University of Kent

Kent Academic Repository

Martins, Juliana Ávila and Smith, Robert J. (2026) *Producing a Red List of Ecosystems for the Brazilian Cerrado*. Conservation Science and Practice, 8 (11). ISSN 2578-4854.

Downloaded from
https://kar.kent.ac.uk/116894/ The University of Kent's Academic Repository KAR

The version of record is available from
https://doi.org/10.1111/csp2.70426

This document version
Publisher pdf

DOI for this version

Licence for this version
CC BY (Attribution)

Additional information

Versions of research works

Versions of Record
If this version is the version of record, it is the same as the published version available on the publisher's web site. Cite as the published version.

Author Accepted Manuscripts
If this document is identified as the Author Accepted Manuscript it is the version after peer review but before type setting, copy editing or publisher branding. Cite as Surname, Initial. (Year) 'Title of article'. To be published in ***Title of Journal*** , Volume and issue numbers [peer-reviewed accepted version]. Available at: DOI or URL (Accessed: date).

Enquiries
If you have questions about this document contact ResearchSupport@kent.ac.uk. Please include the URL of the record in KAR. If you believe that your, or a third party's rights have been compromised through this document please see our Take Down policy (available from https://www.kent.ac.uk/guides/kar-the-kent-academic-repository#policies).

Check for updates

Received: 12 March 2025 | Revised: 28 July 2026 | Accepted: 30 August 2026

DOI: 10.1111/csp2.70426

CONTRIBUTED PAPER

Conservation Science and Practice
A journal of the Society for Conservation Biology
Open Access

WILEY

Producing a Red List of Ecosystems for the Brazilian Cerrado

Juliana Ávila Martins[1,2,3] | **Robert J. Smith**[3]

[1]Centre for Environmental Policy, Imperial College London, London, UK

[2]Institute of Zoology, Zoological Society of London, London, UK

[3]Durrell Institute of Conservation and Ecology, School of Natural Sciences, University of Kent, Canterbury, UK

Correspondence
Juliana Ávila Martins, Centre for Environmental Policy, Imperial College London, South Kensington, SW7 1NE, London, UK.
Email: j.martins23@imperial.ac.uk; javilamartins@gmail.com

Abstract

Land clearance is a key driver of biodiversity loss. This is a particular challenge in the Brazilian Cerrado, the world's most biodiverse savanna biome and a region experiencing a rapid expansion of agriculture. To inform habitat conservation and restoration actions, we used the Red List of Ecosystems (RLE) framework to identify threatened ecosystems within the Cerrado. This biome is divided into 20 ecoregions, and we subdivided each ecoregion into forest, savanna, grassland, and wetland ecosystems. We used remote sensing data from 1985 to 2020 to measure and predict the distribution of each ecosystem and assess its risk of collapse based on Criterion A2b (reduction in geographic distribution over any 50-year period), Criterion B1 (limited extent of occurrence), and Criterion B2 (limited area of occupancy). Of the 80 ecosystems comprising the Cerrado, we assessed 12 as Endangered and 43 as Vulnerable. Most of these threatened ecosystems were identified under Criterion A2b, while Criterion B identified a smaller subset of spatially restricted ecosystems, particularly wetlands, underscoring the importance of applying more than one criterion in the assessment process. By using the Red List of Ecosystems as an international standard, we provide the first globally comparable analysis of the state of the Cerrado, showing that nearly three-quarters of the region's ecosystems are at risk of collapse. This information provides a baseline to inform local policy and practice, helping to conserve biodiversity and maintain ecosystem services within this globally important region.

KEYWORDS

Cerrado, deforestation, ecoregions, ecosystems, Red List of Ecosystems, risk assessment

1 | INTRODUCTION

The planet is facing an unprecedented rate of biodiversity loss driven by anthropogenic actions (Pörtner et al., 2023). Addressing this will depend on aligning biodiversity conservation with economic growth, as the primary driver of habitat loss is increasing food production, especially from livestock (Machovina et al., 2015).

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2026 The Author(s). *Conservation Science and Practice* published by Wiley Periodicals LLC on behalf of Society for Conservation Biology.

Conservation action is urgently needed to mitigate this crisis and should be informed by monitoring data on species and habitat loss. The International Union for Conservation of Nature (IUCN) developed the Red List of Threatened Species as the global standard for identifying endangered species and guiding conservation efforts (Chen et al., 2020). This serves as a standardized tool for assessing the global risk of species extinction (Alaniz et al., 2019; Uribe et al., 2020). Building on the Red List of Threatened Species, the Red List of Ecosystems (RLE) was developed to assess biodiversity at a higher level (Keith et al., 2013). The RLE provides a global framework for assessing and monitoring the conservation status of ecosystems, grounded in large-scale ecological processes and key species interactions. Its main role is to identify threatened ecosystems that are in urgent need of protection or restoration, leading to more informed decision-making in conservation planning and natural resource use (Bland et al., 2017; Etter et al., 2020). To achieve this, the RLE identifies criteria related to the risk of ecosystem collapse, which can occur through irreversible loss of biodiversity, ecological functions, or ecosystem services, as well as through significant loss of area or substantial alterations of the abiotic environment (Keith et al., 2013).

Since its inception in 2008, RLE assessments have been carried out in more than 100 countries (Bland et al., 2019). They span a wide range of ecosystems, from forests in China (Chen et al., 2020), tropical glaciers in Venezuela (Ferrer-Paris et al., 2024), mangroves in Myanmar (Lee et al., 2024), to savannas in South Africa (Skowno & Monyeki, 2021). However, savanna systems, despite being among the most biodiverse and globally threatened ecosystems, remain critically underrepresented in conservation agendas and policies (Williams et al., 2022). There is an urgent need for research on this neglected biome to better understand its risk of ecosystem collapse and inform conservation action. Here, we apply the RLE to assess the vulnerability risk and conservation status of the Brazilian tropical savanna, also known as the Cerrado. It is the most biologically diverse savanna in the world and a global hotspot, with 12,000 species of plants, of which 36% are endemic (Klink & Machado, 2005; Mittermeier et al., 2004), and new species are being discovered every year (Albuquerque et al., 2025; Reynel, 2024). It is the second-largest biome in South America, occupying approximately 2 million km^2 and covering 24% of Brazil's territory (Strassburg et al., 2017).

The Cerrado is also globally important for its agricultural production, playing a major part in making Brazil one of the world's leading soybean producers (Nepstad et al., 2019). This expansion of cropland, combined with livestock farming, is a major contributor to the country's economic growth (Klink & Machado, 2005). It is also the primary threat to Cerrado's ecosystems, leading to persistently high rates of natural habitat loss, in contrast to declining rates in Brazil's other biomes (Klink & Machado, 2005). This has been exacerbated by leakage from anti-deforestation conservation measures in the Amazon, leading to the displacement of soy and cattle production and deforestation activities toward the Cerrado (Moffette & Gibbs, 2021). This impact also reflects how conservation in the Cerrado has been under-resourced by the Brazilian government and the international community, compared to the Amazon and the Atlantic Forest (Lahsen et al., 2016). This is evidenced by the fact that only 8.3% of Cerrado's territory has protected area status, compared to 15% nationally (Françoso et al., 2015).

For these reasons, a RLE assessment is key to identifying potentially threatened ecosystems in the Cerrado that need more conservation and restoration investment. In this study, we used data on vegetation types and ecoregions to assess the Red List status of these ecosystems in Brazil based on their: (i) rate of vegetation cover loss and deforestation (RLE Criterion A), and (ii) current geographic distribution (RLE Criterion B). Through this, we identify which ecosystems within this globally important biome are at risk of collapse and compare our results with previous studies.

2 | MATERIALS AND METHODS

2.1 | Categorization

The IUCN RLE tool is underpinned by five criteria. The first two criteria relate to spatial features: Criterion A is based on declining distributions and Criterion B is based on restricted distributions. The second two relate to functional features: Criterion C is based on degradation of abiotic processes and Criterion D is based on decline of biotic processes. Finally, Criterion E uses spatial and/or functional data in predictive models derived from ecosystem dynamics to assess risk of ecosystem collapse. Based on the criteria assessment, each ecosystem is given an assessment indicating the risk level: Least Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN), Critically Endangered (CR), and Collapsed (CO). An additional two categories indicate poor data availability and whether an assessment has taken place: Data Deficient (DD) and Not Evaluated (NE).

