Biodiversity and conservation of the Cerrado: recent advances and old challenges

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Background

Covering about 2 Mio. km² by the arrival of the first European settlers, the Cerrado savannas are second in extent only to Amazonian forests amongst the South American biomes (Diniz et al. 2010; Eiten 1972; Oliveira and Marquis 2002). The Cerrado sits strategically at the centre of the continent, connecting two open vegetation biomes—the Chaco to the southwest and the Caatinga to the northeast—thus forming a diagonal corridor of dry habitats in South America, and simultaneously establishing a biogeographical barrier between two forest biomes—Amazonia to the northwest and the Atlantic Forest to the southeast (Schmidt and Inger 1951; Vanzolini 1963; Werneck 2011). Moreover, it also occurs as isolated patches within other biomes, presumably relicts of a more extensive past distribution (Barbosa et al. 2007; Carneiro Filho 1993; Cole 1960; Pennington et al. 2000). The relief consists of ancient, extensive plateaus dissected by younger valleys, carved by some of the major drainages of South America, i.e., Paraná-Paraguay, Tocantins-Araguaia, São Francisco and Parnaíba (Albert and Reis 2011; Braun 1970; King 1956; Mittermeier et al. 2000). The climate is of the Aw type in Köppen's classification, distinguished by marked and highly predictable seasonality, dry winters, and annual precipitation ranging from 1300 to 2300 mm (Alvares et al. 2013; Nimer 1989). Soils are old, acidic, nutrient-poor, with high levels of Al and Fe, and strongly influenced by the water regime (Lopes and Cox 1977; Motta et al. 2002; Vendrame et al. 2013). A complex topography and a dynamic geological history created the highly heterogeneous Cerrado landscape (Furley 1999; Sano

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et al. 2019), with a pronounced horizontal compartmentalization of the biota into three major habitat types—grasslands, savannas, and forests—determined by local topography, soils and water availability (Colli et al. 2002; Furley 1999; Nogueira et al. 2005; Oliveira-Filho and Ratter 2002; Ribeiro and Walter 1998). As in other tropical savannas, fires are frequent and most species have adaptations for survival under a regime of periodic burns (Costa et al. 2013; Frost 1985; Hoffmann 2002; Miranda et al. 2009; Mistry 1998; Salgado-Labouriau and Ferraz-Vicentini 1994). The origins of the Cerrado biota date from the Late Cretaceous, presumably evolving from pre-savanna ecosystems between 145 and 65 mya (Aguiar et al. 2020; Colli 2005; Ratter et al. 1997; Romero 1993), although the current biotic configuration has been established much more recently (Simon et al. 2009).

The Cerrado exhibits intricate biogeographic patterns, shaped by local environments and regional constraints, such as proximity to, or isolation from, neighboring domains and areas with contiguous relief (Werneck 2011). Its biodiversity remains poorly understood and every year many new species are described, indicating that significant biodiversity remains to be discovered (Colli et al. 2016; Diniz et al. 2010; Diniz-Filho et al. 2005). The Cerrado is the most diverse tropical savanna in the world and, except for a few tropical forest regions, has the richest vascular plant flora on the planet (Eiten 1994). Due to the rapid expansion of agriculture and livestock, as well as intensive local forest harvesting, ca. 137 animal species of the Cerrado are endangered (Fundação Biodiversitas 2003; IUCN 2013). However, a lack of basic biological knowledge prevents proper evaluation of the degree of threat for most Cerrado species. About 40–55% of the Cerrado has already been converted to croplands, pastures, and planted forests (Machado et al. 2004; Mantovani and Pereira 1998; Sano et al. 2010). Nevertheless, conversion of the Cerrado into Brazil's largest farm has received much less attention than deforestation of Amazonian and Atlantic Forests (Marris 2005; Ratter et al. 1997). With less than 50% of the natural vegetation cover remaining, cleared areas in the Cerrado surpass those in Amazonia (Beuchle et al. 2015; Espírito-Santo et al. 2016; Grecchi et al. 2014). Protected areas represent only 8.3% of the biome and this percentage drops to 6.5% when considering only the fraction covered by native vegetation (Françoso et al. 2015). Besides, climate models that incorporate changes in land use and degradation of Cerrado habitats indicate that significant changes may occur in water and carbon cycles, with profound impacts on regional climate and downstream ecosystem services dependent on water (Hoffmann 2002; Hoffmann and Jackson 2000). Therefore, many studies forecast daunting scenarios for the biome (Machado et al. 2004; Rambaldi and Oliveira 2003; Santos and Câmara 2002; Strassburg et al. 2017). As home to many endemic species and at the same time highly threatened by agricultural expansion, the Cerrado is regarded as a global biodiversity hotspot (Mittermeier et al. 2000; Myers 2003; Myers et al. 2000). Managing potential uses of Cerrado biodiversity and natural resources is thus essential to reconcile economic growth and poverty reduction with environmental protection.

