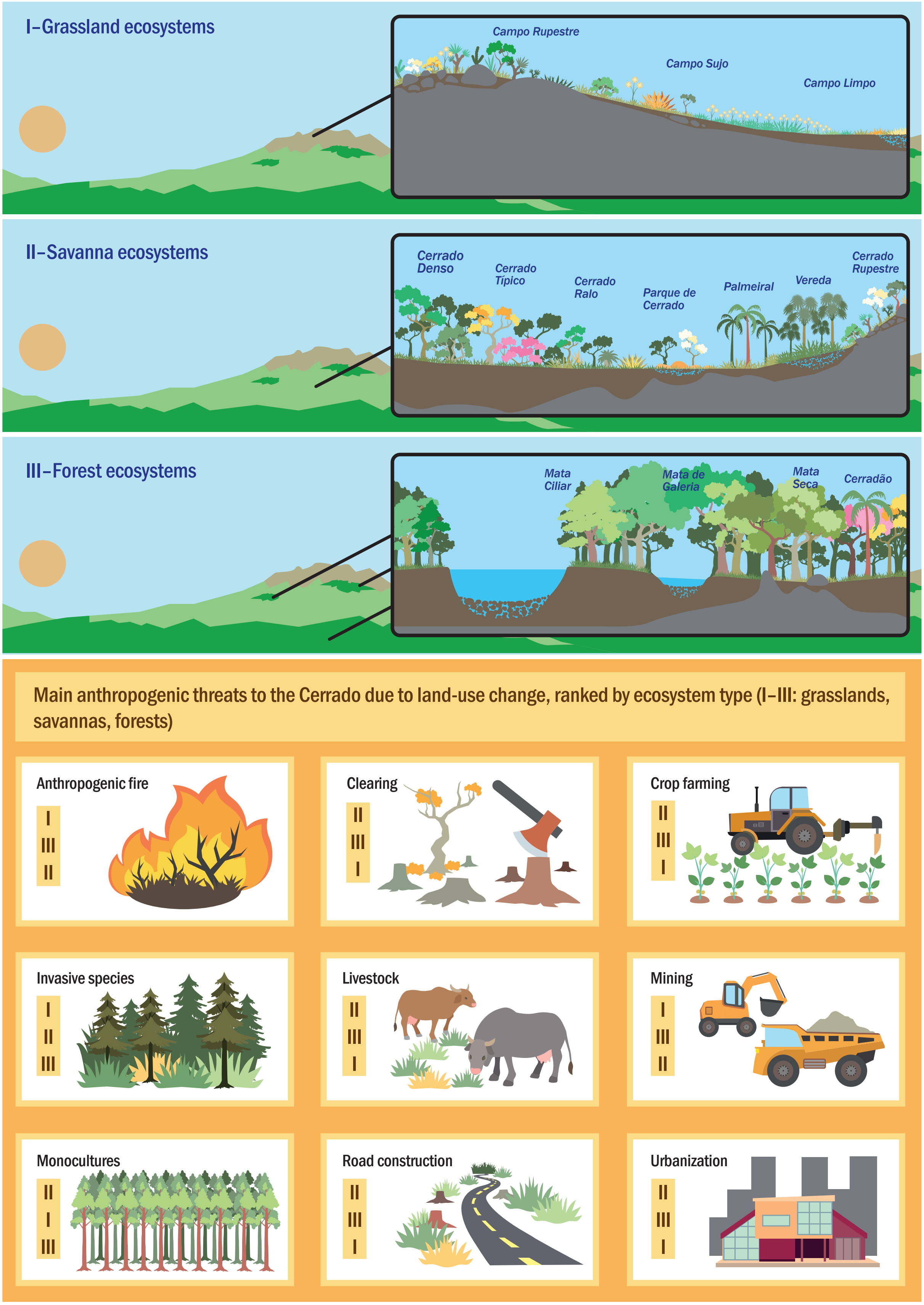

Figure 4. Main anthropogenic threats to the Cerrado resulting from land-use changes, ranked by impact on each ecosystem type (I–III: grassland, savanna, and forest). The ecosystems illustrated are according to Ribeiro and Walter (2008). For more details on each ecosystem, see Box 2. Figure design: Walisson Kenedy-Siqueira.

the Cerrado as the biodiversity hotspot that it is. This implies protecting all of its ecosystems with its own legal instruments, sensitive to their heterogeneity and their ecological centrality in the Brazilian territory.

Not everything grows back: the fire banalization and the increase in Cerrado degradation

The perception of the Cerrado as a homogeneous savanna biome, naturally resistant to fire, is one of the most serious distortions caused by this pernicious simplification. This reductionist view ignores the ecological complexity of the Ecodomain and makes its internal diversity invisible, despite the Cerrado being home to dozens of ecosystems with different structures, dynamics, and degrees of resilience when burned (Coutinho 2006; Ribeiro and Walter 2008). By treating the Cerrado as a uniform biome, public policies and technical discourse end up ignoring the degradation caused by fires. This distortion also weakens the fight against arson, relying on narratives such as “the fire was always there” and “soon everything will grow back”, which function as erasure devices: they disregard the difference between natural and anthropogenic fires, overlook the vulnerability of the most sensitive ecosystems, and exempt human responsibility for the intensification and trivialization of fires.

Many species in the Cerrado, especially woody shrubs, evolved under natural fire regimes and developed morphophysiological adaptations that give them resistance and resilience to this disturbance (Coutinho 1982; Durigan and Ratter 2016; Pivello et al. 2025). These specializations include leathery and hairy leaves, a thick rhytidome that protects internal tissues against heat, and various underground storage structures—such as xylopodia, tubers, bulbs, corms, and rhizomes—as well as deep roots that favor regrowth after fire (Coutinho 1982; Veldman et al. 2015a). Additionally, many woody species exhibit basal or epicormic resprouting capacity. In some of them, fire even acts as an ecological trigger: there are seeds whose germination depends on the passage of fire, whether due to heat, chemical changes in the soil, or the removal of plant cover (Zupo et al. 2021). Due to these adaptive characteristics, some Cerrado ecosystems are classified as a pyrobiome, vegetation adapted to natural fires (Coutinho 2006). However, this relationship does not extend to all species or all ecosystems in the Ecodomain, many of which are highly vulnerable to fire (Coutinho 2006). Forest formations such as Mata de Galeria and Vereda are particularly sensitive, as their species do not have adaptations to resist flames and depend on humid and shaded environments to survive (Fig. 4) (Nunes et al. 2022). The same occurs in areas of Campo Rupestre and Cerrado Rupestre, which are home to a high number of fire-sensitive species that survive on rocky outcrops where the scarcity of natural fuel prevents the spread of flames (Fig. 4) (Neves and Conceição 2010; Pereira and Fernandes 2022a). The invasion of exotic species, especially grasses, which accumulates flammable biomass, has increased the frequency and intensity of fires on mountaintops, putting these species at risk (Neves and Conceição 2010). Understanding the distribution of these adaptations is therefore essential in order to differentiate ecological fire from predatory fire and to build management policies that respect the functional diversity of Cerrado ecosystems.

Even species adapted to fire are not prepared to face the current regime of anthropogenic fires (da Silva Arruda et al. 2024). Natural fires, caused by lightning, are rare and low in frequency, and it can take years or decades for them to reoccur in the same area, allowing vegetation to regenerate. Arson, caused by human action, breaks this cycle. It is estimated that 99% of fires in Brazil are of anthropogenic origin, often linked to clearing, agricultural expansion, and negligence in management (Agência Brasil 2024). These fires occur with increasing frequency, uncontrolled intensity, and outside natural seasonality (Pivello 2011; Diele-Viegas et al. 2022; da Silva Arruda et al. 2024). From 1985 to 2022, fires impacted 40% (792,204 km^2) of the Cerrado Ecodomain, with 63% of this area burning more than once (da Silva Arruda et al. 2024). Although Brazil's current presidential administration managed to reduce clearing in the Cerrado by 25.77% in 2024, according to INPE's PRODES program (INPE 2025), these data do not capture the degradation caused by fire. Recurrent fires compromise the ecological structure of ecosystems, even without the total removal of vegetation. In 2024, the Cerrado recorded around 14.6 million hectares of burned land, the highest number since 2012, revealing a collapse in the ecological regime of fire (WWF 2024). It is important to emphasize that Indigenous peoples are not responsible for this scenario: contrary to what deniers say, they manage fire in a controlled, judicious manner, rooted in traditional knowledge. Their practices involve low-intensity burning, carried out at specific times of the year, with defined objectives and based on natural indicators and sophisticated knowledge that contribute to the conservation of the landscape (Pivello 2011).

Breaking with the myths that sustain the devastation of the Cerrado is more than an ecological imperative; it is an ethical gesture. It is not just about defending vegetation that will "regrow," but about recognizing the collapse of a complex balance that supports biodiversity, ways of life, and climate stability. Fire can be an ally, but when out of control and fueled by predatory economic interests, it becomes a force of destruction. There is a political choice between denying complexity and preserving it. This choice needs to be made with clarity and courage.

