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Anti-environmental political agendas, firearm deregulation and illegal hunting in Brazil

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ABSTRACT

Political ideologies and governance decisions can profoundly influence conservation outcomes in tropical countries, where biodiversity intersects with rapid socio-political change. Brazil—the world's largest tropical country—provides a key case to examine how political agendas and regulatory shifts shape wildlife exploitation across governance frontiers. Using 2046 illegal sport hunting records shared on social media during Jair Bolsonaro's 2019–2022 presidency, we applied a hierarchical zero-inflated binomial model to analyse the municipal-level probability of illegal hunting as a function of ecological, accessibility, socio-economic, and political factors.

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Political variables included electoral support for Bolsonaro as a proxy for alignment with anti-environmental agendas and civilian gun ownership rates reflecting firearm regulatory changes during his administration. Illegal hunting probability was higher in municipalities with greater human population density, higher defaunation levels, more remaining natural habitat, higher GDP per capita, stronger anti-environmental political alignment, and higher gun ownership rates. Standardized coefficients showed that political alignment and gun ownership had effect magnitudes comparable to ecological and accessibility factors. Spatial predictions revealed illegal hunting hotspots within and around the Arc of Deforestation in southern and eastern Amazonia. Our results suggest illegal hunting reflects the convergence of ecological and socio-economic conditions and permissive political contexts. In Amazonia, increased hunting pressure may intensify competition over wildlife resources and undermine the food security of Indigenous peoples and local communities. Brazil's experience illustrates how political narratives and weapon proliferation may restructure wildlife exploitation patterns, highlighting the need for politically insulated environmental enforcement, firearm regulation, and governance resilient to ideological shifts.

1. Introduction

Unsustainable hunting of wild animals poses a significant threat to global biodiversity, triggering cascading effects that disrupt ecosystems and the vital services they provide to humans (Fa et al., 2022). This complex issue is driven by multiple, often overlapping motivations, including subsistence needs, predator control, income generation, and recreational pursuits (Benítez-Lopez et al., 2017; Ingram et al., 2021). Illegal hunting is especially challenging to address as it is influenced by diverse social factors, including culture, and economics, alongside weak enforcement of conservation laws (Lavadinović et al., 2021). In addition, political instability and corruption can undermine conservation efforts, creating conditions where wildlife crime can thrive (Di Minin et al., 2016; Lavadinović et al., 2021). Growing evidence highlights the influence of national political ideologies, particularly nationalism, in driving adverse biodiversity outcomes, including heightened threats to numerous species (Jones et al., 2024). This emphasizes the importance of incorporating political context in conservation policy design, given that governance structures can exacerbate or mitigate the effects of unsustainable practices on biodiversity.

In many tropical regions, conservation challenges are concentrated in what scholars describe as 'governance frontiers'—transitional spaces where environmental authority is fragmented, contested, or undergoing transformation. These areas often emerge where established institutional orders are disrupted, and territorial control is being renegotiated, allowing competing actors to assert new forms of resource governance (Thaler et al., 2019). Governance frontiers are often characterised by weak institutional presence, overlapping legal claims, political instability, and selective law enforcement, creating conditions where illegal environmental practices can flourish (Sundberg, 2006; Rasmussen and Lund, 2018).

Recent political shifts in countries such as the United States, Argentina, and Brazil—often marked by nationalist and anti-environmental agendas—have increasingly clashed with conservation principles, leading to policy reversals and regulatory rollbacks that jeopardize environmental protection and underscore the growing tension between political priorities and biodiversity conservation (Millner and Ollivier, 2016; Ferrante and Fearnside, 2019; Napolitano and Aiezza, 2019; Debat, 2023).

Brazil, long recognized as a global leader in environmental governance, has built a strong framework of environmental legislation that has steadily evolved since 1965, progressively reinforcing its conservation mechanisms. However, during President Jair Bolsonaro's administration (2019–2022), legislative and institutional changes have significantly weakened the country's environmental safeguards (Barbosa et al., 2021). These included the relaxation of environmental licensing, dismantling of environmental inspection and control agencies, the suspension of the internationally supported Amazon Fund, the halting of Indigenous land demarcation, and the drastic reduction in civil society participation in key regulatory bodies such as the National Council for the Environment (CONAMA in Portuguese acronym) (Abessa et al., 2019; Araújo, 2020; Ferrante and Fearnside, 2019).

One particularly controversial measure was the loosening of firearm regulations for civilians categorized as collectors, sport shooters, and hunters (CACs, by their Portuguese acronym) through Decree 9846/2019—later replaced by Decree 11,615/2023 (Cerqueira et al., 2022). This decree authorized individuals with certified firearm proficiency and without criminal records to acquire guns, including for activities such as controlling invasive wild boar (*Sus scrofa*) populations (IBAMA Normative Instruction 03/2013). By 2021, approximately 36 million rounds of ammunition had been sold to CACs (FBSP, 2022), and a year later, the number of active CACs had reached nearly 674,000. Firearms in civilian and CAC possession now far outnumber those held by official security forces, including environmental agencies (Figueiredo et al., 2022).

Recent studies show how political ideologies and firearm regulations significantly influence environmental practices and perceptions, particularly in biodiverse but politically polarized countries like Brazil (El Bizri et al., 2015; Borba and Gomes, 2021). Although sport hunting of native wildlife is de facto prohibited under the 1967's Wildlife Protection Law (Federal Law 5197/67), the expansion of wild boar hunting has opened a loophole in which hunters often use non-selective traps or misidentify species, leading to unintended or deliberate killing of native fauna (Rosa, 2018; Carvalho et al., 2019). These impacts are exacerbated by limited institutional capacity to monitor or enforce species-specific hunting regulations.

Gun culture and firearm accessibility are also deeply entwined with Brazil's social and criminal landscape. While research shows that stronger gun control laws are associated with reductions in violent crime, firearm ownership continues to be culturally and politically promoted (Marinho de Souza et al., 2007; Schneider, 2021). When paired with an anti-environmental agenda, the rise in pro-gun sentiment during Bolsonaro's administration may have increased opportunities and justifications for illegal hunting, particularly in regions where environmental enforcement is weakest (Oliveira and Araújo, 2020).

Brazil provides a powerful case study of how rapid political shifts can erode longstanding environmental protection and enable opportunistic behaviors such as wildlife crime. Understanding the dynamics of illegal hunting in this context offers a national diagnosis and broader insights into how institutional fragility, political ideology, and governance vacuums interact in tropical areas to threaten biodiversity. Using a political ecology lens, we investigated the intersection of demographics, political alignment, firearm accessibility, environmental degradation, and physical access in influencing illegal hunting. Drawing from a unique dataset of illegal sport hunting events shared on Facebook during Bolsonaro's presidency (El Bizri et al., 2024), we tested the hypothesis that this wildlife crime is positively associated with alignment with anti-environmental agendas, greater gun access, and physical accessibility (e.g., roads and rivers), especially in areas with high natural habitat availability and relatively intact fauna.

2. Methods

2.1. Data collection on illegal hunting activities via social media

To compile data on illegal sport hunting events in Brazil, we identified the five most relevant Facebook™ groups, each with tens of thousands of members. These were selected using Facebook's search tool using the keywords "caça" AND "Brasil" ("hunting" AND "Brazil" in English). Facebook's algorithm ranks groups based on keyword relevance, user activity, and popularity; therefore, those appearing at the top of the search results were assumed to be the most thematically relevant and actively engaged in hunting discussions.

Each group—established between 2018 and 2020—was monitored by one researcher. We systematically recorded all posts portraying hunting activities from the group's inception through July 31, 2020, covering a substantial portion of President Jair Bolsonaro's term. We note that the data used in this study, while framed within the 2019–2022 presidential term, is limited to the period up until July 2020. Consequently, the analysis reflects the initial phases of the Bolsonaro administration and may not capture potential policy shifts or political dynamics that occurred after this period, especially under the impacts of the COVID-19 pandemic.

We focused specifically on posts containing photos of sport hunting for meat consumption. Posts were classified as sport hunting for meat consumption only when they showed dead wild animals or carcasses resulting from hunting activity and when the accompanying visual or textual context indicated meat use (e.g., carcass display, butchering, cooking, or references to meat consumption). Posts suggesting other purposes—such as live capture, pest control, keeping wild animals as pets, or explicit commercial sale—were not recorded, as these uses fell outside the scope of this study. When the purpose of the post could not be inferred with sufficient confidence from the image and accompanying text, the post was excluded.

We assigned unique identifiers to each identified post and user. We recorded the posting date, species hunted, number of animals shown per species, and the number of likes and comments. Following El Bizri et al. (2015), any images showing hunting of native Brazilian fauna (e.g., excluding invasive species such as European wild boar) were categorized as illegal sport hunting. Prior research shows that this activity is often practised by individuals with higher income levels who own firearms and do not depend on wild meat for subsistence (El Bizri et al., 2015; Islas et al., 2024). In contrast, subsistence hunting is typically carried out by lower-income rural residents with limited internet access, reducing their presence in social media data. Consequently, the dataset predominantly reflects urban and wealthier segments of the population, rather than Indigenous or remote rural communities. Accordingly, our dataset should be interpreted as a record of illegal sport hunting events associated with meat use, rather than a comprehensive inventory of all forms of wildlife exploitation discussed on social media.

