

CONSERVATION

The value of private properties for the conservation of biodiversity in the Brazilian Cerrado

Paulo De Marco Jr.^{1*}, Rodrigo A. de Souza², André F. A. Andrade¹, Sara Villén-Pérez³, Caroline Corrêa Nóbrega⁴, Luiza Motta Campello⁵, Marcellus Caldas⁶

Areas set aside for conservation within private lands may be key to enhancing biodiversity-friendly landscapes. This conservation strategy should be especially effective in highly threatened regions that are poorly protected by public lands, such as the Brazilian Cerrado. Brazil's Native Vegetation Protection Law has included set-aside areas within private properties, but their relevance to conservation has not been evaluated. We assess whether private lands are contributing to biodiversity in the Cerrado, a global biodiversity conservation priority and major region for food production, where land use conflicts are often at odds with conservation objectives. We determined that private protected areas accommodate up to 14.5% of threatened vertebrate species ranges, which increases to 25% when considering the distribution of remaining native habitat. Moreover, the spatial spread of private protected areas benefits a large number of species. Ecological restoration of private protected lands would improve the benefits of this protection system, especially in the Southeastern Cerrado, where a large economic hub meets a threat hotspot.

Protected areas are the cornerstones for the long-term conservation of biodiversity. They cover about 15% of the terrestrial surface and 7.3% of the ocean surface (1), and global analyses show that they are still insufficient to protect biodiversity (2). The need for complementary strategies to join or reinforce protection networks is especially urgent to deal with the lack of connectivity due to habitat fragmentation. A promising approach is to make landscapes that are now occupied by economic activity more “biodiversity-friendly” (3). Biodiversity-friendly landscapes seek to preserve habitat patches in human-dominated areas to favor the persistence of native species (3), including beneficial animals such as pollinators, predators, and fruit dispersers (4). Most human-dominated areas are under private ownership, and this represents a large proportion of global land, varying from 44.2% in Brazil (5) to 52% in Germany, 75% in the United States (excluding Alaska) (6), and nearly 80% in the United Kingdom and Spain (7). Thus, improving the biodiversity-friendliness of private landholdings could amplify the benefits of the existing protection system by increas-

ing both the total habitat available and the connectivity among remaining habitats (8), ensuring population persistence and richer biodiversity (9). However, conservation prioritization efforts have often overlooked the role of private lands while focusing on public protection networks (10). Here, we provide an evaluation of the relevance of set-aside areas of private land in one of the most important and vulnerable worldwide arenas for the conflict between food production and biodiversity conservation: the Brazilian Cerrado (11). In addition, we present potential scenarios for restoration priorities to optimize the protection of 103 threatened terrestrial vertebrates in the biome.

Biodiversity-friendly landscapes must be designed to increase connectivity among habitat patches and to maintain sufficient habitat to assure the long-term persistence of biodiversity (8, 12). The strategy to implement this approach varies widely across the land-sharing and -sparing continuum and from voluntary to mandatory actions implemented by different countries (13). In parts of Australia, for example, there is a well-established model in which some rights are voluntarily relinquished in favor of conservation under a binding legal agreement and in exchange for economic incentives (14). Similar approaches are also found in the United States and Canada (15). In Latin America, the scheme is similar but shows a larger participation of nongovernmental organizations (NGOs) in land purchase for conservation, especially in Costa Rica, Ecuador, Argentina, and Chile (16). Otherwise, mandatory regulations to protect a portion of every rural property may represent a meaningful strategy for conservation in largely human-dominated landscapes. One of the best-established examples of this policy was

implemented in the Brazilian Forest Code almost a century ago (federal decree no. 23,000, 1934 and federal law no. 4.771/1965). It was originally conceived under a utilitarian view that focused on the importance of vegetation to water resources, soil fertility, and wood storage within rural properties (17). Even so, the Forest Code has important implications for biodiversity conservation today.