Undermining the water tank: the Cerrado's hidden hydrological crisis

Known as Brazil's "water tank," the Cerrado is the cradle to eight of the country's 12 major river basins (Pereira and Fernandes 2022b), including the Paraguay, Paraná, Tocantins-Araguaia, São Francisco, and tributaries to the Amazon. The Cerrado is also home to three immense aquifers, Bambuí, Urucuia, and Guarani, that store large volumes of water. Its deep-rooted plant species not only efficiently capture water during the dry season but also create pathways for the infiltration of rainwater during the wet season, increasing the recharge of aquifers and maintaining river base flow (Zhou et al. 2020). This delicate balance between water capture and infiltration highlights the Cerrado's role as a self-regulating system, maintaining not only its ecosystems but also the livelihoods of downstream communities. However, with the increasing demand for water and continued pressure from agriculture, hydropower, and urban expansion (Latrubesse et al. 2019; Rodrigues et al. 2022), protecting the hydrological integrity of the Cerrado has shifted from a regional concern to a national priority.

Of particular concern is the deteriorating state of freshwater ecosystems, where the most pressing threats stem from unsustainable land-use practices linked to agribusiness and the construction of hydropower dams along previously free-flowing rivers (Latrubesse et al. 2019). The combined effect of large-scale conversion and river fragmentation disrupts the Cerrado's water cycle, undermining its capacity to function as a hydrological buffer (Fernandes et al. 2023a). These freshwater systems provide crucial ecosystem services, including water purification, regulation of flow, maintenance of wetlands, and support for biodiversity (Resende et al. 2021). Their degradation alters water quality, flow regimes, and availability throughout the region (Pereira and Fernandes 2022b). Here lies the paradox: the very sectors most reliant on the Cerrado's water—agribusiness and energy—are accelerating its depletion (Rodrigues et al. 2022). Together, habitat degradation and hydrological disruption trigger profound ecological imbalance, threatening not only the long-term viability of the Cerrado but also the broader Brazilian economy.

Agricultural expansion in the Cerrado has dramatically increased pressure on its hydrological systems (Rodrigues et al. 2022). Reliant on irrigation to sustain year-round soybean and commodity production, farmers draw vast amounts of water from rivers, reservoirs, and increasingly from groundwater. While this has allowed millions of hectares of land to be cultivated, it has also increased the Cerrado's vulnerability to drought and erratic rainfall patterns (Rodrigues et al. 2022). This dependence became particularly evident during the severe drought of 2021, Brazil's worst in nearly a century, when crop failures and overburdened irrigation systems highlighted the fragility of existing water resources (Althoff et al. 2021; Pereira and Fernandes 2022b). In addition, runoff from intensive agriculture contributes to the contamination of rivers and aquifers, further undermining efforts to balance food production with the conservation of freshwater ecosystems (Cabral et al. 2023). Thus, reliance on groundwater has become particularly problematic. These underground reservoirs are essential not only for sustaining wetland ecosystems like Veredas but also for maintaining dry-season river flows throughout the Cerrado. However, excessive water withdrawal for irrigation and widespread agrochemical use have caused significant declines in water tables and raised contamination risks (Cabral et al. 2023). As these aquifers shrink or become polluted, wetland-dependent species lose critical habitat, and nearby communities face growing water insecurity. This chain reaction contributes to biodiversity collapse, undermines ecological resilience, and compromises the Cerrado's ability to withstand future climate and hydrological stressors.

Hydropower infrastructure has intensified the freshwater crisis (He et al. 2024). Under the premise of expanding so-called "clean energy", large hydropower dams have been built on Cerrado rivers, fragmenting waterways and altering natural flow regimes (see Table 1, Fig. 5A). In addition, the proliferation of small hydroelectric plants (SHPs) in Cerrado watersheds further contributes to habitat fragmentation, altered flow regimes, and local ecological impacts. Although the economic benefits of power generation are recognized, studies show that such dams also emit greenhouse gases, increase clearing on surrounding areas, and disrupt fish migration, with underreported social and ecological consequences (Fearnside et al. 2021; He et al. 2024). Old dams remain operational despite their inefficiency, continuing to degrade river biodiversity and ecosystem services. Ironically, attempts to ensure energy

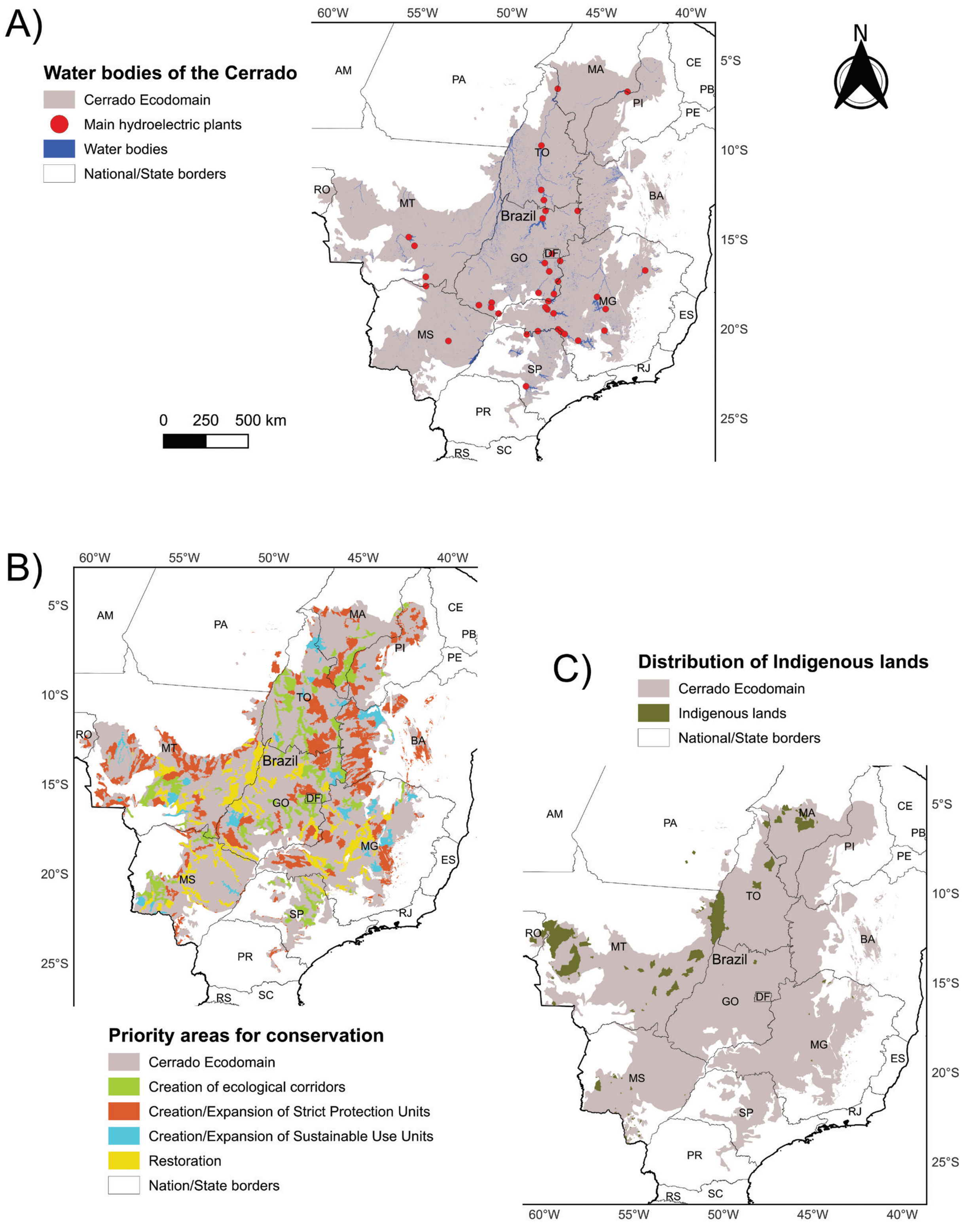

Figure 5. Location of main hydroelectric plants (**A**), priority conservation areas (**B**), and distribution of Indigenous lands in the Cerrado Ecodomain (**C**). These maps were made using the Cerrado shapefile developed by Cássio Cardoso Pereira, and include data adapted from water bodies provided by the Agência Nacional de Águas (2019), priority conservation areas defined by Ministério do Meio Ambiente (2022), and Indigenous lands delineated by FUNAI (2020). Because Ministério do Meio Ambiente (2022) provides multiple datasets for priority areas, many of which overlap or differ in scale and criteria, the layer used here is presented as an adaptation, reflecting the selection of those polygons that most closely align with current international literature and with the objectives of our narrative. Figure design: Cássio Cardoso Pereira.

Table 1. Technical and geographic information on the main hydropower plants located on rivers in the Cerrado Ecodomain, including location, reservoir dimensions, installed capacity, and coordinates. IC: Installed Capacity; NA: Not Available; RA: Reservoir Area; RV: Reservoir Volume.