We then examined publicly accessible profile information to identify the municipality of residence for each user. Although no specific data exist on the travel distances of Brazilian sport hunters, global evidence suggests that hunting events typically occur within 5–16 km of the hunter's home (Baker, 2011; Hampton et al., 2022; Yudha et al., 2022), supporting the use of residence location as a proxy. We also confirmed that all hunting locations (based on the geographic coordinates of municipal centroids extracted using the SIRGAS 2000 datum) fell within the known distribution ranges of the species shown, including range-restricted species like the dwarf porcupine (*Coendou speratus*) (see El Bizri et al. (2024) for more details).

2.2. Demographics and accessibility, political, economic, and environmental variables

Brazilian municipalities represent the smallest constitutionally recognized administrative unit in Brazil and are territorial governance units that encompass both urban and rural areas. Each municipality contains an officially designated urban seat (the municipal headquarters), but its jurisdiction extends across the entire surrounding territory, including agricultural land, forests, rivers, protected areas, and rural communities. Municipalities possess elected mayors and local councils and hold administrative authority over land-use planning, taxation, and some aspects of environmental regulation and local enforcement. Thus, municipalities are not equivalent to cities; rather, they represent complete administrative territories with a certain level of political autonomy. They also constitute the finest spatial scale at which socio-economic, demographic, electoral, and governance-related indicators are consistently available nationwide. Brazilian municipalities vary substantially in area, particularly between densely populated south-eastern regions and sparsely populated Amazonian regions. In our dataset, the mean municipality area was 1525.54 (SD = 5605.42) km^2. However, our objective was not to predict the precise location of hunting events within municipalities, but rather to identify broad socio-ecological and political factors associated with the occurrence of illegal hunting across the country. Many of the predictors considered here operate at regional governance and landscape scales that are appropriately captured at the municipal level.

Using geographic polygons for all Brazilian municipalities (n = 5570) (in decimal degrees, SIRGAS 2000), we extracted municipal-level metrics and organized them into three conceptual groups: (1) demographics and accessibility, (2) ecological context, and (3) political and economic context (see Table 1). For demographics and accessibility, we obtained the municipal area (km^2) and total human population from the Brazilian Institute of Geography and Statistics (IBGE, 2021). From these, we calculated the human population density of the municipality (from year 2022). Road data (state and federal roads, km) were sourced from the National Department of Transport Infrastructure (2021): https://www.gov.br/dnit/pt-br. Data on navigable rivers (km) were obtained from the River and Groundwater Basins of the World (BGR/UNESCO, 2017). We calculated road and river densities by dividing their lengths by municipal area (hereafter 'road density' and 'river density', respectively). Mobile phone network coverage (hereafter 'phone coverage') was obtained from the National Telecommunications Agency (2022) and used as a proxy for internet accessibility to control for the effects of different levels of internet accessibility across Brazilian regions, which may influence the detectability of illegal hunting posts on social media.

Ecological variables included mean terrain elevation (in meters above sea level, derived from ASTER-GDEM-NASA, hereafter 'elevation'), Terrain Ruggedness Index (hereafter 'terrain ruggedness') representing terrain heterogeneity calculated from the digital elevation model by quantifying the mean elevation difference between each raster cell and its eight neighbouring cells for each municipality (e.g., higher ruggedness values represent more heterogeneous and rugged terrain), mean municipal defaunation index (ranging from 0.0 = faunally intact to 1.0 = fully defaunated, hereafter 'defaunation') derived from the interpolated spatial distribution of empirically observed changes in mammal richness across the Neotropics, sourced from Bogoni et al. (2020), and the percentage of remaining natural habitat cover in 2019 (MapBiomas, 2019) (hereafter 'remaining natural habitat'). The defaunation index reflects relative depletion of medium- and large-bodied mammals compared to expected baseline richness, based on empirical assemblage data rather than a predictive composite constructed from covariates. It therefore does not represent a re-expression of those predictors but rather an independent ecological outcome layer reflecting observed mammal assemblage change at broader spatial scales. We included this variable to capture broad-scale faunal integrity and ecological degradation that may influence hunting dynamics independently of habitat availability and elevation alone. In a previous analysis of hunting yield (El Bizri et al., 2024), mammal depletion was associated with reduced harvested biomass and shifts toward smaller-bodied taxa, including birds and reptiles. Therefore, the index is interpreted as a

Table 1
Conceptual justification for predictor variables included in the model of illegal sport hunting probability across Brazilian municipalities. Predictors are grouped into demographic and accessibility factors, ecological context, and political–economic context. The table summarizes the expected direction of each predictor's effect, the underlying rationale linking the variable to hunting occurrence or detection, and key references supporting these hypothesised relationships.

Predictor	Conceptual group	Expected direction	Rationale	Literature support
Human population density	Demographics and accessibility	Positive	Higher population density increases the number of potential hunters, raising the likelihood that illegal hunting events occur and are detected.	Torres et al. (2018); Ziegler et al. (2016)
Road density	Demographics and accessibility	Positive	Roads reduce travel costs and increase forest accessibility, allowing hunters to reach wildlife-rich areas more easily. Road expansion is widely associated with increased hunting and poaching risk.	Benítez-López et al. (2017); Espinosa et al. (2014); Kleinschroth and Healey (2017); Wilkie et al. (2000); Laurance et al. (2006); Laurance et al. (2008)
Phone coverage	Demographics and accessibility	Positive for detection	Digital connectivity may increase the probability that hunting events are shared online or detected through social media monitoring, rather than directly influencing hunting activity itself.	El Bizri et al. (2015); El Bizri et al. (2024); Moloney et al. (2023)
Remaining natural habitat	Ecological context	Positive	Areas with greater remaining natural habitat tend to support higher wildlife abundance and biomass, increasing the likelihood that hunting events occur and are detected.	Benítez-López et al. (2019); Parry et al. (2009); Torres et al. (2018).
Defaunation	Ecological context	Positive	Defaunation reflects broader gradients of human pressure and wildlife exploitation. Areas experiencing stronger faunal depletion may also be those where hunting pressure and human access are historically higher.	Benítez-López et al. (2017); Benítez-López et al. (2019); Bogoni et al. (2020).
Elevation and terrain ruggedness	Ecological context	Negative	High elevation and rugged terrain can reduce accessibility and travel efficiency for hunters, potentially lowering the likelihood of hunting events occurring and being detected.	Branch et al. (2022); Griffiths et al. (2022); Nguimdo et al. (2025).
GDP per capita	Political and economic context	Positive or mixed	Higher income levels may facilitate recreational hunting by enabling access to equipment, vehicles, and firearms, although these effects may vary according to regional socio-economic dynamics, including lower reliance on or interest in hunting in wealthier areas.	El Bizri et al. (2015); Oliveira et al. (2023)
Gun ownership	Political and economic context	Positive	Greater access to firearms increases hunting efficiency and lowers the barriers to wildlife offtake.	Ingram et al. (2025); Graefen and Ingram (2026); Braga-Pereira et al. (2020a)
Anti-environmental political alignment	Political and economic context	Positive	Political alignment with deregulatory and anti-environmental agendas may signal contexts with weaker environmental enforcement and greater social tolerance of wildlife crime.	Abessa et al. (2019); Ferrante and Fearnside (2019); Duffy (2022); Mostafavi et al. (2022)

proxy for broader vertebrate depletion. Prior to inclusion in the final model, we reassessed multicollinearity and confirmed that the defaunation index exhibited low variance inflation relative to other ecological predictors, indicating that it captured ecological variation not fully explained by habitat cover, elevation, or accessibility variables (see Table S1, Supplementary Material).

Political and economic metrics included Gross Domestic Product (GDP) per capita (2021), sourced from IBGE (https://sidra.ibge.gov.br/pesquisa/pib-munic/tabelas); the percentage of votes for Jair Bolsonaro in the second round of the 2022 presidential election (used as a proxy for support for the anti-environmental and deregulatory agenda associated with his presidency, hereafter "anti-environmental political alignment"), obtained from the Superior Electoral Court (https://www.tse.jus.br/eleicoes/eleicoes-2022); and the number of firearms registered under the CACs (Collectors, Sport Shooters, and Hunters) category per municipality in 2022, acquired through a formal request to the Brazilian Federal Police (hereafter 'gun ownership'). Gun ownership was expressed as the proportion of firearms relative to the municipal population.