2.2 | Study area

A biome is a large collection of ecosystems that have relatively uniform climate conditions, such as similar rainfall and temperature patterns, and share similarities in dominant fauna and flora (Osborne, 2000). Biomes can be

25784854, 2026, 11, Downloaded from https://conbio.onlinelibrary.wiley.com/doi/10.1111/csp2.70426 by NICE, National Institute for Health and Care Excellence, Wiley Online Library on [10/11/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

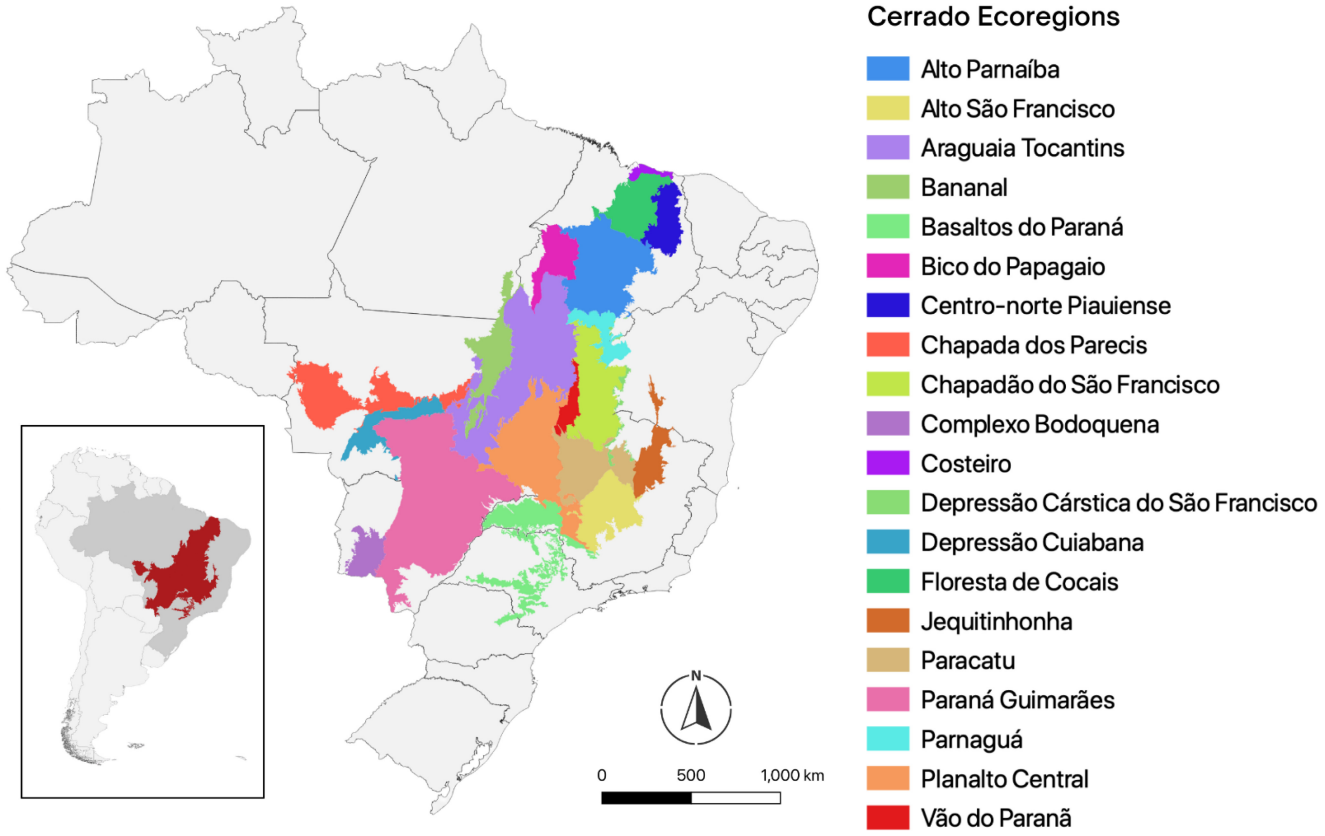


FIGURE 1 Ecoregions of the Cerrado, Brazil.

subdivided into ecoregions, which are defined as the geographically delimited assembly of natural communities that share similar environmental conditions, in which ecological interactions are critical to their long-term survival (Sano et al., 2019). Ecosystems within an ecoregion must be more similar or at least less variable between themselves than ecosystems outside the ecoregion (Omernik & Bailey, 1997). Brazil contains six biomes: the Amazon, Atlantic Forest, Caatinga, Cerrado, Pampa, and Pantanal (Instituto Nacional de Pesquisas Espaciais [INPE], 2020). The Cerrado is divided into 20 ecoregions, delineated by integrating biophysical layers such as relief, climate, soils, geology, geomorphology, and vegetation physiognomy, to group areas with similar environmental characteristics (INPE, 2020; Sano et al., 2019; Figure 1).

In each Cerrado ecoregion, terrestrial ecosystems can be grouped into four broad categories: forests, savannas, grasslands, and wetlands (MapBiomas, 2022). Cerrado's forests are characterized predominantly by their tree species and canopy structure (Ribeiro & Walter, 2008) and can be subdivided into riparian woodland, gallery forest, open-canopy dry forest, and *cerradão*, a closed canopy dry forest (Sawyer et al., 2018). The trees typically have twisted branches, thick bark, and leaves, an adaptation to the dry season and the natural fires of the biome (Sawyer et al., 2018). Cerrado grasslands are predominantly herbaceous, although some physiognomies include scattered shrubs, subshrubs, and occasional small trees (Ribeiro & Walter, 2008). Cerrado wetlands include seasonally or permanently waterlogged ecosystems, such as wet grasslands, veredas (palm swamps), palm groves, wet forests, and swamp gallery forests (Durigan et al., 2022). Cerrado's savanna ecosystems are composed of shrub–herbaceous and arboreal strata and include open woodlands and palm groves sensu stricto (Sawyer et al., 2018). In this paper, we use "savanna ecosystem" to denote this vegetation type within the Cerrado biome. All RLE analyses use this ecosystem-level classification and "biome" is used only for the regional context.

2.3 | RLE assessment

Because the RLE explicitly encourages the use of spatial units that are both ecologically meaningful and useful for management and decision-making (Bland et al., 2017; Keith et al., 2022), it was important to adopt a scale consistent with national conservation planning. In Brazil, ecoregions have been widely adopted in conservation planning since the early 2000s, originally delineated by

25784854, 2026, 11, Downloaded from https://conbio.onlinelibrary.wiley.com/doi/10.1111/csp2.70426 by NICE, National Institute for Health and Care Excellence, Wiley Online Library on [10/11/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

IBAMA/MMA in partnership with WWF and TNC following Dinerstein et al. (1995), and later refined for national biodiversity priority setting (Arruda et al., 2008). The delineation is grounded in biophysical principles, integrating climate, geomorphology, soils, and vegetation physiognomies, and aligning with the official Cerrado biome boundary (Bezerra, 2018; Sano et al., 2019). In this framework, similarity among ecosystems within an ecoregion refers to shared abiotic conditions (e.g., precipitation, geomorphology, and soils), rather than structural or floristic similarity among vegetation types. Although adjacent ecoregions share borders, polygons are non-overlapping and were designed to minimize within-unit heterogeneity while maximizing between-unit differences. This framework has been used in several ecological and spatial planning studies (da Silva Arruda et al., 2024; Ferragutti et al., 2025; Schüler & Bustamante, 2022; Silva et al., 2021). Each Cerrado ecoregion contains four major vegetation types: forest, savanna, grassland, and wetland. Thus, our analysis was based on 80 ecosystems in total.

We used three datasets to map these ecosystems: (1) the Cerrado biome boundary and (2) the Cerrado ecoregion boundaries, both digitized from a 1:250,000-scale map produced by the National Institute for Space Research (INPE, 2020); and (3) 30 m resolution land-cover raster layers derived from satellite imagery for 1985, 1990, 1995, 2000, 2005, 2010, 2015, and 2020 (MapBiomas, 2022). The MapBiomas land-cover dataset provides annual raster layers classified into 25 categories, including natural vegetation types (forest, savanna, grassland, wetland) and anthropogenic uses (pasture, cropland, urban areas, mining, and other non-vegetated classes) (MapBiomas, 2022). For this study, we used these classifications to calculate changes in the total area of natural vegetation over time, without reclassifying or analyzing specific land-cover transitions. Therefore, vegetation loss in our analysis represents a reduction in the mapped extent of each natural ecosystem over time.

Using these datasets, we generated GIS layers for the 80 ecosystems at five-year intervals from 1985 to 2020. We then used this spatial data to assess each ecosystem under Criteria A and B of the IUCN RLE methodology, as described below. When an ecosystem met the thresholds for more than one criterion, we assigned it the highest resulting threat category. Due to the lack of suitable abiotic and biotic data, assessments under Criteria C, D, and E were not possible. However, RLE evaluations are not required to include all the criteria (Keith et al., 2013).