To enforce the sustainable use of natural resources, the Brazilian Forest Code required rural owners to select patches to become legal reserves within their rural properties. The legal reserve area varies between 20% (criteria for most of Brazil) to 80% (for the Amazon) of the property area. By contrast, the location of permanent protection areas is not eligible because they are designed to protect geological stability (e.g., topographic slope higher than 45°) and water resources (e.g., areas around streams, rivers, and springs). The existence of legal reserves and permanent protection areas has suffered long-standing pressure from political and economic sectors, with reiterated attempts to change this legislation during its history. As a consequence, some changes were implemented in the 2012 Native Vegetation Protection Law (federal law no. 12.651/2012) to maintain the general definition for existent categories but allow new deforestation, mainly in the Cerrado biome. The 2012 Forest Code also demands that landowners provide georeferenced information about land uses and protected areas in their rural properties through the Rural Environmental Registry [Cadastro Ambiental Rural (CAR)]. Here, we take the opportunity created by CAR to analyze the spatial distribution of all private protected areas from 684,942 rural properties registered in the Cerrado biome to assess its potential value for the conservation of threatened vertebrate species and to predict the potential benefits of fully restoring set-aside areas. The Cerrado is a wooded grassland, or savanna, covering about 20% of Brazil. It is home to distinctive and threatened species, such as the maned wolf (*Chrysocyon brachyurus*), the giant anteater (*Myrmecophaga tridactyla*), and the highly endangered blue-eyed ground dove (*Columbina cyanopsis*). By 2018, natural vegetation loss reached 90 million ha—45% of Cerrado area—mostly in private property (17, 18).

All analyses are based on the overlap between model predictions of species' ranges and the proportion of private protected areas with a 10-km-by-10-km cell from CAR's polygons. We used conservative estimates of species' ranges based on advanced ecological niche modeling techniques that account for dispersal constraints (19). Landscape-cell relevance to conservation was estimated by giving higher weight to smaller-ranged species, which are proportionally more affected by habitat

¹Departamento de Ecologia, Universidade Federal de Goiás, Goiânia, GO 74 690-720, Brazil. ²Centro Nacional de Informações Ambientais (CENIMA), Instituto Nacional de Meio Ambiente e Recursos Naturais Renováveis (IBAMA), SCEN Ibama, Ed. Sede, Bloco F, Brasília, DF 70818-900, Brazil. ³Universidad de Alcalá, GloCEE – Global Change Ecology and Evolution Research Group, Departamento de Ciencias de la Vida, 28805, Alcalá de Henares, Madrid, Spain. ⁴Aliança da Terra, Av. das Indústrias, 601, Quadra 151 Lote 47 Sala 301, Santa Genoveva, Goiânia, GO 74670-600, Brazil. ⁵Universidade Brasília, Instituto de Geociências, Campus Universitário Darcy Ribeiro ICC, Ala Central, Brasília-DF 70910-900, Brazil. ⁶Department of Geography and Geospatial Sciences, Kansas State University, Manhattan, KS 66502, USA.