2.3. Data analysis

We first conducted descriptive analyses to characterise the spatial and taxonomic distribution of illegal sport hunting records. We quantified the total number of unique hunting posts, the number of municipalities with at least one recorded event, and the mean number of posts per municipality with detected hunting activity. We also summarised the number of animals and species documented across major vertebrate groups (birds, mammals, reptiles, and amphibians). Other patterns and trends in species composition was previously analysed in El Bizri et al. (2024).

Brazil is officially divided into five macroregions (North, Northeast, Central-West, Southeast, and South) by the Brazilian Institute of Geography and Statistics (IBGE). These macroregions contain states and their respective municipalities, representing administrative and socio-economic groupings that structure federal governance and regional policy implementation. Macroregional aggregation provides an institutionally relevant interpretative scale. Therefore, to contextualise spatial patterns, we aggregated municipalities with detected hunting events by Brazilian state and by the country's five official macroregions. For each state and macroregion, we calculated both the absolute number and the proportion of municipalities with at least one hunting record. Although the primary statistical analyses were conducted at the municipality level, municipalities were also colour-coded according to biome in descriptive graphs to provide ecological context. More detailed biome-specific hunting patterns are presented in El Bizri et al. (2024).

We modelled the likelihood of municipalities presenting recorded hunting events implemented within the Generalised Additive Models for Location, Scale and Shape (GAMLSS) framework (Rigby and Stasinopoulos, 2005; Stasinopoulos and Rigby, 2007), which allows flexible specification of distribution families. All analyses were conducted at the municipal level, considering all Brazilian municipalities. We used the presence-absence of hunting events in each municipality (i.e., 0 or 1) under a binomial distribution (link = logit). Municipalities were coded as 1 when at least one illegal sport hunting post was linked to a user residing there, and as 0 when no such posts were detected. We emphasise that these zeros represent non-detection in the Facebook-derived dataset, rather than confirmed absence of illegal hunting activity. Because most municipalities did not present hunting records (86%) and those with hunting records were characterised by a single unique reporting event, count-based models would provide limited additional inferential information beyond occurrence. Modelling counts derived from social media data would also risk conflating hunting activity with heterogeneous user behaviour and internet accessibility.

We adopted a hypothesis-driven, a priori model structure, in which predictors were included in the model based on clear ecological or theoretical rationale (Table 1). The following formula represented the initial model structure: hunting presence or absence$_{i\text{-th-municipality}}$ ~ $\log_{10}$ (human population density) + road density + river density + elevation + terrain ruggedness + defaunation + remaining natural habitat + $\log_{10}$(GDP per capita) + Anti-environmental political alignment + $\log_{10}$(gun ownership). We used a $\log_{10}$ transformation for human population density, GDP per capita, and gun ownership because these variables varied over several orders of magnitude and were strongly right- or left-skewed.

In our study, 790 out of 5570 Brazilian municipalities had recorded illegal sport hunting (14.2%), suggesting that many zeros could represent "false negatives" in which hunting occurred but was not detected. Given the high proportion of municipalities with zero detections and the possibility that some zeros may reflect either true absence or detection limitations, we first compared a standard binomial (BI) model with a zero-inflated binomial (ZIBI) specification (Rigby et al., 2019) under identical model structure using the Akaike Information Criterion (AIC) to assess whether zero inflation improved model fit. The ZIBI framework includes an "inflation" process to account for municipalities that are effectively guaranteed to have zero reports, along with a standard binomial process that governs the remaining municipalities. In this way, the model first identifies locations with no chance of detecting hunting (structural zeros). The remaining locations are then subject to typical binomial variation, which can yield either zeros or positives. Model comparison strongly supported the zero-inflated binomial specification (AIC ZIBI = 4152.97; AIC BI = 4163.68; ΔAIC = 10.71). Based on this, we retained the ZIBI formulation for subsequent analyses, as it can more accurately capture the likelihood of detecting hunting across municipalities (Zuur et al., 2009).

We checked for multicollinearity among fixed predictors using the Variance Inflation Factor (VIF). In large datasets such as ours, the detrimental effects of multicollinearity on the stability and variance of regression coefficients are generally reduced, allowing for more precise estimates. Consequently, higher VIF thresholds may be tolerable. However, regardless of dataset size, we conducted careful statistical analysis and validation to ensure the robustness and interpretability of our models. Following common practice, we considered VIF values lower than 5 to indicate no problematic collinearity (Zuur et al., 2009). None of our predictors exceeded this threshold (range: 1.5–4.6). VIF values for all predictors are shown in **Table S1 (Supplementary Material)**.

To assess residual spatial dependence, we calculated Moran's I statistics on model residuals using 5-nearest-neighbour spatial weights based on municipal centroids. The zero-inflated model without hierarchical structure exhibited statistically detectable spatial autocorrelation (Moran's $I = 3.22$, $p = 0.0006$), indicating residual spatial clustering. Because municipalities are nested within states and ecological regions, and may share unobserved institutional, political, and environmental characteristics, we subsequently incorporated state and biome as random intercepts to account for hierarchical regional structure. After inclusion of these random effects, residual spatial autocorrelation was no longer detectable (Moran's $I = -0.95$, $p = 0.83$), indicating that most detectable spatial dependence was captured by regional and ecological grouping factors. Inclusion of state and biome random effects also substantially improved model fit (AIC reduced from 4152.97 to 3853.35; ΔAIC = 299.62). However, because state and biome random effects represent hierarchical rather than continuous spatial structures, some fine-scale spatial dependence among neighbouring municipalities may still remain unaccounted for.

Considering that political effects might be conditional on ecological context, we also tested an interaction between remaining natural habitat and anti-environmental political alignment. This interaction was selected a priori because our conceptual framework emphasised the possibility that permissive political narratives could have stronger effects where wildlife resources remain available. Although additional interactions are conceptually plausible, we avoided exploring multiple interaction structures to maintain a parsimonious hypothesis-driven framework and reduce the risk of overfitting. The interaction was not statistically significant ($p = 0.08$) and did not improve model fit (ΔAIC = 3.92) and was therefore not kept in the final model.

The final model therefore included fixed effects for socio-economic, ecological, accessibility, and political variables, random intercepts for state and biome, and a zero-inflation component. *P*-values for each predictive variable were calculated to determine the statistical significance of their association with the likelihood of hunting events in municipalities (α = 0.05). For interpretability, regression coefficients from the logit model were exponentiated to obtain odds ratios (OR = e^{β}), and 95% confidence intervals were calculated as $e^{(\beta \pm 1.96 * \mathrm{SE})}$. We also reported the absolute value of the standardized coefficients (|β_std|) to facilitate comparison of relative effect magnitudes across predictors measured on different scales. To do so, we multiplied each estimated coefficient by the standard deviation of its corresponding predictor, which represent the change in log-odds associated with a one standard deviation increase in each predictor.

To evaluate model performance, we calculated the Area Under the Receiver Operating Characteristic Curve (AUC) to assess discriminatory ability between municipalities with and without recorded hunting events. In addition, we estimated model explanatory power using the deviance-based R^2 implemented in the Rsq() function of the gamlss package (Rigby et al., 2019), which provides an appropriate measure of explained variation for models including zero-inflation, smoothers, and random effects. We also calculated Tjur's R^2 to quantify the separation between predicted probabilities of municipalities with and without recorded hunting events.

We finally created a map showing the predicted probability of illegal sport hunting across municipalities, based on the coefficients of the variables in the final model. To do this, we calculated the probabilities for each municipality and matched them with a shape of geospatial boundary data (sourced from IBGE; https://www.ibge.gov.br/geociencias/organizacao-do-territorio/malhas-territoriais/15774-malhas.html). Predicted probabilities were visualized using a gradient colour scale, with darker shades indicating higher likelihoods of illegal sport hunting. We used the 'gamlss' package to run the model, and 'mapproj' and 'ggspatial' to produce the maps. All analyses were conducted in RStudio, Version 2023.09.1 + 494 (Posit Team, 2025).

2.4. Ethical considerations

Given that illegal sport hunting is a sensitive topic in Brazil, we followed Roulet et al.'s (2017) method for conducting covert research. Of the five Facebook groups selected for data collection, three were "open" with unrestricted access, while two were "closed" requiring administrator approval to join. All membership requests to closed groups were approved within 24 h, and our only interaction was limited to these join requests. No direct engagement with administrators or members occurred and all data (users' municipalities) are publicly available information. No personal information was used, and no interviews were conducted.

Consultations with various ethics boards and legal experts confirmed that the study was exempt from national ethical review and participant consent requirements under Brazilian regulations (CNS Resolution 510, 2016), as it relied on voluntarily shared online data. The closed groups, with about 40,000 members each, were treated as publicly accessible due to minimal access restrictions. Since the study did not involve personal opinions or direct interactions with individuals, it did not require human subjects' approval. However, an additional ethics review was conducted and approved by CIFOR-ICRAF's ethics board due to the sensitivity of the data.

