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Essays and Perspectives

Roadway seizures reveal widespread illegal wild meat use and faunal downsizing in Brazil

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HIGHLIGHTS

- Nationwide PRF seizures reveal 9,479 animals and 9.3 t of wild meat (2017–2024).
- Birds dominate in Caatinga and Pampa; mammals supply most biomass overall.
- Seizures reflect defaunation: more individuals but lower biomass in degraded states.
- Mammal decline linked to substitution by birds; reptiles show distinct transport bias.
- Roadway seizure data offers a cost-effective barometer of illegal wild meat use.

GRAPHICAL ABSTRACT

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ABSTRACT

Illegal and unsustainable wild meat use is simplifying vertebrate assemblages across the Neotropics, yet robust information on offtake magnitude and use patterns remains scarce. We used nationwide road-seizure records from Brazil's Federal Highway Police (Polícia Rodoviária Federal; PRF) from 2017 to 2024, focusing on hunted animals and wild meat intercepted during transport, to quantify the scale and composition of illegal offtake. We then tested whether these enforcement records reproduce expected ecological signals of illegal hunting by examining whether seizure yield and taxonomic composition track state-level defaunation. Across 314 independent events, PRF intercepted ~9,479 individual animals, totalling ~9.3 t of biomass, revealing substantial

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and taxonomically structured pressure on wildlife. The Amazon and Caatinga biomes accounted for the largest shares of events and individuals, respectively. Seized birds dominated numerically in Caatinga, whereas mammals supplied most biomass overall, with reptiles contributing disproportionately in the Amazon and Cerrado–Pantanal biomes. Generalized linear models showed that with increasing defaunation, events involved more individuals but less biomass per seizure, and the mean body mass of seized vertebrates declined. In addition, the proportion of mammals decreased while birds became more prevalent. This convergence with known depletion patterns indicates that road-seizure data can serve as a cost-effective barometer of illegal wild-meat use and its defaunation-linked "downsizing" effect. Targeted responses should pair highway and riverine enforcement, standardize inter-agency reporting (species, counts, biomass, geolocation, product form), and combine access control with community partnerships, livelihood alternatives, and health-risk communication to reduce demand and long-term ecological and public-health impacts.

Introduction

Wild meat remains an essential source of protein and other nutrients for the sustenance of millions of people worldwide. However, the illegal and unsustainable use of wild meat poses one of the most significant threats to biodiversity (Fa et al., 2003), with far-reaching ecological, socioeconomic, and public health consequences (Bennett, 2002). Encompassing both the illegal hunting of wild animals and the subsequent trade, transport, and consumption of their meat, the illegal use of wild meat exerts severe pressure on wildlife populations and ecosystem functioning.

Brazil, which holds a large portion of the Neotropics and its hyperdiverse ecosystems, faces escalating biodiversity loss driven by multiple human-induced pressures (Mittermeier et al., 1997; Soares-Filho et al., 2014). The illegal exploitation of wild animals for their meat in Brazil has led to levels of faunal depletion comparable to the defaunation associated with the European conquest (Bogoni et al., 2024). Large-bodied vertebrates are especially affected, with cascading impacts on ecosystem resilience and key ecological processes, such as seed dispersal and carbon storage (Bogoni et al., 2022).

Historically, hunting in Brazil was recognized as a legal cultural practice under Law No. 23,672/1934 (Brasil, 1934; Fernandes-Ferreira et al., 2014). However, this changed with Law No. 5,197/1967 (Brasil, 1967), which criminalized the hunting and trade of wild animals. Current Brazilian legislation (e.g., the Environmental Crimes Law No. 9, 605/1998; Brasil, 1988) distinguishes between predatory hunting (e.g., commercial hunting) and non-predatory hunting (e.g., hunting to "satiate hunger" typically practiced by people in remote rural areas, wildlife control, scientific research, or sport hunting, provided it is authorized by environmental agencies) (El Bizri et al., 2015). However, government-sanctioned hunting programs involving wild meat have been sporadic, short-term, and lack permanent legal frameworks; currently, no formal, ongoing program exists. As a result, illegal wild meat use remains widespread across Brazil. For example, El Bizri et al. (2020) estimated that over 10,000 tonnes of wild meat are illegally traded and consumed annually in urban areas of the central Brazilian Amazon. Additionally, illegal sport hunting is pervasive across all Brazilian biomes and is frequently and openly documented on social media platforms such as YouTube™ and Facebook™ (El Bizri et al., 2015, 2024).

The clandestine nature of illegal wild meat use presents significant challenges for direct monitoring. Field-based data collection is limited by legal sensitivities and logistical barriers (Verdade and Seixas, 2013), and the absence of systematic national records undermines effective conservation responses (Bragagnolo et al., 2019). As an alternative, seizure data—especially from transportation routes—have become a valuable proxy for understanding spatial and temporal patterns of illegal wild meat use, if enforcement effort and reporting biases are accounted for (Underwood et al., 2013; Wittemyer et al., 2014).

Most studies in Brazil using seizure data have focused on the live animal pet trade, often at local or regional scales. For example, Oliveira et al. (2020) reported that birds comprised 84.8% of wildlife seizures in Rio Grande do Norte state, while Nascimento et al. (2015) observed a dominance of finches and parrots in Amazonas state. Only a few studies have specifically addressed the use of illegal wild meat. Chagas et al. (2015) analyzed hunting-related seizures across 16 states and found that armadillos (Family Dasypodidae), pacas (*Cuniculus paca*), and capybaras (*Hydrochoerus hydrochaeris*) were the most frequently seized taxa.