*Corresponding author. Email: pdemarco@ufg.br



Check for updates

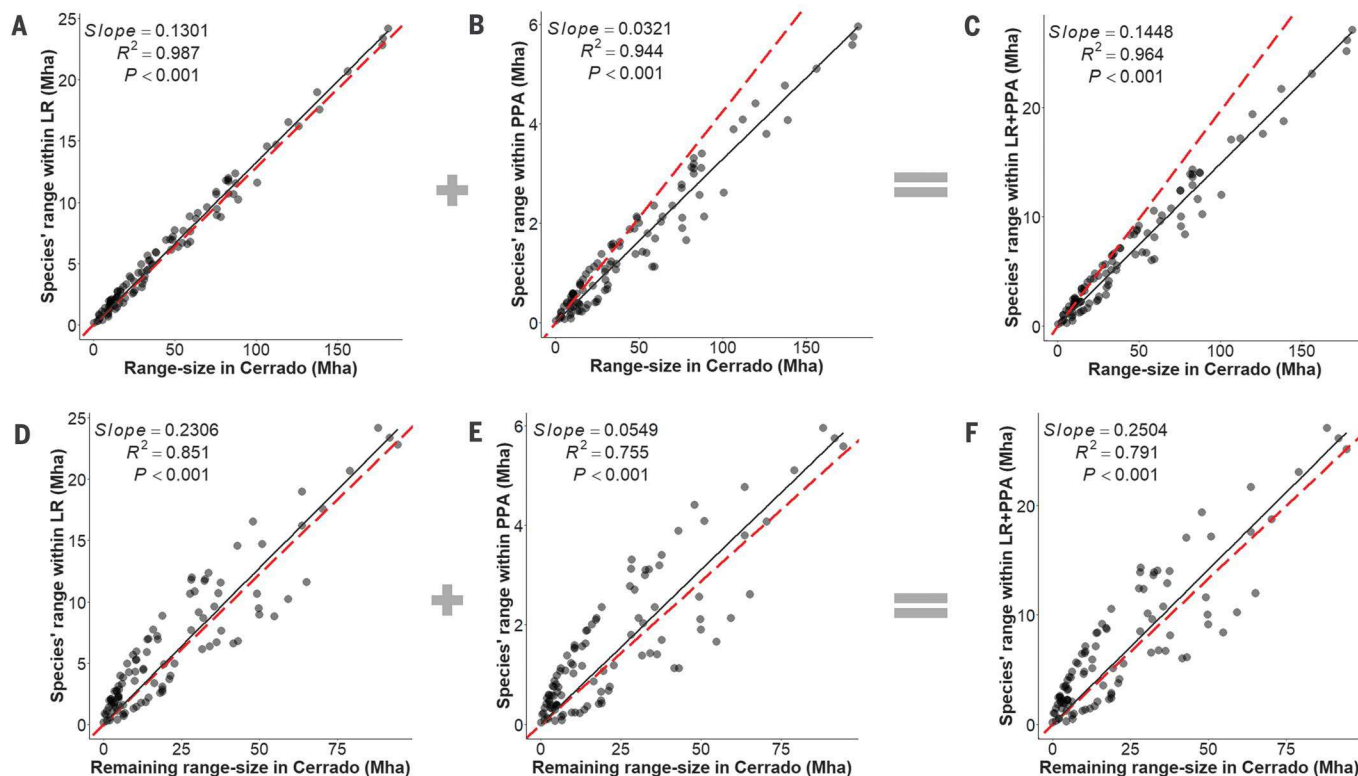


Fig. 1. The proportion of distributional range of threatened vertebrate species that falls within legal reserves and permanent protection areas in relation to its range size in the Cerrado biome. (A to F) Historical species' ranges that overlap legal reserves (LR) (A) and permanent protection areas (PPA) (B), as estimated by the regression through the origin (black lines), are 13.01 and 3.21%, respectively. The null expectation (red dashed line) is that each species overlaps both categories according to the proportion of those classes across the whole Cerrado area (12.80% for legal reserves and 4.20% for permanent protection areas). The predicted mean proportion of species

distribution within total private protected areas (C) is 14.48%. The portion of species' ranges with available remaining habitat that overlaps with legal reserves (D) and permanent protection areas (E) is larger (black lines; 23.06 and 5.49%, respectively) and presents a larger interspecific variation but is close to the null expectation (red dashed line). After discounting habitat loss, the predicted mean proportion of species distributions within total private protected areas (F) is high (25.04%) and close to the null expectation. The estimate of the overlap (slope of black line) is indicated in each plot, together with the R^2 and its statistical significance.

loss. Moreover, we assumed that species can persist in the private protected patches independently of their size, isolation, or type of surrounding matrix because species-specific sensitivity to these variables is unknown for most of the species we evaluated (20). We start by assuming that private protected areas are fully restored, though a considerable part of those set-aside areas is, at present, not well preserved and suffers from human interference (11). This assumption is relevant because their restoration is mandatory even under the current Forest Code (21). Thus, our analysis assesses the conservation value if restoration is properly implemented. Finally, we explore this further by indicating where restoration will bring higher benefits to biodiversity.