To minimize risks associated with photo sharing and ensure compliance with Brazil's General Data Protection Law (13.709/2018), we followed Di Minin et al.'s (2021) and Morcatty et al.'s (2024) guidelines for social media data use to implement several precautions. Specifically, we limited data collection to essential information, pseudonymised usernames and group names, and adhered to ethical standards set by Kosinski et al. (2015) and Martinez-Martin et al. (2018). This meant avoiding direct communication with users and not collecting or sharing information that could identify individuals or reveal exact locations. Group names were omitted from this publication, and detailed geolocation maps were excluded to protect hunters' identities.

3. Results

We detected 2046 unique illegal sport hunting posts shared by individuals residing in 790 municipalities across all five macroregions and 27 Brazilian states (Fig. 1). On average, 2.8 hunting events were posted per municipality where hunting activity was recorded. These posts documented the hunting of at least 4658 animals from 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%). For a more detailed description of species hunted, regional specificities and the methods used to identify species, see El Bizri et al. (2024).

The states of Rio Grande do Sul (South region) and Pará (North region) had the highest number of municipalities with hunting events (Fig. 2). The North macroregion had the largest relative share of municipalities with hunting records, with most states reporting events in over 25% of their municipalities. Records in Rondônia, Amazonas, and Pará were found in nearly 50% of municipalities. The Federal District, comprising a single municipality, showed a 100% rate.

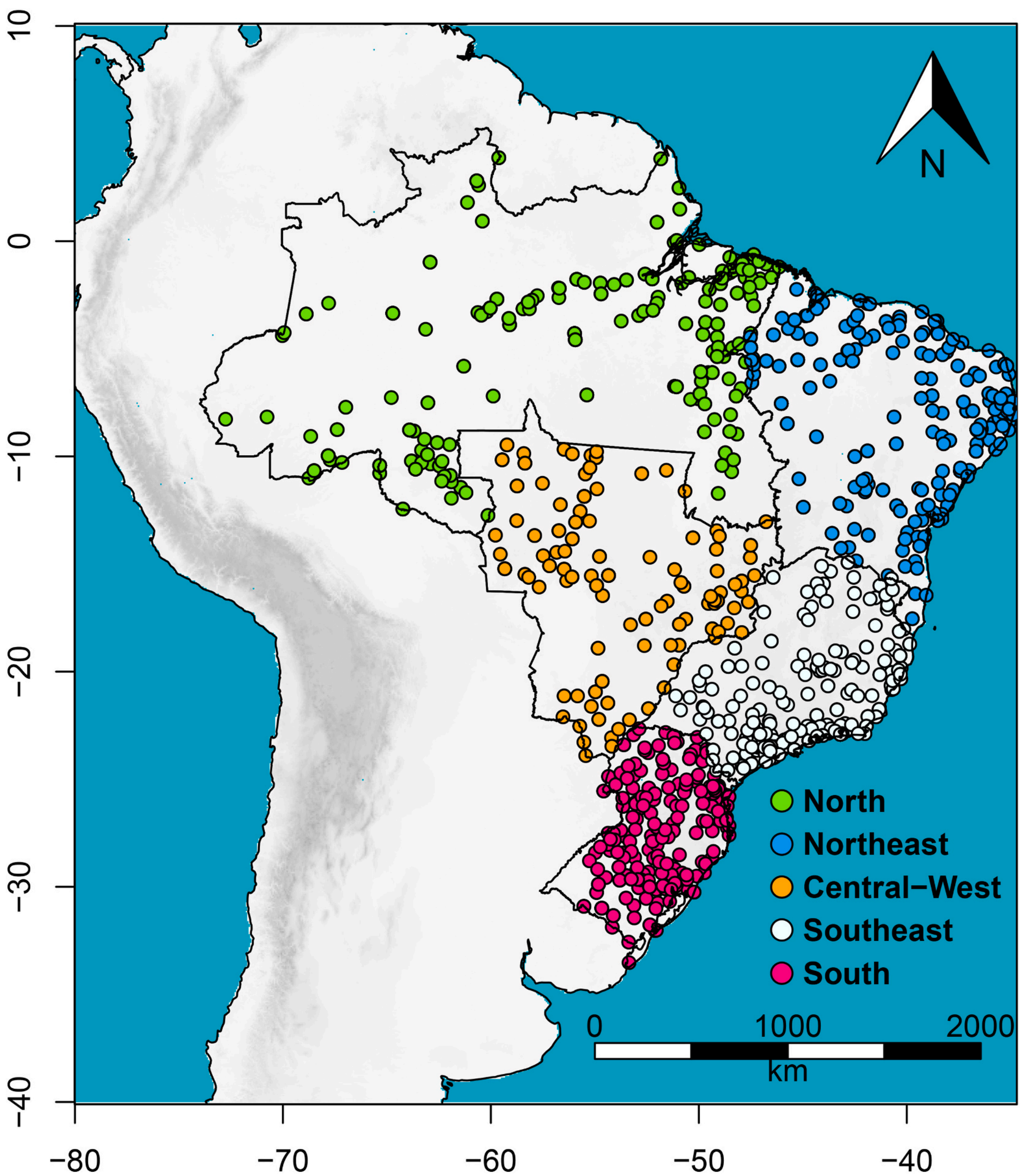

Fig. 1. A map of Brazil within South America (grey) highlighting the distribution of illegal hunting records (dots) per Brazilian macroregion, obtained during surveys conducted on five sport hunting groups on Facebook between 2018 and 2020.

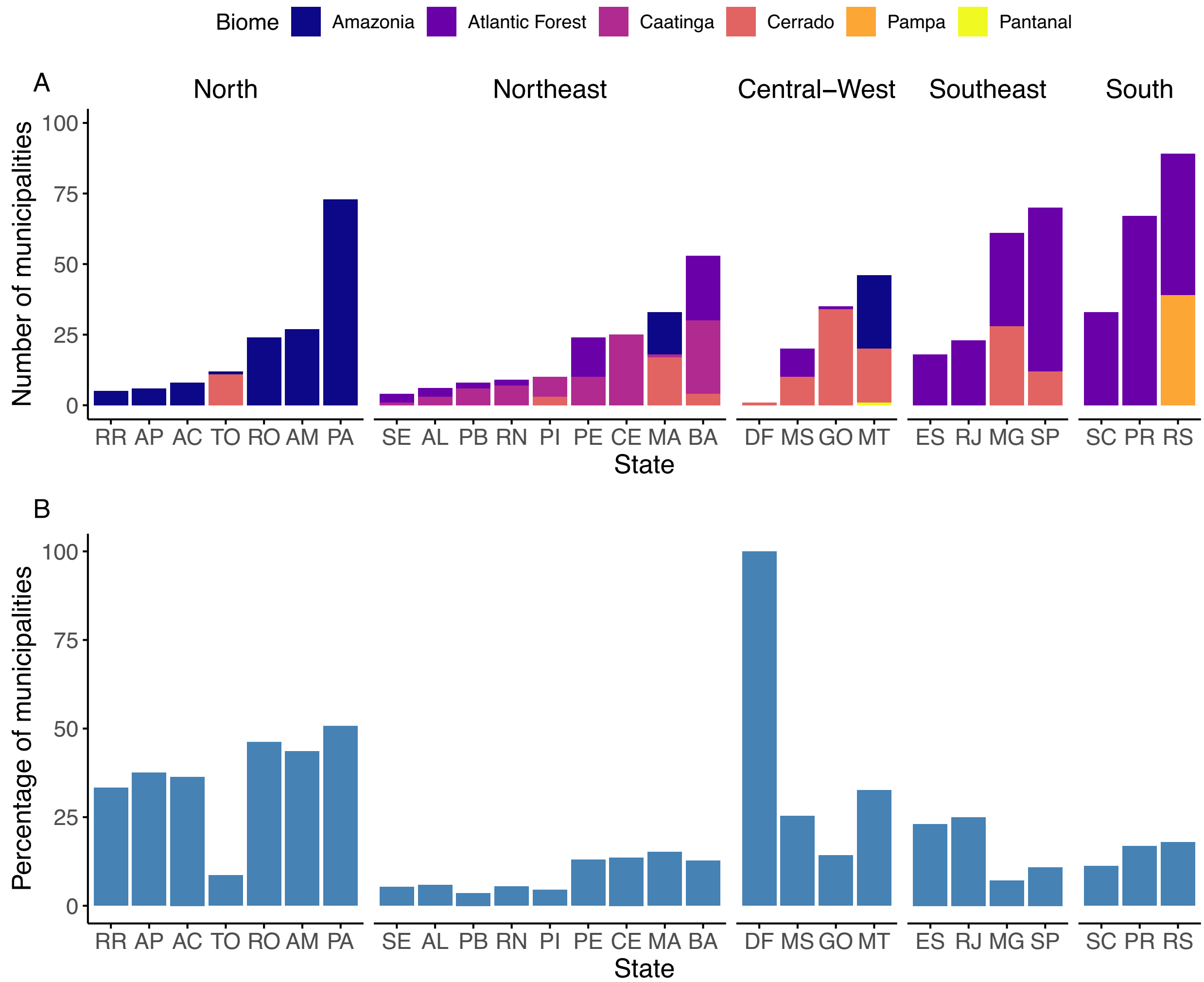

Fig. 2. **A.** Number of municipalities in which hunting took place ($n = 790$), by state, according to the macroregion and biome of the municipalities. **B.** Proportion of municipalities in each state that had records of hunting. Abbreviation of Brazilian States - North Region: AC: Acre| AP: Amapá | AM: Amazonas | PA: Pará | RO: Rondônia | RR: Roraima | TO: Tocantins; Northeast Region: AL: Alagoas | BA: Bahia | CE: Ceará | MA: Maranhão | PB: Paraíba | PE: Pernambuco | PI: Piauí | RN: Rio Grande do Norte | SE: Sergipe; Central-West Region: DF: Distrito Federal | GO: Goiás | MT: Mato Grosso | MS: Mato Grosso do Sul; Southeast Region: ES: Espírito Santo | MG: Minas Gerais | RJ: Rio de Janeiro | SP: São Paulo; South Region: PR: Paraná | RS: Rio Grande do Sul | SC: Santa Catarina.

