Received: 16 August 2023 | Revised: 29 May 2024 | Accepted: 3 June 2024

DOI: 10.1111/cobi.14334

Conservation Biology

CONTRIBUTED PAPER

# Exposing illegal hunting and wildlife depletion in the world's largest tropical country through social media data

Hani R. El Bizri[1,2,3,4] | Marcela A. Oliveira[4,5] | Aline Pessutti Rampini[6,7] | Simon Knoop[8] | Julia E. Fa[1,9] | Lauren Coad[1,6] | Thais Queiroz Morcatty[3,4,10,11] | Gabriel Favero Massocato[12,13,14] | Arnaud L. J. Desbiez[12,15] | João Vitor Campos-Silva[4,16,17,18] | Daniel Zani La Laina[11] | José Maurício Barbanti Duarte[19] | Rafael Sá Leitão Barboza[20] | Zilca Campos[21] | Marcélia Basto da Silva[22] | Sarah Mângia[23] | Daniel J. Ingram[24] | Juliano A. Bogoni[25,26,27]

[1]Center for International Forestry Research (CIFOR), Bogor, Indonesia

[2]School of Science, Engineering and Environment, University of Salford, Salford, UK

[3]Research Group on Terrestrial Vertebrate Ecology, Mamirauá Sustainable Development Institute, Tefé, Brazil

[4]Rede de Pesquisa em Diversidade, Conservação e Uso da Fauna da Amazônia (RedeFauna), Manaus, Brazil

[5]Programa de Pós-Graduação em Conservação e Uso de Recursos Naturais, Universidade Federal de Rondônia, Rondônia, Brazil

[6]Department of Zoology, University of Oxford, Oxford, UK

[7]Sainsbury Wellcome Centre, University College London, London, UK

[8]Living Gaia e.V., Berlin, Germany

[9]Department of Natural Sciences, School of Science and the Environment, Manchester Metropolitan University, Manchester, UK

[10]Department of Geography, University College London, London, UK

[11]Oxford Wildlife Trade Research Group, Oxford Brookes University, Oxford, UK

[12]Instituto de Conservação de Animais Silvestres-ICAS, Campo Grande, Brazil

[13]Houston Zoo, Houston, Texas, USA

[14]Instituto de Pesquisas Ecológicas (IPÊ), Nazaré Paulista, Brazil

[15]RZSS – The Royal Zoological Society of Scotland, Edinburgh, UK

[16]Institute of Biological and Health Sciences, Federal University of Alagoas, Maceió, Brazil

[17]Instituto Juruá, Manaus, Brazil

[18]Instituto Nacional de Pesquisas da Amazônia (INPA), Manaus, Brazil

[19]Núcleo de Pesquisa e Conservação de Cervídeos (NUPECCE), Universidade Estadual Paulista (UNESP), Jaboticabal, Brazil

[20]Programa de Pós-Graduação em Biodiversidade – PPGBio. Laboratório de Etologia Teórica e Aplicada – LETA, Laboratório Interdisciplinar de Anfíbios e Répteis – LIAR, Universidade Federal Rural de Pernambuco – UFRPE, Recife, Brazil

[21]Laboratório de Vida Selvagem, Embrapa Pantanal, Corumbá, Brazil

[22]Centro de Educação Aberta e a Distância, Universidade Federal do Piauí, Teresina, Brazil

[23]Instituto de Biociências, Universidade Federal de Mato Grosso do Sul, Campo Grande, Brazil

[24]Durrell Institute of Conservation and Ecology, School of Anthropology and Conservation, University of Kent, Canterbury, UK

[25]Universidade de São Paulo (USP), Escola Superior de Agricultura "Luiz de Queiroz" (ESALQ), Departamento de Ciências Florestais, Laboratório de Ecologia, Manejo e Conservação de Fauna Silvestre (LEMaC), Piracicaba, Brazil

[26]Universidade Federal de Mato Grosso do Sul (UFMS), Programa de Pós-Graduação em Ecologia e Conservação, Campo Grande, Brazil

[27]Laboratório de Mastozoologia, Universidade do Estado de Mato Grosso, Cáceres, Brazil

**Correspondence**
Hani R. El Bizri, Center for International Forestry Research (CIFOR), Bogor, Indonesia. Email: hanibiz@gmail.com
Juliano A. Bogoni Universidade de São Paulo (USP), Escola Superior de Agricultura "Luiz de Queiroz" (ESALQ), Departamento de Ciências Florestais, Laboratório de Ecologia, Manejo e Conservação de Fauna Silvestre (LEMaC), Piracicaba, Brazil. Email: bogoni.ja@gmail.com

**Article impact statement**: Social media data uncover hidden patterns of illegal hunting and wildlife depletion and highlight urgent need for policy change in Brazil.

**Funding information**
UK Research and Innovation, Grant/Award Numbers: ES/S008160/1, MR/W006316/1; Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, Grant/Award Number: 88887.717863/2022-00; Gordon and Betty Moore Foundation, Grant/Award Number: GBMF9258; Conselho Nacional de Desenvolvimento Científico e Tecnológico, Grant/Award Number: 150261/2023-3; United States Agency for International Development

## Abstract

Globally, illegal sport hunting can threaten prey populations when unregulated. Due to its covert nature, illegal sport hunting poses challenges for data collection, hindering efforts to understand the full extent of its impacts. We gathered social media data to analyze patterns of illegal sport hunting and wildlife depletion across Brazil. We collected data for 2 years (2018–2020) across 5 Facebook groups containing posts depicting pictures of illegal sport hunting events of native fauna. We described and mapped these hunting events by detailing the number of hunters involved, the number of species, the mean body mass of individuals, and the number and biomass of individuals hunted per unit area, stratified by Brazilian biome. We also examined the effects of defaunation on hunting yield and composition via regression models, rank–abundance curves, and spatial interpolation. We detected 2046 illegal sport hunting posts portraying the hunting of 4658 animals (~29 t of undressed meat) across all 27 states and 6 natural biomes of Brazil. Of 157 native species targeted by hunters, 19 are currently threatened with extinction. We estimated that 1414 hunters extracted 3251 kg/million km$^2$. Some areas exhibited more pronounced wildlife depletion, in particular the Atlantic Forest and Caatinga biomes. In these areas, there was a shift from large mammals and reptiles to small birds as the main targeted taxa, and biomass extracted per hunting event and mean body mass across all taxonomic groups were lower than in other areas. Our results highlight that illegal sport hunting adds to the pressures of subsistence hunting and the wild meat trade on Brazil's wildlife populations. Enhanced surveillance efforts are needed to reduce illegal sport hunting levels and to develop well-managed sustainable sport hunting programs. These can support wildlife conservation and offer incentives for local communities to oversee designated sport hunting areas.

**KEYWORDS**
conservation culturomics, defaunation, Facebook, overexploitation, poaching, recreational hunting, threatened species, wildlife crime

## INTRODUCTION

Hunting wildlife has been common practice in human societies throughout history (Andermann et al., 2020; Milner-Gulland et al., 2003). People still hunt wild animals for food and for income through trade in meat or byproducts (Ingram et al., 2021), and predators are hunted to protect people, crops, and livestock (e.g., Jędrzejewski et al., 2017). Worldwide, many people hunt for recreation (i.e., sport hunting) (Di Minin, Clements, et al., 2021; Loveridge et al., 2006; Oliveira et al., 2021; Ripple et al., 2016), which includes trophy collection (e.g., antlers) (Loveridge et al., 2006).

Although sport hunting can have negative impacts on prey animal behavior, fitness, and population dynamics and thus lead to a decline in species richness and abundance (Di Minin, Clements, et al., 2021; Ripple et al., 2016), strictly controlled and regulated sport hunting can contribute to biodiversity conservation through generation of income for local communities, support of environmental agencies, and control of invasive species (Di Minin et al., 2016). Hunting is influenced by wealth (Brashares et al., 2011), human density, migration, local development, and proximity to wildlife resources (Benítez-López et al., 2017; Ripple et al., 2016). Taste and taboos also determine which animals are hunted (Chausson et al., 2019; Morsello et al., 2015). In many parts of the tropics and subtropics, hunting rates are estimated to be high enough to pose a threat to many animal populations (Fa et al., 2022). In particular, overhunting of large vertebrates can lead to severe declines in their population numbers (Dirzo et al., 2014). Loss of these species, often important seed dispersers, not only affects the composition of animal communities, but also can jeopardize the overall functioning of tropical ecosystems (Abernethy et al., 2013; Ripple et al., 2016).