We show that an average of 13.01% of the range of threatened species falls within legal reserves [slope of the regression of range within legal reserves and total species' range in Cerrado, forced through the origin; coefficient of determination (R^2) = 0.987; Fig. 1A]. This value is only slightly higher than the null

expectation, which is the percentage cover of legal reserves in Cerrado (12.86%). The similarity to the null expectation suggests that these areas are representative of the environmental variation in the Cerrado favoring better representation of species' distribution ranges of threatened vertebrates. This hypothesis was supported both by the frequency distribution of public and private areas in relation to first climatic principal components analysis (PCA) and by the overlap of the entire environmental variation of the Cerrado (figs. S2-1 and S2-2). The mean proportion of the predicted species ranges that fall within permanent protection areas is lower (3.21%; the slope of the regression; R^2 = 0.944; Fig. 1B). This prediction is also slightly lower than the null expectation that species overlap is only determined by the proportion of this category in the whole Cerrado (4.26%). Applying the same analysis for the current public (federal and state levels) protected area system in the Cerrado shows that only 13.78% of species' ranges is protected, slightly lower than the null expectation

based on the coverage of public protected network in this region (15.30%; fig. S2-3). Private protected land is more evenly distributed across the Cerrado and thus is better suited to benefit a larger number of species. This is a desirable quality that contrasts with the public protection system, which is biased toward less-favorable lands for agriculture and does not represent the distribution of most threatened species (10). Otherwise, private land may represent an even higher proportion of threatened species' ranges if we restrict the analysis to the available remnants of native vegetation in the Cerrado. In that case, the predicted mean proportion of species' ranges within legal reserves is 23.06% and, for permanent protection areas, is 5.49% (R^2 = 0.851 for legal reserves and R^2 = 0.756 for permanent protection areas; Fig. 1, D and E). The general agreement to the null expectation still holds, but there is an increased scattering that suggests higher interspecific variation in their level of protection. This variation supports the nonrandom distribution of habitat loss in the