The zero-inflated binomial model demonstrated strong discriminatory ability (AUC = 0.79), indicating good capacity to distinguish municipalities with and without recorded hunting events. Around 13% of municipalities represent structural zeros, i.e., municipalities with effectively no probability of detecting illegal hunting events through social media. Deviance-based R^2 was 0.13, indicating moderate explanatory power after accounting for hierarchical state and biome structure. Tjur's R^2 was 0.18, reflecting substantial separation between predicted probabilities of municipalities with and without detected hunting events. Random intercept variance was substantial at both the state ($\sigma = 0.81$) and biome ($\sigma = 0.54$) levels. The corresponding intraclass correlation coefficients, calculated on the latent logit scale, indicated that approximately 17% of variance in hunting detection probability was attributable to state-level clustering and 8% to biome-level clustering. After controlling for fixed predictors, state-level random intercepts corresponded to a 0.21–4.57-fold variation in odds relative to the national baseline, representing nearly a 22-fold difference between the lowest and highest states. Biome-level variation was smaller but still meaningful, with a 0.56–1.93-fold variation in baseline odds (see Fig. S1, Supplementary Information). Taken together, these validation metrics support the use of predicted probabilities to identify broad spatial patterns and relative hotspots of illegal hunting.

In terms of demographics and accessibility, human population density was strongly positively associated with hunting probability ($\beta = 1.391$, $p < 0.0001$). A tenfold increase in population density (log10 transformed) was associated with a 4.02-fold increase in the odds of detecting illegal hunting (OR = 4.02, 95% CI: 3.25–4.96). River density was positively associated with hunting probability ($\beta = 2.513$, $p = 0.0012$), corresponding to an OR of 12.34 (95% CI: 2.70–56.45). Although statistically significant, this estimate showed relatively wide confidence intervals, indicating greater uncertainty in the magnitude of this effect. In contrast, road density showed a strong negative association ($\beta = -2.831$, $p < 0.0001$), with an OR of 0.06 (95% CI: 0.03–0.14), indicating substantially lower odds of hunting detection in municipalities with higher road density. Mobile phone coverage was not significantly associated with hunting probability ($\beta = 0.00059$, $p = 0.872$) (Fig. 3).

In terms of ecological variables, remaining natural habitat cover was strongly positively associated with hunting probability ($\beta = 1.874$, $p < 0.0001$). Municipalities with higher proportions of remaining natural habitat had approximately 6.52 times higher odds of detecting illegal hunting (95% CI: 4.21–10.12). Defaunation was also positively associated with hunting probability ($\beta = 1.807$, $p = 0.002$), corresponding to an OR of 6.09 (95% CI: 1.94–19.16), indicating higher hunting detection in municipalities where mammalian faunas are more depleted. Elevation and terrain ruggedness showed no significant association with hunting

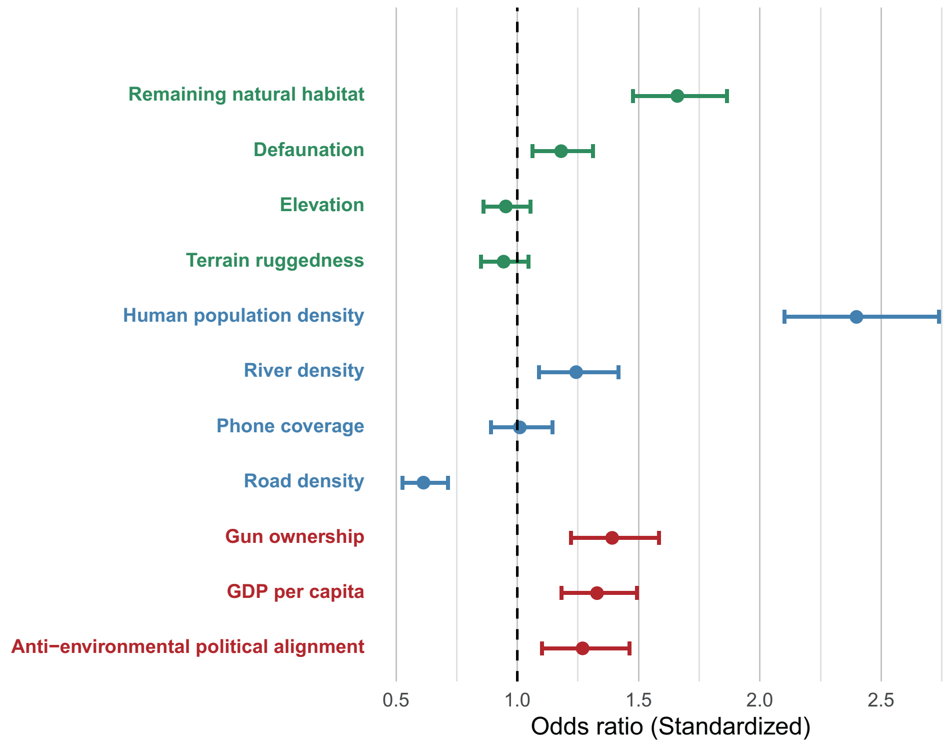

Fig. 3. Standardized effect sizes of predictors associated with the probability of detecting illegal sport hunting across Brazilian municipalities. Points represent odds ratios estimated from the zero-inflated binomial model fitted with standardized predictors, and horizontal bars indicate 95% confidence intervals. The dashed vertical line denotes the null effect (OR = 1). Variables are grouped according to conceptual categories: ecological context (green), demographics and accessibility (blue), and political–economic factors (red), and ordered by the magnitude of standardized coefficients to facilitate comparison among predictors measured on different scales. Positive associations indicate higher odds of hunting detection with increasing predictor values, whereas negative associations indicate reduced odds. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

($\beta = -0.00017$, $p = 0.347$; OR = 1.00, 95% CI: 0.999–1.000; $\beta = -0.00251$, $p = 0.29$; OR = 1.00, 95% CI: 0.993–1.002) (Fig. 3).

Finally, in terms of political and economic factors, GDP per capita was positively associated with hunting probability ($\beta = 0.868$, $p < 0.0001$). A tenfold increase in GDP per capita (log10 transformed) corresponded to a 2.38-fold increase in the odds of detecting illegal sport hunting (95% CI: 1.66–3.41). Gun ownership also showed a strong positive effect ($\beta = 0.809$, $p < 0.0001$), corresponding to an OR of 2.24 (95% CI: 1.63–3.09), indicating that municipalities with higher firearm prevalence had substantially higher odds of hunting occurrence. Anti-environmental political alignment was positively associated with hunting probability ($\beta = 1.269$, $p = 0.001$), with an OR of 3.56 (95% CI: 1.67–7.56). This coefficient represents the effect of a full-unit increase in vote share (0 to 100%), with a 10 percentage-point increase in vote share corresponding to approximately a 14% increase in the odds of hunting detection (Fig. 3).

Based on the standardized coefficients, human population density exhibited the strongest association with hunting probability ($|\beta\_std| = 0.875$), followed by remaining natural habitat ($|\beta\_std| = 0.507$) and road density ($|\beta\_std| = 0.489$). Gun ownership also showed a substantial standardized effect ($|\beta\_std| = 0.330$), followed by that of GDP per capita ($|\beta\_std| = 0.284$) and anti-environmental political alignment ($|\beta\_std| = 0.238$). River density ($|\beta\_std| = 0.217$) and defaunation ($|\beta\_std| = 0.166$) followed, while elevation ($|\beta\_std| = 0.049$), terrain ruggedness (0.058)

Table 2
Model results showing the influence of demographic and accessibility, ecological, and political–economic variables on the probability of detecting illegal sport hunting across Brazilian municipalities. The table reports estimated coefficients (β), standard errors (SE), odds ratios (OR) with 95% confidence intervals, and *p*-values for each predictor. Variables are ordered within conceptual groups according to the absolute value of standardized coefficients (|β_std|), allowing comparison of relative effect magnitudes among predictors measured on different scales.