Records of seized items from the Federal Highway Police (PRF) offer a unique, underutilized dataset for analyzing illegal wild meat use at a national scale. PRF seizures focus on the transport of animals and their derivatives along Brazil's extensive road network, providing critical insights into the logistics, geographic flows, and structural drivers of illegal wild meat use across regions. However, the validity of using such data to describe hunting patterns is still unclear. In this study, we used PRF's nationwide road seizure data over 7 years to address the significant gaps in understanding illegal hunting across Brazil. More specifically, our objectives were to understand (1) the distribution and taxa composition of illegal hunting across different Brazilian biomes; and (2) whether seizure data can effectively reflect patterns of illegal wildlife use across Brazil. To do so, we assessed the diversity of seized taxa and proportion of threatened species; estimated and compared the number of individual animals and biomass seized; and analyzed the patterns of yield and composition of seized species across gradients of defaunation to assess how these metrics compare with previous studies on illegal hunting across the country.

Methods

Study area

This study was conducted across the entire Brazilian territory, which spans six major biomes: broadleaf humid forests (Amazon and Atlantic Forest), seasonal wetlands (Pantanal), savannah (Cerrado), grasslands (Pampa), and semi-arid environments (Caatinga). This diversity of habitats supports exceptional species richness, making Brazil one of the most biodiverse countries in the world (Mittermeier et al., 1997; Soares-Filho et al., 2014). Approximately 60% of Brazil's territory is still covered by native vegetation remnants (Oliveira et al., 2017). However, as the largest tropical country globally, Brazil faces a multifaceted environmental crisis that poses severe threats to its biodiversity. Since Colonial times, Brazil has primarily developed as an agricultural nation (McNeill, 1986). This devastation has been particularly severe over the past 60 years due to modern mechanization, deforestation, and the prevalence of criminal fires (McNeill, 1986; Silva-Jr et al., 2020). In parallel, these environmental pressures have been accompanied by recurrent and large-scale illegal wild meat use, further exacerbating biodiversity loss (Bogoni et al., 2022; El Bizri et al., 2024).

Data collection

Considering records from 4th July 2017 to 29th December 2024, we have created a comprehensive database containing all recent seizure reports from the entire Brazilian Federal Highway Police (PRF) related to Article 29 of Law N°. 9,605/98 (Brasil, 1998). We obtained these data through direct access to the PRF's online database, known as the BOP

System, restricted to PRF agents, given that the manuscript's first author (JRWO) is an active PRF agent. The reports include complete specimens or parts of wild animals from native Brazilian fauna, covering migratory species and others that inhabit Brazilian territory, even if only for part of their life cycle.

The initial phase involved screening and interpreting occurrences to create a standardized database where any discrepancies were corrected based on the evidence within the reports. In this study, we focused on seizure data related to illegal wild meat use (whether for trade or not), including only cases where the meat was the primary product seized and where the evidence clearly showed animals had been killed through hunting activities. Accordingly, we excluded cases involving animals killed during transportation due to poor conditions or animals found dead in residential properties, commercial establishments, or breeding facilities. No live animals were considered, as these are mostly trafficked for pets.

Data analysis

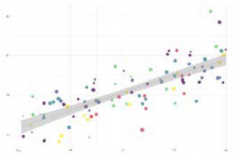
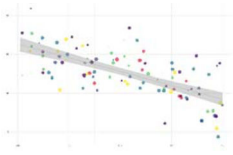
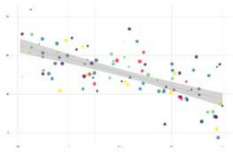
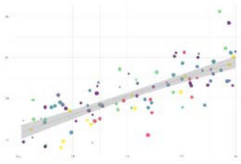
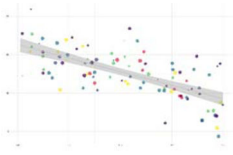
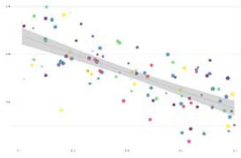
We performed descriptive analyses to quantify patterns of wild meat seizures recorded by the Federal Highway Police across Brazil. Metrics included the total number of seizure events; the number of municipalities where seizures occurred; species and taxonomic group richness seized per biome; and the number and proportion of threatened species. We also estimated the mean and total number of seized animals and biomass per event, both in aggregate and disaggregated by species and biome. Metrics were summarized using means and standard deviations (SD) where appropriate.

To assess how the yield and composition of seized wild meat vary across gradients of faunal depletion, we analyzed seizure records with defaunation levels throughout Brazil. Our hypotheses were informed by patterns previously described in illegal hunting data obtained from Facebook posts (El Bizri et al., 2024), which provided expectations for how wild meat use may shift with increasing ecological degradation. These anticipated trends—detailed in Table 1—not only guided our analysis but also allowed us to evaluate whether seizure records reflect known ecological patterns, thereby contributing to the validation of seizure data as a proxy for illegal hunting activity in Brazil.