2.3.1 | Criterion A

Criterion A is based on an ecosystem's reduction in geographic distribution and can be assessed based on the previous 50 years (subcriterion 1), the future 50 years (subcriterion 2a), a 50-year period that can include the past, present, and future (subcriterion 2b), and a historical reduction, since approximately 1750 (subcriterion 3). As our dataset showed the distribution of each ecosystem over 1985–2020, we applied subcriterion 2b, measuring rates of reduction for the 35-year period and modeling rates of reduction for the subsequent 15 years. We calculated the area of each ecosystem at each time point using the *Raster Layer Unique Values Report* tool in QGIS (version 3.24). To project change between 2020 and 2035, we first calculated the Absolute Rate of Decline (ARD) and the Proportional Rate of Decline (PRD) for each ecosystem between 1985 and 2020 (Keith et al., 2013; Rodríguez et al., 2011) using the following equations:

$$\text{Absolute rate of decline} = \frac{\text{Area}_{t2} - \text{Area}_{t1}}{\text{Year}_{t2} - \text{Year}_{t1}}$$

$$\text{Proportional rate of decline} = 100 \times \left(1 - \left(\frac{\text{Area}_{t2}}{\text{Area}_{t1}}\right)^{\frac{1}{(\text{Year}_{t2} - \text{Year}_{t1})}}\right)$$

We then determined whether the ARD or the PRD provided a more accurate representation of change for each ecosystem by comparing predicted and observed declines between 1985 and 2020. We calibrated both the ARD and PRD projection models using 2000 as the reference year and selected the rate that minimized the deviation from the observed area in that year (Chen et al., 2020). Using this rate, along with the shape of the trajectory across the time series, we identified the best-fitting model. The selected approach was then applied to project ecosystem coverage in 2035 and calculate the percentage of vegetation loss for each ecosystem between 1985 and 2035. Following the IUCN RLE criteria, ecosystems were classified as Vulnerable if vegetation loss was ≥20% and <50%, Endangered if ≥50% and < 80%, and Critically Endangered if ≥80% (Keith et al., 2013).

2.3.2 | Criterion B

Criterion B is based on an ecosystem's geographic distribution (Keith et al., 2013) and can be assessed based on its extent of occurrence (EOO; subcriterion 1), area of occupancy (AOO; subcriterion 2), or the number of highly threatened locations (subcriterion 3). We applied subcriteria B1 and B2 for all 80 ecosystems; subcriterion B3 was not applicable. For subcriterion B1, we calculated each ecosystem's EOO every 5 years between 1985 and 2020, defined as the area of the minimum

25784854, 2026, 11, Downloaded from https://conbio.onlinelibrary.wiley.com/doi/10.1111/csp2.70426 by NICE, National Institute for Health and Care Excellence, Wiley Online Library on [10/11/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

convex polygon enclosing all patches of that ecosystem (Keith et al., 2013). We converted the raster maps to vector layers using the QGIS *Polygonise* tool, and all patches belonging to each ecosystem class were selected. We then generated the minimum convex polygon using the *Minimum Bounding Geometry* tool in QGIS and measured its area, which was taken as the EOO value. Based on this area and whether it declined continuously between 1985 and 2020, ecosystems were classified as Vulnerable if EOO was >20,000 km^2 and ≤ 50,000 km^2, Endangered if >2000 km^2 and ≤ 20,000 km^2, and Critically Endangered if ≤2000 km^2, following IUCN RLE criteria (Keith et al., 2013).

For subcriterion B2, we calculated each ecosystem's AOO every 5 years between 1985 and 2020 (Rodríguez et al., 2011). We created 10 × 10 km grid cells over each ecosystem's extent and calculated AOO in R following the updated RLE guidelines, rather than excluding all cells with <1% ecosystem coverage (IUCN, 2024). Instead, cells containing the smallest ecosystem area were sequentially removed until the cumulative excluded area reached, but did not exceed, 1% of the total ecosystem area. Because MapBiomas Collection 6 was no longer available, these calculations were repeated using Collection 10 (MapBiomas, 2025). Based on the resulting AOO value and whether it declined continuously between 1985 and 2020 (Keith et al., 2013), ecosystems were classified as Vulnerable if their AOO was >20 and ≤50, Endangered if >2 and ≤ 20, and Critically Endangered if ≤2.

3 | RESULTS

In 1985, approximately 56% of the Brazilian Cerrado was covered by savanna, 26% by forest, 14% by grassland, and 4% by wetland. Differences in the proportional composition of vegetation types across ecoregions are shown in Figure S1. By 2020, total natural vegetation coverage had declined by 20%, with forests and grasslands each decreasing by 21%, savannas by 20%, and wetlands by 10% (Figure 2). Temporal trajectories of the four major ecosystem types across the Cerrado are shown in Figure S2.

This habitat loss, combined with the naturally limited extent of some ecosystems, resulted in 55 of the 80 Cerrado ecosystems being classified as threatened (Table 1). None were identified as Critically Endangered, but 12 were Endangered and 43 were Vulnerable. Most threatened ecosystems were identified under Criterion A2b, with 48 classified as Vulnerable or Endangered, followed by 12 under Criterion B1 and 8 under Criterion B2. Across all ecosystems, the PRD produced lower error for the 1985–2020 period than the ARD. Therefore, PRD was used to project ecosystem coverage for 2035 (Figure 3, Table S1).

The three criteria highlighted distinct vegetation types as threatened, although 12 ecosystems met thresholds under more than one criterion (Table 1; Table S2). Under Criterion A, 14 forest, 12 wetland, 11 savanna, and 11 grassland ecosystems were classified as threatened, spanning 19 ecoregions. Under Criterion B1, three ecosystems of each vegetation type (forest, savanna, grassland,

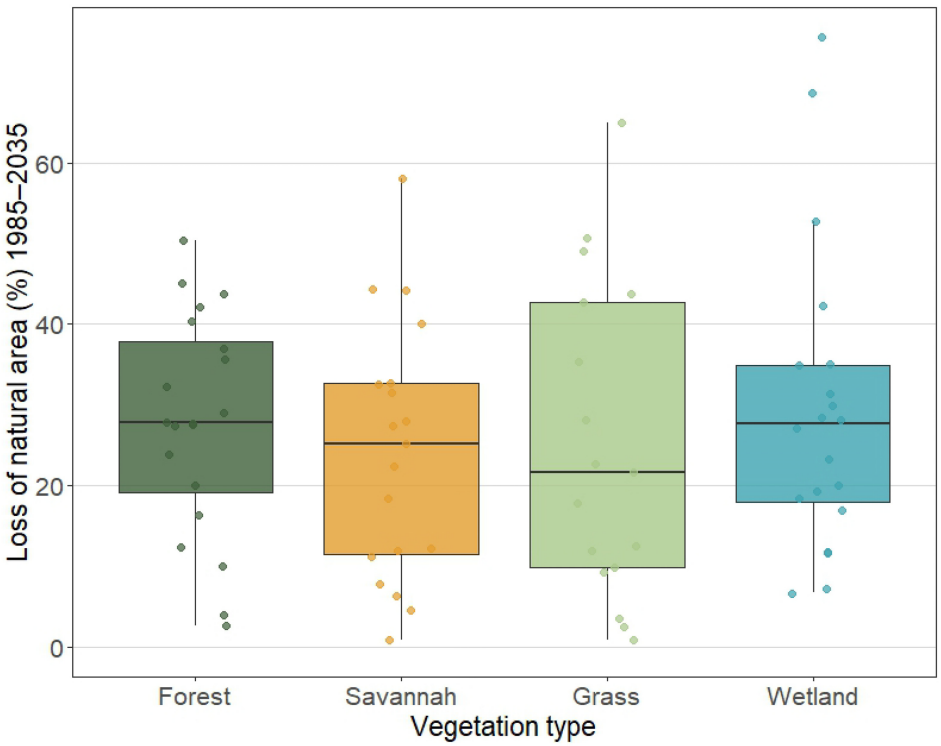


FIGURE 2 Proportional loss of natural area (%) between 1985 and 2035 across vegetation types in the Cerrado. Boxplots show the distribution of natural area loss for forest, savanna, grassland, and wetland formations across 20 ecoregions.

25784854, 2026, 11, Downloaded from https://conbio.onlinelibrary.wiley.com/doi/10.1111/csp2.70426 by NICE, National Institute for Health and Care Excellence, Wiley Online Library on [10/11/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 1 Ecoregions and threat status for each ecosystem in the Cerrado according to the International Union for Conservation of Nature (IUCN) Red List of Ecosystems criteria (A2b, B1, B2). Following Red List guidelines, the overall threat status of each ecoregion was determined by the highest level of risk recorded across the evaluated criteria and ecosystem types. Vulnerable (VU) is shown in yellow; endangered (EN) is shown in orange. Icons represent the four ecosystems: = forest, = grassland, = wetland, = savannah.

Ecoregion name	A2b				B1				B2				Combined			
Alto Parnaíba																
Alto São Francisco																
Araguaia Tocantins																
Bananal																
Basalto																
Bico do Papagaio																
Centro Norte Piauense																
Chapada dos Parecis																
Chapadão São Francisco																
Complexo Bodoquena																
Costeiro																
Depressão Cárstica São Francisco																
Depressão Cuiabana																
Floresta de Cocais																
Jequitinhonha																
Paracatu																
Paraná Guimaraes																
Parnaguá																
Planalto Central																
Vão do Paranã																

and wetland) were assessed as threatened across three ecoregions. Under Criterion B2, two ecosystems of each vegetation type were classified as threatened, distributed across two ecoregions. When combining Criteria A and B, 16 forest, 13 grassland, 13 wetland, and 13 savanna ecosystems were classified as threatened (Table 1).