Hydropower plant name	State	RA (km^2)	RV (m^3)	IC (MW)	Latitude, Longitude
Usina Hidrelétrica Amador Aguiar	Minas Gerais	63.77	8963830000.00	450.00	18°47'20"S, 48°08'55"W
Usina Hidrelétrica Assis Chateaubriand	Mato Grosso do Sul	15.40	71600000.00	29.50	20°40'32"S, 53°34'05"W
Usina Hidrelétrica Batalha	Goiás, Minas Gerais	138.00	1781610000.00	52.50	17°20'47"S, 47°29'30"W
Usina Hidrelétrica Boa Esperança	Maranhão	400.00	NA	237.30	06°44'58"S, 43°33'58"W
Usina Hidrelétrica Caçu	Goiás	16.93	227450000.00	65.00	18°31'58"S, 51°08'55"W
Usina Hidrelétrica Cana Brava	Goiás	139.00	2300000000.00	450.00	13°24'03"S, 48°08'26"W
Usina Hidrelétrica Casca III	Mato Grosso	0.35	NA	12.42	15°21'53"S, 55°26'53"W
Usina Hidrelétrica Corumbá I	Goiás	65.00	1500000000.00	375.00	17°59'14"S, 48°32'01"W
Usina Hidrelétrica Corumbá III	Goiás	77.42	972000000.00	96.45	16°47'21"S, 47°56'08"W
Usina Hidrelétrica Corumbá IV	Goiás	173.00	3700000000.00	127.00	16°19'23"S, 48°11'03"W
Usina Hidrelétrica Emborcação	Goiás, Minas Gerais	476.59	17724720000.00	1192.00	18°26'49"S, 47°59'12"W
Usina Hidrelétrica Espora	Goiás	28.06	NA	32.00	18°40'41"S, 51°51'57"W
Usina Hidrelétrica Estreito	Maranhão	555.00	5400000000.00	1087.00	06°35'14"S, 47°27'34"W
Usina Hidrelétrica Furnas	Minas Gerais	1440.00	22950000000.00	1216.00	20°40'01"S, 46°19'04"W
Usina Hidrelétrica Gafanhoto	Minas Gerais	1.52	2420000.00	14.00	20°05'57"S, 44°50'56"W
Usina Hidrelétrica Irapé	Minas Gerais	137.16	5954880000.00	399.00	16°44'15"S, 42°34'30"W
Usina Hidrelétrica Itiquira I	Mato Grosso	2.10	NA	30.40	17°4'57"S, 54°53'11"W
Usina Hidrelétrica Jaguara	Minas Gerais, São Paulo	34.60	90000000.00	424.00	20°01'26"S, 47°26'01"W
Usina Hidrelétrica Jurumirim	São Paulo	449.00	NA	98.00	23°12'34"S, 49°13'50"W
Usina Hidrelétrica Luís Carlos Barreto de Carvalho	São Paulo	46.70	1418000000.00	1050.00	20°09'11"S, 47°16'46"W
Usina Hidrelétrica Luís Eduardo Magalhães	Tocantins	630.00	5190000000.00	902.50	09°45'17"S, 48°22'22"W
Usina Hidrelétrica Manso	Mato Grosso	427.00	7300000000.00	210.00	14°52'18"S, 55°47'09"W
Usina Hidrelétrica Marechal Mascarenhas de Moraes	Minas Gerais	250.00	4040000000.00	476.00	20°17'05"S, 47°03'49"W
Usina Hidrelétrica Maribondo	Minas Gerais, São Paulo	438.00	6150000000.00	1440.00	20°18'14"S, 49°11'51"W
Usina Hidrelétrica Miranda	Minas Gerais	50.60	1120000000.00	408.00	18°54'29"S, 48°02'32"W
Usina Hidrelétrica Nova Ponte	Minas Gerais	443.00	12792000000.00	510.00	19°08'14"S, 47°41'35"W
Usina Hidrelétrica Paranoá	Distrito Federal	39.48	560000000.00	30.00	15°47'45"S, 47°46'24"W
Usina Hidrelétrica Peixe Angical	Tocantins	294.10	2740000000.00	498.75	12°14'07"S, 48°23'13"W
Usina Hidrelétrica Ponte De Pedra	Mato Grosso	14.50	35000000.00	176.1	17°35'13"S, 54°54'29"W
Usina Hidrelétrica Porto Colômbia	Minas Gerais, São Paulo	143.00	1525000000.00	320.00	20°07'33"S, 48°34'20"W
Usina Hidrelétrica Queimado	Goiás, Minas Gerais	36.26	477980000.00	105.00	16°12'38"S, 47°19'23"W
Usina Hidrelétrica Retiro Baixo	Minas Gerais	22.58	241590.00	84.70	18°52'41"S, 44°46'51"W
Usina Hidrelétrica Salto	Goiás	60.20	NA	116.00	18°48'30"S, 51°10'15"W
Usina Hidrelétrica Salto do Rio Verdinho	Goiás	43.12	NA	93.00	19°08'34"S, 50°45'12"W
Usina Hidrelétrica São Domingos	Goiás	1.86	7580000.00	14.30	13°25'11"S, 46°22'14"W
Usina Hidrelétrica São Salvador	Tocantins	104.00	NA	243.00	12°48'26"S, 48°14'13"W
Usina Hidrelétrica Serra da Mesa	Goiás	1784.00	54400000000.00	1272.00	13°49'48"S, 48°18'23"W
Usina Hidrelétrica Serra do Facão	Goiás	218.84	5199000000.00	212.58	18°02'46"S, 47°40'31"W
Usina Hidrelétrica Três Marias	Minas Gerais	1040.00	19459000000.00	396.00	18°12'52"S, 45°15'50"W

sustainability by harnessing the Ecodomain's rivers are now contributing to their ecological degradation. Protecting freshwater ecosystems in the Cerrado will require forward-looking policies, including decommissioning obsolete dams, stricter regulation of irrigation practices, and urgent restoration of degraded riparian zones.

Threatened flora and fauna and conservation challenges

The Cerrado is one of the most biodiverse and threatened regions on the planet, recognized as one of the 35 global biodiversity hotspots. It combines extremely high levels of endemism with extensive loss of native vegetation cover (Myers et al. 2000). This Ecodomain harbors more than 3,200 vertebrate species, including approximately 2,047 terrestrial species—of which 340 are endemic (Vieira-Alencar et al. 2025), and around 1,200 freshwater fish species, with several taxa restricted to basins such as Tocantins-Araguaia, São Francisco, and Paraná (Lima and Ribeiro 2011). In addition, it hosts a vascular flora with approximately 13,000 angiosperm species, representing approximately 27% of the Brazilian flora, about 4,400 of which are exclusive to the Ecodomain (Flora e Funga do Brasil 2024). Even more striking, the invertebrate fauna may exceed 90,000 estimated species, although it remains marked by major taxonomic and ecological knowledge gaps (Embrapa 2023). While birds and mammals account for the highest proportions of threatened vertebrate species in the Cerrado, plants and invertebrates lead in absolute numbers. By cross-referencing data from several lists in the literature, we estimate that around 600 angiosperms and between 400 and 450 invertebrates are formally classified as threatened in Brazil (see Table 2, Fig. 6 for more details). These numbers surpass the total number of all threatened terrestrial vertebrates in the Cerrado combined, revealing a scenario in which organisms that sustain key ecological functions such as pollination, decomposition, and soil fertility are disappearing silently and often beyond the public's awareness. This asymmetry between ecological impact and institutional attention undermines the resilience of the Cerrado, and highlights the urgent need for more comprehensive conservation strategies.

Despite recent advances in the description and mapping of species, data on the conservation status of Cerrado taxa reveal an underrepresentation that is still critical. Among the 340 known endemic terrestrial vertebrates, only 57 have been officially classified as globally threatened by the IUCN. Another 70 species, or more than 20% of the total, have not been assessed or are listed as "data deficient", which prevents any reliable judgment about their extinction risk (Vieira-Alencar et

Table 2. Updated estimates of biodiversity in the Cerrado, including the total number of species per taxonomic group, proportion of endemism, and approximate number of threatened species. Data were adapted from the IUCN Red List (2024), the Flora and Funga of Brazil portal (2024), the official national list of threatened species by Ministério do Meio Ambiente (2022), terrestrial vertebrate data from Vieira-Alencar et al. (2025), freshwater fish data from Lima and Ribeiro (2011), and invertebrate data from Embrapa (2023).

Taxonomic group	Total species	Endemic species	Threatened species* (n)	Percentage threatened (%)
Plants**	13,000	4,400	1,061	8.16
Mammals	354	42	40	11.30
Birds	982	45	50	5.09
Reptiles	419	129	20	4.77
Amphibians	292	124	15	5.14
Fish	1,200	400	30	2.50
Invertebrates	90,000	Thousands (uncertain estimate)	450	0.50

*Threatened species counts reflect only the subset of taxa formally assessed, which may underestimate risk in poorly sampled groups. **Plants refer to vascular and non-vascular plants, including bryophytes, lycophytes, ferns, gymnosperms, and angiosperms, encompassing the diverse vegetation typical of the Cerrado flora.