Although traditionally focused on Amazonian and Atlantic forests, studies on Neotropical biodiversity and conservation have recently turned to open biomes, especially the Cerrado. For instance, a search performed on 7 March 2020 in the Web of Science (All Databases), using “Cerrado AND (conservation OR *diversity)”, returned 4297 articles published between 1948 and 2019. The article publication rate changed little until the late 1990s, but rose sharply in the twenty-first century (Fig. 1). The bulk (93.5%) of published articles is associated with Brazilian institutions, followed by ones in the USA and the UK, featuring still incipient but meaningful academic collaborations (Fig. 2). Moreover, most articles are associated with institutions in Distrito Federal, São Paulo, Goiás, Minas Gerais, Mato Grosso do Sul, and Mato Grosso (Fig. 3), stressing the importance of adequate

Fig. 1 Cumulative number of articles on Cerrado biodiversity and conservation retrieved from the Web of Science (All Databases) on 7 March 2020, using the expression “Cerrado AND (conservation OR *diversity)”. The solid line represents a cubic smoothing spline (Green and Silverman 1994) fitted to the data

funding for research groups and graduate programs, especially those in less privileged regions of central Brazil (Bortolozzi and Gremski 2004; Borges 2008). In this Special Issue, 13 articles present recent advances and major challenges related to biodiversity and conservation of the Cerrado. They reflect not only a great deal of knowledge produced mainly during the last two decades but also the persistence of some old challenges, such as the meager coverage of protected areas in the Cerrado and the paucity of studies involving invertebrates, fungi, and microorganisms. We hope this Special Issue will increase awareness of the importance of this biome, and stimulate future work to overcome these limitations so that scientific knowledge of the Cerrado can help society make informed decisions affecting its’ biodiversity and conservation.

Synopsis

Any effort to address the biodiversity and conservation of a large region depends on a sound understanding of its boundaries and regionalization. Françoso et al. (2020) used tree species inventories from almost 600 localities to identify biogeographic districts and provide a geographic framework for conservation planning and scientific research prioritization in the Cerrado. They recognize seven biogeographic districts characterized by climatic conditions and tree species composition. By assessing their rate of land conversion and coverage by protected areas, they show that districts in the southern and southwestern Cerrado have endured most land conversion and are the least protected. At the same time, those in the north and northeast are less impacted and better protected, stressing their greater need for conservation and management actions. Marques et al. (2020) conducted

Fig. 2 Treemap depicting the number of articles on Cerrado biodiversity and conservation according to continent and country of authors' institutional affiliation. Articles were retrieved from the Web of Science (All Databases) on 7 March 2020, using the expression "Cerrado AND (conservation OR *diversity)"

a detailed analysis of satellite imagery to assess the spatiotemporally dynamic boundary between the Cerrado and Amazonia. They demonstrate how this boundary is broad, complex, and interdigitating, and that the abrupt line separating the two biomes in official maps is inadequate for biodiversity conservation in the region. Further, they show that the Cerrado–Amazonia transition suffered more deforestation than either the Cerrado savannas or Amazonian forests over the last 30 years, resulting in the loss of ecotonal forests and threatening their unique biota.