We extracted municipality-level values from the mammal defaunation index developed by Bogoni et al. (2020), which integrates environmental and anthropogenic pressures into a continuous scale from 0.0 (intact fauna) to 1.0 (fully defaunated). Although data on defaunation levels for other taxonomic groups are limited, previous studies have shown mammal defaunation patterns to be a suitable indicator of broader ecological changes (Dirzo et al., 2014). For each Brazilian state, we calculated an average defaunation score based on the municipalities where wild meat seizures were recorded. Using states as the unit of analysis, we examined whether defaunation levels were associated with differences in (1) wild meat yield, measured as the mean number of individuals and total biomass per seizure event; and (2) taxonomic composition, including the average body mass of seized birds, mammals, and reptiles, and their relative contribution to the total number of individuals seized.

We applied generalized linear models using distribution families appropriate for the data under testing (e.g., Gaussian, depending on distributional assumptions assessed with the Shapiro–Wilk test ($p > 0.05$); if not normal, we alternatively used Gamma for strictly positive skewed data bound from 0 to ∞ or zero-adjusted Gamma when the data included zeros; and Weibull distribution for right-skewed data. We calculated p-values and pseudo-R^2 values to assess the significance of the relationship and model fit, respectively. Data were analyzed using R Studio (version 2023.09.1 + 494) and the *gamlss* package (Rigby and Stasinopoulos, 2005).

Table 1
The main hypotheses tested in our study, based on a previous seminal study (El Bizri et al., 2024), show the potential relationships between defaunation (x axis) levels and hunting seizures (y axis).

Hypothesis	Graphical representation
Positive correlation between defaunation (x axis) and the average number of individuals per seizure event (y axis) Rationale: The loss of large-bodied species in defaunated areas means that hunters target a larger number of small-bodied species.	
Negative correlation between defaunation (x axis) and average biomass yield per seizure event (y axis) Rationale: The loss of large-bodied species in defaunated areas means that hunters target small-bodied species, and even though these species are harvested in higher numbers, this is not enough to compensate for the loss in biomass.	
Decline in average species body mass (y axis) with defaunation (for all taxonomic classes; x axis) Rationale: The loss of large-bodied species in defaunated areas means that hunters target small-bodied species. This is expected to occur in all taxonomic classes (mammals, birds, and reptiles).	
Increase in bird representation (% of individuals; y axis) with defaunation (x axis) Rationale: Large-bodied mammals are usually the preferred and most targeted species. In defaunated areas, the loss of these species means that hunters will turn to other groups, such as birds.	
Decline in mammal representation (% of individuals; y axis) with defaunation (x axis) Rationale: Large-bodied mammals are usually the preferred and most targeted species and are the first to suffer declines in their populations or local extinction in defaunated areas.	
Decline in reptile representation (% of individuals; y axis) with defaunation (x axis) Rationale: Large-bodied reptiles are also one of the most targeted species and suffer declines in their populations or local extinction in defaunated areas.	

Results

We recorded a total of 314 independent seizure events (Fig. 1), with the highest numbers recorded in the Amazon (n = 116; 36.9%) and Caatinga (n = 88; 28%). The Cerrado-Pantanal region recorded 50 events (15.9%), the Atlantic Forest had 32 events (10.2%), and the Pampa had 28 events (8.9%). The total number of seized individuals amounted to 9,479 specimens (Table 2). The Caatinga biome accounted for the largest total number of individuals seized (n = 7,950), with birds comprising the overwhelming majority (97.5%). Birds also constituted the dominant group in the Atlantic Forest (82.9%) and Pampa (91.1%). In contrast, mammal seizures were more prominent in the Amazon (42.2% of individuals) and Cerrado-Pantanal (65%). The Caatinga recorded the highest average number of individuals seized per event (mean = 90.3; SD = 540) while the Cerrado-Pantanal region showed the lowest values (mean = 2.44; SD = 3.21).

In terms of biomass (see Table 2), 9,280.85 kg was recorded in total. Mammals made up the largest proportion of the total seized biomass (5,272 kg), followed by reptiles (2,160 kg) and birds (1,848 kg). Mammals contributed most significantly to total biomass in the Amazon (1,759 kg) and Pampa (1,698 kg). Reptile biomass was concentrated in

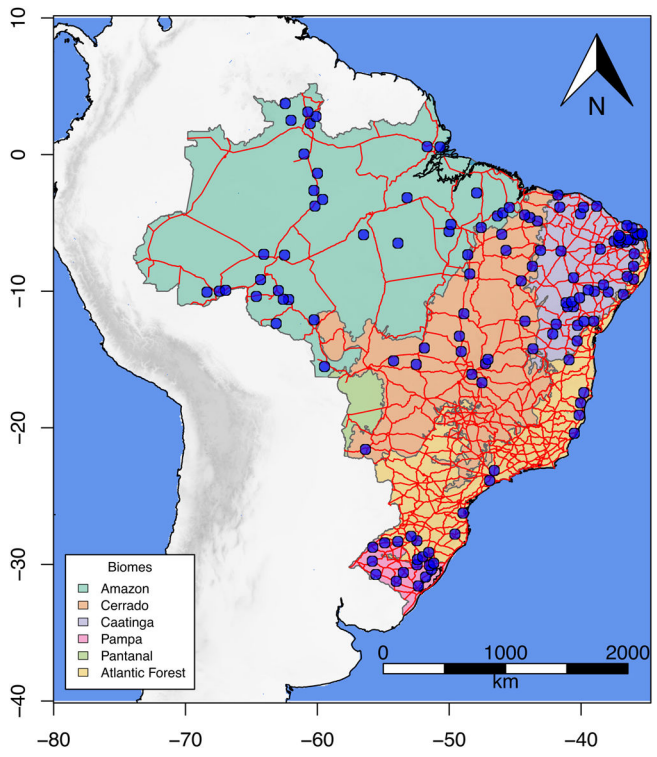


Fig. 1. Distribution of 314 independent events (blue dots) of hunting seizures performed by the PRF throughout Brazil during the last seven years (2017-2024). Red lines represent the federal highway network patrolled by the PRF.