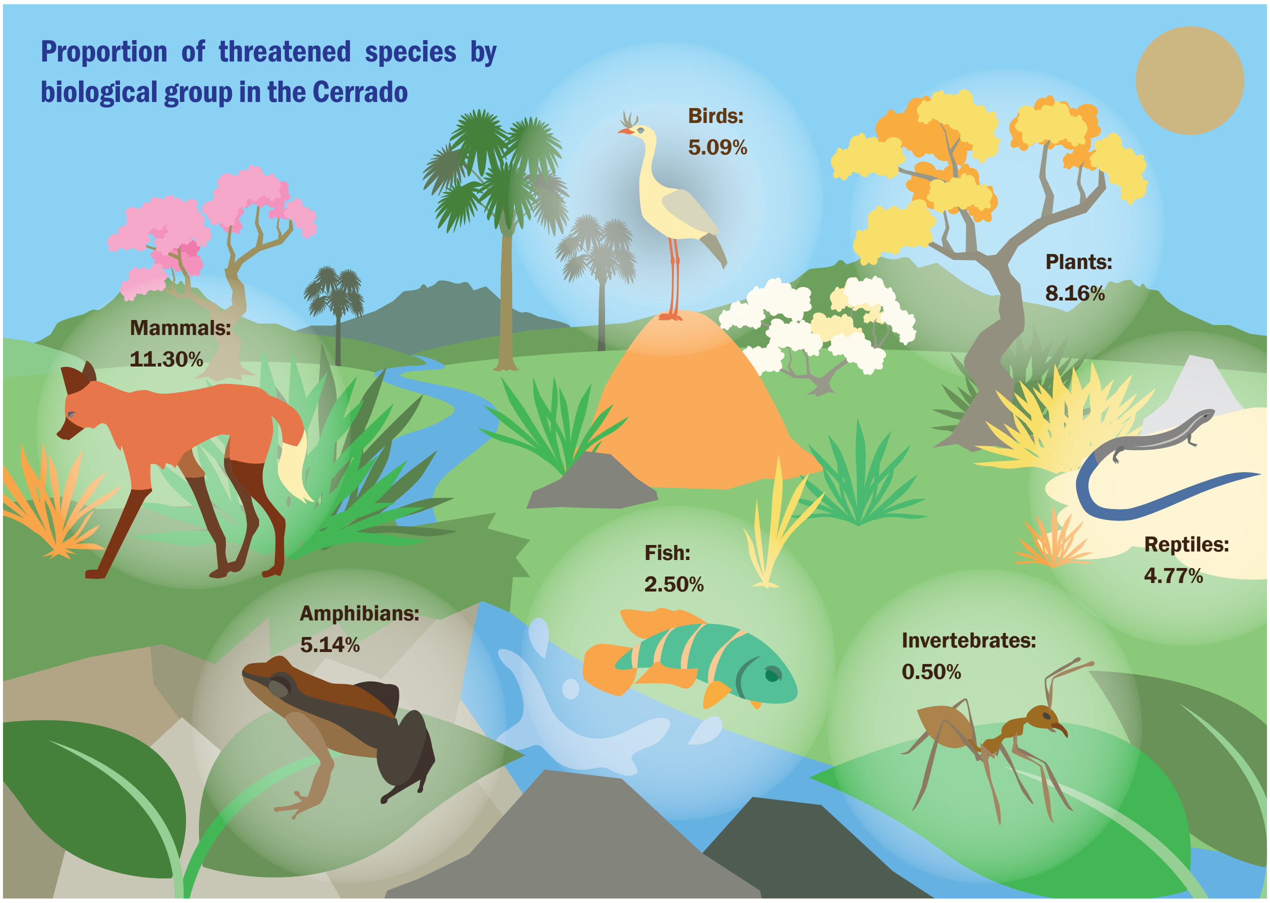

Figure 6. Percentage distribution of threatened species among different biological groups in the Cerrado. The information was adapted from the IUCN Red List (2024), the Flora and Funga of Brazil portal (2024), the official national list of threatened species by Ministério do Meio Ambiente (2022), terrestrial vertebrate data from Vieira-Alencar et al. (2025), freshwater fish data from Lima and Ribeiro (2011), and invertebrate data from Embrapa (2023). See Table 2 for more details. Figure design: Walisson Kenedy-Siqueira.

al. 2025). This pattern reveals a historical bias: even within vertebrates, groups such as reptiles and amphibians—especially anurans with restricted distributions and cryptic habits—remain neglected in research and conservation agendas. The situation is even more serious for invertebrates and plants: less than 1% of known invertebrates and only a fraction of the Cerrado's angiosperms have been formally assessed for extinction risk. In addition, we emphasize that Ecodomains such as the Cerrado lack specific lists. Threatened species lists are generally at the global, national, and state levels, and often do not align with each other, making integrated and coherent assessments difficult. Many species widely distributed in Brazil or in the Americas, such as *Puma concolor* (Lineu, 1771), may not be threatened at the continental scale, but are critically endangered in specific regions like the Cerrado, where local pressures are intense and continuous (ICMBio 2018). The absence of regional assessments compromises everything from the creation of protected areas to the development of public policies, action plans, and funding instruments. It is in this void of information that many extinctions occur invisibly, even before science records the existence of the species.

The synthesis of these data highlights a structural paradox: the Cerrado harbors one of the most remarkable biodiversities on the planet, yet it remains one of the least protected and most underestimated Ecodomains (Colli et al. 2020). Many of the endemic species, some only recently described and others invisible to environmental legislation, do not occur within "conservation units" (Brazil's protected areas for biodiversity) (Vieira-Alencar et al. 2025). It is necessary to broaden conservation criteria, also incorporating plants, invertebrates, and microorganisms into inventories, assessments, and management actions. In addition, it is important to recognize that countless species may be disappearing before even being described by science, a loss that goes beyond taxonomy and erodes the very processes that sustain ecosystems. This diversity is not limited to species counts but includes the ecological interactions that maintain life in the ecosystems. The reproduction and dispersal of Cerrado plants are deeply rooted in interactions with fauna (Kuhlmann and Ribeiro 2016a, 2016b), especially through bee pollination (Pereira et al. 2022c) and seed dispersal by birds and mammals (Kuhlmann and Ribeiro 2016a, 2016b; Pereira et al. 2022c). The disruption of these ecological links, driven by the loss of pollinators and dispersers, not only compromises plant regeneration but also threatens the persistence of animal species themselves, revealing a cycle of mutual dependence that underpins the biodiversity of the Cerrado. Protecting the Cerrado, therefore, requires a more inclusive, preventive conservation policy, grounded in the true diversity of its biological components.

Finally, given the speed at which Cerrado is being destroyed, it is urgent to adopt conservation strategies that combine both *in situ* and *ex situ* actions (Box 2) (Diniz-Filho et al. 2020). In the Cerrado, *in situ* conservation involves strengthening and expanding protected areas, ecological corridors, and Indigenous territories, as well as implementing adaptive management plans in response to climate change and human pressure (Colli et al. 2020). *Ex situ* conservation, in turn, should be carried out through seed banks, living collections in botanical gardens, and conservation breeding centers, thus playing a strategic role for species with critical populations, highly fragmented distributions, or those threatened by extreme events such as large-scale fires. In the case of Brazil's officially threatened plant species, for example, only about 21% are currently represented in *ex situ* collections, which reveals enormous potential for expanding these initiatives (Silveira et al. 2018). The integration of these approaches, combined with strong public policies and applied science, is the most promising path to prevent the biological diversity of the Cerrado from becoming a lost heritage.

Inverted forest: challenges and pathways to conserve and restore a carbon sink

At first glance, the Cerrado may appear as a seemingly "sparse" or "poor" Ecodomain in most of its ecosystems, especially when compared to dense tropical forests. However, this perception overlooks one of its most remarkable features: most of the Cerrado's biomass lies underground (Fig. 7) (Terra et al. 2023). Its trees and shrubs have roots that can reach depths of over 15 m, forming a true inverted forest that sustains the vegetation during long dry periods and assists in recharging underground aquifers. This underground structure is not just an adaptation to water scarcity but also serves as one of the main carbon reservoirs of the Ecodomain, stabilizing carbon in the deepest soil layers (Terra et al. 2023). The Cerrado biomass stores, on average, approximately 158 tons of carbon per hectare, with about 87% located belowground and only about 13% aboveground, based on extensive sampling carried out across the Ecodomain (Fig. 7) (Terra et