Although research on sport hunting is common in North America, Africa, and Europe (Di Minin, Clements, et al., 2021), there have been limited studies on this topic in South America, including Brazil. Brazil is the largest and the most biodiverse tropical country in the world (Mittermeier et al., 2005). Typically, >50% of the presumed species richness in the country has been extirpated by habitat loss and overhunting, except in large wilderness areas, such as the Amazon (Bogoni et al., 2020a). Faunal depletion is particularly severe (>70%) in the semiarid Caatinga and interior plateaus of the Atlantic Forest (Bogoni et al., 2020a).

The 1967 Wildlife Protection Law (Federal Law 5,197/67 [Brasil, 1967]) provides guidelines for establishing sport hunting clubs, but in practice, it effectively bans hunting of native wildlife species for sport in Brazil. The Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) has

not officially defined hunting seasons, species, or quotas for native wildlife at the national level since the enactment of the law. Short-lived attempts at sport hunting programs (e.g., waterfowl hunting in Rio Grande do Sul state) were rapidly revoked (El Bizri et al., 2015). Further regulations in 1998 (Federal Law 9,605/98 [Brasil, 1998]) broadly criminalized environmental crimes, including hunting. The regulation of certified collectors, sport shooters, and hunters (Colecionador, Atirador Desportivo, e Caçador [CACs]) through Decree 9,846/2019 (now replaced by Decree 11,615/2023) allowed individuals who met specific criteria—such as no criminal records and proficiency in handling firearms—to obtain authorization from the Brazilian Army to engage in collecting firearms, sport shooting, and hunting activities specifically for the control of the invasive European wild boar (*Sus scrofa*) (IBAMA Normative Instruction 03/2013, suspended since August 2023). Hunting of any native wildlife is currently de facto illegal in Brazil, with some exceptions for Indigenous people and when specifically authorized by Brazilian authorities for people in a "state of necessity" (i.e., in need of food), to protect against predatory or destructive actions of animals, and for scientific purposes (Antunes et al., 2019). At least 9 additional state laws (e.g., Law 6.670 of 2023 from Amazonas, Law 1.117 of 1994 from Acre, Complementary Law 5 of 1994 from Amapá, and Law 17.729 of 2021 from Ceará) explicitly forbid sport hunting; many also prohibit dissemination or advertising encouraging or suggesting hunting or depicting practices and activities that cause the death of an animal (Juras & Araújo, 2009).

Information on the extent, characteristics, geographical distribution, and consequences of illegal sport hunting in a large tropical country, such as Brazil, can help policy makers facilitate effective management strategies (Alves & Souto, 2011; El Bizri et al., 2015). However, given that sport hunting of native wildlife is illegal in Brazil, accessing information on even the most basic aspects of this activity, such as geographic scope and target species, is challenging (Bragagnolo et al., 2019). This is because hunters generally distrust researchers and are unwilling to admit to being involved in illegal activities when direct survey methods are employed (van Vliet et al., 2015). In such scenarios, social media data can emerge as a potent information reservoir on illegal sport hunting (e.g., Di Minin et al., 2015; El Bizri et al., 2015; Ladle et al., 2016). Social media platforms provide users with the ability to form online communities centered around sharing and exchange of visual content in the form of photos and videos. These digital spaces enable individuals with similar interests to come together and engage in a dynamic and interactive manner. They provide a content-rich source of information to assess who is interacting with nature and where and when, how users interact with each other, and preferences for the content shared (Di Minin et al., 2015).

Evidence from IBAMA and RENCTAS (a Brazilian nongovernmental organization that collects data and intelligence on wildlife trafficking) reveals that Facebook and WhatsApp are the primary channels for sharing information on wildlife hunting and trade in Brazil (Morcatty et al., 2022; Wyatt et al., 2022). By contrast, limited details are available in the literature on the use of Instagram and TikTok for these activities, especially concerning native species.

We compiled data from illegal sport hunting records shared by hunters on social media groups to provide first-hand information on this secretive activity in Brazil. Due to the private and individualized nature of WhatsApp, which poses challenges for research and raises ethical concerns related to privacy and consent, we prioritized the use of Facebook. We conducted a comprehensive analysis of the scale, geographic scope, and impacts of illegal sport hunting nationwide. To do so, we investigated the diversity of hunted taxa and proportion of threatened species; estimated and compared the number of individual animals and biomass harvested in the different Brazilian biomes; and analyzed hunting yield trends and composition of hunted species to assess how hunting outcomes reflect wildlife depletion in different parts of the country.

## METHODS

### Data collection on hunting events on social media

Illegal sport hunting pertains to hunting endeavors primarily carried out by individuals with nontraditional lifestyles. These individuals possess ample personal income to purchase firearms and acquire alternative meat sources, rendering them independent of relying on wild animals for sustenance (El Bizri et al., 2015). People living in remote rural areas, where individuals with lower per capita income predominantly reside, typically engage in subsistence hunting but have limited access to internet connectivity to engage in social media posts (IBGE, 2021). In line with this, there is a concentration of hunting activities in areas of higher human density that also have a higher human development index (HDI) and lower poverty levels than average in Brazil (data in Appendix S1). The social media posts we analyzed are therefore more likely to include individuals from more urban and developed areas, rather than Indigenous peoples and those hunting out of necessity. Following El Bizri et al. (2015), we treated all posts of non-Indigenous hunting as illegal sport hunting events. While acknowledging that a small number of these posts could be related to hunting for necessity, we considered these instances negligible.

We collected information on illegal sport hunting events in Brazil from 5 large (i.e., composed by tens of thousands of members) Facebook groups. We used the following keywords to find these groups with Facebook's search engine: "*caça*" AND "*Brasil*" in Portuguese (equivalent to *hunting* and *Brazil* in English). Due to the constant stream of new content in these groups (approximate a daily average of 50 posts) and considering the limited number of researchers available for manual data collection (5 of the authors), we strategically selected the first 5 groups that surfaced in our search results. Each data collector was responsible for one group. The ranking of groups in Facebook's search engine is influenced by several factors, typically including the relevance of the group to the search query, level of user engagement and activity in the group, and the group's overall popularity. These criteria suggested that the groups appearing at the top of the search results were likely to be the most pertinent and active regarding our topic of interest.

The 5 selected illegal sport hunting groups were created from 2018 to 2020. We documented the number of participating members in each group as an indicator of the level of involvement in illegal sport hunting across these 5 groups. We then scrolled through the posts in each group, starting from the oldest one, and gathered information about all hunting photos posted from that date until 31 July 2020. Posts contained one or several photos of the same hunting event. Because illegal sport hunting in Brazil usually involves the consumption of the meat (El Bizri et al., 2015), we refrained from collecting data from any photos that explicitly depicted wildlife conflict instances (such as the killing of snakes) in which the meat was not being used. To verify the context of these photos, at the moment of data collection we checked the post's description and the accompanying comments related to the killing incident without storing any content from these descriptions or comments. For all hunting posts identified, we created a unique identifier (for both post and user) and documented the following information: posting date, species hunted, number of comments and likes, and number of individuals hunted of each species.

We then accessed the profile of the user to collect information on the municipality the hunter lived in, which is visible to any other Facebook member. We extracted the geographical coordinates with decimal degrees and the SIRGAS 2000 datum from each of these locations. It was difficult to obtain precise locations of hunting events, so we relied on the municipalities listed in user profiles as the locations of these activities. We did this primarily because hunters likely do not share specific locations of their activities to avoid legal consequences, which meant there were no geotags or comments that could help us pinpoint exact hunting locations. There was also the possibility of long-distance travel by hunters to hunt in other localities. To ensure the accuracy of the locations and minimize speculation about hunters' movements, we assessed whether the municipalities listed in the users' profiles were within the distribution range maps (IUCN, 2023) of the targeted species and aligned with records from the Global Biodiversity Information Facility (GBIF, 2024) for all species and WikiAves (2024) database for birds. Only 6 records (0.29%) of the locations potentially lay outside the expected geographical distribution of the species (Appendix S2). This alignment was confirmed even in cases involving species with highly limited geographical ranges, such as the dwarf porcupine (*Coendou speratus*).

Aligned with this assumption, in tropical regions, hunting activities of rural people typically occur in the vicinity of the hunter's residence, often within a radius of approximately 5–16 km (Baker, 2011). Despite the lack of data on distances traveled by sport hunters in Brazil, average distances of sport hunters are likely to be similar to distances in other parts of the world (e.g., Australia 4.81 km [Hampton et al., 2022]; Indonesia 11.49 km [Yudha et al., 2022]). These average distances would typically still be within the same municipal boundaries in Brazil, indicating that hunters might not travel as far as one might assume. Our reliance on verifiable data helped us avoid speculative conclusions in the absence of concrete evidence or existing literature on widespread hunting travel in Brazil.