Threatened forest, savanna, and grassland ecosystems are concentrated in the central and southern Cerrado (Figure 4a–c), whereas threatened wetlands are primarily found in the north (Figure 4d). The ecoregions with the highest number of threatened ecosystems occur in the central Cerrado, with Basalto, Complexo da Bodoquena, Costeiro, Depressão Cárstica do São Francisco, Paracatu, Paraná Guimarães, and Vão do Paranã, each containing four threatened ecosystems (Figure 4e).

4 | DISCUSSION

4.1 | Conservation status of the Cerrado ecoregions

The Cerrado is one of 36 global biodiversity hotspots because of its high levels of species richness and

25784854, 2026, 11, Downloaded from https://conbio.onlinelibrary.wiley.com/doi/10.1111/csp2.70426 by NICE, National Institute for Health and Care Excellence, Wiley Online Library on [10/11/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

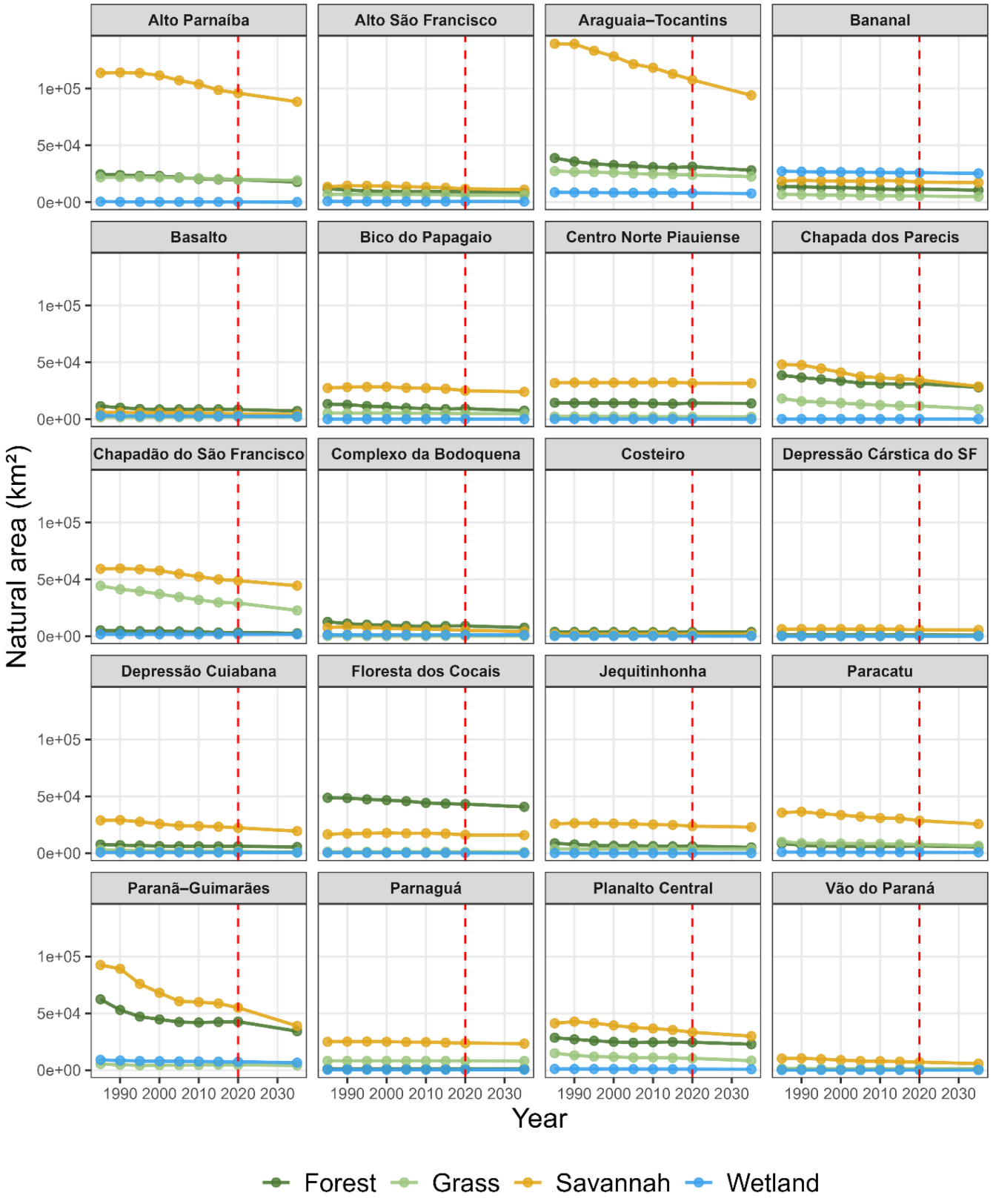


FIGURE 3 Temporal trends in natural area (1985–2035) across Cerrado ecoregions. Each panel shows changes in the natural area (km^2) of the four main vegetation formations (forest, savanna, grassland, and wetland) from 1985 to 2020 (solid lines) and projected to 2035 (dashed red line).

25784854, 2026, 11, Downloaded from https://conbio.onlinelibrary.wiley.com/doi/10.1111/csp2.70426 by NICE, National Institute for Health and Care Excellence, Wiley Online Library on [10/11/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

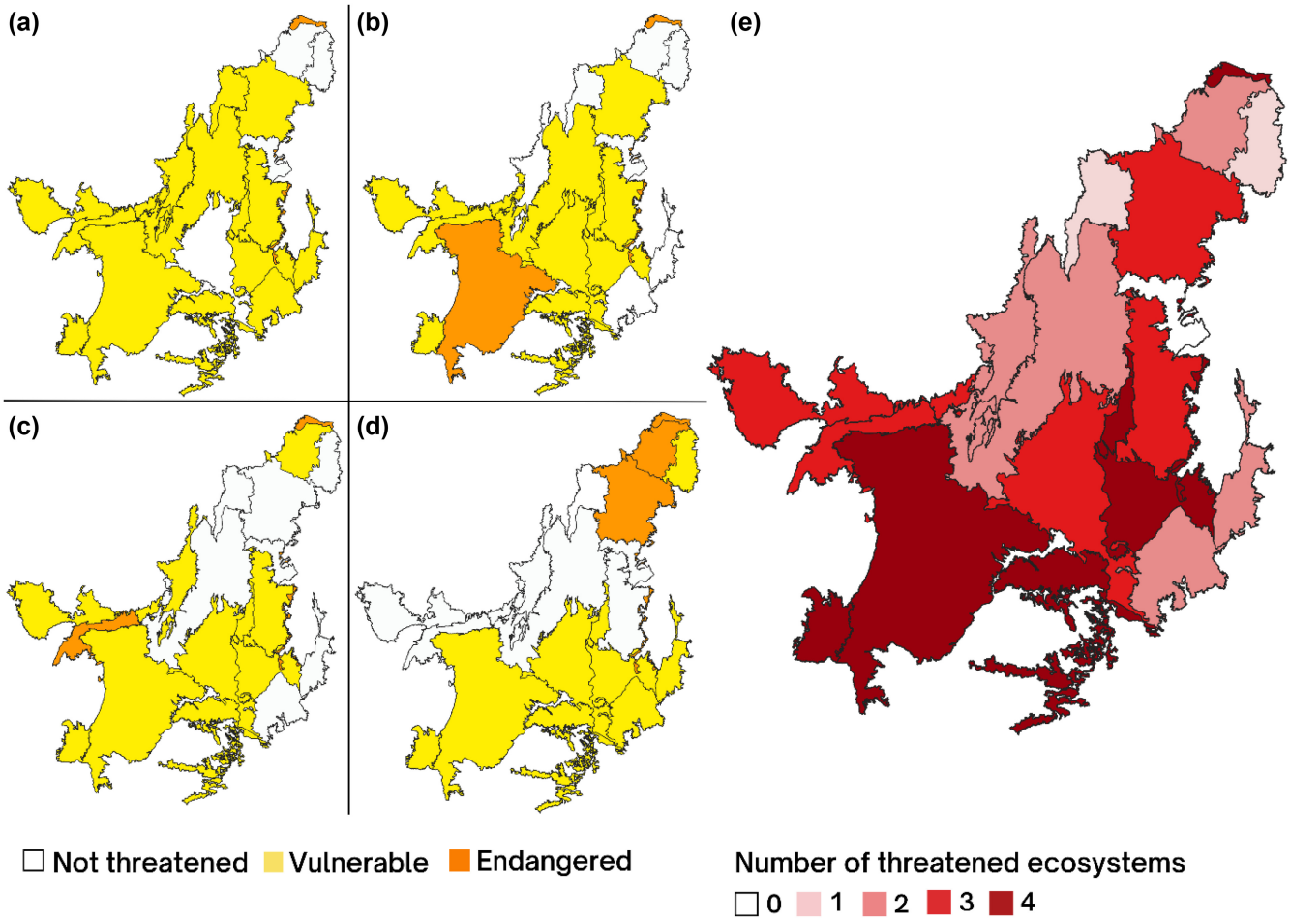


FIGURE 4 Ecoregions containing threatened ecosystems. (a) Forests, (b) savannas, (c) grasslands, and (d) wetlands show the threat status of each ecosystem type across ecoregions according to the International Union for Conservation of Nature (IUCN) Red List of Ecosystems criteria. Colors correspond to the highest threat category recorded for that ecosystem within each ecoregion (yellow = Vulnerable; orange = Endangered). (e) Number of threatened ecosystem types within each ecoregion (from 0 to 4).