the Amazon (1,461 kg) and Cerrado-Pantanal (665 kg), while bird biomass was highest in the Caatinga (1,168 kg). The average biomass per event in the Amazon was 28.2 ± 88.8 kg; the Cerrado-Pantanal was 26.89 ± 52.2; Caatinga was 22.3 ± 80.6 kg; Atlantic Forest (17.8 ± 22.6); and Pampa biome, with the highest biomass seized per event on average: 76.4 ± 136.9 kg. Across all records, the mean biomass per seizure event was 29.6 ± 83.6 kg (95% CI: 20.3–38.8 kg).

A total of 47 different species were identified (Table 2). Only 12 species were seized in at least two biomes (see Supplementary Material 1), indicating a prevalence of hunting of *Cuniculus paca* (all biomes), *Dasypus novemcinctus*, and *Pecari tajacu* (seized at Amazon, Caatinga, Cerrado, and Atlantic Forest). Species richness was highest in the Amazon (25 species), followed by the Caatinga (20), Cerrado-Pantanal (13), Atlantic Forest (8), and Pampa (5). Mammals represented the majority of identified taxa (n = 22), followed by birds (n = 21) and reptiles (n = 4); no amphibians were recorded in the dataset. Regarding conservation status, 41 species were classified as Least Concern, while 7 were listed as Threatened (i.e., Vulnerable, Endangered, or Critically Endangered) according to IUCN criteria. Threatened species were most frequently seized in the Amazon (n = 6), with isolated cases in Caatinga (n = 1) and Cerrado-Pantanal (n = 2). No threatened species were recorded in the Pampa or Atlantic Forest seizures. Among threatened species seized by PRF, 5 were mammals (*Tapirus terrestris; Tayassu pecari, Alouatta* sp. [Amazonia], *Priodontes maximus* [Cerrado], and *Tolypeutes tricincitus* [Amazonia and Caatinga]), 1 bird (*Crax fasciolata* [Amazonia and Cerrado]), and 1 reptile (*Podocnemis unifilis* [Amazonia]).

The most seized mammal species were: (i) *Cuniculus paca* – lowland paca (n = 70 individuals); (ii) *Cavia aperea* – Brazilian guinea pig (n = 61 individuals); and (iii) *Hydrochoerus hydrochaeris* – capybara (n = 48). Among reptiles, the hunting of *Podocnemis unifilis* (Yellow-spotted Amazon River Turtle) resulted in the killing of an additional 210 individuals. The most seized bird was the eared dove (*Zenaida auriculata*) (n = 1,156) (Fig. 2). Dasypodidae (armadillos), Cuniculidae (lowland paca), and Caviidae (large rodents such as capybara and Brazilian guinea pigs) were the most seized mammalian families, accounting for n = 254 individual events (a total of 2,699.65 kg). Podocnemididae

Table 2
Descriptive statistics from PRF seizure events between 2017-2024 in Brazil.

Descriptive statistic	Biome					Total
	Amazon	Atlantic Forest	Caatinga	Cerrado-Pantanal*	Pampa	
Number of seizure events	116 (36.9%)	32 (10.2%)	88 (28.0%)	49 + 1 (15.9%)	28 (8.9%)	314 (100%)
Average ± SD number of individuals seized per event	4.1 ± 19.5	9.7 ± 17.1	90.3 ± 540	2.44 ± 3.21	22.2 ± 50.4	30.2 ± 287.9
Average ± SD biomass per seizure event (kg)	28.2 ± 88.8	17.8 ± 22.6	22.3 ± 80.6	26.8 ± 52.2	76.4 ± 136.9	29.6 ± 83.6
Number of species identified[1]	25	8	20	13	5	47[2]
Number of taxa	24	10	14	12	7	28[3]
Mammals	12	6	11	10	3	22[4]
Birds	9	2	9	3	2	21[4]
Reptiles	4	0	0	0	0	4
Non-Threatened (Least Concern)	12	6	18	8	5	50
Threatened ("VU"; "EN"; "CR")**	6	0	1	2	0	7[5]
Overall number of individuals seized	476	310	7.950	122	621	9,479 (total)
Unidentified specimens	NA	2	NA	NA	1	3
Mammals (total and %)	204 (42.2)	47 (15.8)	194 (2.4)	79 (65.3)	54 (8.7)	578
Birds (%)	49 (10.1)	247 (82.9)	7.754 (97.5)	25 (20.7)	566 (91.1)	8,641
Reptiles (%)	230 (47.6)	2 (0.7)	8 (0.1)	17 (14.0)	NA	257
Mammals' total biomass (kg)	1,759	423	768	624.17	1,698	5,272.17
Birds' total biomass (kg)	50.7	139	1,168	49.6	441	1,848.3
Reptiles' total biomass (kg)	1,461	7.58	26.8	665	–	2,160.38
Non-identified						
Total biomass	3,270.7	569.58	1,962.8	1,338.17	2,139	9,280.85