Large areas in the Pantanal typically have their seat of government in the Brazilian Cerrado; thus, we summarized the data of these 2 biomes as Cerrado–Pantanal. We acknowledge the distinct ecological characteristics of the Pantanal and Cerrado biomes, but our study areas were limited by our reliance on municipal boundaries for geographical data. This led to an overlap where the Pantanal is largely encapsulated within the Cerrado's municipal counties. Due to this constraint and the absence of more precise hunting event locations, we were unable to distinctly separate occurrences in the Pantanal from those in the Cerrado. The Pantanal, Brazil's smallest and mostly roadless biome with a few large municipal counties with administrative centers in the Cerrado, has a comparatively minor impact on our spatial results and conclusions regarding hunting practices.

For species documentation, photos of specimens were analyzed independently by at least 2 of us with experience in identifying the taxonomic groups assessed. We identified hunted species based on updated scientific publications, online resources, and field guides (Ávila-Pires, 1995; Birds of the World, 2022; CITES, 1995; de Sá et al., 2014; Develey & Endrigo, 2004; Heyer, 2005; Heyer et al., 1990; Magalhães et al., 2020; Perlo, 2009; Silva et al., 2018). In cases where a species' classification was ambiguous or consensus among assessors could not be reached, we used genus, family, and occasionally order or class to classify the recorded taxa. Species body mass (adult body size, averaged by both male and female weight) of all hunted species was obtained from Jones et al. (2009) and Wilman et al. (2014). For those species for which we did not have body mass data, mainly Reptilia, we consulted specific literature, search engines (e.g., https://reptile-database.reptarium.cz/; https://www.iucnredlist.org/species; https://www.inaturalist.org/), our own field data, or all 3. For those taxa for which we could only ascribe genus, family, order, or class, we used the average body mass of all species within that taxonomic level with distribution ranges that intersected with the hunting location. All species-level taxa were classified according to the International Union for Conservation of Nature (IUCN) Red List threat categories (i.e., vulnerable, endangered, and critically endangered) (IUCN, 2023).

## Descriptive statistics

We used descriptive statistics to compute diverse parameters, including municipality counts with recorded hunting activities and the tally of hunting events, hunters, species, and threatened species. We also quantified the total number of hunted individuals and biomass in aggregate and stratified by species and biome. Additionally, we computed the mean and standard error for variables, such as the number of hunting events, individual captures, and harvested biomass per hunter and per biome. To gauge public engagement, we tallied likes and comments on posts. Hunting events were geographically visualized across biomes by employing geographic coordinates from municipality data. The biomass of hunted vertebrates, stratified by taxonomic class (birds, mammals, and reptiles) was estimated per million

square kilometers in each biome. Frequency histograms were leveraged to visualize body mass concentration distribution (ln $x + 1$) across different taxa and biomes. Maps for amphibians were not built due to the limited amount of data.

## Defaunation gradient analyses

We investigated trends in hunting outcomes and composition, aiming to comprehend how hunting practices shift along a defaunation gradient in Brazil. We computed the mean defaunation level of each municipality in Brazil by extracting values of the defaunation index from a raster created by Bogoni et al. (2020a) for the entire Neotropical realm. This defaunation index encapsulates anthropogenic and environmental drivers and ranges from 0.0 (faunally intact) to 1.0 (fully defaunated) for mammal species richness. Although data on defaunation levels for other taxonomic groups (birds, reptiles, amphibians) are limited, mammal defaunation patterns can serve as an indicator of broader ecological changes (Dirzo et al., 2014). We calculated the average defaunation level per Brazilian state based on the average defaunation of the municipalities for which we recorded hunting events posted on Facebook.

With each Brazilian state as a sampling unit, we investigated the correlation between a state's average defaunation level and response variables related to hunting yield (average individuals and biomass hunted per event) and hunting composition (average body mass of hunted mammals, birds, and reptiles and representativeness [proportion of individuals] of these groups in the hunted population). We selected quasibinomial distribution for proportional data and either gamma or Gaussian distribution for mean values. We applied the latter when the data were normally distributed (Shapiro–Wilk test $p > 0.05$). Additionally, we computed the pseudo-$R^2$ statistic to provide a measure of the model's explanatory power. We then constructed rank–abundance curve plots to compare species abundance decay across Brazilian biomes in each taxonomic class.

## Spatial interpolation

We used spatial interpolation to estimate total average hunting offtakes per hunting event per square kilometer (number of individuals and species body mass and biomass [kilograms per square kilometer]) across Brazil. Spatial autocorrelation of hunting profiles was examined with the Moran index (Moran, 1950). When spatial autocorrelation was significant, we used kriging interpolation (Cressie, 1993). This method uses a weighted average of the known data points to estimate values at unknown locations, where the weights are determined by the spatial covariance between data points (Cressie, 1993). Our analyses resulted then in country-scale maps at approximately 4.5-km pixel resolution.

All statistical analyses were conducted with R 4.0.5, using the R packages rgdal, sf, raster, and gstat, along with their associated dependencies (Bivand et al., 2023; Hijmans, 2023; Pebesma, 2004, 2018).

## Ethical considerations

Given that sport hunting remains a prohibited and delicate subject in Brazil, we adhered to Roulet et al.'s (2017) method for conducting covert research. Three of the 5 selected Facebook groups were listed as "open" with no restriction of access, whereas the other 2 were listed as "closed," which means that approval from a group administrator is required to join the group. No explicit instructions were provided for joining the closed groups, and all our membership requests were approved within 24 h. The only contact we had with closed Facebook groups was confined to our request to join; we did not engage directly with administrators or group members. All our data, except the user's municipality (information freely accessible from user profiles), was obtained solely from the photos posted by group members. Throughout the data collection phase, no personal information was utilized, and no interviews were conducted.

After consulting various committee boards and legal experts in Brazil, the study was deemed exempt from the requirement of undergoing a national ethical review or obtaining consent from participants, according to Brazilian regulations (CNS Resolution 510, 2016). This exemption was granted due to the study's reliance on voluntarily shared online data. The analyzed closed groups, each consisting of approximately 40,000 members, were considered publicly accessible because they lacked explicit access restrictions. Moreover, the research did not involve personal viewpoints or direct engagement with human subjects. Nevertheless, considering the sensitive nature of the information, an additional ethics review for the project was conducted and accepted by CIFOR-ICRAF's ethics review board.

To mitigate possible risks linked to photo sharing and to align with data protection regulations, notably Brazil's General Personal Data Protection Law (13.709/2018), and guidelines presented in Di Minin, Fink, et al. (2021) for leveraging social media data, we introduced a range of precautions throughout the process of data collection, curation, and reporting. These measures included restricting the information collected to only essential data for analysis purposes and pseudonymizing all data, including usernames and group names. Moreover, we strictly adhered to the ethical guidelines outlined in Kosinski et al. (2015) and Martin et al. (2018) by refraining from engaging in communication with social media users and abstaining from collecting, retaining, or publishing information that could be directly linked to specific individuals, including the location of the posting event and graphical content. This approach entailed omitting group names from this publication and not providing detailed, per-species geolocation maps, including those used for cross-referencing our findings with species distributions. Such measures guarantee confidentiality and avoid the unintended revelation of personal identities or precise locations that could potentially expose hunters or areas with the presence of rare and threatened species. However, to maintain transparency, the 6 records deviating from expected species distributions are in red in Appendix S2.