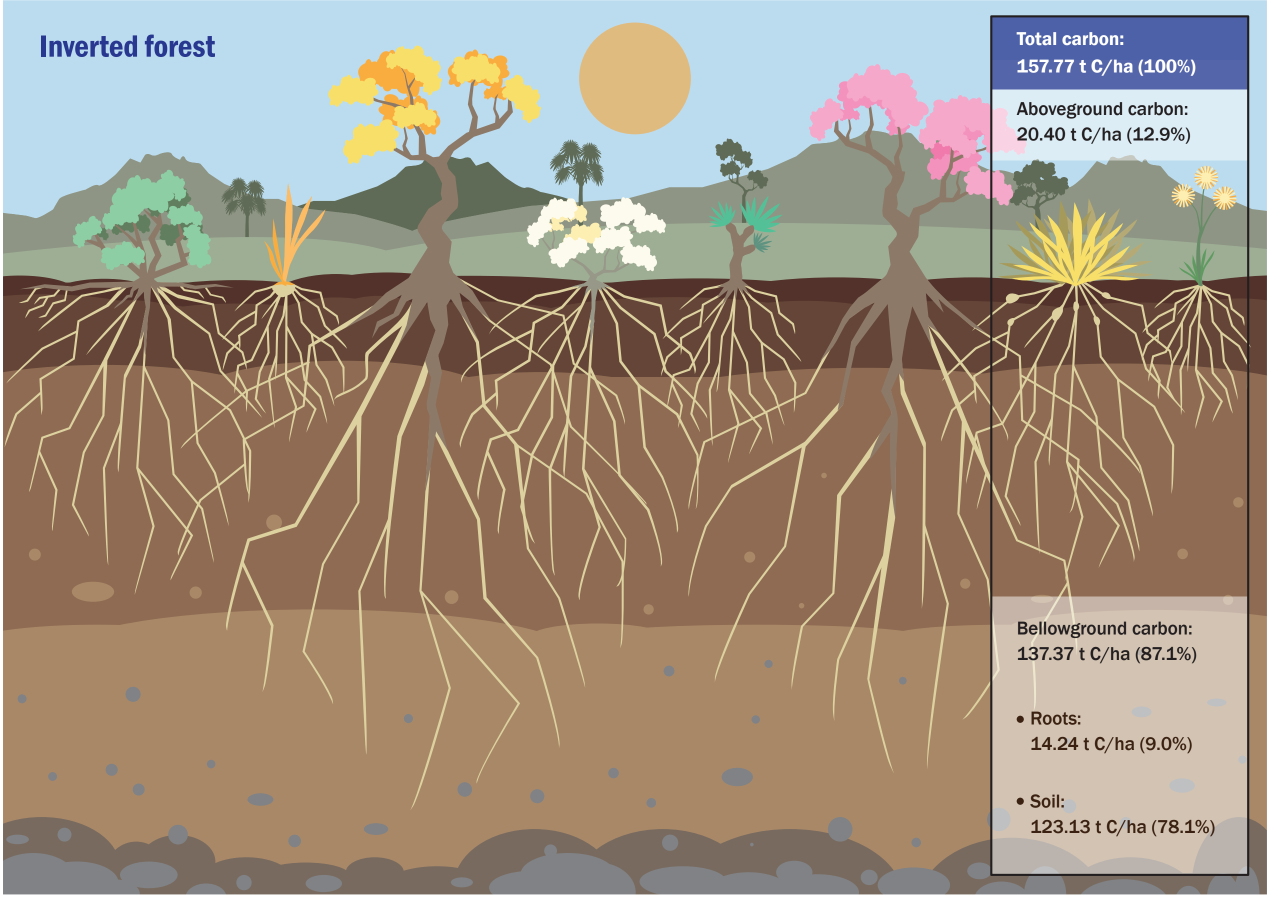

Figure 7. Schematic representation of the distribution of carbon stocks in the Cerrado, characterized as an "inverted forest" due to the predominance of biomass and carbon belowground. Estimates were obtained from Terra et al. (2023). Figure design: Walisson Kenedy-Siqueira.

al. 2023). These numbers reveal that most of the Cerrado's carbon lies where the eye cannot see and that any intervention that compromises the soil or roots can release large amounts of CO_2 into the atmosphere, reversing the Ecodomain's role as a natural carbon sink. Preserving this underground structure is, therefore, essential for maintaining the region's climate and water stability (Box 2).

In this context, afforestation—the planting of trees in areas that were not historically forested—becomes a threat disguised as a solution (Box 2) (Veldman et al. 2015b; Fernandes et al. 2016; Veldman et al. 2019). Although promoted as a climate mitigation strategy, when applied to naturally open ecosystems such as the Cerrado, it can do more harm than good. Replacing native vegetation with homogeneous exotic plantations, such as *Pinus* spp. L. or *Eucalyptus* spp., can alter water dynamics, harm herbaceous biodiversity, increase soil erosion, and accelerate the decomposition of soil organic matter, transforming ecosystems that once acted as carbon sinks into carbon sources (Veldman et al. 2015b; Fernandes et al. 2016; Veldman et al. 2019; Pereira et al. 2024b). Misguided restoration using species not naturally found in these ecosystems can have the same harmful consequences as afforestation. It is more effective and more cost-efficient to conserve what already works than to try to rebuild what has been lost (Pereira et al. 2024b). We must, above all, fight for what remains: protecting the remaining intact fragments of the Cerrado is the most direct and efficient way to preserve its ecological and climatic role.

But conserving what survives is not enough. After halting further loss of the original Cerrado vegetation, it will be necessary to restore degraded areas, especially regions overtaken by abandoned croplands and exhausted pastures, which today occupy vast portions of the territory without ecological or productive function (Box 2) (Pereira et al. 2024b). In these empty landscapes, restoration presents a concrete opportunity for environmental and climate recovery, as long as it is guided by diversity, functionality, and ecological context (Pereira et al. 2024b). Although natural regeneration is desirable, it depends on the integrity of the soil seed bank, which has proven to be severely compromised in degraded areas in the Cerrado Ecodomain (Dairel and Fidelis 2020). Studies show that global warming and land-use changes favor the germination of invasive species seeds in these seed banks (Kenedy-Siqueira et al. 2025), such as *Melinis minutiflora* P. Beauv. and *Urochloa brizantha* (A. Rich.) R. D. Webster, which inhibits the regeneration of native flora (Hoffmann and Haridasan 2008; Damasceno et al. 2018). To overcome these barriers, the strategic use of *in situ* and *ex situ* seed banks are essential (Table 2), integrated with techniques such as biomass transposition, which can accelerate the structural and functional recovery of native vegetation (Buisson et al. 2021; Pilon et al. 2023).

However, the available nurseries still lack the diversity needed to restore the Cerrado with ecological fidelity (Silveira et al. 2018). Collections are dominated by a few tree species, while grassland plants, fundamental to the structure and resilience of the Ecodomain, remain neglected (Schmidt et al. 2019). In addition, the efficacy of seed bank-based restoration depends on the presence of species with high viability and the ability to adapt to novel local edaphoclimatic conditions (Martins and Engel 2007). Challenges such as the dominance of invasive species in seed banks and the limited longevity of some seeds require continuous monitoring and adaptive management (Dairel and Fidelis 2020). This situation forces restoration practitioners to resort to generic sets of species, creating homogeneous landscapes that are ecologically fragile and disconnected from local realities (Toma et al. 2024). However, integrating soil seed banks with complementary techniques, such as biomass transposition, offers a promising approach to accelerate the recovery of plant community structure and function (Buisson et al. 2021; Pilon et al. 2019, 2023). Therefore, restoring the Cerrado requires more than planting; it demands rebuilding ecological connections based on reference ecosystems (Pereira et al. 2024b), with investment in seed supply chains, applied research, and long-term public policies. Only through such comprehensive efforts can we truly cultivate a sustainable future.

Protecting the Cerrado: the role of conservation units and the need for expansion

The Cerrado is currently facing a serious environmental threat. The unbridled clearing of Cerrado, the disorderly expansion of agricultural frontiers, and the increasing fragmentation of natural ecosystems are placing unprecedented pressure on this Ecodomain (Strassburg et al. 2017). Given this context, we have not only a moral duty but an urgent collective responsibility to conserve what remains before we irreversibly lose one of the planet's ecological pillars. The National System of Conservation Units (SNUC) is a Brazilian conservation policy instrument, established by Law No. 9985 of July 18, 2000 (Presidência da República 2000), that is one of the main legal tools to curb environmental degradation (Box 2). The SNUC aims to create Conservation Units (UCs), conserve biodiversity, protect natural resources, ensure the maintenance of ecosystem services, value cultural diversity, promote sustainable development in its surroundings, guarantee the rational use of natural resources for present and future generations, and contribute to the mitigation of climate change (Presidência da República 2000). Its benefits go beyond territorial limits, contributing directly to environmental stability on regional and global scales (Strassburg et al. 2017; Pereira et al. 2024b).

The Cerrado currently has 706 UCs, divided into two major categories provided for by the SNUC: strictly protection and sustainable use (see Box 2, Table 3, Fig. 8; for detailed information on all UCs, see Suppl. material 1). The main objective of full protection UCs is to preserve nature, allowing only indirect use of natural resources, such as scientific research, environmental education, and controlled ecotourism, without compromising protected ecosystems. Sustainable use UCs allow the exploitation of natural resources in a planned and responsible manner, reconciling conservation with sustainable human activities (Presidência da República 2000). Of the UCs in the Cerrado, 233 are strictly protection, with emphasis on Parques Nacionais (PARNAs; n = 16), Parques Estaduais (n = 69), Parques Naturais Municipais (n = 63), Reservas Biológicas (n = 13), Estações Ecológicas (n = 30), Refúgios de Vida Silvestre (n = 13), and Monumentos Naturais (n = 29). In contrast, 473 UCs focus on sustainable use, including Áreas de Proteção Ambiental (APAs; n = 145), Reservas Particulares do Patrimônio Natural (RPPNs; n = 277), Florestas Nacionais (FLONAs; n = 8), Florestas Estaduais (n = 9), Áreas de Relevante Interesse Ecológico (n = 27), Reservas Extrativistas (RESEXs; n = 5), and Reservas de Desenvolvimento Sustentável (n = 2; see Box 2, Table 3, Fig. 8; for detailed information on all UCs, see Suppl. material 1). However, despite the high number of UCs in the Cerrado, most of them have a small territorial extension, which means that approximately 8% of the Ecodomain's total area is effectively protected, of which less than 3% are fully protected areas—a percentage insufficient to guarantee its ecological resilience and the conservation of its biodiversity (Strassburg et al. 2017; Rausch et al. 2019; Pereira and Fernandes 2022b).

Table 3. Distribution of conservation units within the Cerrado Ecodomain, organized by unit type, management category, number of units, and percentage of units. For more details on all Conservation Units, see Suppl. material 1.