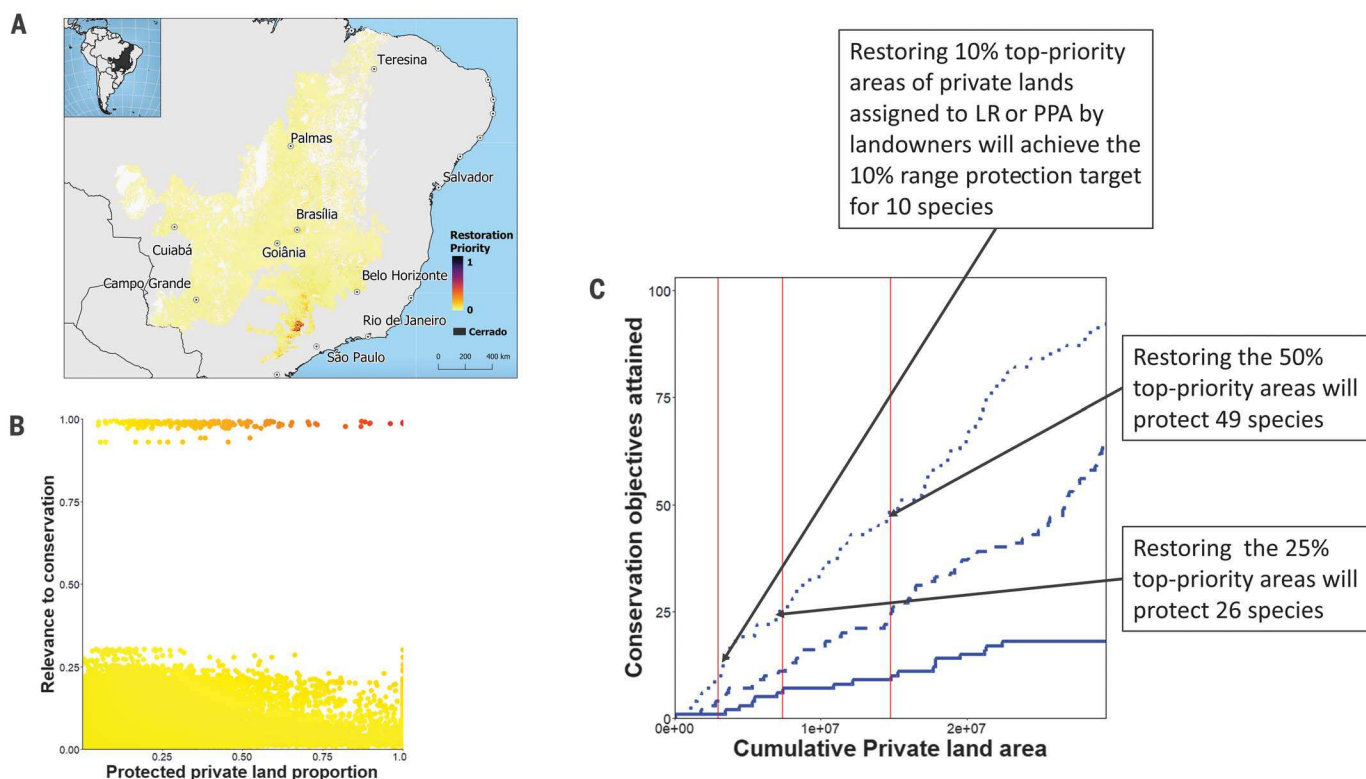


Fig. 2. Priority areas for the restoration of private lands based on their contribution for threatened species conservation. (A and B) Identification of restoration priorities within private protected areas (A) and their distribution in the Cerrado (B) based on their relevance to threatened species conservation, considering both the biodiversity relevance index and private protected area size. (C) Prediction of the conservation milestones that would

be reached as an increased number of private protected areas are restored after the prioritization established in (A). Conservation milestones are determined in terms of the number of species that would benefit and the percentage of their range that would be preserved. The dotted, dashed, and solid blue lines represent the conservation targets of 10, 15, and 20% of species range size, respectively.

Cerrado, which causes different levels of exposure among species (20).

The combined effect of legal reserves and permanent protection areas may protect up to 14.48% of species' distribution ranges in the Cerrado ($R^2 = 0.964$; Fig. 1C). This prediction increases to 25.04% after discounting for current habitat loss outside private protected assigned areas ($R^2 = 0.791$; Fig. 1F). This coverage is consistently higher than that expected from the distribution of total private protected area in the Cerrado (9.7%) and the remaining habitat in these protected areas (19.7%). Our results show that private lands may protect nearly 25% of the remaining climatically suitable habitats for threatened vertebrates in the Cerrado, so that its relevance for conservation is much higher than is now assumed. This also evidences the importance of habitat restoration within set-aside private lands, which is expected to occur under the current legal system. First, an increase in habitat amount due to restoration of private protected areas is expected to increase species' population sizes and reduce their risk of extinction (22). In addition, an increase in connectivity among remaining habitats is

expected to favor species' dispersion and persistence in the landscape (3).

Different private lands are not equally important to species conservation across the Cerrado region. The spatial variance of the relevance to the conservation index (Fig. 2, A and B) shows that a small set of 192 cells, mostly distributed in the most highly affected São Paulo state, has a disproportional importance to conservation. Those areas are part of the distribution of at least 70 small-ranged species and still bear a relatively large amount of protected land to restore within its predicted distribution. The entire set retains nearly 145,000 ha of protected private land, with an estimated cost of restoration not higher than \$60 million based on assisted regeneration methods, which is only 0.02% of the exports value of the Brazilian agribusiness sector in 2021 (<https://indicadores.agricultura.gov.br/agrostat/index.htm>). An analysis of potential scenarios for the prioritization of areas within set-aside private lands shows that after ordering all Cerrado cells according to their relevance for conservation, the cumulative protected private land area points to a positive scenario. Restoration

of the 10% top-priority cells will achieve the goal of 10% range protection for 10 threatened species, a 25% restoration will achieve the same goal for 26 species, and a 50% restoration will achieve the same goal for 49 species. More ambitious conservation targets (15 or 20% of species' range protection; Fig. 2C) are attained only for a small number of species or under optimistic restoration scenarios. For instance, restoring 75% of the protected private land would protect 20% of the range of 17 species, which includes many small-ranged species that are well represented in the Cerrado biome. We argue that an explicit policy to assure restoration will return clear conservation benefits based on those scenarios.