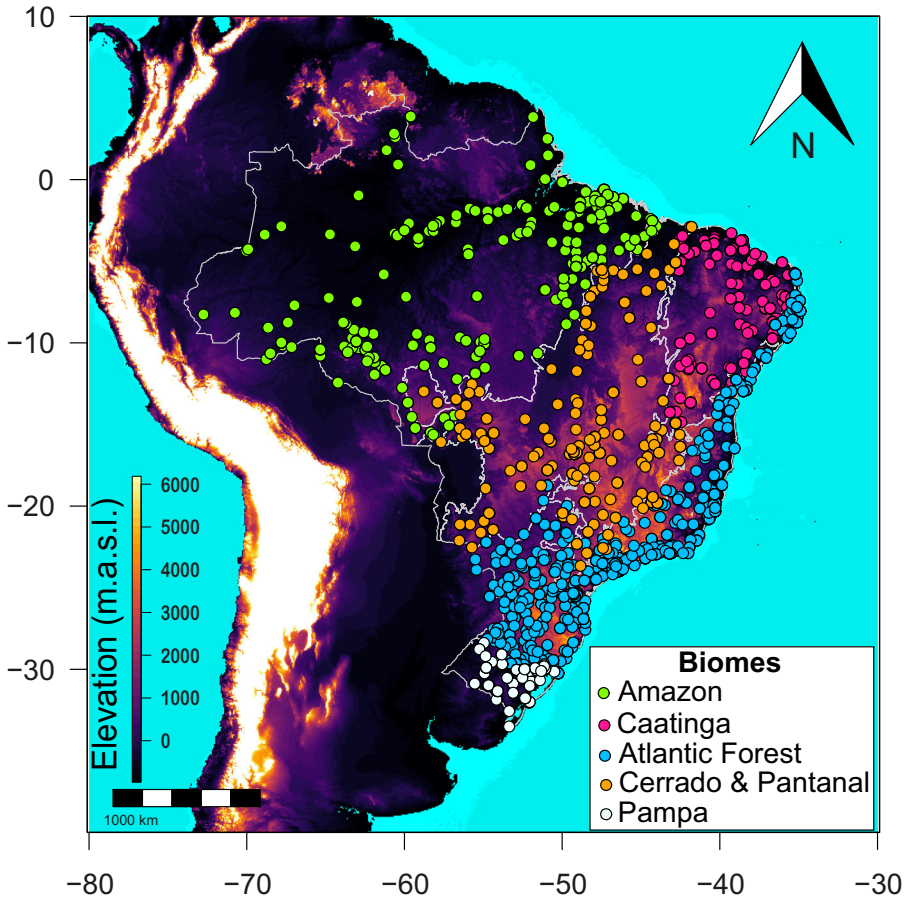


**FIGURE 1** Spatial distribution of 2046 hunting events of tetrapods (mammals, birds, reptiles, and amphibians) based on social media data throughout Brazil by biome where hunts presumably took place. The elevational profile is based on data openly available at ASTER Global Digital Elevation (https://asterweb.jpl.nasa.gov/gdem.asp).

## RESULTS

### Extent and patterns of illegal sport hunting across Brazil

We detected 2046 distinct hunting occurrences of 1414 individual hunters across 790 municipalities, representing 14.2% of all municipalities in Brazil. These events spanned all 27 Brazilian states and encompassed 6 distinct biomes (Figure 1). The largest number of hunting events occurred in the Amazon biome ($n$ = 707; 34.6%) followed by the Atlantic Forest ($n$ = 688; 33.6%), Cerrado–Pantanal ($n$ = 387; 18.9%), Caatinga ($n$ = 161; 7.9%), and Pampa ($n$ = 103; 5%) (Table 1). Content related to illegal sport hunting amassed 421,374 likes (mean [SE] = 171.6 [4.9] likes/post) and elicited a total of 45,854 comments (averaging 18.7 [0.7] comments per post). In total, 4658 animals (2.3 [0.1] individuals/hunting event) were hunted, representing a total undressed biomass of 29,656.35 kg (14.5 [0.6] kg/hunting event). We recorded a minimum of 157 native wild species: 75 birds (47.8% of all native wild species), 51 mammals (32.5%), 26 reptiles (16.6%), and 5 amphibians (3.1%) (Figure 2) (complete details per species in Appendix S2).

The most hunted species were lowland paca (*Cuniculus paca*) ($n$ = 556 individuals; 11.9% of all individuals hunted) and eared dove (*Zenaida auriculata*) ($n$ = 445; 9.6%) (Figure 2). Rodentia, Cingulata, and Artiodactyla were the most hunted mammals. Caimans (Crocodilia) were the most hunted reptiles in terms of individuals and biomass (6 species, 69 individuals, 2886 kg), but chelonians (Testudines) were the most hunted in terms of number of species, representing 14 (54.0%) of all reptile species hunted. Nineteen (12.1%) of the hunted species were threatened with extinction, and 7 (4.5%) were categorized as near threatened (Appendix S2).

In the Amazon, mammals constituted the dominant focus of hunting activities (77.9% of targeted individuals), whereas in the Cerrado–Pantanal region, they constituted 51.0%. Birds were the target of most hunters in the Caatinga (75.0%), Atlantic Forest (52.8%), and Pampa (51.2%). Reptiles and amphibians were the least hunted group across all biomes (<10% of individual animals). In terms of biomass, reptiles surpassed birds and ranked second only to mammals as the most hunted taxa across all biomes.

Based on these figures, the overall hunting offtake per unit area was 3251 kg/million km$^2$ for the 2 sampled years

**TABLE 1** Descriptive statistics from social media data on illegal sport hunting in Brazil obtained from 5 Facebook groups.

| Descriptive statistic | Biome | | | | | |
|---|---|---|---|---|---|---|
| | Amazon | Atlantic Forest | Caatinga | Cerrado–Pantanal | Pampa | Total |
| Number of hunters | 442 | 518 | 108 | 268 | 78 | 1414 |
| Number of events | 707 | 688 | 161 | 387 | 103 | 2046 |
| Average number of events per hunter (SE) | 1.6 (0.1) | 1.3 (0.04) | 1.5 (0.1) | 1.4 (0.1) | 1.3 (0.1) | 1.5 (0.03) |
| Average number of individuals per event (SE) | 1.6 (0.05) | 2.5 (0.3) | 5.0 (0.6) | 1.9 (0.1) | 2.8 (0.4) | 2.3 (0.1) |
| Average biomass per event (kg) (SE) | 18.7 (1.3) | 10.2 (0.6) | 5.8 (0.7) | 13.8 (1.2) | 30.2 (4.7) | 14.5 (0.6) |
| Number of species | 85 | 93 | 49 | 60 | 28 | 157 |
| Mammals | 31 | 34 | 18 | 21 | 7 | 51 |
| Birds | 35 | 44 | 26 | 32 | 18 | 75 |
| Reptiles | 18 | 11 | 5 | 6 | 2 | 26 |
| Amphibians | 1 | 4 | 0 | 1 | 1 | 5 |
| Threatened | 14 | 7 | 1 | 5 | 1 | 18 |
| Number of individuals | 1108 | 1716 | 811 | 732 | 291 | 4658 |
| Mammals (%) | 863 (77.9) | 671 (39.1) | 180 (22.2) | 373 (51.0) | 120 (41.2) | 2207 (47.4) |
| Birds (%) | 165 (14.9) | 906 (52.8) | 608 (75.0) | 334 (45.6) | 149 (51.2) | 2162 (46.4) |
| Reptiles (%) | 79 (7.1) | 51 (3.0) | 23 (2.8) | 18 (2.5) | 16 (5.5) | 187 (4.0) |
| Amphibians (%) | 1 (0.1) | 88 (5.1) | 0 (0) | 7 (1.0) | 6 (2.1) | 102 (2.2) |
| Biomass (kg) | 13216.8 | 7042.0 | 940.5 | 5344.6 | 3112.6 | 29656.4 |
| Mammals (%) | 10726.1 (81.2) | 6021.3 (85.5) | 628.1 (66.8) | 4650.8 (87.0) | 2387.4 (76.7) | 24413.7 (82.3) |
| Birds (%) | 210.1 (1.6) | 447.6 (6.4) | 172.5 (18.3) | 175.4 (3.3) | 166.7 (5.4) | 1172.3 (4.0) |
| Reptiles (%) | 2280.5 (17.2) | 563.2 (8.0) | 139.8 (14.9) | 517.5 (9.7) | 558.0 (17.9) | 4059.0 (13.7) |
| Amphibians (%) | 0.07 (0.0) | 9.87 (0.1) | 0.00 (0.0) | 0.91 (0.0) | 0.48 (0.0) | 11.33 (0.0) |
| Mean body mass (kg) (SE) | 12.5 (0.8) | 4.3 (0.4) | 1.2 (0.5) | 8.0 (0.9) | 11.8 (1.7) | 6.8 (0.4) |
| Mammals | 12.6 (0.8) | 9.4 (0.5) | 3.4 (1.0) | 12.6 (1.2) | 20.2 (2.3) | 11.3 (0.5) |
| Birds | 1.5 (0.2) | 0.5 (0.1) | 0.3 (0.05) | 0.5 (0.1) | 1.1 (0.7) | 0.5 (0.1) |
| Reptiles | 28.9 (4.4) | 10.9 (2.3) | 6.1 (2.9) | 28.8 (5.1) | 34.9 (7.1) | 21.7 (2.1) |
| Amphibians | 0.070 | 0.090 (0.003) | 0.000 | 0.080 | 0.080 | 0.09 (0.003) |

(1626 kg/million km$^2$/year), and the number of individuals per unit area was 510 individuals/million km$^2$ in the 2 years (255 individuals/million km$^2$/year) (Figure 3).