* As only one individual of *Cuniculus paca* was seized at Pantanal, we combined its record with the Cerrado Biome.
[1] Only complete information until species' information (N = 193 of 314).
[2] Non-duplicated species among different biomes. 12 species were seized in at least two different biomes (see Supplementary Material 1). A total of 48 different species were seized.
[3] Non-duplicated taxa among different biomes. 14 taxa were seized in at least two different biomes (See Supplementary Material 1). A total of 28 different taxa were seized.
[4] Non-duplicated species within each group: mammals, birds, and reptiles.
[5] Only *Crax fasciolata* (known as "*mutum-de-penacho*") was seized at both Amazon and Cerrado biomes; and *Tolypeutes tricinctus* (known as "*tatu-bola*") was seized at Caatinga and Amazon biomes.

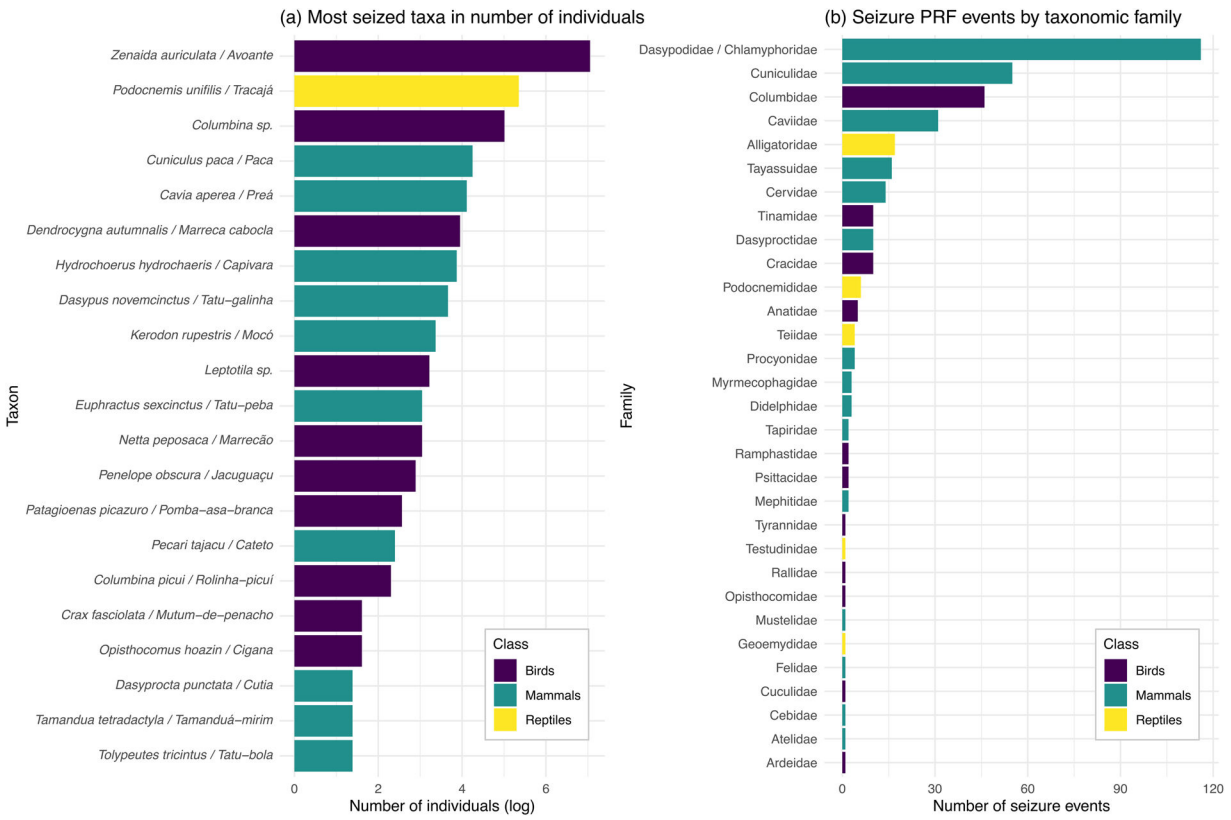


Fig. 2. Number of (a) individuals seized (in log-scale) among the 20 most hunted taxa and (b) PRF seizure events by targeted taxonomic order throughout Brazil between 2017-2024.

(Amazon river turtles) was the most seized reptile family (n = 210 individuals accounting for 945 kg), followed by Alligatoridae (caimans).

States with higher average defaunation scores—based on the index developed by Bogoni et al. (2020)—tended to exhibit distinct patterns in wild meat seizure profiles. Specifically, the number of individuals seized per event increased with rising defaunation levels (Fig. 3a), but the mean biomass seized per event declined as defaunation intensified (Fig. 3b). This pattern was mirrored in the declining average body mass of seized mammals (Fig. 3c), birds (Fig. 3d), and reptiles (Fig. 3e) along the defaunation gradient. Moreover, changes in taxonomic composition accompanied these trends. The relative proportion of mammals in the seizures dropped markedly in more defaunated states (Fig. 3f), while birds became increasingly dominant in the offtakes (Fig. 3g). No significant trend was detected for reptiles (Fig. 3h). Collectively, apart from Fig. 3h, these findings followed the expected trends in Table 1 based on other studies.