The Cerrado is a highly heterogeneous landscape and some of its regions are subject to severe threats and deserve special attention, including the Cerrado–Amazonia transition, which coincides with an “arc of deforestation,” and rupestrian grasslands, mainly from the upper parts of the Espinhaço mountain range. Morandi et al. (2020) compared the tree diversity and biomass of typical cerrado vegetation between the Cerrado–Amazonia transition and the central area of the Cerrado. Further, they assessed the effects of temperature and precipitation on biomass and explored the species diversity *versus* biomass relationship. They found no difference in tree diversity between the two regions. However, they show that typical cerrado vegetation holds more biomass at the periphery than at the centre

Fig. 3 Histogram depicting the distribution of articles on Cerrado biodiversity and conservation according to authors' institutional affiliation. Articles were retrieved from the Web of Science (All Databases) on 7 March 2020, using the expression “Cerrado AND (conservation OR *diversity)”. EMBRAPA: Empresa Brasileira de Pesquisa Agropecuária, IFG: Instituto Federal de Goiás, INPA: Instituto Nacional de Pesquisas da Amazônia, UEG: Universidade Estadual de Goiás, UFG: Universidade Federal de Goiás, UFLA: Universidade Federal de Lavras, UFMG: Universidade Federal de Minas Gerais, UFMS: Universidade Federal de Mato Grosso do Sul, UFMT: Universidade Federal de Mato Grosso, UFPA: Universidade Federal do Pará, UFPR: Universidade Federal do Paraná, UFRJ: Universidade Federal do Rio de Janeiro, UFS-CAR: Universidade Federal de São Carlos, UFU: Universidade Federal de Uberlândia, UFV: Universidade Federal de Viçosa, UnB: Universidade de Brasília, UNEMAT: Universidade do Estado de Mato Grosso, UNESP: Universidade Estadual Paulista, UNICAMP: Universidade Estadual de Campinas, USP: Universidade de São Paulo

of the biome, resulting from higher temperatures and more significant precipitation at the periphery. Moreover, they found no relationship between tree diversity and biomass, indicating that protected areas with high tree biomass for the compensation of greenhouse gas emissions will not necessary hold a great diversity of trees, highlighting difficult trade-offs between the conservation of biodiversity and the reduction of greenhouse gases in the sites. Fernandes et al. (2018¹) show that rupestrian grasslands have one of the highest levels of plant endemism in the world but have also experienced some of the highest rates of habitat conversion due to mining activities, tourism, and infrastructure development. By forecasting its distribution under different climatic scenarios, they predict a catastrophic loss of 82% of their range, impacting ecosystem services, including water and food security in some of the most populous regions of Brazil.

Knowledge of Cerrado biodiversity has increased exponentially during the last two decades (Fig. 1). Notably, there have been significant advances in assessing spatial patterns of genetic diversity, the primary ingredient for evolution (e.g., Fenker et al. in press). Intraspecific genetic diversity plays a crucial role in species survival and adaptation, especially in the face of human-induced climate change and habitat loss (Laikre et al. 2020). Ballesteros-Mejia et al. (2020) assessed patterns of plant genetic variation across the Cerrado, emphasizing areas of high diversity and priority areas for conservation, and also determining the role of environmental characteristics and human impacts on genetic variation. They show that genetic richness decreases from north to south, being lower in regions

¹ This contribution was published in advance of the completion of the Special Issue.

with a high human development index, most likely attributable to habitat loss and fragmentation, and that variables related to energy, temperature, and precipitation are associated with genetic and allelic richness—but not with genetic diversity. They stress the importance of genetic studies in the northern Cerrado and within protected areas to enable better assessments of species conservation status and population management. Diniz-Filho et al. (2020) used the genetic diversity of a Cerrado tree to define conservation priorities based on predicted range shifts induced by climate change and habitat loss. They found a higher projected environmental suitability but a reduced proportion of natural habitats in southern Cerrado. Thus, in situ conservation seems adequate in the northern range of the species, where numerous natural remnants should hold more genetic diversity despite the reduced climatic suitability. In contrast, ex situ strategies should prove better in the southern part of the range, given the high levels of human occupation and despite the higher climatic stability. Different prioritization strategies for stable and unstable regions in the future should result an efficient conservation programme for the species.