## Defaunation and changes in hunting outcomes and composition

Brazilian states with higher defaunation levels (as extracted from Bogoni et al. [2020a]) had higher numbers of individuals hunted per hunting event (Figure 4a) but a lower average biomass harvested per event (Figure 4b) and a lower average body mass for hunted mammals (Figure 4c), birds (Figure 4d), and reptiles (Figure 4e). Furthermore, a distinct trend suggesting possible substitution emerged: birds increasingly replaced mammals and reptiles in terms of proportion of individuals in the hunting offtakes in defaunated areas (Figure 4f–h).

Rank–abundance plots revealed steeper curves in the Caatinga (the most defaunated biome) than in other biomes, particularly for mammals likely because of a dominance by a few mammal species in the hunting offtake. In contrast, the Amazon and Cerrado–Pantanal exhibited shallower curves due to a more even distribution of species in hunting offtake (Figure 5a).

Our interpolation map also highlighted differences in hunting outcomes across Brazil. The highest concentration of hunted individuals per unit area was in the Caatinga, Pampa, and interior plateaus of the Atlantic Forest, but these were largely of small species and therefore resulted in lower biomass extracted per hunting event in these biomes (Figure 5b). Conversely, the northwestern Amazon, Cerrado, and Pantanal had a concentration of large hunted species and a correspondingly higher biomass extracted per hunting event than other biomes (Figure 5b).

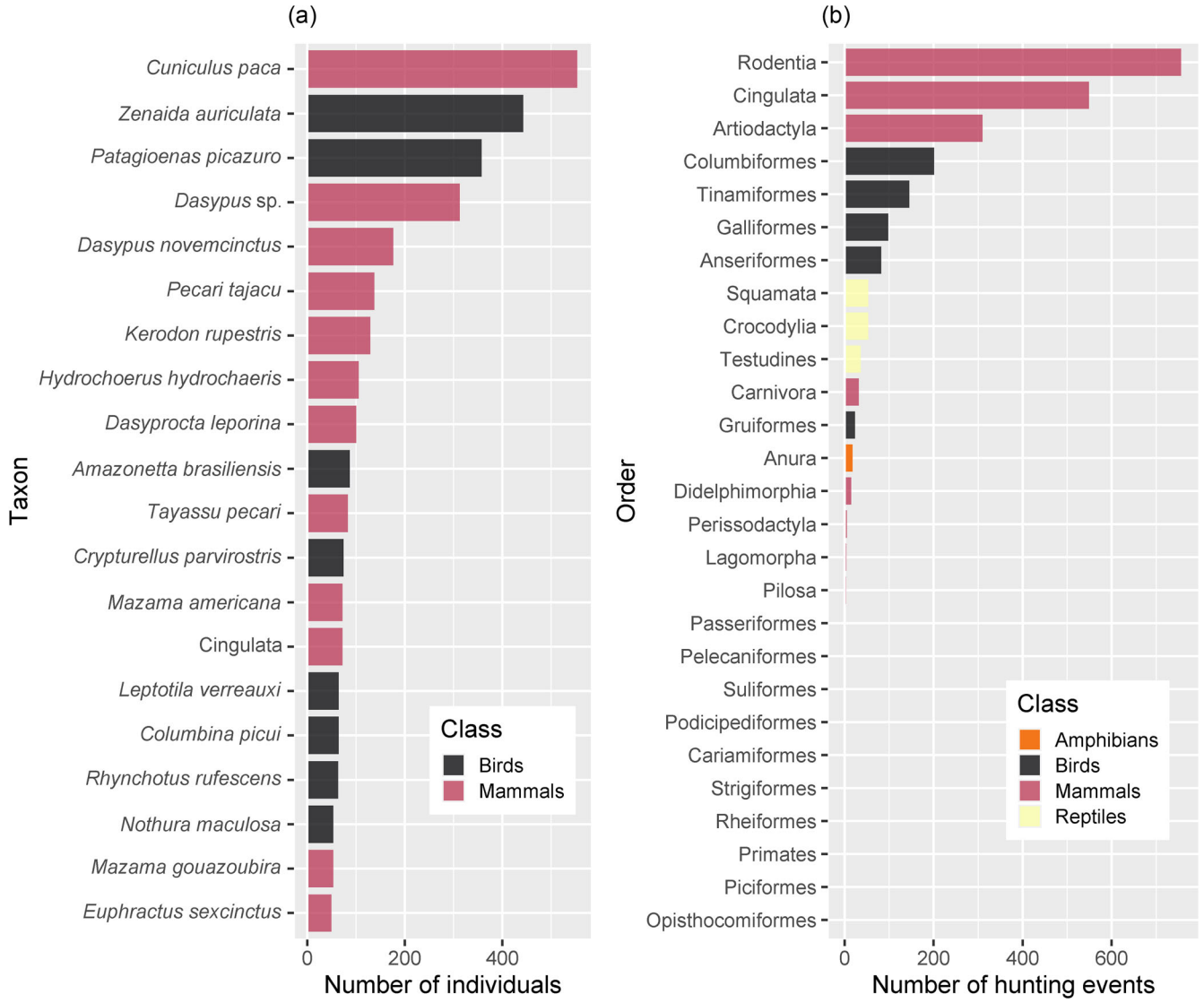


**FIGURE 2** Number of (a) individuals hunted among the 20 most hunted taxa and (b) hunting events by targeted taxonomic order throughout Brazil.

## DISCUSSION

### Magnitude and patterns of illegal sport hunting

We found strong evidence of widespread illegal sport hunting throughout Brazil. However, our data likely underestimated the total level of illegal sport hunting in the country because information was collected from only 5 Facebook groups (many more groups likely exist). Moreover, hunters posting in these 5 groups may not have disclosed all their catches online, and many active hunters may not have social media accounts or may choose not to share their hunting experiences online. Despite these caveats, we found that the 1414 sampled hunters extracted 3251 kg/km$^2$/year. A substantial portion of illegal sport hunting in Brazil might be conducted by CACs. This group is not only the primary civilian demographic with access to guns, but it is also the largest group authorized to hunt the invasive European wild boar with firearms in Brazil. They have been identified as actively participating in illegal sport hunting activities across the country (Lopes, 2023). In support of this, data from direct interviews with urban hunters targeting native species in Rondônia state indicate that approximately 43% (21 out of 49) of these hunters are registered as CACs (M.A.O., unpublished data). Furthermore, about 89% of the urban hunters interviewed in a recent study in the same state reported engaging in hunting for sport (Oliveira et al., 2023).

Assuming that a fraction of CACs ($n$ = 673,818) engage in sport hunting, the estimated annual biomass of native vertebrates illegally hunted across the entire Brazilian territory, based on per-capita data in our study, could reach approximately 486 kg/km$^2$/year (~4136 t of wild meat) under a 25% engagement rate; 972 kg/km$^2$/year (~8272 t) under a 50% engagement rate; and 1458 kg/km$^2$/year (~12,408 t of wild meat) under a 75% engagement rate. In the Brazilian Amazon, where