Variable	Coefficient (β)	SE	OR	95% CI (OR)	p-value	|β_std|
Demographics and accessibility						
Human Population Density	1.391	0.108	4.02	3.25–4.96	<0.0001	0.875
Road density	−2.831	0.449	0.06	0.03–0.14	<0.0001	0.489
River density	2.513	0.776	12.34	2.70–56.45	0.0012	0.217
Phone coverage	0.00059	0.00364	1	0.99–1.01	0.872	0.01
Ecological context						
Remaining natural habitat	1.874	0.223	6.52	4.21–10.12	<0.0001	0.507
Defaunation	1.807	0.584	6.09	1.94–19.16	0.002	0.166
Elevation	−0.00017	0.00018	1	0.999–1.000	0.347	0.049
Terrain ruggedness	−0.00251	0.00237	1	0.993–1.002	0.29	0.058
Political and economic context						
Gun ownership	0.809	0.162	2.24	1.63–3.09	<0.0001	0.33
GDP per capita	0.868	0.182	2.38	1.66–3.41	<0.0001	0.284
Anti-environmental political alignment	1.269	0.387	3.56	1.67–7.56	0.001	0.238

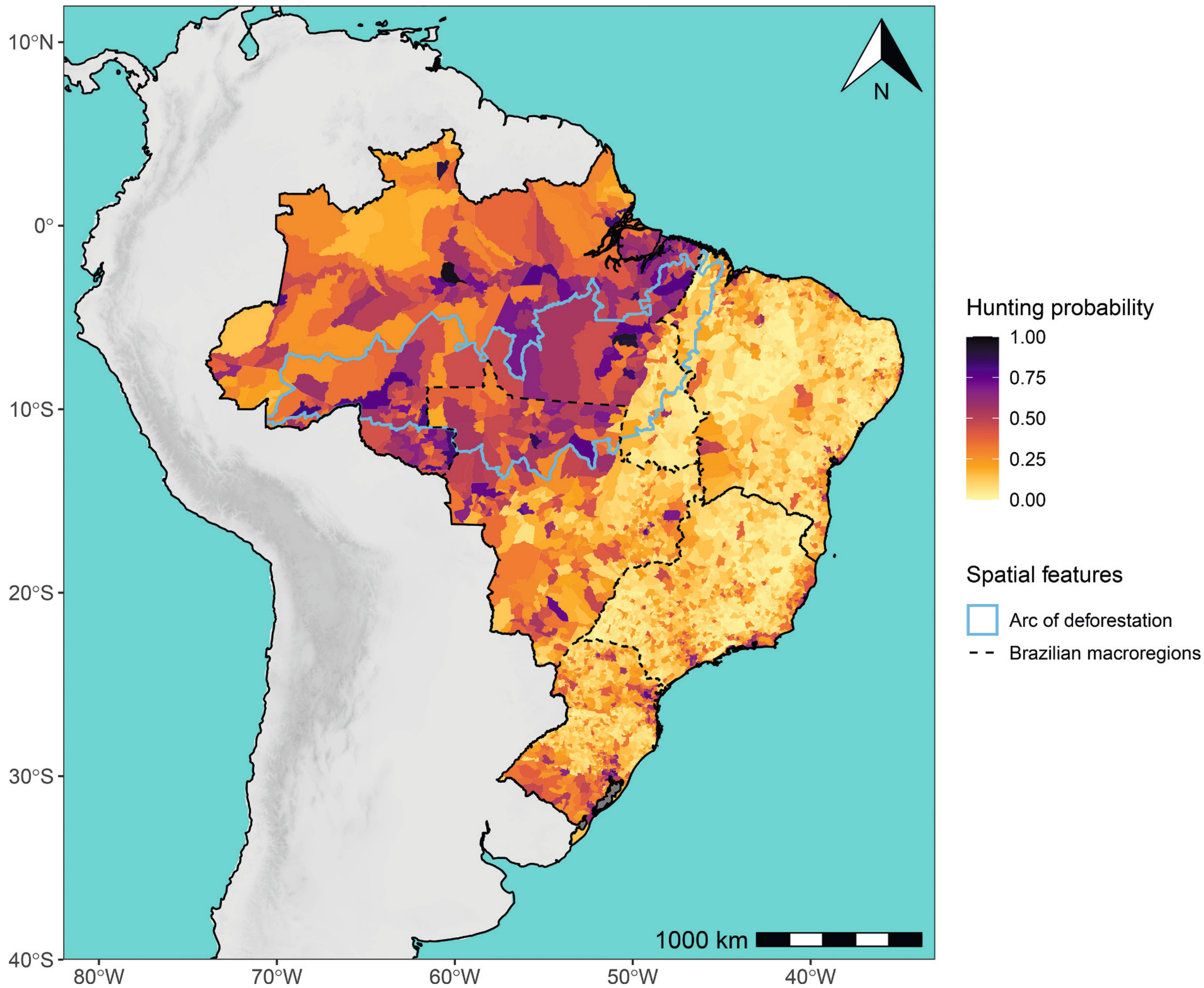

Fig. 4. Predicted probability of illegal sport hunting occurrence at the municipal level across Brazil, estimated from a hierarchical zero-inflated binomial model based on 2046 hunting events documented on social media and georeferenced to 790 municipalities during the 2019–2022 presidential administration. Warmer colours indicate a higher probability of recorded hunting occurrence. The light blue polygon indicates the **Arc of Deforestation**, a frontier region comprising municipalities along the southern and eastern edges of the Amazon biome that have historically concentrated the majority of forest clearing detected by satellite monitoring. This belt reflects the main zone of agricultural expansion, cattle ranching, and infrastructure development in the Brazilian Amazon. Dashed lines indicate the boundaries of Brazilian macroregions (see Fig. 1 for name references). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and phone coverage ($|\beta\_std| = 0.010$) exhibited comparatively minimal standardized effects (Table 2).

The predicted probability map presented indicators of broad spatial patterns and relative hotspot risk of illegal hunting. Predicted probabilities were higher in the North of Brazil, especially in the Amazon, in particular in and around the "Arc of Deforestation" zone–a group of municipalities in the region that extends across parts of Mato Grosso, Pará, Rondônia, Amazonas, Acre, and Maranhão states that have historically concentrated the majority of forest clearing detected by satellite monitoring (Fig. 4). Hotspots of illegal hunting were also identified along parts of the densely populated Atlantic Forest coast, and the grasslands of the Pampa.

4. Discussion

Our analysis reveals a complex interplay of demographic, ecological, political, and economic factors associated with illegal sport hunting in Brazil. Across tropical regions, hunting pressure is often inferred indirectly through proxies such as distance to settlements, accessibility indices, or human footprint metrics. In contrast, our study is based on a large national-scale dataset of documented illegal sport hunting events derived from digital trace data, providing direct evidence of hunting occurrence rather than inferred pressure. Furthermore, while most research on hunting in tropical systems focuses on subsistence hunting or bushmeat trade, illegal sport hunting remains comparatively underquantified despite its potential conservation impacts. By explicitly focusing on this modality, our study contributes to filling an important gap in the literature.

Overall, our results indicate that illegal hunting is widespread in the country, but occurring especially across social, political and environmental contexts where enabling conditions align—dense human populations near wildlife-rich habitats, increased access to firearms, and political narratives that normalise anti-environmental behaviour. In addition, the residual heterogeneity of random effects indicates that unmeasured institutional, socio-political, or ecological processes operating at higher administrative levels continue to structure hunting detection probability beyond the included covariates.

Our dataset extends into the early months of the COVID-19 pandemic (March–July 2020). Although heterogeneous mobility restrictions and enforcement changes may have influenced hunting behaviour or its online detectability in some regions, the predictors used in our model represent structural and temporally stable characteristics of municipalities (e.g., infrastructure density, habitat availability, political alignment). These are unlikely to have shifted materially during this short interval. Nonetheless, pandemic-related socio-economic and behavioural changes may have introduced additional heterogeneity in detection patterns and should be considered when interpreting results.

Urbanisation and population growth are associated with changes in local wildlife populations, with research indicating lower wildlife abundance in hunted areas compared to unhunted ones (Benítez-López et al., 2019). Our study shows that human population density was significantly associated with illegal hunting, likely due to the sheer number of potential actors and elevated demand for wildlife products. Surprisingly, road density was negatively associated with hunting, possibly due to improved enforcement and monitoring in road-dense areas or because these areas support less wildlife due to fragmentation and disturbance (Laurance et al., 2009). Only seven municipalities (0.89%) with hunting records had above-average road densities, while 408 municipalities (51.7%) had high population densities (HPD) exceeding the overall mean for Brazil. This suggests that sport hunting is concentrated in more densely populated areas with limited infrastructure. However, the negative association between municipal road density and hunting probability should not be interpreted as evidence that road expansion reduces wildlife pressure. Rather, it suggests that illegal sport hunting detection is not concentrated in the most road-dense municipalities. This finding is consistent with the possibility that hunting risk in frontier regions is determined less by formal road density per se than by expanding access through agricultural frontiers, unpaved roads, and informal secondary-road networks. These dynamics may be particularly relevant in emerging Amazonian frontiers such as the BR-319 corridor, where road upgrading and associated land occupation can increase penetration into relatively intact forest blocks even where formal infrastructure remains sparse (Ferrante et al., 2021).