Our results support the importance of private lands to the protection of threatened Cerrado species. They indicate that restoring private protected areas is an important conservation goal that deserves special funds and attention. We show that, at least for the conservation of threatened terrestrial vertebrate species, it is possible to devise a prioritization scheme to guide the restoration efforts of those areas. In addition, private protected area restoration would also have direct effects on

essential ecosystem services. Based on recent calculations of carbon storage in Cerrado areas (23), we made a conservative estimate that shows that the restoration of private protected areas could capture 12×10^6 tonnes of carbon, which is a substantial contribution toward the 2°C climate target (24). Restoring private set-aside areas may also improve pollination services for major crops, such as soybean, and other relevant croplands of fruits and vegetables. Although those services are not always recognized by private owners (25), private land protection still carries the possibility of increasing the visibility of its benefits, thereby boosting restoration efforts. The choice to dedicate land and resources for biodiversity conservation is political and influenced by the value that people place on biodiversity (26). Conservation in private lands may increase the perception of ecosystem services and promote willing-to- conserve attitudes (27), thus reinforcing society's positive view of biodiversity conservation.

REFERENCES AND NOTES

- UN Environment World Conservation Monitoring Centre (UNEP-WCMC), International Union for Conservation of Nature (IUCN), National Geographic Society (NGS), "Protected Planet Report 2018" (UNEP-WCMC, IUCN, and NGS, 2018).
- D. Leclère et al., *Nature* **585**, 551–556 (2020).
- F. P. L. L. Melo, V. Arroyo-Rodríguez, L. Fahrig, M. Martínez-Ramos, M. Tabarelli, *Trends Ecol. Evol.* **28**, 462–468 (2013).
- M. Duru et al., *Agron. Sustain. Dev.* **35**, 1259–1281 (2015).
- G. Sparovek et al., *Land Use Policy* **87**, 104062 (2019).
- Headwaters Economics, "A profile of land use" (Headwaters Economics, 2018).
- L. A. Powell, *Anim. Biodivers. Conserv.* **35**, 295–306 (2012).
- V. Arroyo-Rodríguez et al., *Ecol. Lett.* **23**, 1404–1420 (2020).
- J. I. Watling et al., *Ecol. Lett.* **23**, 674–681 (2020).
- U. Oliveira et al., *Sci. Rep.* **7**, 9141 (2017).
- R. Rajão et al., *Science* **369**, 246–248 (2020).
- L. Fahrig, *J. Biogeogr.* **40**, 1649–1663 (2013).
- S. Kamal, M. Grodzińska-Jurczak, G. Brown, *J. Environ. Plann. Manage.* **58**, 576–597 (2015).
- C. L. Archibald et al., *Environ. Sci. Policy* **115**, 99–107 (2021).
- J. O'Leary, A. R. Rissman, *Land Use Policy* **51**, 76–84 (2016).
- Environmental Law Institute, *Legal Tools and Incentives for Private Lands Conservation in Latin America: Building Models for Success* (Environmental Law Institute, 2003).
- B. Soares-Filho et al., *Science* **344**, 363–364 (2014).
- Projeto MapBiomass, *Coleção 7 da Série Anual de Mapas de Cobertura do Uso do Solo do Brasil* (2022); https://mapbiomas-br-site.s3.amazonaws.com/Estatísticas/1_-TABELA_GERAL_COL7_MAPBIOMAS_BIOMAS_UF_FINAL.xlsx.
- P. Mendes, S. J. E. Velazco, A. F. A. de Andrade, P. De Marco, *Ecol. Modell.* **431**, 109180 (2020).
- P. De Marco Jr. et al., *Biodivers. Conserv.* **29**, 1637–1658 (2020).
- K. de Mello et al., *Environ. Sci. Policy* **120**, 1–10 (2021).
- J. J. O'Grady, D. H. Reed, B. W. Brook, R. Frankham, *Biol. Conserv.* **118**, 513–520 (2004).
- B. Zimbres et al., *For. Ecol. Manage.* **499**, 119615 (2021).
- Y. M. Wei et al., *Nat. Clim. Chang.* **11**, 112–118 (2021).
- F. P. Lima, R. P. Bastos, *Ecosyst. Serv.* **40**, 101029 (2019).
- A. R. Whittaker, *People Nat.* **2**, 450–467 (2020).
- F. Pereira Lima, R. Pereira Bastos, *Ecosyst. Serv.* **44**, 101121 (2020).
- P. De Marco Jr. et al., Species distribution data and distribution of private and public protected areas in Cerrado, Brazil. *Dryad* (2023); <https://doi.org/10.5061/dryad.7pvmcvdz5>.