endemism, and of habitat loss, much of which is driven by global demand for soybeans and beef (Strassburg et al., 2017). This habitat loss continues, as we found that 20% of natural vegetation in Brazil was cleared between 1985 and 2020 (Figure 2). Savanna ecosystems had the highest area of vegetation loss, as expected given the greater coverage in the Cerrado (Figure S2). However, in terms of percentage loss, forests, grasslands, and savannas all lost approximately 20% of their coverage, with wetlands being less affected (Figure 2). Much of this loss occurred legally, as Brazil's Forest Code allows landowners to clear up to 80% of their properties, leaving approximately 40 million hectares of land at risk of future conversion (Soares-Filho et al., 2014). Protected areas and other effective area-based conservation measures (OECMs) could help mitigate this loss, yet only 8.7% of the biome is currently protected (Pacheco et al., 2018). This is despite the Brazilian government's commitment to protect 17% of the Cerrado by 2020, a shortfall of approximately 20 million hectares (Larsen et al., 2015). Without achieving this last target, in 2022 Brazil signed the Kunming-Montreal Global Biodiversity Framework (GBF) of the UN Convention on Biological Diversity, which commits to protect 30% by 2030.

The GBF uses headline indicators to track progress and guide action (Convention on Biological Diversity, 2022a). The RLE is one of the official headline indicators used to assess achievement of the GBF's goals and targets, particularly those related to maintaining and restoring biodiversity, encompassing ecosystems, species, and genetic diversity (Goal A), as well as the targets for ecosystem protection and restoration (Convention on Biological Diversity, 2022b). Our map (Figure 4), combined with other socio-economic data, can help identify important biodiversity areas (Botts et al., 2020; Jones et al., 2022), for spatial planning (Target 1), set priorities for restoration (Target 2) (Etter et al., 2020), and guide the expansion of protection and OECMs (Target 3) (Botts et al., 2020; Etter et al., 2020; Keith et al., 2024). In

25784854, 2026, 11, Downloaded from https://conbio.onlinelibrary.wiley.com/doi/10.1111/csp2.70426 by NICE, National Institute for Health and Care Excellence, Wiley Online Library on [10/11/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

the Cerrado, where substantial conversion remains legally permissible under the Forest Code, achieving the "30 × 30" target will require more than creating new protected areas. OECMs, incentives on private lands, restoration, and connectivity will be essential to reduce future loss and secure ecological corridors. As a GBF headline indicator, repeating the RLE assessment also offers a basis for national reporting and progress tracking.

The link between threat status and conservation priorities is less straightforward for the 12 ecosystems classified as Endangered. For example, some ecosystems were classified as threatened under subcriterion B2 because of their restricted area of occupancy, even when they were not among those with the highest recent rates of vegetation loss. In some instances, protection levels for these ecosystems are relatively high, with the Bananal and Costeiro ecoregions having 46.3% and 38.3% protected area coverage, respectively (Sano et al., 2019). However, most of the ecosystems have lower coverage (Sano et al., 2019) and are threatened by high levels of anthropogenic loss, especially forests, savannas, and grasslands. Thus, the ecosystems that meet Criterion A2b due to ongoing habitat loss and Criterion B due to limited distribution should probably be considered priorities for conservation action.

Looking at the pattern of results is also important for interpreting the 43 ecosystems classified as Vulnerable. In particular, they show that, across three ecoregions (Basalto, Paracatu, and Paraná Guimarães), all four ecosystems are threatened under Criterion A2b. This level of threat, driven by habitat loss, is concerning and reflects the fact that this region forms part of Brazil's 'new agricultural frontier', with agricultural production expanding from the southern and southeastern portions to the northern parts of the biome (Lemes et al., 2020). Land-use change in the Cerrado reflects not only biophysical suitability but also evolving political and economic incentives. Since the 1980s, federal credit programs (e.g., PRODECER) and infrastructure investments have promoted agricultural expansion into central Brazil, particularly in the "MATOPIBA" region (Garrett et al., 2018). We also found that the most threatened ecosystems are concentrated in this region, consistent with previous studies (Schüler & Bustamante, 2022). Reforms to the Forest Code in 2012 further legalized high levels of conversion, allowing up to 80% clearing in private lands (Soares-Filho et al., 2014). These policy shifts coincide with the acceleration of vegetation loss observed in our time series. This same region was highlighted in previous studies, mainly due to government incentives for agriculture and soy expansion credits since the early 2000s (Araújo et al., 2019; de Souza et al., 2020). Alongside domestic policies, international supply-chain and trade mechanisms also shaped patterns of loss and protection. For instance, a voluntary zero-deforestation agreement adopted by major soy traders in 2006, the Amazon Soy Moratorium, curbed deforestation in Amazonia but displaced soy expansion toward the Cerrado (Gibbs et al., 2015; Moffette & Gibbs, 2021).

This pattern of agricultural expansion also explains why only one ecoregion, Parnaguá, did not contain any threatened ecosystems. This is partly because of its relatively high protected area coverage, which at 20.7% makes it one of only four ecoregions with over 17% of its area legally protected (INPE, 2020; Sano et al., 2019). In addition, research has shown that farmers in these regions adhere more closely to the New Forest Code (Sano et al., 2019). Nonetheless, even these ecoregions experienced a decline in vegetation cover, and so might be expected to contain threatened ecosystems in the future once levels of vegetation clearance meet the RLE thresholds.

4.2 | RLE methodology

The RLE methodology is widely used around the world and there are always trade-offs when applying a global standard to a specific region, particularly in terms of data requirements and the generalisability of the criteria. A crucial first step in the RLE process is identifying an appropriate ecosystem map. The IUCN recommends using a map based on their ecosystem typology, while also emphasizing the importance of aligning with national policy frameworks (Keith et al., 2015). For Brazil, this is relatively straightforward because the Cerrado ecoregion map provides a spatial framework designed to support conservation planning and other environmental decision-making processes (Sano et al., 2019). However, these ecoregions are relatively broad, so we further divided them into forest, savanna, grassland, and wetland ecosystems based on the national land cover map. This approach allows for a detailed assessment of ecosystems based on their specific ecological characteristics and regional context, aligning with both global standards and local policy requirements. These ecosystem datasets are open-access and provide annual land cover data since 1985, which we used to conduct an RLE assessment based on Criteria A and B (MapBiomas, 2022). No equivalent data exist to enable an evaluation based on Criteria C, D, and E across all ecosystems, although previous research suggests this would be feasible if ambitious (Burns et al., 2015; Sievers et al., 2020).

This does not mean, however, that the data used to assess Criterion A and Criterion B were not without

25784854, 2026, 11, Downloaded from https://conbio.onlinelibrary.wiley.com/doi/10.1111/csp2.70426 by NICE, National Institute for Health and Care Excellence, Wiley Online Library on [10/11/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

limitations. For Criterion A, the main challenge was assessing the savanna ecosystems, which account for 56% of the remaining native vegetation in the Cerrado. Detecting savanna loss through remote sensing is particularly difficult because these ecosystems span a wide gradient of tree densities relative to forests or grasslands and display greater variation in phenological patterns (de Souza et al., 2021). It should also be noted that some of the savannas have been severely impacted by cattle grazing, which is not detectable from the available remote sensing datasets and is therefore only identifiable by applying Criterion C, D, or E (Moffette & Gibbs, 2021). Although our assessment focused on total natural area loss, future studies could use the MapBiomas transition matrices to examine shifts between natural vegetation types (e.g., savanna to grassland) and to explore the potential influence of changing climate and fire regimes on these transitions.

For Criterion B, subcriterion B1 needed to be treated with caution. This is because our ecosystem classification was based on patches of the same vegetation type within the same ecoregion, so the minimum convex polygons that contained all the ecosystem fragments tended to be approximately the same size as the associated ecoregion (Table S1). As a result, threatened ecosystems under Criterion B1 were generally found in small ecoregions. Although subcriterion B2 was expected to capture finer-scale variation within ecoregions, in our analysis it also identified all ecosystem types as threatened within the same ecoregions, suggesting that this pattern may also reflect ecoregion size.

Previous assessments of threatened ecosystems in the Cerrado focused on habitat loss, protected area coverage, and environmental compliance with the New Forest Code (Sano et al., 2019). Our RLE results complement these findings but differ notably for ecosystems with a high proportion of protected areas. For example, Bananal was considered less threatened by Sano et al. (2019) because its protected area coverage is 40.6%, whereas our RLE assessment classified it as Vulnerable under Criterion A. While Sano et al.'s framework provides valuable information on protection and compliance, our RLE analysis offers a complementary perspective by focusing on the ecological risk of collapse, derived directly from the rate and extent of vegetation loss. This shift in emphasis highlights where ecosystems are most vulnerable, regardless of current management effectiveness. By operating at a finer spatial scale and subdividing each ecoregion into forests, savannas, grasslands, and wetlands, we identified which specific ecosystem types are undergoing the most rapid conversion. This approach captures localized patterns of degradation that broader national assessments may overlook, providing a more detailed picture of the spatial heterogeneity of risk across the biome.