Discussion

Using seven years of nationwide Federal Highway Police (PRF) records, we show that illegal wild meat use in Brazil is both substantial and taxonomically structured. One limitation of this study is that PRF seizure records reflect uneven surveillance effort and infrastructure. Patrolling intensity is not standardized across space or time, and enforcement is restricted to federal highways, which introduces a transportation-mode bias relative to fluvial or secondary-road routes. For example, the density of federal highways per unit area is substantially lower in the Amazon than in the Atlantic Forest or southern biomes, meaning that lower seizure frequencies in some regions may reflect reduced patrol exposure rather than lower hunting or transport activity. Consequently, some spatial patterns reported here may partially reflect patrol distribution and road infrastructure rather than underlying hunting pressure. Future research should explicitly incorporate proxies of enforcement effort (e.g., kilometers of federal highways, checkpoint density, or patrol hours) to enable effort-corrected analyses of illegal wild meat flows. In addition, integrating socioeconomic (e.g., income, urbanization, market access) and environmental variables (e.g., forest cover) will be essential to disentangle ecological drivers of hunting from enforcement and reporting processes.

Across 314 independent events, at least 9,479 individuals and 9,281 kg of biomass were seized, with the Amazon and Caatinga accounting for the largest shares of events and individuals, respectively.

Taxonomic dominance varied with regional socioecological and landscape structure. In Caatinga and the Pampa, large offtakes of small-bodied columbids (e.g., *Zenaida auriculata*) drove the numerical totals, consistent with long-standing rural hunting traditions and simplified vertebrate assemblages under chronic defaunation (Leal et al., 2005; Alves et al., 2009; Souza et al., 2022). In contrast, Amazonian seizures contained more mammals and reptiles by biomass—an expected pattern in a biome where access via rivers facilitates movement of heavier carcasses and where larger species persist longer along defaunation gradients.

Crucially, the state-level trends we detect along Brazil's mammal defaunation gradient (Bogoni et al., 2020) replicate those reported from an entirely different data stream—Facebook hunting posts analyzed by El Bizri et al. (2024): as defaunation increases, events involve more individuals but less biomass, and the mean body mass of hunted mammals, birds, and reptiles' declines; composition shifts from mammals toward birds, pointing to a potential substitution effect where large-bodied mammals are progressively replaced by smaller avian species in regions experiencing higher faunal depletion. We recovered all of these signals (except a weak trend for reptiles). This convergence across disparate observation processes (highway enforcement vs. social-media data) strengthens the inference that PRF seizures capture real hunting pressures rather than idiosyncrasies of patrol effort.