ACKNOWLEDGMENTS

This work is dedicated to G. Fonseca, who spent a lifetime dedicated to biodiversity conservation in Brazil and worldwide. We thank E. Bruna and G. Fonseca for their invaluable contributions to an early version of this manuscript. **Funding:** P.D.M. is continuously supported by a CNPq productivity grant (310547/2020-2). S.V.-P. was supported by Comunidad de Madrid and Universidad de Alcalá (2017-T2/AMB-6035; 2022-T1/AMB-237), Sustainability Victoria (CM/JIN/2019), and Ecological Transition and Demographic Challenge (2020/00085/001). M.C. is supported by National Science Foundation NSF-BCS 2117533: Agri-environmental Conservation Incentives in the Extreme Wildfire Context of the U.S. Southern Plains. A.F.A.A. is supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq - 165174/2020-0). **Author contributions:** Conceptualization: P.D.M., R.A.S., C.C.N., M.C.; Methods (geographical data management): R.A.S., L.M.C.; Methods (ecological models): A.F.A.A., R.A.S., S.V.-P., C.C.N.; Data analysis: P.D.M., A.F.A.A.; Writing – first draft: P.D.M., C.C.N., R.A.S.; Writing – review: P.D.M., M.C., S.V.-P. **Competing interests:** The authors declare that they have no competing interests. **Data and availability:** All data (species distribution models and spatialized private and public conservation distribution) are available from the Dryad dataset repository (28). **License information:** Copyright © 2023 the authors, some rights reserved; exclusive licensee American Association for the Advancement of Science. No claim to original US government works. <https://www.science.org/about/science-licenses-journal-article-reuse>

SUPPLEMENTARY MATERIALS

science.org/doi/10.1126/science.abq7768

Material and Methods

Figs. S1 and S2

References (29–49)

MDAR Reproducibility Checklist

Submitted 8 June 2022; accepted 1 March 2023

10.1126/science.abq7768



The value of private properties for the conservation of biodiversity in the Brazilian Cerrado

Paulo De Marco, Jr., Rodrigo A. de Souza, Andr F. A. Andrade, Sara Villn-Prez, Caroline Corra Nbrega, Luiza Motta Campello, and Marcellus Caldas

Science, **380** (6642), .

DOI: 10.1126/science.abq7768

Private land protection

To protect high rates of biodiversity, a large amount of global land must be under some sort of protection. In regions where public land is not prioritized nor widely distributed, it is possible that protection of private land could contribute to species conservation. In Brazil, a native vegetation law instituted decades ago has provided an opportunity for evaluation of the role of private land in conserving species. De Marco *et al.* looked at mammal species protected by these private set-asides in the Brazilian Cerrado and found that they covered up to 25% of species ranges (see the Perspective by Machado and Aguiar). Such areas play an even more important role when ecologically intact or restored. —SNV

View the article online

<https://www.science.org/doi/10.1126/science.abq7768>

Permissions

<https://www.science.org/help/reprints-and-permissions>

Use of this article is subject to the [Terms of service](#)

Science (ISSN) is published by the American Association for the Advancement of Science. 1200 New York Avenue NW, Washington, DC 20005. The title *Science* is a registered trademark of AAAS.

Copyright © 2023 The Authors, some rights reserved; exclusive licensee American Association for the Advancement of Science. No claim to original U.S. Government Works