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Ophiophagy in Brazilian birds: a contribution from a collaborative platform of citizen science

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Abstract
Citizen science is the interaction of the non-academic community in scientific studies, often extended to collaborative platforms. We analyzed 168 photographs shared in a Brazilian citizen science platform to understand the feeding interactions between birds and snakes in Brazil, comparing our findings to published data. We searched for patterns in bird taxa and behaviour correlated with ophiophagy, snake groups most vulnerable to predation, and biases resulting from citizen science data. Records were made mostly in south-eastern and southern Brazil. Both birds and snakes recorded are primarily diurnal, terrestrial, and use open habitats. Predators represent especially birds of prey, but nine other families were observed, and most of the identified snakes belong to Dipsadidae and Colubridae. Venomous snakes were observed, suggesting that birds must deploy strategies to avoid injuries. Finally, we added a new vertebrate item to the diet of the white-faced ibis (*Plegadis chihi*). Data biases of citizen science platforms, which in this work include differences in the number of records between different geographic regions and periods of day, must be considered. However, this kind of data can be a powerful tool for understanding life history patterns and natural history of birds and other animals.

Keywords Community science · Natural history · Predator–prey interaction · Raptor, Snakes · WikiAves

Introduction

Predator–prey relationships are fundamental ecological processes involving different individuals, expected to influence and reflect complex population dynamics (Cresswell 2008). Considering birds and snakes, previous studies suggest that snakes can often be the predator (Travaglia-Cardoso et al. 2016; Groen et al. 2020; Santos-Filho et al. 2021) but also the prey (DuVal et al. 2006; Costa et al. 2009, 2014; Zocche et al. 2018; Medrano-Vizcaíno 2019). Records of snakes predated by birds have gradually increased in numbers over time, enhancing knowledge of the feeding habits of each species. However, in the Neotropics, most of these records are intermittent and scattered in natural history studies, and often not published in English.

The circumstances of predation events must be interpreted with caution, since many bird species, especially birds of prey, usually consume already dead snakes, which is considered scavenging rather than predatory instances (Sazima and Abe 1991). Confirmed predation-prey interactions between birds and snakes recorded in previous studies suggests that, to a large extent, avian predators of snakes are birds of prey, such as the burrowing owl, *Athene cunicularia* (Martins et al. 2003); the white-tailed hawk, *Geranoaetus albicaudatus* (Sawaya et al. 2003); the laughing falcon, *Herpetotheres cachinnans* (DuVal et al. 2006; Costa et al. 2009, 2014; Medrano-Vizcaíno 2019), the roadside hawk, *Rupornis magnirostris* (Zocche et al. 2018); and the barn owl, *Tyto furcata* (Travaglia-Cardoso

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and Almeida-Santos 2012). However, predation records also extend to other bird clades, such as passerines (Tozetti 2010; Sazima and D'Angelo 2011), cariamids (Travaglia-Cardoso and Almeida-Santos 2012), herons (Franz et al. 2007), and vultures (Almeida et al. 2010).

Snakes display several morphological and behavioural traits that enhance their predatory skills (Greene 1997). Although venom and constriction probably evolved together with feeding strategies (e.g. Holding et al. 2021), their capability of acting as defence should not be disregarded. For example, mammals that often prey on venomous snakes share adaptations to resist the toxic effect of envenomation (Voss and Jansa 2012; Drabeck et al. 2020). Therefore, an intriguing aspect of the predator–prey relationship between birds and snakes involves the ability of avian predators to escape injuries when subduing snakes. Successful predation must involve morphological, behavioural, or chemical strategies that enable the predator to survive (Wall and Shine 2007). In birds that prey on snakes, the decapitation of the snake's head seems to be a shared behavioural strategy that enables successful predation (e.g. Martins et al. 2003; Medrano-Vizcaíno 2019; Santos et al. 2021).