The direction of these effects is also consistent with theory and pan-

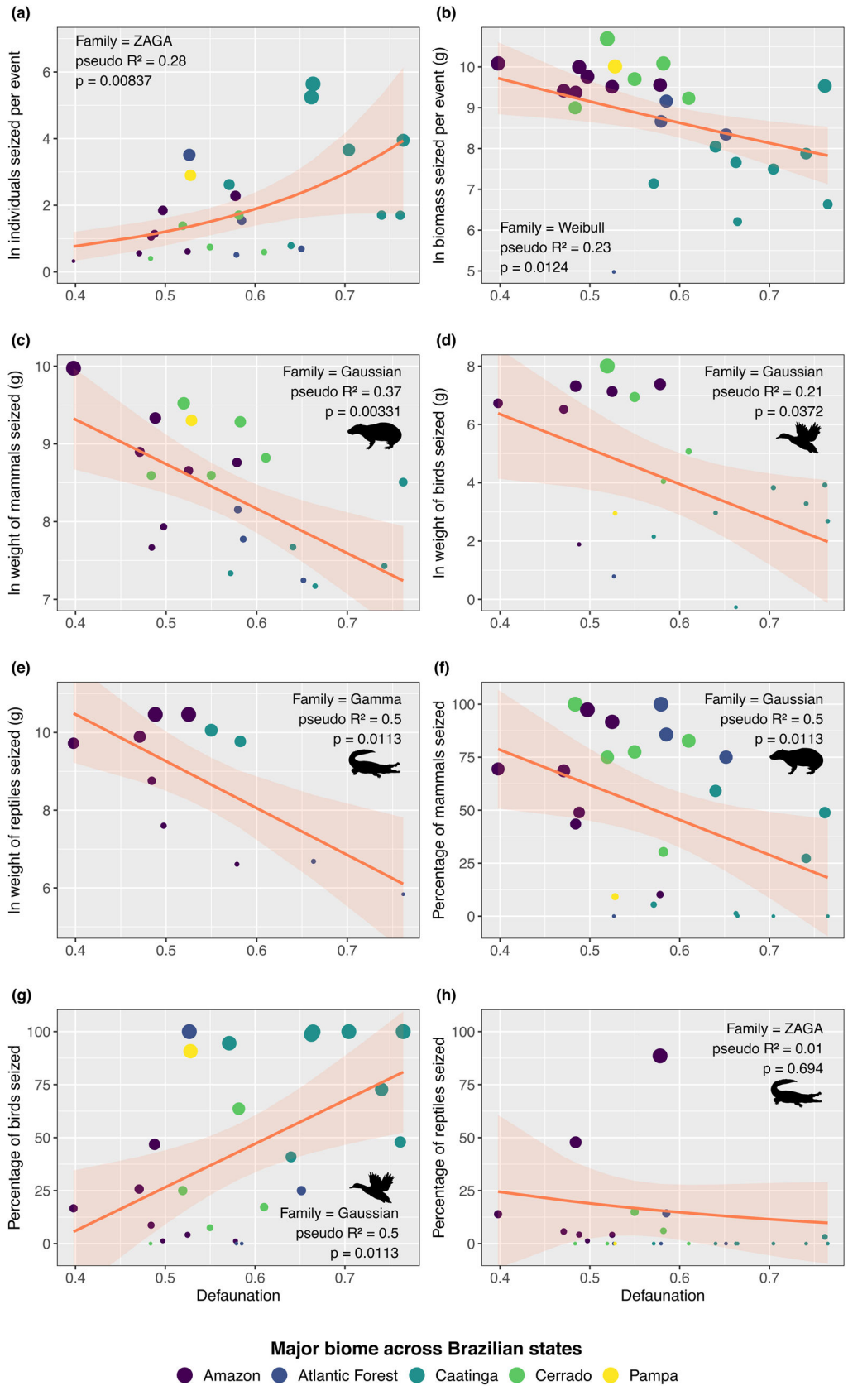


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Fig. 3. Relationship between defaunation level (0.0, faunally intact; 1.0. fully defaunated) and metrics of hunting yield and composition across Brazilian states: (a) mean number of individuals recorded per seizure event, (b) mean biomass hunting recorded per seizure event, (c) mean body mass of mammal individuals (sum of biomass divided per total number of individuals), (d) mean body mass of bird individuals (sum of biomass divided per total number of individuals), (e) mean body mass of reptile individuals (sum of biomass divided per total number of individuals), (f) representativeness of mammals within the total number of individuals seized, (g) representativeness of birds within the total number of individuals seized, and (h) representativeness of reptiles within the total number of individuals hunted (point size, relative values on the y-axis; colors, major biomes).

tropical evidence on hunting selectivity and accessibility. Hunters preferentially target large mammals until depleted, with pressure propagating outward from roads/rivers and towns, and with birds increasingly composing offtakes as mammal decline (Dirzo et al., 2014; Benítez-López et al., 2017). Moreover, the most frequently seized mammal taxa in our dataset (*Cuniculus paca*, *Dasypus* spp., *Hydrochoerus hydrochaeris*) mirror those found previously in multi-state police reports (Chagas et al., 2015), reinforcing that PRF records align with known national patterns. At the same time, we acknowledge the generic caveats of seizure-based inference, in which interception and reporting rates vary with resources, tactics, and geography (Underwood et al., 2013). Yet, as those authors argue for ivory, careful modelling and triangulation can reveal robust trends despite such biases. Future work should quantify effort covariates (e.g., patrol hours, checkpoint locations) and test indices that may predict seizures more faithfully (Bogoni et al., 2020; Gallego-Zamorano et al., 2020).

Reptiles deviated from the mammal–bird patterns; unlike those classes, their proportional representation did not change monotonically along the mammal-based defaunation index. A likely explanation is a pathway-related bias, because PRF checkpoints primarily intercept road-moved meat. Many reptile flows, particularly turtles and caimans, are riverine, frequently involve live individuals and eggs transported by boat, and are butchered later, movements that can bypass federal highways and thus our inclusion criteria (Schneider et al., 2011; Pantoja-Lima et al., 2014; see Methods). A second factor is event structure and seasonality. Chelonian harvests are highly seasonal and aggregative (e.g., nesting/egg-harvest periods), producing fewer but heavier consignments, and increasing variance around any state-wide trend (Caputo et al., 2005). Together, these mechanisms explain why reptiles contributed substantially to biomass yet produced a weak composition–defaunation signal. Importantly, they do not undermine the broader convergence we observe between PRF seizures and independent hunting data; instead, they reveal a transport-mode and product-form bias that can be mitigated by complementing highway operations with targeted riverine surveillance and by integrating datasets (El Bizri et al., 2024).

The relatively low absolute number of seizure events (314 events over 90 months, averaging ~3.5 seizures per month nationwide) illustrates the limited coverage of enforcement relative to the scale of Brazil. For instance, the absolute biomass of mammals intercepted by PRF in the Amazon is much lower than independent estimates of illegal wild meat use from surveys with consumers, such as the ~10,000 tonnes per year reported for central Amazonia by El Bizri et al. (2020). Most hunting, processing, and distribution occur in informal and decentralized networks, often using riverine routes, small roads, or direct local consumption that bypasses federal highways altogether. In addition, limited patrol coverage across vast areas further constrains interception. Rather than indicating low hunting activity, this low interception rate is more plausibly interpreted as reflecting constrained financial, logistical, and human resources available for wildlife enforcement in a continental-scale country. Consequently, PRF seizure records should be interpreted as a sparse observational sample of a much larger and largely hidden illegal hunting system. This reinforces our analytical focus on relative patterns (e.g., composition, size structure, defaunation gradients) rather than absolute volumes.