River density was positively associated with hunting detection probability. In much of Amazonia and other forested regions, rivers function as primary transport corridors, enabling access to otherwise remote forest interiors. Unlike road infrastructure—which is often associated with deforestation and urbanisation—river networks may facilitate hunting activity while maintaining relatively high faunal integrity. The wide confidence intervals associated with this estimate suggest spatial heterogeneity in the strength of this relationship, likely reflecting regional differences in settlement patterns and hydrological structure. Nevertheless, the positive association highlights the importance of considering fluvial accessibility alongside terrestrial infrastructure when assessing hunting pressure across tropical landscapes.

Mobile phone coverage was not significantly associated with hunting detection probability. Although digital connectivity could influence the likelihood of posting illegal activities online, this result suggests that spatial patterns in detected hunting are not merely an artefact of network infrastructure. Furthermore, Brazil exhibits relatively high mobile coverage across urban areas, limiting the explanatory power of this variable once other socio-political factors are accounted for. The absence of a significant effect strengthens the interpretation that observed spatial patterns reflect underlying hunting dynamics rather than simple differences in digital access.

Ecologically, municipalities with higher levels of mammal defaunation were more likely to present illegal hunting events. Defaunation often reflects long-term hunting pressure and the progressive depletion of large-bodied species that are typically preferred by sport hunters (Bogoni et al., 2022; El Bizri et al., 2024). In a previous analysis of hunting yield using the same dataset, mammal depletion was associated with reduced harvested biomass and a shift toward smaller-bodied taxa such as birds and reptiles (El Bizri et al., 2024). These findings are further corroborated by independent nationwide seizure records from Brazil's Federal Highway Police, which revealed widespread illegal wild meat use across the country and documented similar signatures of faunal downsizing, including reduced biomass and shifts in taxonomic composition with increasing defaunation (Wendt-Oliveira et al., 2026). Such patterns suggest compensatory dynamics in which hunters increase effort or diversify taxonomic targets as large mammals become scarce, potentially increasing the frequency of hunting events to maintain similar returns. At the same time, municipalities with greater remaining natural habitat showed a higher probability of hunting occurrence. This apparent combination of habitat availability and faunal depletion likely reflects the dynamics of frontier landscapes, particularly within the Arc of Deforestation, a belt of municipalities along the southern and eastern Amazon where agricultural expansion, infrastructure development, and forest conversion have historically concentrated both deforestation and wildlife exploitation (see Fig. 4). Notably, this region also emerged as the main hotspot of illegal hunting probability in our analysis, reinforcing the interpretation that frontier dynamics simultaneously concentrate remaining wildlife resources and the pressures that drive their exploitation. These frontier regions still retain substantial forest cover capable of supporting wildlife populations, but they are simultaneously subject to intense human pressure and progressive faunal depletion. Consequently, they function both as biodiversity refuges and as focal areas for illegal extraction. For instance, illegal sport hunters in the Amazon extracted over 13,000 kg of wild meat in only two years based on social media records (El Bizri et al., 2024). These findings highlight the importance of strengthening conservation governance and enforcement in frontier landscapes where natural habitats persist but ecological integrity is already eroding and several large-bodied species, including ungulates and carnivores, face local extirpation or severe population declines (Bogoni et al., 2020; El Bizri et al., 2024).

Political and economic factors were significantly correlated with illegal hunting dynamics in Brazil. Municipalities with higher GDP per capita had a higher probability of illegal hunting activity. These trends suggest that illegal sport hunting in Brazil is likely associated with wealthier individuals. This contrasts with the subsistence hunting typically undertaken by economically less affluent, rural populations (El Bizri et al., 2015; Oliveira et al., 2023; Islas et al., 2024). The political landscape shaped by anti-environmental agendas and regulatory rollbacks also played a significant role. Municipalities exhibiting stronger anti-environmental political alignment were more likely to present illegal hunting activity (Passos, 2023). The standardized magnitude of political alignment was comparable to key environmental predictors such as river density and exceeded that of defaunation and elevation, highlighting the independent contribution of political context to illegal hunting occurrence.

Researchers have described Bolsonaro's administration as marked by anti-environmental rhetoric and governance decisions undermining environmental protections (Ferrante and Fearnside, 2019; Mendes Motta et al., 2023). These included authoritarian measures to defend global agribusiness while downplaying environmental issues (Mendes Motta et al., 2023) and promoting anti-environmentalism as a form of nationalist identity (Menezes and Barbosa, 2021). This has significantly influenced public perception and political decisions toward environmental agendas in Brazil, such as fostering distrust toward environmental NGOs (Deutsch, 2021), fuelling hostility toward Indigenous communities (Gonçalves and Cafrune, 2023), and normalising damaging natural resource exploitation (Ferrante and Fearnside, 2019). This association between political alignment and illegal hunting patterns underscores the need for targeted interventions addressing these socio-political dimensions (Keane et al., 2008; Bragagnolo et al., 2019; Lavadinović et al., 2021).

Importantly, firearm possession itself emerged as one of the strongest standardized predictors of illegal hunting probability, indicating that access to weapons likely functions as a direct enabling mechanism rather than merely reflecting broader political alignment. Firearms substantially increase hunting efficiency, range, and lethality, allowing hunters to target large-bodied and otherwise difficult-to-capture species. Previous research in African systems showed that the proliferation of automatic weapons during armed conflicts has been directly linked to sharp wildlife declines, illustrating how weapon circulation can structurally amplify hunting pressure (Braga-Pereira et al., 2020a). In the Brazilian context, the relaxation of firearm regulations during the Bolsonaro administration dramatically increased civilian access to weapons. Our results suggest that this expansion of gun ownership may have lowered the material and logistical barriers to engaging in illegal sport hunting, thereby facilitating its spatial expansion beyond traditional subsistence contexts. Unlike demographic accessibility variables, which determine opportunity, firearm prevalence represents a tangible technological capacity that can directly scale hunting intensity.

It is important to note that although electoral support for Jair Bolsonaro was positively associated with the probability of recorded illegal hunting, this relationship should be interpreted as correlational rather than causal. Our analysis does not demonstrate that political alignment directly causes increased hunting activity; rather, it indicates that municipalities with higher vote share for Bolsonaro were more likely to present recorded illegal sport hunting events. Political alignment may itself be spatially structured alongside other socio-economic and land-use characteristics. For example, regions with stronger agribusiness presence, large private landholdings, frontier expansion dynamics, or historically weaker environmental enforcement may also display higher levels of support for deregulatory political agendas. Although our model includes controls for socio-economic indicators, habitat availability, accessibility, and firearm prevalence, unmeasured contextual factors—such as land tenure concentration, agricultural intensification, or informal enforcement norms—may also contribute to the observed association.

Our predicted map reveals that illegal hunting is widespread across Brazil, with clear hotspots in coastal areas—where human population density is highest—and along the frontiers between the Cerrado, Amazon, and Pantanal biomes, where large tracts of natural habitat remain and both gun ownership and anti-environmental political alignment are elevated. Our results are particularly concerning in the Amazon region, where wild meat constitutes a fundamental component of traditional food systems for Indigenous peoples and rural communities (Nunes et al., 2019). Recent large-scale assessments estimate that wild meat provides a substantial proportion of dietary protein and key micronutrients for millions of rural inhabitants across Amazonia, highlighting its central role in nutritional security and cultural practices (Antunes et al., 2025). At the same time, our analyses identified relatively high probabilities of illegal sport hunting across parts of the Amazon and especially along frontier landscapes associated with agricultural expansion and deforestation (commonly referred to as "Arc of Deforestation"). These regions coincide with areas where wildlife productivity is already declining as a result of habitat loss and increasing human pressure. The expansion of recreational or politically permissive hunting under such conditions may therefore generate competition over the same wildlife resources that sustain traditional hunting systems. In heavily transformed frontier regions such as the Amazon, the combined effects of habitat degradation, agricultural expansion, and increased hunting pressure could undermine the ecological basis of Indigenous and local food systems, with potential consequences for both biodiversity conservation and food security (Antunes et al., 2025). In addition, the concentration of illegal hunting hotspots within the Arc of Deforestation is particularly concerning because this region has also been identified as an area where zoonotic disease risks associated with wildlife hunting are elevated (e.g., Boubli et al., 2026). For example, recent studies indicate that hunting of armadillos—resilient species that persist in degraded landscapes and often dominate hunting yields in defaunated areas—is linked to leprosy transmission in Brazil, particularly within the Arc of Deforestation. This suggests that the same socio-ecological processes driving increased hunting pressure and biodiversity loss may also amplify risks to human health (Aliaga-Samanez et al., 2025).