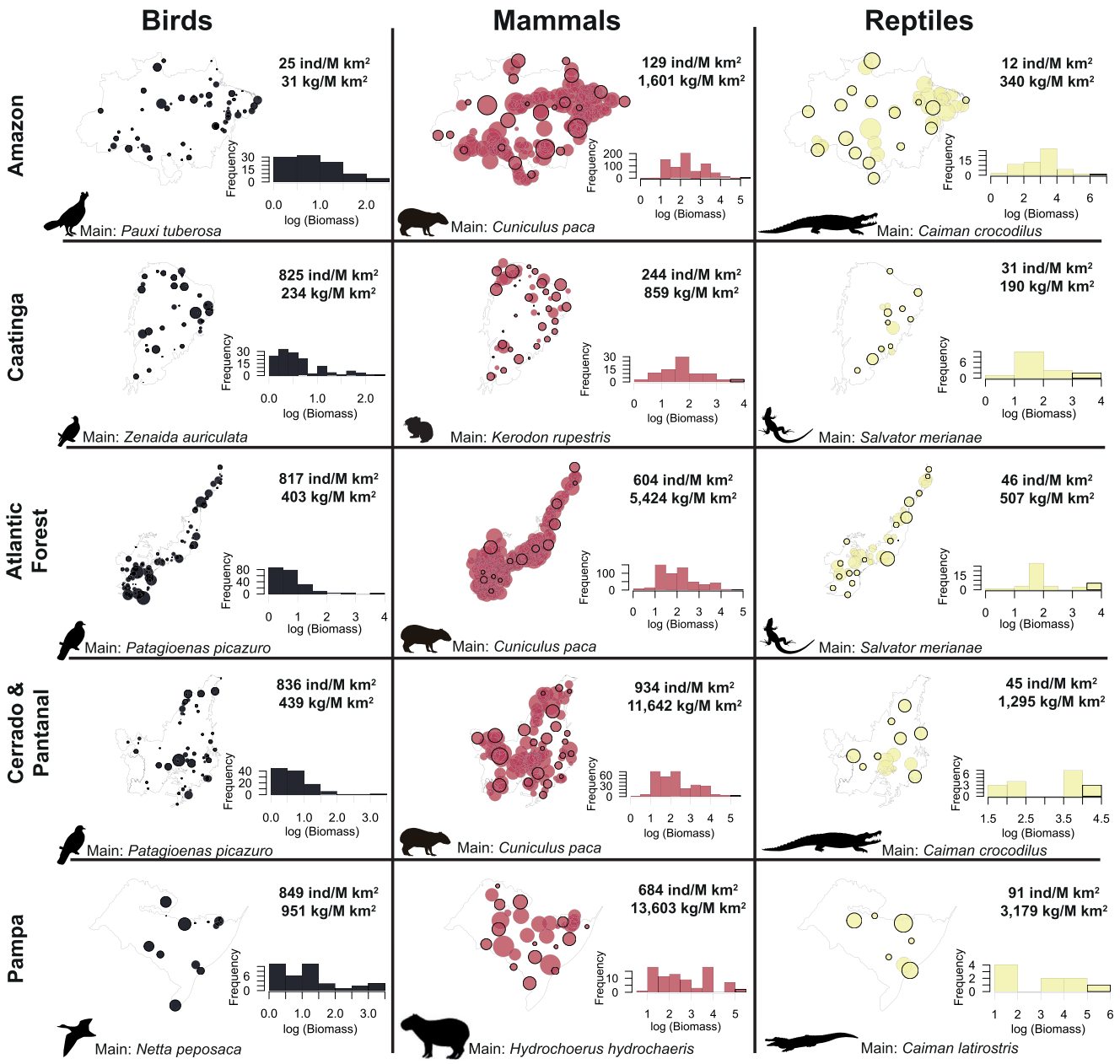


**FIGURE 3** Biome-scale segmentation of number of individuals and biomass per unit area, main hunted species, and frequency of illegal sport hunting events relative to biomass distribution of birds, mammals, and reptiles throughout Brazil (scale, natural log for better visualization).

estimates of subsistence hunting yields are available, sport hunting offtakes at 50% engagement rate by CACs would represent roughly 9% of the total wild meat harvested for subsistence (89,224 t) (Peres, 2000). This is comparable to the biomass traded in wild meat markets (10,691 t) (El Bizri et al., 2020) in the same geographical region. These figures, though not based on empirical evidence, serve as a theoretical estimate to gauge the potential impact of illegal sport hunting. These estimates rely on substantial assumptions and warrant careful consideration. Given the clandestine nature of illegal sport hunting, there is a lack of precise data on the number of active sport hunters participating in illicit hunting of native fauna in Brazil, whether registered as CACs or not. The need to improve the monitoring of illegal hunting practices in Brazil is urgent.

We faced challenges in pinpointing precise hunting locations, which we derived from the municipalities listed in user profiles and their overlap with known species distribution ranges. Such limitations are characteristic of research on sensitive data from social media, where users often refrain from geotagging or disclosing their exact locations. Acknowledging these challenges, we suggest that it is critical to determine whether records falling outside known species distribution ranges indicate gaps in current knowledge of species distributions or if they reflect instances of long-distance hunting. We propose

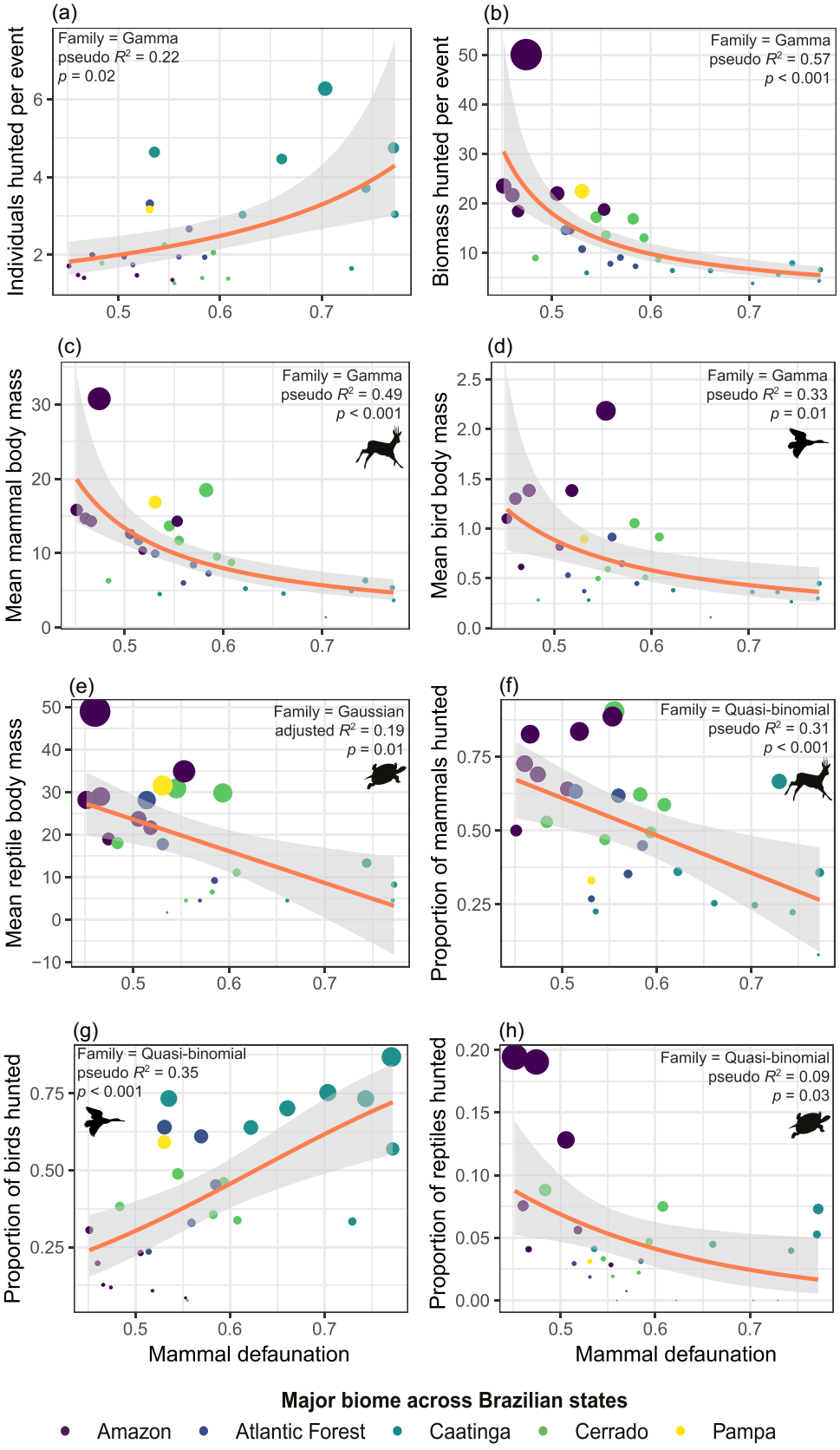


**FIGURE 4** Relationship between defaunation level (0.0, faunally intact; 1.0. fully defaunated) and metrics of hunting yield and composition across Brazilian states: (a) mean number of individuals hunted per hunting event, (b) mean biomass hunting per hunting event, (c) mean body mass of mammal individuals hunted (sum of biomass divided per total number of individuals), (d) mean body mass of bird individuals hunted (sum of biomass divided per total number of individuals), (e) mean body mass of reptile individuals hunted (sum of biomass divided per total number of individuals), (f) representativeness of mammals within the total

*(Continues)*

**FIGURE 4** (Continued)

number of individuals hunted, (g) representativeness of birds within the total number of individuals hunted, and (h) representativeness of reptiles within the total number of individuals hunted (point size, relative values on the *y*-axis; colors, major biomes). Refer to Appendix S3 for an annotated version of this figure with labels for the different Brazilian states.