Across other savanna systems, assessments of biodiversity state show patterns consistent with those observed in the Cerrado. Many other studies have shown alarming outcomes of the rapid devastation of savannas worldwide (Mustin et al., 2017; Mwangi & Ostrom, 2009; Vargas et al., 2015; Woinarski et al., 2011). In Colombia, the Llanos piedmont savannas were classified as Critically Endangered after losing 86% of their original extent, with agricultural and livestock expansion identified as a principal driver of the geographic reduction (Criterion A) (Etter et al., 2017). In South Africa, a national assessment found many savanna ecosystems to be threatened under Criterion A (long-term reduction), while Criterion B identified those with fragmented or restricted distributions (Skowno & Monyeki, 2021). This pattern is similar to our results, in which A2b drives most listings and B2 identifies spatially restricted and small-extent ecosystems. At the planning level, African case studies show that RLE categories were used to design and manage protected and conserved areas in savanna-dominated landscapes (Botts et al., 2020; Keith et al., 2024), highlighting the potential for similar risk-based approaches to guide conservation strategies in the Cerrado.

The RLE methodology is a valuable tool for assessing ecosystem risks and guiding conservation efforts, and we found it could also be successfully applied to the Cerrado. This is important because the Cerrado is being degraded at an alarming rate, and our results have identified a number of ecosystems at risk of collapse due to land clearance and/or their small extent. Our study highlights the benefits of using this standardized approach to compare patterns across ecoregions, identifying patterns of vegetation loss and understanding the threatening processes. In particular, it highlights the complex relationship between protected area coverage and ecosystem threat status in an agricultural frontier, where there are plenty of opportunities to clear natural vegetation outside protected areas. The next crucial step is to implement interventions that mitigate these threats, using RLE data to guide the establishment of new conservation target actions. We also recommend that Brazil should adopt global best practice and use the RLE to underpin ecosystem conservation and restoration policies more broadly, developing indicators of ecosystem threat, enhancing infrastructure policy, and integrating RLE into legislation, land-use planning, and protected area management (Bland et al., 2019; Keith et al., 2015; Skowno & Monyeki, 2021).

25784854, 2026, 11, Downloaded from https://conbio.onlinelibrary.wiley.com/doi/10.1111/csp2.70426 by NICE, National Institute for Health and Care Excellence, Wiley Online Library on [10/11/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

ACKNOWLEDGMENTS

We thank the Durrell Institute of Conservation and Ecology (DICE) and the University of Kent for all the assistance. We extend our thanks to the MapBiomas project and the Brazilian Ministry of the Environment for providing open access and high-quality data on this important topic, which made this research possible. Finally, we thank Dr. Kayque Telles and Dr. Michel Valette for their support and valuable contributions.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The primary datasets used in this study were sourced from the publicly available MapBiomas project. These datasets can be accessed directly via the MapBiomas website via https://brasil.mapbiomas.org/downloads/. Additionally, the data analyzed in this study, including those processed using QGIS and transformed into Excel files, are available from the corresponding author, Juliana Ávila Martins, upon request.

ORCID

Juliana Ávila Martins https://orcid.org/0000-0002-5465-8276
Robert J. Smith https://orcid.org/0000-0003-1599-9171

REFERENCES

Alaniz, A. J., Pérez-Quezada, J. F., Galleguillos, M., Vásquez, A. E., & Keith, D. A. (2019). Operationalizing the IUCN red list of ecosystems in public policy. *Conservation Letters*, *12*, e12665. https://doi.org/10.1111/conl.12665

Albuquerque, N. R., Martins, R. H., Carvalho, P. S., Shepard, D. B., & Santana, D. J. (2025). A new species of parrot snake, Leptophis (Serpentes: Colubridae), from the Brazilian Cerrado. *PeerJ*, *13*, e18528. https://doi.org/10.7717/peerj.18528

Araújo, M. L. S., Sano, E. E., Bolfe, É. L., Santos, J. R. N., dos Santos, J. S., & Silva, F. B. (2019). Spatiotemporal dynamics of soybean crop in the Matopiba region, Brazil (1990–2015). *Land Use Policy*, *80*, 57–67. https://doi.org/10.1016/j.landusepol.2018.09.040

Arruda, M. B., Proença, C. E. B., Rodrigues, S. C., Campos, R. N., Martins, R. C., & Martins, E. S. (2008). Ecorregiões, unidades de conservação e representatividade ecológica do bioma Cerrado [Ecoregions, protected areas, and ecological representativeness of the Cerrado biome]. In S. M. Sano, S. P. de Almeida, & J. F. Ribeiro (Eds.), *Cerrado: Ecologia e flora* (Vol. 1, pp. 229–272). Embrapa Cerrados/Embrapa Informação Tecnológica (In Portuguese).

Bezerra, A. S. (2018). *Considerações sobre conservação da biodiversidade nas ecorregiões do bioma Cerrado* [Considerations on biodiversity conservation in the ecoregions of the Cerrado biome] [Master's thesis, Universidade de Brasília]. https://repositorio.unb.br/handle/10482/33072 (In Portuguese).

Bland, L. M., Keith, D. A., Miller, R. M., Murray, N. J., & Rodríguez, J. P. (Eds.). (2017). *Guidelines for the application of IUCN red list of ecosystems categories and criteria: Version 1.1*. International Union for Conservation of Nature. https://portals.iucn.org/library/sites/library/files/documents/2016-010-v1.1.pdf

Bland, L. M., Nicholson, E., Miller, R. M., Andrade, A., Carré, A., Etter, A., Ferrer-Paris, J. R., Herrera, B., Kontula, T., Lindgaard, A., Pliscoff, P., Skowno, A., Valderrábano, M., Zager, I., & Keith, D. A. (2019). Impacts of the IUCN red list of ecosystems on conservation policy and practice. *Conservation Letters*, *12*, e12666. https://doi.org/10.1111/conl.12666

Botts, E. A., Skowno, A. L., Driver, A., Holness, S., Maze, K., Smith, T., Daniels, F., Desmet, P., Sink, K., Botha, M., Nel, J., & Manuel, J. (2020). More than just a (red) list: Over a decade of using South Africa's threatened ecosystems in policy and practice. *Biological Conservation*, *246*, 108559. https://doi.org/10.1016/j.biocon.2020.108559

Burns, E. L., Lindenmayer, D. B., Stein, J., Blanchard, W., McBurney, L., Blair, D., & Banks, S. C. (2015). Ecosystem assessment of mountain ash forest in the central highlands of Victoria, south-eastern Australia. *Austral Ecology*, *40*(4), 386–399. https://doi.org/10.1111/aec.12200

Chen, G., Wang, X., & Ma, K. (2020). Red list of China's forest ecosystems: A conservation assessment and protected area gap analysis. *Biological Conservation*, *248*, 108636. https://doi.org/10.1016/j.biocon.2020.108636

Convention on Biological Diversity. (2022a). *Kunming–Montreal Global Biodiversity Framework* (CBD/COP/DEC/15/4). https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-04-en.pdf.

Convention on Biological Diversity. (2022b). *Monitoring framework for the Kunming–Montreal Global Biodiversity Framework* (CBD/COP/DEC/15/5). https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-05-en.pdf.

da Silva Arruda, V. L., Conciani, D. E., da Silva, W. V., Shimbo, J. Z., & Segura-García, C. (2024). Assessing four decades of fire behavior dynamics in the Cerrado biome (1985–2022). *Fire Ecology*, *20*, 64. https://doi.org/10.1186/s42408-024-00298-4

de Souza, A. A., Galvão, L. S., Korting, T. S., & Almeida, C. A. (2021). On a data-driven approach for detecting disturbance in the Brazilian savannas using time series of vegetation indices. *Remote Sensing*, *13*, 4959. https://doi.org/10.3390/rs13244959

de Souza, A. A., Galvão, L. S., Korting, T. S., & Prieto, J. D. (2020). Dynamics of savanna clearing and land degradation in the newest agricultural frontier in Brazil. *GIScience & Remote Sensing*, *57*, 965–984. https://doi.org/10.1080/15481603.2020.1835080

Dinerstein, E., Olson, D. M., Graham, D. J., Webster, A. L., Primm, S. A., Bookbinder, M. P., & Ledec, G. (1995). *A conservation assessment of the terrestrial ecoregions of Latin America and the Caribbean*. World Wildlife Fund & World Bank.