4.1. The complex relationship of people, culture, socio-political context and illegal hunting

Illegal hunting is a multifaceted global challenge with deep social and cultural roots and is influenced by history, politics, economics and the environmental context. Hunting has had multiple meanings and definitions worldwide in different epochs of humanity; it has been prohibited as a symbol of tyranny, used as a tool of oppression, symbolising the power and control of ruling classes over people and wildlife (West et al., 2006). During the era of the European imperialism, game reserves and hunting laws have been implemented to exclude local communities from their traditional hunting grounds (Brockington and Igoe, 2006) and, therefore, illegal hunting has also been seen as a symbol of freedom and self-sufficiency, particularly in contexts where it represents a connection to nature and traditional ways of life (von Essen et al., 2017). With the rapidly increasing risk of species extinctions and the globalisation of demand for 'exotic' species and their parts (Courchamp et al., 2006), almost all countries have implemented some form of hunting restrictions. Contemporary conservation approaches have been critiqued for reproducing exclusionary governance practices that privilege biodiversity outcomes over local rights and livelihoods, often producing social tensions and resistance among affected communities. Additionally, illegal hunting has been linked to armed conflicts, further complicating conservation efforts (Braga-Pereira et al., 2020a, 2020b; Braga-Pereira et al., 2021).

Individual income is a significant motive for illegal hunting. However, a considerable portion of illegal hunters are driven by multiple overlapping reasons, including political motivations (Duffy et al., 2016). Socio-cultural, socio-economic, and political drivers together represent 84% of the motivations for illegal hunting, underscoring the issue's complexity (Lavadinović et al., 2021). Recognizing this complexity is essential for aligning conservation practices with social justice goals (Montgomery et al., 2020).

4.2. Strategies for addressing illegal hunting in Brazil

To effectively address illegal hunting in Brazil and prevent further biodiversity loss, a comprehensive, multifaceted strategy addressing both ecological and socio-political dimensions is essential. In a broad perspective of environmental governance, promoting political accountability and fostering alliances with local and regional governments are crucial to closing governance gaps in areas with high illegal hunting rates (Bragagnolo et al., 2019).

Enhancing law enforcement and wildlife monitoring in high-risk areas, particularly those with significant natural habitats and high human populations, is a critical first step (Critchlow et al., 2015). Prior research has shown that increased patrols and surveillance reduce illegal hunting activities by making it more challenging for poachers to operate unnoticed (Hilborn et al., 2006; Franco et al., 2025). Implementing advanced monitoring technologies like drones and camera traps could further strengthen enforcement efforts in remote and ecologically sensitive areas (Mulero-Pázmány et al., 2014; Bogoni et al., 2020). Moreover, policies aimed at regulating gun ownership and stricter enforcement of hunting laws can help curb hunting activities.

Public awareness and behaviour change campaigns through community engagement initiatives are vital to alter socio-political attitudes toward hunting and promote wildlife conservation. For example, targeted education and social marketing campaigns to educate society on the ecological impacts of poaching could shift public perceptions and reduce the cultural acceptance of illegal hunting. Community-based conservation programs that promote alternative livelihoods and involve local stakeholders in wildlife protection efforts have successfully reduced illegal hunting (Wilson-Holt and Roe, 2021; Keane et al., 2008). These initiatives should be tailored to specific socio-political contexts, particularly in areas with strong political support for pro-hunting policies. However, some evidence suggests that these interventions may be additive, not replacements for hunting (Wright et al., 2016).

Therefore, in regions where hunting is deeply ingrained in local culture, the development of sustainable sport hunting programs can offer a balanced approach that respects their practices while contributing to wildlife conservation. When properly managed, sustainable hunting programs can generate significant financial resources for conservation efforts, reduce illegal hunting activities, and foster local community involvement in wildlife management. One successful example is Namibia's community-based conservation programs, where sustainable trophy hunting is permitted within conservancies managed by local communities. This approach has increased wildlife populations and has significant economic benefits for these communities. Revenues from hunting permits and trophy fees is reinvested into conservation efforts, such as patrols to prevent illegal hunting, wildlife monitoring, and habitat restoration (Lindsey et al., 2007). In Brazil, where hunting has a controversial but culturally accepted history, implementing similar community-based models could help balance conservation goals with local traditions. However, these initiatives would need to be tailored to the specificities of each region, since the Brazilian hunting culture differs largely from the hunting culture in African countries, not only because of the ecology of target species but also because of hunters' profiles and motives (Lubilo and Hebinck, 2019). By creating programs that allow regulated, sustainable hunting, it is possible to channel funds into critical conservation initiatives while reducing the incentives for illegal hunting. Such programs must include strict monitoring, community participation, and transparent reinvestment of revenues into local conservation efforts.

Our findings also illustrate how the broader institutional and political environment deeply influences illegal hunting in Brazil. The concentration of hunting hotspots in regions with weak environmental governance—such as the Amazon-Cerrado-Pantanal frontier—reflects the operational realities of tropical governance frontiers. In these areas, local and regional institutions often face limited enforcement capacity, shifting political mandates, and an lack of interagency coordination. The dismantling of environmental oversight mechanisms during Bolsonaro's administration further exacerbated these weaknesses, making it more difficult for regulatory institutions to act independently of political pressures (Ferrante and Fearnside, 2019; Oliveira and Araújo, 2020). However, these implications are not limited to Bolsonaro's term. Although the current Lula administration differs markedly in environmental discourse and has overseen great declines in Amazon deforestation, support for completing BR-319 shows that important governance contradictions remain in frontier regions, where infrastructure expansion may reopen pathways for land grabbing, forest occupation, and associated wildlife pressure (Kelly and Boadle, 2024). Our findings therefore point both to the legacy of Bolsonaro's anti-environmental agenda and to the continued need for environmental governance, firearm control, and precaution in the planning of frontier infrastructure.

Therefore, tackling illegal hunting requires targeted institutional reforms. Strengthening environmental enforcement must go hand in hand with measures to ensure political insulation of environmental agencies, particularly in frontier zones where pressures are greatest. Federal–state cooperation needs to be formalised through stable governance coalitions, and legal protections must be implemented to prevent future regulatory rollbacks (Barnes, 2026). Importantly, firearm regulation policies must be better integrated with wildlife protection frameworks to ensure that increases in gun access do not undermine conservation efforts. These governance-oriented interventions are essential to addressing the structural vulnerabilities that enable illegal hunting to persist.

It is also essential to regulate the content shared on social media to discourage illegal behaviors. Social media platforms, including Facebook, have significant potential to curb content sharing and reinforce illegal sport hunting. They can enforce existing terms of service by proactively removing content related to illegal hunting through advanced detection tools and automated algorithms. Additionally, tech companies could implement stricter penalties for users violating these policies and collaborate with conservation organizations and law enforcement to improve monitoring and enforcement systems (Xu et al., 2020; Morcatty et al., 2022). Public accountability measures, such as transparency in reporting illegal activity removal rates, are also essential (Ingram et al., 2024).

Finally, interdisciplinary research efforts must continue to explore the complex interactions between ecological, socio-economic, and political factors influencing illegal hunting in Brazil. Integrating ecological data, such as habitat degradation and species distribution, with socio-economic analysis is critical for designing more effective conservation strategies. Ultimately, a comprehensive, interdisciplinary approach is essential for addressing the complex drivers of illegal hunting and creating adaptive conservation strategies that address ecological threats and underlying socio-political conditions.

CRediT authorship contribution statement

Hani R. El Bizri: Writing – original draft, Visualization, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Thais Queiroz Morcatty:** Writing – original draft, Visualization, Investigation, Formal analysis, Data curation. **Marcela A. Oliveira:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Aline Pessutti Rampini:** Writing – review & editing, Formal analysis, Data curation. **Simon Knoop:** Writing – review & editing, Investigation. **Julia E. Fa:** Writing – review & editing, Supervision, Funding acquisition. **Kacie Henson:** Writing – review & editing, Writing – original draft. **Camila Alvez Islas:** Writing – review & editing, Formal analysis. **Gabriel Favero Massocato:** Writing – review & editing, Data curation. **Arnaud L.J. Desbiez:** Writing – review & editing, Data curation. **João Vitor Campos-Silva:** Writing – review & editing, Data curation. **Daniel Zani La Laina:** Writing – review & editing, Data curation. **José Maurício Barbanti Duarte:** Writing – review & editing, Data curation. **Rafael Sá Leitão Barboza:** Writing – review & editing, Data curation. **Zilca Campos:** Writing – review & editing, Data curation. **Sarah Mângia:** Writing – review & editing, Data curation. **Daniel J. Ingram:** Writing – review & editing. **Juliano A. Bogoni:** Writing – original draft, Visualization, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2026.111989.

Data availability

Data will be made available on request.

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