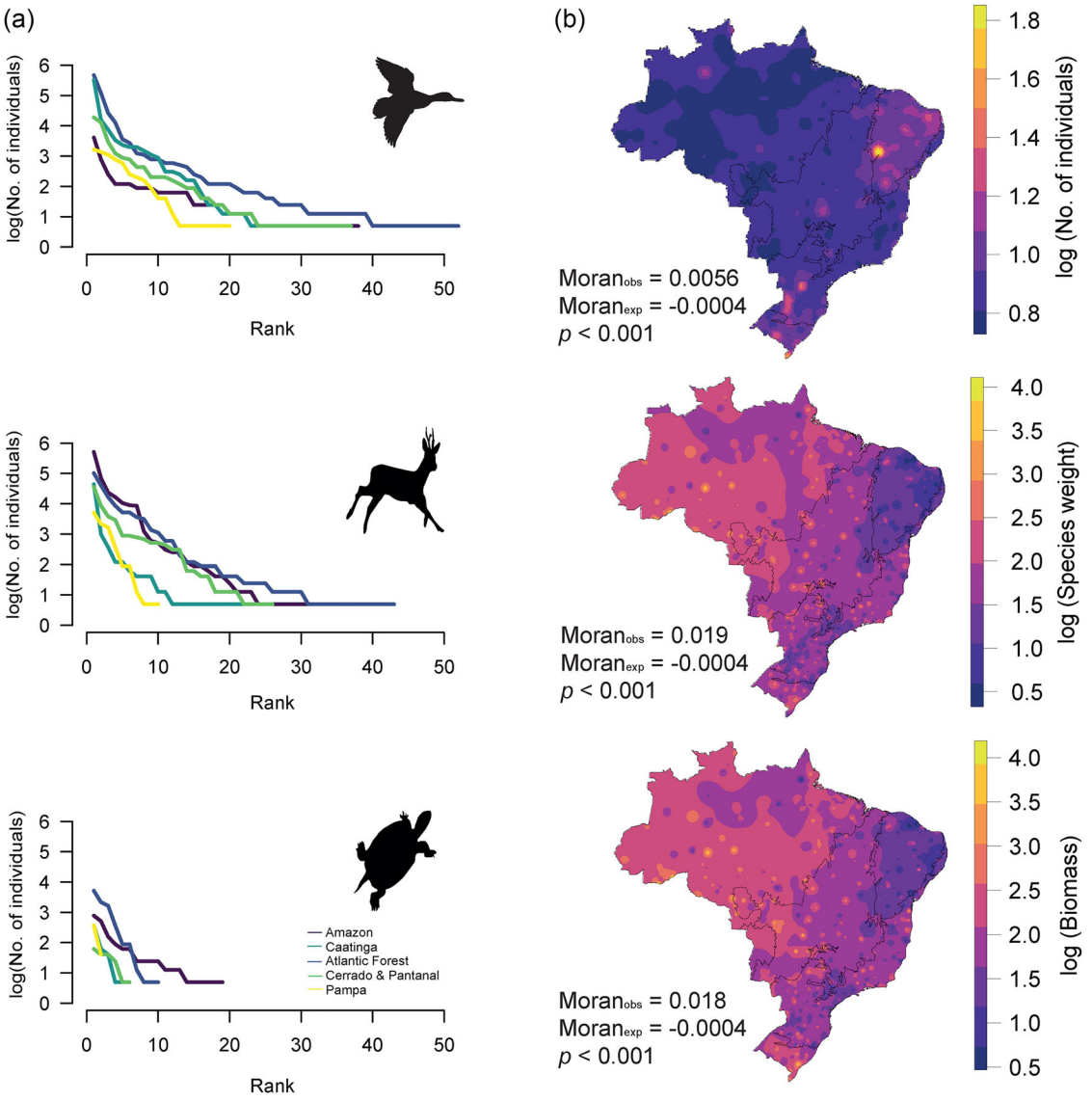


**FIGURE 5** (a) Biome-scale rank abundance (*x*-axis, species ranked according to their abundance) of illegal sport hunting of birds (top), mammals (middle), and reptiles (bottom) and (b) spatial interpolation and autocorrelation values of illegal sport hunting offtake (mean number of individuals, mean body mass, and biomass) per unit area throughout Brazil (top, individuals/km$^2$; middle, kg/km$^2$; bottom, kg/km$^2$; scale, natural log for better visualization).

that future research focus on examining hunters' mobility more closely. This would yield a more detailed understanding of hunter behavior in Brazil and contribute valuable insights for the development of more effective conservation strategies.

In terms of species hunted for sport, the lowland paca (~8 kg) was the most hunted across Brazil. This species is extensively hunted for food by local communities in many regions of Brazil and intensely consumed and traded across Latin America (El Bizri et al., 2018; Mayor, 2022; Gomes et al., 2023). It is the second-highest occurring taxon in YouTube videos of illegal sport hunting in Brazil (El Bizri et al., 2015). It is especially valued by hunters for its good flavor (Valsecchi & Amaral, 2009). The widespread hunting and consumption of lowland pacas carry substantial health risks due to their association with the transmission of life-threatening diseases, such as polycystic echinococcosis (San José et al., 2023). Illegal sport hunters transport these animals from their natural habitats to urban centers (Oliveira et al., 2023), creating dangerous pathways that further increase the risk of disease spread. Given these factors, sustainably managing this species

should become a focal point for conservation aimed not only at protecting biodiversity but also at mitigating public health risks.

The large numbers of doves, pigeons, and armadillos hunted likely reflect the extensive distribution of these groups and their ability to thrive in human environments (Marini et al., 2010). The fact that turtles and tortoises were the main targeted reptiles in terms of number of species (14 species and 52 individuals) defied expectations because these species may be considered less glamorous or charismatic in the eyes of hunters. Additionally, the hunting methods employed for these species, such as fishing or manual collection, may not involve active chasing, which could limit the motivation for hunters to share photos on social media of hunting events involving these species.

## Evidence of wildlife depletion and shifting hunting patterns in Brazil

Hunting yield and composition showed clear signs of a phenomenon referred to as hunting down the food chain (first used by Pauly et al. [1998] in reference to fishing). In this situation, larger species—which have longer generation times and are more susceptible to hunting—are quickly depleted by hunting. This creates a shift from hunting of medium- and large-bodied species to hunting of smaller bodied vertebrates, such as small birds (Benítez-Lopez et al., 2017; Peres & Palacios, 2007). Our results showed a clear correlation between the defaunation index and the characteristics of hunting offtakes. This suggests that observed shifts in hunting practices could serve as effective barometers of an area's environmental status and offers a valuable tool for future research and conservation efforts. Highly defaunated areas showed a high number of individuals extracted per hunting event, indicating that hunters were compelled to target a larger number of smaller bodied individuals to compensate for the loss of larger species. However, this compensatory strategy appeared to be ineffective because there was a clear trend of lower overall biomass per hunting event in the same defaunated areas. In states with relatively lower average hunting offtakes (in kilograms per hunting event), there was a prevalence of hunting of smaller bodied individuals across all taxonomic groups and a switch from mammals and reptiles to birds as the main target taxa. Declines and extinctions of large-bodied species have been documented in defaunated areas of Brazil (Alves et al., 2016; Bogoni et al., 2020a). The loss of large-bodied species through overhunting can have significant ecological implications, triggering cascade effects that can affect other species and crucial ecosystem processes (Bogoni et al., 2020b). Overhunting can pose risks even to the remaining small fauna, which becomes the new target in overexploited areas, further exacerbating the depletion of Brazil's vertebrate communities.

Our interpolation maps provided further indication of wildlife depletion and showed areas where this phenomenon is occurring in the country. For the Atlantic Forest, where substantial habitat degradation has taken place (only about 12% of its original forest cover remains), our maps indicated widespread illegal sport hunting. This prevalence is likely influenced by greater accessibility of the local population to the internet and thus Facebook. Additionally, the ease of physical access to forested areas, facilitated by the region's high population density and an extensive network of roads, contributes to high levels of sport hunting (Bogoni et al., 2020a; Ribeiro et al., 2009). We found at least 93 tetrapods were hunted here (26 more than previously estimated [ICMBio, 2018]), of which 3 are threatened species, including a recently described porcupine (the endangered *C. speratus*) (Pontes et al., 2013). As for the Atlantic Forest, the semiarid Caatinga biome has also a long history of overexploitation (Leal et al., 2005), which has led to the highest defaunation rates in Brazil (>70% of the expected or historical species richness extirpated [Bogoni et al., 2020a]). Up to the 1950s, hunting was for subsistence, particularly during droughts (Alves et al., 2009; Mendonça et al., 2016; Souza et al., 2022). However, currently, as many as 77% of hunters in the biome are sport hunters (Alves et al., 2009).