Within the highly diverse Cerrado flora, several species are essential for the welfare of rural communities or are close relatives of cultivated species, being potentially useful for crop improvement. Sá et al. (2020) assessed the effects of land use and management upon the demography of an intensively used fruit palm endemic to the Cerrado. They show that, despite pressures from fruit harvesting and cattle ranching, most populations had good recruitment, but regeneration was meager under more intense land use and management. Therefore, populations in industrial farms under intense land use may be doomed, while those in small properties managed by traditional peoples and family farmers should persist. Supporting traditional peoples and family farmers effectively contributes to the in situ conservation of Cerrado's biodiversity in multiple-use landscapes. Simon et al. (2020) assessed the species conservation status of Cerrado wild relatives of cassava. They found many endemic species of cassava in the Cerrado, several of which are threatened with extinction owing to narrow geographic ranges and habitat loss. A substantial number of species was described recently, indicating that the diversity of cassava in the Cerrado has been very much underestimated. Species richness and endemism are highest in the Cerrado highlands, and more than half of the endemics are not represented in protected areas. More protected areas are therefore needed, particularly in areas with a concentration of rare and endemic species, to ensure effective in situ conservation of these crop wild relatives.

Human-induced habitat loss and climate change are rapidly increasing the extinction risk of Cerrado endemic species. Soon, ex situ breeding programmes may become commonplace for recovering populations that are threatened with extinction or already extinct in the wild. Machado et al. (2020) use a threatened songbird to examine scenarios that could produce viable populations in nature and to determine where reintroductions should take place. Their results suggest that reintroductions of a small number of individuals in several areas, with annual supplementation of a few individuals, could lead to long-term success. Nevertheless, few regions were found to be appropriate for reintroductions, including palm swamps (*veredas*) in central Cerrado. Further, they indicate that connecting habitat fragments, along with habitat matrix and fire management, are needed in places where reintroductions could be carried out.

A nefarious combination of rapid agribusiness and infrastructure development, ill-designed and poorly enforced environmental laws, alongside few incentives for research and conservation are engendering a major biodiversity collapse in the Cerrado (Alves et al. 2018; Fernandes et al. 2017; Overbeck et al. 2018; Strassburg et al. 2017). De Marco et al. (2020) assessed species and landscape vulnerability for threatened species of Cerrado mammals. They demonstrate that agriculture and transport infrastructure are the primary

drivers of habitat loss and that highly preserved landscapes are mostly found in the northern Cerrado. At the same time, climatically suitable areas for threatened mammals coincide with profoundly impacted landscapes in the southern Cerrado. Their results underscore the necessity of conservation programmes focused on the survival of populations from highly impacted landscapes. Human-induced environmental impacts also translate into increased frequency and severity of fires in the Cerrado. Costa et al. (2020) assessed the effects of fire-induced microclimatic shifts upon Cerrado lizard communities. They found that fire suppression enhanced habitat structural complexity, whereas burning had the opposite effects; half of the lizard species were favoured in the fire-protected plot, while the other half was favoured in burned plots. Lizard body condition and survival rates were not affected by fire regimes, suggesting a dominant role of thermoregulation opportunities afforded by habitat structure—instead of food availability or predation rates—upon community structure. Their findings indicate that even sporadic fires can profoundly affect Cerrado lizard communities and that protecting some habitat patches from burning is essential to maximize the maintenance of lizard diversity.

The Cerrado harbours a rich and endemic biota that is hugely important to the economy in Brazil. Is it feasible to attain a balance between economic development and biodiversity conservation? Lemes et al. (2020) used areas suitable for agriculture to identify priority places to implement monocultures and modeled species distributions, avoiding sites with high conservation value, and used species dispersal abilities to minimize the distance between present-day and future suitable areas for species persistence. They found habitat conversion threatened species persistence and that unrestricted agricultural expansion into future species distributions is possible due to severe decreases in suitable areas for many species. Ecological knowledge should guide agriculture expansion to spare future areas suitable for Cerrado species. Monteiro et al. (2020) identify spatial conservation priorities that minimize the risk of land conversion while retaining sites with high value for threatened plants at risk from climate change in the Cerrado. They show that scenarios that maximize conservation impact reduced total vegetation loss, while still covering large proportions of species ranges inside protected areas and priority sites. Hence, vegetation information could represent a reliable surrogate for overall biodiversity, allowing for the achievement of species representation and conservation impact.

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