Conservation Unit type	Category	Number of Units	Percentage of Units (%)
Área de Proteção Ambiental	Sustainable use	145	20.54
Área de Relevante Interesse Ecológico	Sustainable use	27	3.82
Estação Ecológica	Strictly protection	30	4.25
Floresta Estadual	Sustainable use	9	1.27
Floresta Nacional	Sustainable use	8	1.13
Monumento Natural	Strictly protection	29	4.11
Parque Estadual	Strictly protection	69	9.77
Parque Nacional	Strictly protection	16	2.27
Parque Natural Municipal	Strictly protection	63	8.92
Refúgio de Vida Silvestre	Strictly protection	13	1.84
Reserva Biológica	Strictly protection	13	1.84
Reserva de Desenvolvimento Sustentável	Sustainable use	2	0.28
Reserva Extrativista	Sustainable use	5	0.71
Reserva Particular do Patrimônio Natural	Sustainable use	277	39.25

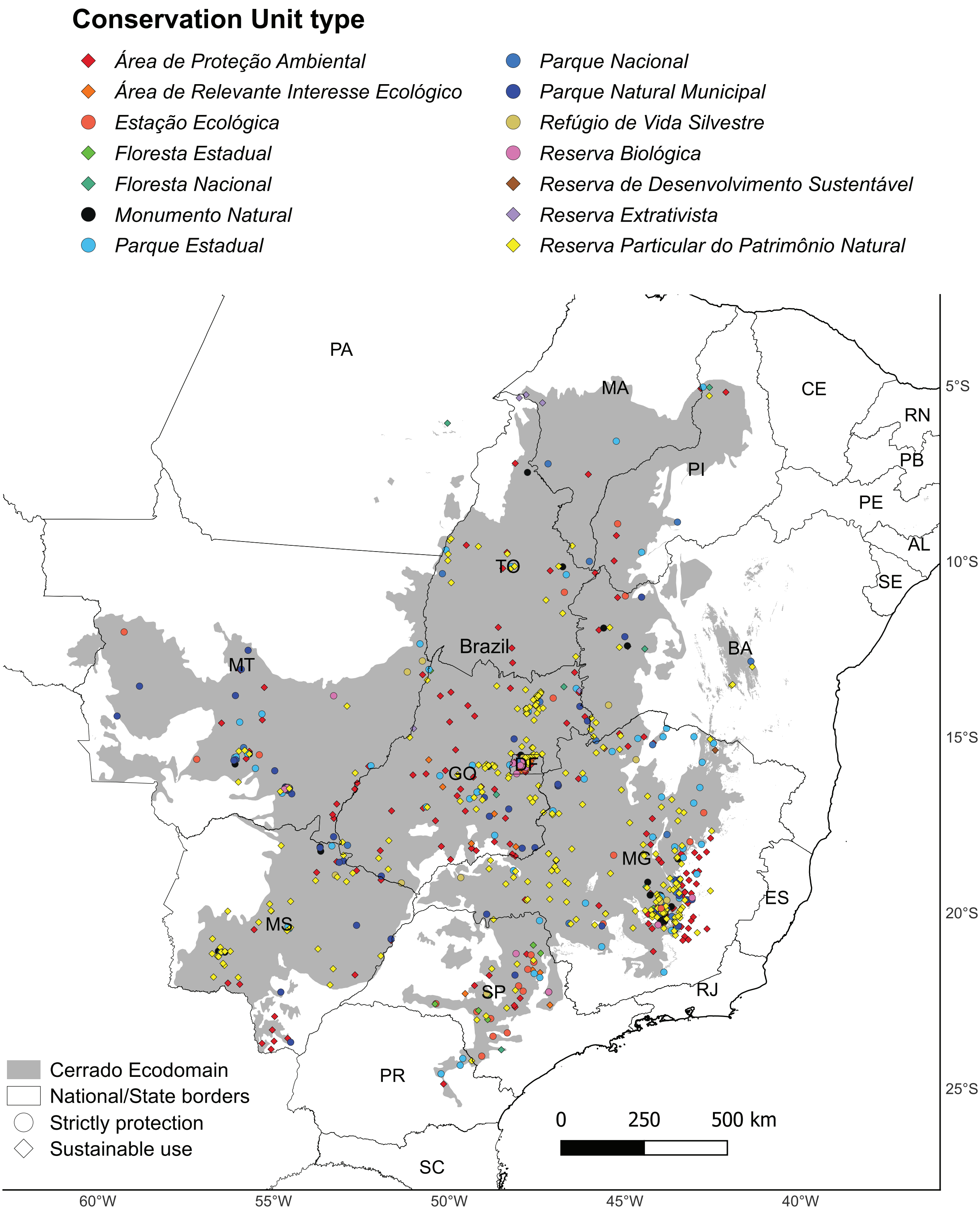

Figure 8. Spatial distribution of the 705 Cerrado Ecodomain Conservation Units organized by Unit type. Each colored dot represents a unit, grouped into 14 Unit types according to the National System of Conservation Units (SNUC). For more details on each of these units, see Suppl. material 1. This map was made using the Cerrado shapefile developed by Cássio Cardoso Pereira, which incorporates refined boundaries of the Ecodomain. Figure design: Cássio Cardoso Pereira.

The modest proportion of protected areas in the Cerrado contrasts sharply with international goals, such as the former Aichi Target 11, linked to the Convention on Biological Diversity (CBD), which recommended protecting 17% of terrestrial biomes by 2020 (Convention on Biological Diversity 2020), and the Kunming-Montreal Global Biodiversity Framework, which proposes increasing this level to 30% by 2030 (Convention on Biological Diversity 2024). These goals are considered minimum levels necessary to ensure ecological representation and connectivity between natural habitats. However, between 2019 and 2023, the area of UCs in the Cerrado grew by only 0.7% (Instituto de Pesquisa Ambiental da Amazônia 2024), keeping the Ecodomain far below these global commitments. It is therefore essential to expand the connection of UCs, especially in areas already identified as priorities for biodiversity conservation (Fig. 5B) (Strassburg et al. 2017; Morandi et al. 2020). These regions were delimited based on spatial analyses that considered criteria such as biological diversity, degree of threat, ecological connectivity, and the presence of endemic and threatened species, revealing large portions of the Ecodomain that remain unprotected, especially in areas of agricultural frontiers and high anthropic pressure (Fig. 5B). Furthermore, studies indicate that well-targeted restoration strategies, especially in critical areas such as ecological corridors, can prevent up to 83% of projected extinctions of endemic plants (Strassburg et al. 2017), reinforcing the importance of integrating conservation and functional reconnection of the landscape.

Given the data and challenges presented, it is clear that protecting the Cerrado is a priority that transcends the environmental agenda, it involves water security, social justice, food sovereignty, and a commitment to future generations. Expanding UCs, strengthening the SNUC, respecting traditional territories, and recognizing the intrinsic value of the Cerrado are vital and urgent steps that cannot be postponed. However, in addition to creating new protected areas, it is essential to consider the functional connectivity between natural fragments (Fig. 5B) (Morandi et al. 2020). The fragmentation of the Cerrado, driven by agricultural expansion and intensive land use, compromises gene flow, ecological integrity, and the survival of endemic and endangered species (Klink and Machado 2005). The implementation of ecological corridors between conservation units, especially in regions of high human pressure, represents an effective strategy to mitigate this isolation and increase the resilience of the Ecodomain (Morandi et al. 2020). Finally, making these actions viable on a scale compatible with the challenges requires the coordinated engagement of public authorities, companies, and international actors, with the strengthening of climate and environmental financing mechanisms focused on conservation (Strassburg et al. 2017; Pereira et al. 2024b). Instruments such as the new Global Biodiversity Fund, launched in 2023 by 186 countries, represent a promising step in the international mobilization for nature-based solutions, with the potential to finance the restoration of strategic ecosystems such as those found in the Cerrado (Pereira et al. 2023). Preserving the Cerrado means preserving life in all its forms and this is a collective choice that requires political will, coordinated action, and the courage to see this territory not as an economic frontier, but as a natural heritage that urgently needs to be defended.

Forest Code: legal limits, ecological risks

The Brazilian Forest Code (Law 12,651, of 05/25/2012: Presidência da República 2012) was established with the purpose of making land use exploration compatible with environmental conservation, through the establishment of standards aimed at protecting native vegetation in different territorial contexts (Box 2) (Presidência da República 2012). However, its application in the Cerrado has proven insufficient in view of the ecological vulnerability of the Ecodomain (Pereira and Fernandes 2022b; Pereira et al. 2024a). The minimum percentages currently required by the Forest Code, 20% of Reserva Legal—an area in each property that must be kept in the original vegetation (see Box 2)—or 35% in the areas of the Legal Amazon region—an area of 5 million km^2 that encompasses Brazil's "Amazon biome" and part of the "Cerrado biome"—have been adopted as a legal ceiling, when they should represent a minimum level of conservation (Metzger et al. 2019). Weak enforcement, combined with low effectiveness of sanctions, contributes to the persistence of illegalities and the acceleration of environmental degradation processes, such as recurrent clearing of vegetation, fires, inappropriate land use, and encroachment on protected areas (Metzger et al. 2019; Pereira et al. 2024a). Furthermore, even when these percentages are formally respected, the resulting fragments of native vegetation tend to present a high degree of isolation and functional impairment, forming islands surrounded by monocultures and pastures that, in general, show advanced signs of degradation.