The most species-rich biomes, the Amazon and Pantanal wetlands, are the best conserved in Brazil (Bogoni et al., 2020a). Although they did not kill the largest number of individual animals, sport hunters in the Amazon extracted the highest biomass, over 13,000 kg in approximately 2 years of social media posting. Some of the largest species were hunted in the Amazon, but it was the second lowest value of hunted biomass per square kilometer. We argue that the Amazon is underrepresented in our sample due to its low human density of primarily rural peoples, without internet access, who hunt mostly for subsistence. Most biomass hunted in the Amazon was from large-bodied mammals, and it had the lowest representation of birds in hunted offtake in terms of individuals and biomass. Several large-bodied species may be extirpated or have severely depleted populations in other biomes (e.g., white-lipped peccary [*Tayassu pecari*] and lowland tapir [*Tapirus terrestris*]), leaving the Amazon as one of their last refuges.

## Regulatory challenges regarding sport hunting in Brazil

Our findings revealed a concerning situation regarding sport hunting in Brazil. Since 2019, the Brazilian government implemented numerous regulatory acts to increase access to guns, resulting in a significant rise in the number of firearms owned by civilians (Cerqueira et al., 2022). In 2021, approximately 36 million units of ammunition were sold to CACs (FBSP, 2022). Moreover, in 2022, the number of active CACs reached 673,818—a 5-fold increase from 2018 (117,467). The number of CACs is highest in São Paulo, Paraná, and Santa Catarina (FBSP, 2022), hotspots of hunting events in our study (Figure 3). The number of firearms in the hands of CACs and civilians now far exceeds the number of weapons owned by civil organizations, such as police or environmental agencies (Figueiredo et al., 2022). Hunters who legally hunt the invasive European wild boar are also likely hunting native species, which cannot be controlled given the lack of institutional capacity.

Given the magnitude and extent to which sport hunting is illegally practiced in Brazil and its potential environmental

impacts, it is imperative to find alternative solutions to better manage and protect Brazilian native wildlife. Because sport hunting is so well established, people might ignore the illegality of the activity if it fits within their social norms (Commerçon et al., 2021; Morsello et al., 2015). This is at a certain level legitimized through the internet and social influence (Commerçon et al., 2021), where sport hunters identify themselves with and join very large groups of people practicing the same act, making them less afraid of posting content about it.

New approaches to investigate illegal activities not available before, such as searches through social media platforms, are an important tool in assessing the impacts of illegal activities related to wildlife. However, there is a great need to regulate contents on social media as a first step toward dismantling the criminal network of people sharing illegal content and potentially recruiting new hunters. The publication of this type of content by social media platforms makes platform owners accomplices to illegal hunting, according to Brazilian legislation (Federal Law 2,848/40). In July 2021, the Brazilian environmental agency took a big step and, for the first time, fined Meta (the owner of Facebook and WhatsApp) US$2 million for failing to remove illegal content related to wildlife trading (Morcatty et al., 2022). Due to the worldwide reach of social networks, such as Facebook, companies must assume a greater commitment to create policies and implement tools to control content and avoid incitement of wildlife crimes (Ingram et all., 2024); lack of compliance should result in tougher penalties.

Because Brazilian environmental policies are not adequately enforced and agencies have limited resources for surveillance, there is a large lack of compliance and impunity for environmental crimes, such as illegal hunting. In addition, corruption in agencies intensifies poor enforcement of environmental laws (Aklin et al., 2014). Thus, it is urgent to improve law enforcement efforts. For this to occur, it is imperative to increase funding for conservation agencies, such as the IBAMA, to improve surveillance of illegal activities that harm Brazil's environment and to provide them with more resources to track and arrest illegal sport hunters. In addition, stricter penalties for illegal hunting can be implemented, such as higher fines and longer prison sentences. These 2 strategies combined may serve as a deterrent for would-be poachers and help reduce the number of illegal hunting incidents (Milner-Gulland & Leader-Williams, 1992).

Concurrently, public awareness about the dangers and impacts of illegal hunting needs to increase. Education campaigns can teach people about the importance of protecting native species and the negative impact of illegal hunting on the environment. These campaigns should target sport hunters and the Brazilian public because both groups could help address the problem. In Brazil, the reasons for hunting, ranging from subsistence to recreation, are affected by socioeconomic status and cultural tradition. Understanding these reasons is crucial to developing targeted awareness and behavior change strategies, including social marketing campaigns. In the Brazilian Amazon, social marketing campaigns aimed at enhancing knowledge and altering attitudes toward wildlife conservation have effectively reduced the demand for wild meat in urban areas (Chaves et al., 2018). Exploring campaigns featuring celebrities and digital influencers, as seen in successful initiatives in China, could be considered to promote proenvironmental behavior and combat poaching (Carpenter & Song, 2016; Chang et al., 2019; Commerçon et al., 2021). Prioritizing research to determine the drivers of illegal sport hunting is vital for shaping effective interventions in the future.

Among interventions aiming to reduce illegal hunting, the most controversial one is the legalization and regulation of sport hunting (Bragagnolo et al., 2019; Di Minin, Clements, et al., 2021). Sport hunting, if well regulated, could generate significant income for the management and conservation of wildlife (Roper, 2006). Regulation of sustainable sport hunting programs has had positive outcomes in several countries, generating funds for wildlife conservation actions and income for local communities (Arnett & Southwick, 2015; Di Minin et al., 2016). Regulatory frameworks in Brazil, including the Wildlife Protection Law, Portaria 150 – COLOG/EB 64447.045758/2019-29, and Bill 5544/20, provide the foundation for establishing sustainable sport hunting programs. These regulations outline guidelines for the creation of amateur hunting clubs, licensing of hunters, and acquisition of firearms. Nevertheless, state-level laws prohibiting sport hunting and a growing public sentiment that tolerates hunting only for essential needs, not for sport, pose substantial challenges to the acceptance and execution of sport hunting programs, even when justified for conservation purposes (Batavia et al., 2019; Bragagnolo et al., 2019). To achieve sustainable hunting practices, sport hunting regulations (e.g., quotas and hunting seasons) should be based on scientific principles (e.g., reproduction, distribution, population dynamics, density, and conservation status of the species) and be regulated and managed by national and regional governmental agencies and rural and local communities (Bragagnolo et al., 2019; Di Minin, Clements, et al., 2021). For successful and sustainable implementation of hunting regulations, effective monitoring, enforcement, and compliance are needed, as are increased operational and research capacity of regulatory agencies.

Our results showed that social media data can be used to shed light on covert activities, such as illegal hunting in Brazil, and offer researchers new perspectives and tools to understand and combat threats to wildlife in other parts of the globe. We can argue that there is a need for further monitoring and evaluation of sport hunting to estimate hunting offtakes and current impacts on Brazilian fauna more accurately. Further exploration into the motivations and influencers behind hunting across diverse Brazilian regions is warranted to formulate tailored solutions. In essence, our findings spotlight not only the widespread prevalence of sport hunting in Brazil, but also its substantial intensity and the pressing need for more targeted management and regulation of these practices.

## ACKNOWLEDGMENTS

This project was funded by the Gordon and Betty Moore Foundation through grant GBMF9258 to the Comunidad de Manejo de Fauna Silvestre en la Amazonía y en Latinoamérica (COMFAUNA) and the UK Research and Innovation's Global

Challenges Research Fund (UKRI GCRF) Trade, Development and the Environment Hub project (ES/S008160/1). We thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior—Brasil (CAPES) for a PNPD research fellowship to M.A.O. (88887.717863/2022-00). J.A.B. is supported by a Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) postdoctoral fellowship (150261/2023-3). D.J.I. acknowledges support from UK Research and Innovation (Future Leaders Fellowship grant MR/W006316/1). J.E.F. and L.C. were funded by USAID as part of the Bushmeat Research Initiative of the CGIAR research program on Forests, Trees, and Agroforestry.

## ORCID

*Hani R. El Bizri* https://orcid.org/0000-0003-1524-6292
*Julia E. Fa* https://orcid.org/0000-0002-3611-8487
*Thais Queiroz Morcatty* https://orcid.org/0000-0002-3095-7052
*Daniel J. Ingram* https://orcid.org/0000-0001-5843-220X
*Juliano A. Bogoni* https://orcid.org/0000-0002-8541-0556

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## 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:** El Bizri, H. R., Oliveira, M. A., Rampini, A. P., Knoop, S., Fa, J. E., Coad, L., Morcatty, T. Q., Massocato, G. F., Desbiez, A. L. J., Campos-Silva, J. V., La Laina, D. Z., Duarte, J. M. B., Barboza, R. S. L, Campos, Z., da Silva, M. B., Mângia, S., Ingram, D. J., & Bogoni, J. A. (2024). Exposing illegal hunting and wildlife depletion in the world's largest tropical country through social media data. *Conservation Biology*, *38*, e14334. https://doi.org/10.1111/cobi.14334