Durigan, G., Munhoz, C. B., Zakia, M. J. B., Oliveira, R. S., Pilon, N. A. L., do Valle, R. S. T., Walter, B. M. T., Honda, E. A., & Pott, A. (2022). Cerrado wetlands: Multiple ecosystems deserving legal protection as a unique and irreplaceable treasure. *Perspectives in Ecology and Conservation*, *20*, 185–196. https://doi.org/10.1016/j.pecon.2022.06.002

Etter, A., Andrade, A., Nelson, C. R., Cortés, J., & Saavedra, K. (2020). Assessing restoration priorities for high-risk ecosystems:

25784854, 2026, 11, Downloaded from https://conbio.onlinelibrary.wiley.com/doi/10.1111/csp2.70426 by NICE, National Institute for Health and Care Excellence, Wiley Online Library on [10/11/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

An application of the IUCN red list of ecosystems. *Land Use Policy*, *99*, 104874. https://doi.org/10.1016/j.landusepol.2020.104874

Etter, A., Andrade, A., Saavedra, K., & Cortés, J. (2017). *Red list of terrestrial ecosystems of Colombia: Volume 1, continental, coastal and marine ecosystems*. Instituto Humboldt. https://assessments.iucnrle.org/systematics/1

Ferragutti, A. C., Lenza, E., Mews, H. A., Maracahipes, L., Pilon, N., Pereira, J. C. M., Campos-Filho, E. M., & Silvério, D. V. (2025). Spatio-temporal variability in seed production of tree species: Implications for restoration in the Cerrado–Amazonia transition zone. *Restoration Ecology*, *33*(1), e14299. https://doi.org/10.1111/rec.14299

Ferrer-Paris, J. R., Llambí, L. D., Melfo, A., & Keith, D. A. (2024). First red list of ecosystems assessment of a tropical glacier ecosystem to diagnose the pathways towards imminent collapse. *Oryx*, *58*(6), 735–745. https://doi.org/10.1017/S0030605323001771

Françoso, R. D., Brandão, R., Nogueira, C. C., Salmona, Y. B., Machado, R. B., & Colli, G. R. (2015). Habitat loss and the effectiveness of protected areas in the Cerrado biodiversity hotspot. *Natureza & Conservação*, *13*, 35–40. https://doi.org/10.1016/j.ncon.2015.04.001

Garrett, R. D., Koh, I., Lambin, E. F., le Polain De Waroux, Y., Kastens, J. H., & Brown, J. C. (2018). Intensification in agriculture-forest frontiers: Land use responses to development and conservation policies in Brazil. *Global Environmental Change*, *53*, 233–243. https://doi.org/10.1016/j.gloenvcha.2018.09.011

Gibbs, H. K., Rausch, L., Munger, J., Schelly, I., Morton, D. C., Noojipady, P., Soares-Filho, B., Barreto, P., Micol, L., & Walker, N. F. (2015). Brazil's soy moratorium. *Science*, *347*, 377–378. https://doi.org/10.1126/science.aaa0181

Instituto Nacional de Pesquisas Espaciais. (2020). *Earth observation general coordination: Monitoring program of the Amazon and other biomes—Notices, Cerrado biome*. http://terrabrasilis.dpi.inpe.br/downloads/

International Union for Conservation of Nature. (2024). In D. A. Keith, J. R. Ferrer-Paris, S. M. M. Ghoraba, S. Henriksen, M. Monyeki, N. J. Murray, E. Nicholson, J. Rowland, A. Skowno, J. A. Slingsby, A. B. Storeng, M. Valderrábano, & I. Zager (Eds.), *Guidelines for the application of IUCN red list of ecosystems categories and criteria (version 2.0)*. IUCN. https://doi.org/10.2305/CJDF9122

Jones, K. R., von Hase, A., Costa, H. M., Rainey, H., Sidat, N., Jobson, B., White, T. B., & Grantham, H. S. (2022). Spatial analysis to inform the mitigation hierarchy. *Conservation Science and Practice*, *4*(6), e12686. https://doi.org/10.1111/csp2.12686

Keith, D. A., Ferrer-Paris, J. R., Nicholson, E., Bishop, M. J., Polidoro, B. A., Ramirez-Llodra, E., Tozer, M. G., Nel, J. L., Mac Nally, R., Gregr, E. J., Watermeyer, K. E., Essl, F., Faber-Langendoen, D., Franklin, J., Lehmann, C. E. R., Etter, A., Roux, D. J., Stark, J. S., Rowland, J. A., & Kingsford, R. T. (2022). A function-based typology for Earth's ecosystems. *Nature*, *610*, 513–518. https://doi.org/10.1038/s41586-022-05318-4

Keith, D. A., Ghoraba, S. M. M., Kaly, E., Jones, K. R., Oosthuizen, A., Obura, D., Costa, H. M., Daniels, F., Duarte, E., Grantham, H., Gudka, M., Norman, J., Shannon, L. J., Skowno, A., & Ferrer-Paris, J. R. (2024). Contributions of the IUCN red list of ecosystems to risk-based design and management of protected and conserved areas in Africa. *Conservation Biology*, *38*(3), e14169. https://doi.org/10.1111/cobi.14169

Keith, D. A., Rodríguez, J. P., Brooks, T. M., Burgman, M. A., Barrow, E. G., Bland, L., Comer, P. J., Franklin, J., Link, J., McCarthy, M. A., Miller, R. M., Murray, N. J., Nel, J., Nicholson, E., Oliveira-Miranda, M. A., Regan, T. J., Rodríguez-Clark, K. M., Rouget, M., & Spalding, M. D. (2015). The IUCN red list of ecosystems: Motivations, challenges, and applications. *Conservation Letters*, *8*, 214–226. https://doi.org/10.1111/conl.12167

Keith, D. A., Rodríguez, J. P., Rodríguez-Clark, K. M., Nicholson, E., Aapala, K., Alonso, A., Asmussen, M., Bachman, S., Basset, A., Barrow, E. G., Benson, J. S., Bishop, M. J., Bonifacio, R., Brooks, T. M., Burgman, M. A., Comer, P., Comín, F. A., Essl, F., Faber-Langendoen, D., & Zambrano-Martínez, S. (2013). Scientific foundations for an IUCN red list of ecosystems. *PLoS One*, *8*, e62111. https://doi.org/10.1371/journal.pone.0062111

Klink, C. A., & Machado, R. B. (2005). Conservation of the Brazilian Cerrado. *Conservation Biology*, *19*, 707–713. https://doi.org/10.1111/j.1523-1739.2005.00702.x

Lahsen, M., Bustamante, M. M. C., & Dalla-Nora, E. L. (2016). Undervaluing and overexploiting the Brazilian Cerrado at our peril. *Environment: Science and Policy for Sustainable Development*, *58*, 4–15. https://doi.org/10.1080/00139157.2016.1229537

Larsen, F. W., Turner, W. R., & Mittermeier, R. A. (2015). Will protection of 17% of land by 2020 be enough to safeguard biodiversity and critical ecosystem services? *Oryx*, *49*, 74–79. https://doi.org/10.1017/S0030605313001348

Lee, C. K. F., Nicholson, E., Duncan, C., Grantham, H. S., Keith, D. A., Tizard, R., & Murray, N. J. (2024). Assessing the conservation status of mangroves in Rakhine, Myanmar. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *34*(1), e4058. https://doi.org/10.1002/aqc.4058

Lemes, L., De Andrade, A. F. A., & Loyola, R. (2020). Spatial priorities for agricultural development in the Brazilian Cerrado: May economy and conservation coexist? *Biodiversity and Conservation*, *29*, 1683–1700. https://doi.org/10.1007/s10531-019-01719-6

Machovina, B., Feeley, K. J., & Ripple, W. J. (2015). Biodiversity conservation: The key is reducing meat consumption. *Science of the Total Environment*, *536*, 419–431. https://doi.org/10.1016/j.scitotenv.2015.07.022

MapBiomas. (2022). *MapBiomas project—Collection 6 of the annual land cover and land use maps of Brazil*. https://brasil.mapbiomas.org/en/collection/colecao-6/

MapBiomas. (2025). *MapBiomas project—Collection 10 of the annual land cover and land use maps of Brazil (1985–2024)*. https://brasil.mapbiomas.org/en/collection/colecao-10/

Mittermeier, R. A., Robles Gil, P., Hoffmann, M., Pilgrim, J., Brooks, T. M., Mittermeier, C. G., Lamoreux, J., & da Fonseca, G. A. B. (2004). *Hotspots revisited: Earth's biologically richest and most endangered terrestrial ecoregions*. CEMEX.