These patterns also point to practical priorities consistent with Brazil's legal framework (Brasil, 1967, 1998) and prior recommendations to standardize enforcement datasets (Chagas et al., 2015). To maximize the value of seizure records for conservation and enforcement, it is essential to move toward an integrated, multi-agency surveillance framework. PRF road-based data systematically underrepresent fluvial trade routes, which are central to the movement of aquatic reptiles (e.g., chelonians, caimans), large carcasses, and live animals in Amazonia and other river-dominated regions. Therefore, PRF datasets should be formally integrated with riverine surveillance data from environmental agencies and navy/port authorities, as well as with state-level road enforcement bodies (e.g., environmental military police). Intelligence-led, multi-modal operations should pair road checkpoints—which capture mammal and bird flows well—with riverine checkpoints and seasonal task forces focused on nesting and egg-harvest windows for chelonians. Well-defined supply chains and hotspots documented for the Amazonian turtle trade indicate that such operations can be cost-effective (Pantoja-Lima et al., 2014; Schneider et al., 2011). Standardizing reporting across agencies (species identifications, counts, biomasses, coordinates, and product form) will enable bias-aware trend modelling (Underwood et al., 2013) and routine triangulation with complementary sources, including social media monitoring, which has already revealed defaunation-linked downsizing of offtakes (El Bizri et al., 2024). Finally, because the strongest substitution toward small birds occurs in more defaunated states, prevention should combine access control near towns and along road–river gateways (Benítez-López et al., 2017) with demand-side measures and community partnerships (e.g., see Franco et al. (2025) for an example of high effectiveness of community-based patrolling in curbing environmental crimes the Amazon). For chelonians, community-based nesting protection and, where lawful and evidence-based, regulated egg harvest have improved outcomes in parts of Amazonia, though careful governance is essential (Caputo et al., 2005).

Wild meat hunting and consumption in Brazil have important socio-economic and public health dimensions that extend well beyond biodiversity impacts. In Amazonia, for example, wild meat plays a significant role in rural food systems, contributing substantial amounts of dietary protein, micronutrients, and economic value for millions of inhabitants (Antunes et al., 2025). These socio-ecological linkages mean that wild meat use is often embedded in cultural practice and livelihood strategies, determined by local access, market reach, and urban–rural dynamics (El Bizri et al., 2020; Chaves et al., 2017). At the same time, the illegal nature of much hunting in Brazil reflects weak governance, social acceptability of hunting practices, and overlapping motivations ranging from subsistence to recreation and income generation (El Bizri et al., 2024). Contact with wildlife along the hunting–butchering–transport chain also presents public health risks due to zoonotic and food-borne exposures, as documented globally for wild meat systems and increasingly recognized in South America (Tumelty et al., 2023). In Brazil, studies have reported health risks associated with the consumption of specific hunted species, such as armadillos - one of the most seized species in our study - and the potential for increased transmission of diseases such as leprosy (Aliaga-Samanez et al., 2025).

These socio-economic and health dimensions mean that enforcement alone may be insufficient or counterproductive if not coupled with context-sensitive strategies that consider drivers of wild meat use, food security implications, and community norms. Integrated interventions combining strengthened wildlife governance and surveillance, community partnerships, sustainable livelihood options, and targeted health risk communication are more likely to align conservation and human well-being objectives in Brazil's diverse social landscapes. In conclusion,

seizure data from roadways contain sufficient ecological evidence to support actions against wildlife crimes. Among the main drivers of Neotropical defaunation, illegal hunting for wild meat stands out for both its widespread prevalence and intensity across Brazil. Despite decades of research on defaunation, political and institutional barriers continue to hinder effective regulation, allowing illegal and unsustainable practices to persist. Mitigating this threat requires moving beyond generic solutions by tailoring management to local socioeconomic contexts and addressing the effective causes of hunting. Building strategic alliances with communities in low-governance regions is crucial to transform them into partners for conservation. Ultimately, curbing the impacts of illegal hunting is essential to secure human–wildlife coexistence. Therefore, we conclude that in the face of the significant oversimplification of vertebrate faunas across Brazil, it is essential for authorities to increase investments in collaborative monitoring (e.g., involving various branches of the Brazilian government) and intelligence efforts tailored to the local context.

CRediT authorship contribution statement

JRWO: Conceptualization, Formal Analysis, Methodology, Validation, Formal Analysis, Investigation, Visualization, Writing—Original Draft, Writing—Review & Editing.

MMT: Conceptualization, Formal Analysis, Methodology, Software, Validation, Data Curation, Investigation, Visualization, Writing—Original Draft, Writing—Review & Editing.

HEB: Conceptualization, Formal Analysis, Methodology, Software, Validation, Data Curation, Investigation, Visualization, Writing—Original Draft, Writing—Review & Editing.

CLGRW: Conceptualization, Validation, Formal Analysis, Writing—Review & Editing.

NMRG: Conceptualization, Validation, Formal Analysis, Writing—Review & Editing.

JAB: Conceptualization, Formal Analysis, Methodology, Software, Validation, Data Curation, Investigation, Visualization, Writing—Original Draft, Writing—Review & Editing.

Data availability

All data and R codes are available on GitHub (https://github.com/masemuta/huntingseizure).

Declaration of competing interest

The authors declare they have no conflict of interest.

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Appendix A. Supplementary data

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