This scenario is intensified when observing Áreas de Preservação Permanente (APPs: "permanent protection areas" in public and private properties that must maintain their original vegetation, such as riverbanks, hilltops, and steep slopes, which play a critical role in maintaining water stability, containing erosion processes, and in ecological connectivity (Box 2). However, these environments have been systematically pressured by different economic vectors: hilltops and slopes are targets of mining and real estate speculation, while riverbanks and wetlands suffer from the advance of mechanized agriculture, intensive livestock farming, artificial drainage, and the disorderly expansion of rural infrastructure (Metzger et al. 2019). These impacts compromise essential functions such as water infiltration, sediment retention, and aquifer recharge. This neglect is even more serious when it comes to non-forest formations, such as Campo Rupestre, whose constant threat of exclusion from preservation devices lacks technical or ecological justification (Overbeck et al. 2024). Despite their relevance, the APP strips currently provided for in the Forest Code are ecologically insufficient to guarantee such functions in contexts of increasing climate instability.

The current delimitation of APPs along watercourses presents a profound ecological incongruence when applied to Cerrado ecosystems, especially forested ones, since small watercourses are not associated with smaller forests. While standing forests can be protected, this problem is particularly masked when ecosystems are already degraded and cleared, as simply observing a stream in the middle of a pasture does not convey to people the idea of the forest that previously existed. According to the law, rivers up to 10 m wide must maintain a minimum strip of 30 m of native vegetation on each bank (Presidência da República 2012), a value that, from an ecological perspective, is substantially less than the average natural width of Matas Ciliares, which can exceed 100 m before transitioning to other ecosystem types (Ribeiro and Walter 2008). This discrepancy is exacerbated by the fact that, in the Cerrado, the vast majority of watercourses are narrow, so that, according to the legislation, only exceptionally wide rivers (200 to 600 m) would have their Matas Ciliares fully preserved, a very rare situation in the region, since such wide rivers are generally found only in the Amazon Ecodomain. Even more serious is the case of Matas de Galeria, the Cerrado's evergreen forests, with a denser canopy and taller trees than in other Cerrado forest ecosystems (Ribeiro and Walter 2008). These forests typically occur between the crevices of the region's valleys, covering most of the region's smaller streams and watercourses (Fig. 9). Therefore, it is a contradiction that such ecosystems receive a minimum protection of only 30 meters, when many of them can exceed the width of Matas Ciliares. Thus, this 30-meter width ignores the natural average width of this ecosystem and undermines its function of regulating the microcli-

Figure 9. Ecotone showing a Mata de Galeria amidst a Campo Sujo matrix in Congonhas, Minas Gerais, Brazil. The current delimitation of Permanent Protection Areas (APPs) along watercourses, based solely on their widths, does not reflect the ecological reality of Matas de Galeria. These dense, evergreen forests occur in valleys and are associated with small watercourses, but the legislation only guarantees a 30-meter width of protection for rivers up to 10 meters wide. This measure ignores the natural width of Matas de Galeria, compromising their ecological function, such as regulating the microclimate, providing habitats, and water provision. While standing forests can be protected, this problem is particularly exacerbated when ecosystems are already degraded and deforested, as simply observing a stream in the middle of a pasture or urban area doesn't convey to people the idea of the forest that previously existed. Therefore, legally defining the extent of APPs based solely on the size of the water body, rather than the actual extent of the riparian ecosystem, makes restoration of these areas unfeasible due to the loss of their natural extent due to land-use changes. For information on these ecosystems, see Box 2, Fig. 4. Photo credit: Cássio Cardoso Pereira.

mate, providing habitats, supporting complex ecological interactions, and impairs ecological services, including water supply (Fig. 9). While standing forests can be protected, this problem is particularly exacerbated when ecosystems are already degraded and cleared, as simply observing a stream in the middle of a pasture or an urban area does notconvey to people the idea of the forest that previously existed. Therefore, legally defining the extent of APPs based solely on the size of the water body, rather than the actual extent of the riparian ecosystem, disregards the ecology of these ecosystems and makes restoration of these areas unfeasible due to the loss of their natural extent caused by land-use changes. Finally, the situation is further aggravated in Reservas Legais, different from APPs and located within rural properties, where the law requires only the preservation of the spring, without requiring conservation of the adjacent watercourse, allowing the almost complete suppression of riparian forests in these areas.

Institutional neglect also becomes evident in the case of marshland formations, such as Veredas, marshes, and swamps, which, despite being recognized as protected by law, remain invisible in territorial planning and public policies (Bassani et al. 2025). These areas fulfill essential functions of storing and gradually releasing water, contributing decisively to the water stability of the Ecodomain. However, they have been progressively degraded due to the lack of accurate mapping, fragmentation of vegetation, and the incidence of unmonitored illegal interventions such as drainage, intensive agricultural use, and soil compaction (Bassani et al. 2025). Even with legal protection, these areas remain vulnerable due to institutional fragility and low budgetary prioritization in monitoring, active protection, and restoration actions.

It is clear that the Forest Code needs to be reformed, but Brazil's current political configuration means that this will have to wait. Currently (in 2025) Brazil's National Congress is controlled by voting blocks that threaten virtually all of the country's environmental legislation and make introducing new environmental proposals counterproductive. The "ruralists" (representatives of large landholders) have 59% of the seats in the Chamber of Deputies and 62% in the Senate (Frente Parlamentar da Agropecuária 2025); this overlaps with the eight political parties that make up the Centrão ("big center") voting block (Testa et al. 2024) that controls 69% of the Chamber of Deputies and 75% of the Senate (Congresso Nacional 2025), in addition to holding the presidencies of both chambers. The ruralists and "centrão" together, discounting the overlap, hold 77% of the Chamber of Deputies and 85% of the Senate. The "centrão" has supported important ruralist proposals in weakening environmental control, as in 2023 when several key responsibilities were removed from the Ministry of Environment and Climate Change and the Ministry of Indigenous Peoples.

Proposing amendments to strengthen the Forest Code would merely provide an opportunity for anti-environmental voting blocks to introduce amendments that would further weaken environmental control even further. This is shown by a bill (PL 2159/2021: Câmara Legislativa 2025) known as the "bill of devastation" that was originally introduced in 2021 to strengthen the environmental licensing system but that has now been converted through amendments to essentially destroy that system (Fearnside 2025). Filling out a self-declared online form substitutes for licensing for projects classed as having "small" or "medium" impact, the latter being a class that includes mine tailings dams that burst causing major disasters at Mariana in 2015 and Brumadinho in 2019. Projects even in the most severe impact category would have a "special" licensing process guaranteeing approval within one year if they are deemed to be "strategic" by a committee representing economic and political interests.

When Brazil's political scenario becomes more favorable to environmental legislation, changes to the Forest Code are needed on five converging fronts: (1) increasing the minimum percentage of Reserva Legal to 35% throughout the Cerrado, as the national standard for the Ecodomain; (2) expanding the APP strips by at least 50 meters along all watercourses; (3) expanding the APP category, recognizing new plant formations that have been historically neglected, such as the Corredores de Valo—hedgerows dug by enslaved people during the colonial period, and which were naturally colonized by species native to the region, with high biodiversity and capable of maintaining and making biological connections (Castro and van den Berg 2013; Alvarenga et al. 2025; Ávila et al. 2025); (4) improving the mechanisms for monitoring and applying environmental fines, with penalties proportional to the damage caused and focusing on recidivism; and (5) mandatory environmental traceability, with the exclusion of illegal producers from national and international production chains (Fernandes et al. 2023b). No responsible production system can accept inputs that are produced in violation of Brazilian legislation. Strengthening governance over land use in the Cerrado is not only an ecological imperative but also a strategy for climate security and intergenerational justice.

Recognizing and protecting Indigenous lands

Indigenous peoples have influenced the Cerrado region for thousands of years, likely since their arrival in South America (Araujo et al. 2012). They may have initially played a significant role in the extinction of much of the megafauna that once inhabited the area, although some scholars attribute these extinctions primarily to climate change following the glacial period (Barnosky and Lindsey 2010). Since then, Indigenous practices such as fire management and traditional agriculture have had a notable impact on the structure of the vegetation, supporting the diversity of plants and animals that survived that first wave of extinction (Antonelli 2023). Their land management strategies have also contributed to the expansion of savanna ecosystems over forested areas, shaping the Cerrado as it exists today.

Although these historical ecological transformations continue to be debated academically, one undeniable truth persists: Indigenous peoples have inhabited the Cerrado for millennia and are an intrinsic part of its ecosystem. When Brazil was first colonized by Europeans, Indigenous communities were already established across the Cerrado, which remained completely preserved. The Cerrado, spanning over 2 million km^2, was intact, untouched by large-scale exploitation. The presence of Indigenous peoples today is not an external force altering the landscape, but rather a fundamental component of its balance. Unlike exploitative hunting practices driven by commercial interests, Indigenous hunting is carried out for survival, guided by cultural traditions and ecological knowledge that ensure the sustainability of local species. Any narrative suggesting that Indigenous peoples initiated environmental degradation or contributed to the devastation of the Cerrado is misleading. Rather than disruptors, they have been its guardians (Resende et al. 2021; Lima et al. 2024; Virtanen et al. 2025), maintaining a deep connection with the land and preserving its biodiversity for thousands of years (Resende et al. 2021).