Moffette, F., & Gibbs, H. K. (2021). Agricultural displacement and deforestation leakage in the Brazilian legal Amazon. *Land Economics*, *97*(1), 155–179. https://doi.org/10.3368/wple.97.1.040219-0045R

Mustin, K., Carvalho, W. D., Hilário, R. R., Costa-Neto, S. V., Silva, C. R., Vasconcelos, I. M., Castro, I. J., Eilers, V.,

25784854, 2026, 11, Downloaded from https://conbio.onlinelibrary.wiley.com/doi/10.1111/csp2.70426 by NICE, National Institute for Health and Care Excellence, Wiley Online Library on [10/11/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Gonçalves, H. S., Maia, J. M. F., Santos, M. P. D., Vale, J. R. B., & Funi, C. (2017). Biodiversity, threats and conservation challenges in the Cerrado of Amapá, an Amazonian savanna. *Nature Conservation*, *22*, 107–127. https://doi.org/10.3897/natureconservation.22.13823

Mwangi, E., & Ostrom, E. (2009). A century of institutions and ecology in East Africa's savannas: Linking institutional robustness and ecological resilience. *Ecology and Society*, *14*(2), 10. https://doi.org/10.5751/ES-02818-140210

Nepstad, L. S., Gerber, J. S., Hill, J. D., Dias, L. C. P., Costa, M. H., & West, P. C. (2019). Pathways for recent Cerrado soybean expansion: Extending the soy moratorium and implementing integrated crop livestock systems with soybeans. *Environmental Research Letters*, *14*(4), 044029. https://doi.org/10.1088/1748-9326/aafb85

Omernik, J. M., & Bailey, R. G. (1997). Distinguishing between watersheds and ecoregions. *Journal of the American Water Resources Association*, *33*, 935–949. https://doi.org/10.1111/j.1752-1688.1997.tb04115.x

Osborne, P. L. (2000). *Tropical ecosystems and ecological concepts*. Cambridge University Press.

Pacheco, A. A., Neves, A. C. O., & Fernandes, G. W. (2018). Uneven conservation efforts compromise Brazil to meet the target 11 of convention on biological diversity. *Perspectives in Ecology and Conservation*, *16*, 43–48. https://doi.org/10.1016/j.pecon.2017.12.001

Pörtner, H.-O., Scholes, R. J., Agard, J., Archer, E., Arneth, A., Bai, X., Barnes, D., Burrows, M., Chan, L., Cheung, W., Diamond, S., Donatti, C., Duarte, C., Eisenhauer, N., Foden, W., Gasalla, M., Handa, C., Hickler, T., Hoegh-Guldberg, O., & Xue, J. (2023). Overcoming the coupled climate and biodiversity crises and their societal impacts. *Science*, *380*, eabl4881. https://doi.org/10.1126/science.abl4881

Reynel, C. R. (2024). A new species of Zanthoxylum (Rutaceae) from the Brazilian Cerrado. *Novon*, *32*(1), 94–96. https://doi.org/10.3417/2024897

Ribeiro, J. F., & Walter, B. M. T. (2008). As principais fitofisionomias do bioma Cerrado [the main vegetation physiognomies of the Cerrado biome]. In S. M. Sano, S. P. de Almeida, & J. F. Ribeiro (Eds.), *Cerrado: Ecologia e flora* (Vol. 1, pp. 151–212). Embrapa Cerrados/Embrapa Informação Tecnológica. https://www.alice.cnptia.embrapa.br/alice/bitstream/doc/186922/1/CERRADO-Ecologia-e-flora-VOL-1-152-213.pdf (In Portuguese)

Rodríguez, J. P., Rodríguez-Clark, K. M., Baillie, J. E., Ash, N., Benson, J., Boucher, T., Brown, C., Burgess, N. D., Collen, B., Jennings, M., Keith, D. A., Nicholson, E., Revenga, C., Reyers, B., Rouget, M., Smith, T., Spalding, M. D., Taber, A., Walpole, M., & Zamin, T. (2011). Establishing IUCN red list criteria for threatened ecosystems. *Conservation Biology*, *25*, 21–29. https://doi.org/10.1111/j.1523-1739.2010.01598.x

Sano, E. E., Rodrigues, A. A., Martins, E. S., Bettiol, G. M., Bustamante, M. M. C., Bezerra, A. S., Couto, A. F., Vasconcelos, V., Schüler, J., & Bolfe, E. L. (2019). Cerrado ecoregions: A spatial framework to assess and prioritize Brazilian savanna environmental diversity for conservation. *Journal of Environmental Management*, *232*, 818–828. https://doi.org/10.1016/j.jenvman.2018.11.108

Sawyer, D., Mesquita, B., Coutinho, B., Almeida, F. D., Figueiredo, I., Lamas, I., Pinto, P., & Kasecker, T. (2018). *Ecosystem profile: Cerrado biodiversity hotspot—Full report*. Supernova. https://www.cepf.net/sites/default/files/cerrado-ecosystem-profile-en-updated.pdf

Schüler, J., & Bustamante, M. M. C. (2022). Spatial planning for restoration in Cerrado: Balancing the trade-offs between conservation and agriculture. *Journal of Applied Ecology*, *59*, 2616–2626. https://doi.org/10.1111/1365-2664.14262

Sievers, M., Roy Chowdhury, M., Adame, M. F., Bhadury, P., Bhargava, R., Buelow, C., Friess, D. A., Ghosh, A., Hayes, M. A., McClure, E. C., Pearson, R. M., Turschwell, M. P., Worthington, T. A., & Connolly, R. M. (2020). Indian Sundarbans mangrove forest considered endangered under red list of ecosystems, but there is cause for optimism. *Biological Conservation*, *251*, 108751. https://doi.org/10.1016/j.biocon.2020.108751

Silva, P. S., Nogueira, J., Rodrigues, J. A., Santos, F. L. M., Pereira, J. M. C., DaCamara, C. C., Daldegan, G. A., Pereira, A. A., Peres, L. F., Schmidt, I. B., & Libonati, R. (2021). Putting fire on the map of Brazilian savanna ecoregions. *Journal of Environmental Management*, *296*, 113098. https://doi.org/10.1016/j.jenvman.2021.113098

Skowno, A., & Monyeki, M. S. (2021). South Africa's red list of terrestrial ecosystems (RLEs). *Land*, *10*(10), 1048. https://doi.org/10.3390/land10101048

Soares-Filho, B., Rajão, R., Macedo, M., Carneiro, A., Costa, W., Coe, M., Rodrigues, H., & Alencar, A. (2014). Cracking Brazil's forest code. *Science*, *344*, 363–364. https://doi.org/10.1126/science.1246663

Strassburg, B., Brooks, T., Feltran-Barbieri, R., Iribarrem, A., Crouzeilles, R., Loyola, R., Latawiec, A. E., Oliveira Filho, F. J. B., Scaramuzza, C. A. D. M., Scarano, F. R., Soares-Filho, B., & Balmford, A. (2017). Moment of truth for the Cerrado hotspot. *Nature Ecology & Evolution*, *1*, 0099. https://doi.org/10.1038/s41559-017-0099

Uribe, E., Etter, A., Luna-Acosta, A., Diazgranados, M. C., Acosta, A., Alonso, D., Chasqui, L., Gómez-López, D. I., Rodríguez-Rodríguez, J. A., Osorno-Arango, A., Navas-Camacho, R., Jaramillo, L., Sánchez, L., Rojas-Aguirre, S., Ricaurte-Villota, C., & Coca-Domínguez, O. (2020). *Lista Roja de los Ecosistemas Marinos y Costeros de Colombia (Versión 1)* [Red list of the Marine and Coastal Ecosystems of Colombia (version 1)] [Technical report]. Conservación Internacional, Pontificia Universidad Javeriana, & INVEMAR. https://iucnrle.org/static/media/uploads/references/published-assessments/uribe_etal_2020_rle_colombia-marine.pdf (In Spanish).

Vargas, R., Etter, A., & Sarmiento, A. (2015). Land use changes and carbon stocks in the savannas of Colombia. *Environmental Research Letters*, *10*(12), 124012. https://doi.org/10.1088/1748-9326/10/12/124012

Williams, B. A., Watson, J. E. M., Beyer, H. L., Grantham, H. S., Simmonds, J. S., Alvarez, S. J., Venter, O., Strassburg, B. B. N., & Runting, R. K. (2022). Global drivers of change across tropical savannah ecosystems and insights into their management and conservation. *Biological Conservation*, *276*, 109786. https://doi.org/10.1016/j.biocon.2022.109786

Woinarski, J. C. Z., Legge, S., Fitzsimons, J. A., Traill, B. J., Burbidge, A. A., Fisher, A., Firth, R. S. C., Gordon, I. J., Griffiths, A. D., Johnson, C. N., McKenzie, N. L., Palmer, C., Radford, I. J., Rankmore, B., Ritchie, E. G., Ward, S., &

25784854, 2026, 11, Downloaded from https://conbio.onlinelibrary.wiley.com/doi/10.1111/csp2.70426 by NICE, National Institute for Health and Care Excellence, Wiley Online Library on [10/11/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Ziembicki, M. (2011). The disappearing mammal fauna of northern Australia: Context, cause, and response. *Conservation Letters*, *4*(3), 192–201. https://doi.org/10.1111/j.1755-263X.2011.00164.x

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Martins, J. Á., & Smith, R. J. (2026). Producing a Red List of Ecosystems for the Brazilian Cerrado. *Conservation Science and Practice*, *8*(11), e70426. https://doi.org/10.1111/csp2.70426

25784854, 2026, 11, Downloaded from https://conbio.onlinelibrary.wiley.com/doi/10.1111/csp2.70426 by NICE, National Institute for Health and Care Excellence, Wiley Online Library on [10/11/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License