For a long time after the Portuguese arrived on the Brazilian coast in 1500 CE, the effects of colonization remained largely confined to the Atlantic Forest region (Jepson et al. 2010). This dynamic began to shift with the expansion of gold and gemstone mining, followed by the rise of cattle ranching in the 18th and 19th centuries. However, the most profound transformation of the Cerrado occurred in the mid-20th century, when Brazil's capital was moved to the Central Plateau, at the heart of the Cerrado. The resulting influx of agricultural technologies for large-scale production of soybeans, introduced by farmers from the country's southern and southeastern regions, accelerated the environmental change, pushing agricultural frontiers deeper into Indigenous territories and triggering devastating consequences for these communities (Klink and Machado 2005).

Despite these mounting pressures, Indigenous land rights remained largely unaddressed until 1988, when the current Brazilian Federal Constitution was adopted, mandating the re-demarcation of all Indigenous lands within five years. Yet, this politically contentious process remains incomplete, leaving many territories in a state of uncertainty (Lima et al. 2024). Currently, around 100,000 Indigenous people from at least 83 different ethnic groups inhabit the Cerrado (IBGE 2023), distributed across around 109 recognized territories—most of them overlapping large continuous areas of the Cerrado-Amazon border—in an area of approximately 8,800,000 hectares, that is, 4.4% of the area that was originally Cerrado, in addition to other claimed and regularized areas (Fig. 5C). Although their presence in the region is deeply rooted, a significant portion of these lands have yet to receive full legal recognition, exposing Indigenous communities to ongoing territorial disputes and environmental threats, particularly the ongoing movement of deforesters and land grabbers who have been expelled from the Amazon and are invading land on the Amazon-Cerrado border (Begotti and Peres 2019; Pereira et al. 2024a).

Recent legislative actions by the Brazilian Congress have exacerbated this crisis. The law of the Marco Temporal ("time stamp") (Law no. 14,701, of 10/20/2023, see Presidência da República 2023) stipulates that only Indigenous peoples who can prove they occupied their territories at the time of the 1988 constitution have rights to those lands. This policy presents a significant obstacle to the recognition of new Indigenous lands, particularly in regions where occupation by non-Indigenous invaders surged in the early to mid-20th century. At the same time, agribusiness-backed proposals seek to legalize large-scale soy plantations and cattle ranches on Indigenous lands. If approved, such measures risk transforming these territories into extensions of industrial agriculture, accelerating biodiversity loss, weakening the Cerrado's ecological resilience (Lima et al. 2024), and reducing the size of Indigenous territories (Portela et al. 2024).

Mobilizing knowledge and adding value for Cerrado sustainability

Ensuring the sustainability of the Cerrado requires mobilizing knowledge across Brazil's diverse socioeconomic landscape, especially among those who inhabit or directly depend on this ecosystem (Klink and Machado 2005; Bennett et al. 2017). Fostering a deeper understanding of its ecological significance helps dismantle the misconception that only densely forested areas are environmentally valuable (Overbeck et al. 2015; Silveira 2025). As citizens become more informed, they are empowered to advocate for the Cerrado's protection and hold policymakers accountable, particularly those with vested interests in intensive exploitation (Rajão et al. 2020). Concrete examples of environmental disasters, such as the Mariana mining disaster in 2015 and the Brumadinho mining disaster in 2019, named after the municipalities to which the affected districts and villages belong (although their impacts extended far beyond these municipalities), illustrate the consequences of inadequate governance and highlight the urgent need for stronger environmental oversight (Pereira et al. 2024c). Grounded in both scientific evidence and traditional knowledge, this growing civic awareness provides the foundation for an alternative development model rooted in ecological integrity and long-term resilience (Strassburg et al. 2014, 2017).

In this context, a key strategy is to transition from an extractive to a regenerative economic logic by adopting a "value-over-volume" approach to the Cerrado's productive systems. This entails not only improving the efficiency of existing agricultural practices, but also decisively curbing the expansion of extensive cattle ranching and large-scale soy monocultures, which remain the primary drivers of Cerrado clearing and ecological degradation (Pereira et al. 2024b). To make this transition more operational, we suggest models that can guide conservation projects in the Cerrado. These models include: community-based restoration programs that integrate local ecological knowledge with scientific monitoring; (ii) cooperative production chains centered on native biodiversity, where communities collectively manage harvesting, processing, and certification; (iii) regenerative agro-silvopastoral systems that reintroduce native species into productive landscapes; and (iv) territorial governance arrangements that combine ecological corridors, Indigenous management practices, and sustainable-use mosaics. In place of these models, efforts should prioritize ecological restoration and increasing the value of native Cerrado resources through more-sustainable alternatives such as premium certified products, including fruits, seeds, roots, bark, resins and oils, unconventional honey and propolis, and payments for ecosystem services (Lambin et al. 2018; World Economic Forum 2024). The Cerrado can reposition itself as a leading global example of equitable land-use transition, one that reconciles nature, economy, and social justice within a climate-resilient future (Ripple et al. 2024).

Finally, it is essential to reclaim the very meaning of "sustainable development" (Fearnside 2023). It goes far beyond green marketing or ornamental landscaping—it is about preservation, restoration, and the creation of viable alternatives to destructive land use (Parris and Kates 2003). It does not mean expanding monocultures or paving over ecosystems in the name of progress, as seen in the proliferation of soybean plantations or the unchecked urbanization of former pastures under the guise of "eco-friendly" neighborhoods. Instead, it requires a structural reorientation: recovering degraded areas, investing in nature-based economies, and empowering communities to lead the stewardship of their territories. This includes not only Indigenous peoples but also other traditional communities such as Quilombolas and Geraizeiros, whose practices support biodiversity conservation. These groups play key roles in maintaining biodiversity, including the conservation of pequi, the ornamental plant trade such as sempre vivas, and sustainable use networks (da Silva et al. 2025). To fully realize this shift, conservation must be incentivized through national and international collaboration (Latrubesse et al. 2019;

Pereira et al. 2023). In Brazil, mechanisms such as the ICMS Ecológico (Ecological Value-Added Tax, a fiscal policy that redistributes part of the state sales tax to municipalities based on their efforts to protect and conserve natural areas) provide fiscal incentives to municipalities that protect natural areas, rewarding local governments financially for maintaining and restoring native ecosystems, thereby strengthening local conservation efforts. Product certification schemes—such as Forest Stewardship Council, Rainforest Alliance Certification, and Union for Ethical BioTrade Certification—can also provide financial rewards and market access. Business expertise is vital in the early stages to assist communities with cooperative formation and commercialization logistics, ensuring benefits are retained locally (Ajates Gonzalez 2017; Natura &Co 2020). Carbon credit recognizing the Cerrado's deep-root biomass may become another income source, but this depends on as-yet unsettled institutional arrangements to avoid abuse, fraud, and unrealistic accounting for carbon benefits (Fearnside 2012; West et al. 2024). We must also advocate for payments for environmental services such as water provision, as well as support the payment of carbon credits to Indigenous territories to support their survival and the maintenance of their lands. The Cerrado should be positioned prominently on the global sustainability agenda, making its critical role in climate regulation and biodiversity impossible to ignore. Through heightened awareness and strategic alliances, we can develop conservation approaches that harmonize ecological integrity with social equity.

Conclusions

We conclude that conserving the Cerrado necessitates full recognition of its extraordinary biodiversity, ecological complexity, sociocultural value, and pivotal role in regulating Brazil's climate. This preservation depends on actions that go far beyond the specific reinforcement of existing policies: it is necessary to reformulate legal frameworks, significantly expand the number and scope of Conservation Units, adequately manage production areas, ensure the effectiveness of public policies, value traditional knowledge, and foster regenerative economies that respect the ecological limits of the territory. The Cerrado can no longer be seen as a mere agricultural frontier or "expansion reserve." It is a living system, essential to national and global environmental stability. Maintaining its ecosystems and associated biodiversity is a prerequisite for addressing contemporary crises involving climate, water and food, as well as social and ethical issues. Future solutions must integrate science, participatory governance, and socio-environmental justice, promoting a development model anchored in protection of the remaining original vegetation followed by the restoration of degraded areas. This development model must include equitable distribution of resources and co-responsibility between the state, civil society, and the productive sector. Strengthening research, monitoring, environmental education, and community initiative networks will be crucial to transforming knowledge into transformative action. We reinforce the urgency of repositioning the Cerrado at the center of the environmental agenda and recognizing that ensuring its continuity also means ensuring that the Cerrado's biodiversity continues to contribute vigorously to the planet's environmental balance and to building a more just, resilient, and diverse future.

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The authors have declared that no competing interests exist.

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Author contributions

Cássio Cardoso Pereira conceived the ideas; Cássio Cardoso Pereira and Lara Ribeiro Maia collected the data used in this manuscript; Cássio Cardoso Pereira and Walisson Kenedy-Siqueira made the figures; Cássio Cardoso Pereira led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Supplementary material 1

Conservation Units (UCs) located in the Cerrado Ecodomain, encompassing different management categories, with information on name, category, federative state, total area, and geographic coordinates

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