In ornithology, citizen science, also called collaborative science, has been used as a source of natural history information for scientific ends (Bhattacharjee 2005; Mamede et al. 2017; deGroote et al. 2021). Citizen science can be defined as the participation of non-academic people in scientific studies, which can include the collection of large data sets (McCaffrey 2005), helping in fieldwork (Mamede et al. 2017), or engaging on conservation actions for biodiversity (Cooper et al. 2007; Şekercioglu 2012; Ellwood et al. 2017). This unification between science and nature enthusiasts is extended through collaborative platforms, such as eBird (Sullivan et al. 2009). Examples of collaborative platforms in Brazil are WikiAves (https://www.wikiaves.com.br/) and Biofaces (https://biofaces.com/), which promote information sharing, including lists of species, sounds, and digital images. Analyzing citizen science databases can provide key information for studies on the ecology of birds and leverage knowledge about their natural history (McCaffrey 2005; Cunha and Fontenelle 2014; Mamede et al. 2017; Aplin et al. 2021). For example, photographic records from the WikiAves platform added new records of food items of the white-eared puffbird, *Nystalus charuru* (Crozariol and Gomes 2010). Data from eBird and WikiAves platforms also enabled the description of new patterns of geographic temporal occurrence for many bird species (e.g. DeGroote et al. 2021), besides solving problems of inconsistent data already published in literature (Schubert et al. 2019). Citizen science data can also be used to analyze the impacts of urbanization on bird diversity (Callaghan et al. 2019a; Barbosa et al. 2021) and highlight suitable policies to increase habitat heterogeneity in urban green areas, seeking to increase bird diversity (Callaghan et al. 2019a; Callaghan et al. 2019b; Barbosa et al. 2021). Therefore, citizen science is an increasing practice that contributes globally to scientific knowledge.

In this work, we used photographs shared on the Brazilian citizen science platform WikiAves to gather natural history information involving the feeding interactions between birds and snakes. We explored the WikiAves database for records of snakes eaten by birds, comparing our findings to published data, looking for patterns relating to (1) which taxa of birds are snake predators or consumers; (2) which snakes are most vulnerable to bird predation or consumption; (3) which avian morphological or behavioural traits enable these feeding interactions; and (4) which data bias should be considered in the observed patterns. Finally, we added a new predation record provided by citizen science collaboration. All information was then summarized in this single article to elucidate patterns and highlight the importance of birds as snake predators and consumers in tropical environments.

Methods

We analyzed images available on the Brazilian citizen science platform WikiAves, selecting the option "Advanced search" to reveal only bird feeding records. We used two filters available on the website ("Food" and "Feeding/Hunting") to assist in the selection of images. Both filters were used simultaneously, and the results were examined and selected manually. We selected only images containing elongated animals being preyed on or consumed by birds. We also analyzed the comments added by the author of each record reporting prey and predator interaction, when available. We separated all records of elongated prey into five groups: snakes, lizards, amphisbaenians, fishes, and non-identified taxon.

We eliminated duplicates when two images had the same location, date, and author, and also when more than one author recorded and published the same interaction moment. We examined each picture carefully to identify when the bird species in the photo and the background environment were identical and checked on data location, date, and author's comments. We considered new records of ophiophagous birds, species that had no previous data reporting snake predation both in literature or eBird platform.

We used the records published between May 2005 and June 2020, and all images published until this date were examined and compiled for the analysis. We prepared a spreadsheet with the metadata of each record (Supplementary Material S1) including all pertinent variables recorded by the authors: location, time, photo web link, bird and

prey identification at the lowest taxonomic level, predation description when available in the comments added by the author, and if the bird attack was directed at the head of the snake.

In the WikiAves platform, all birds are identified at the species level by field-experienced moderators or senior users. However, bird identification was also double-checked by two of the authors (MMS and PRM). For snake identification, two of the authors (ES and OME-N) used field guides and matched geographic ranges of species with locality informed in the photo. Each specimen was identified at the lowest taxonomic level, and we searched for ophiophagy records involving these taxa in several natural history studies (Supplementary Material S2 and S3 for a complete list of ophiophagy references).

Data harvesting and use were in accordance with the policies of the website (WikiAves 2021) and Brazilian copyright laws (Brasil 1998, 2013).

Results

Because predation events are difficult to interpret through photographs, and only 22% of the authors confirmed predation instances in the comment section (Supplementary Material S1), we chose to consider the events as either predation or necrophagic consumption. Therefore, we found a total of 168 records of birds preying or consuming elongated animals (Supplementary Material S1), of which 111 were snakes, and 58 were other identified (e.g. amphisbaenians, fishes, and lizards) or non-identified taxa. In one record, the same bird, a laughing falcon, was holding both a snake and an amphisbaenian at the same time.

Almost 70% of records were made in Brazil's south-eastern and southern regions, followed by the midwest, north, and northeast (Fig. 1). Feeding interactions were mostly (88%) observed during daytime (from 7:00 to 18:00 h); 10% during twilight (before 6:59 or from 18:01 to 19:00 h); and

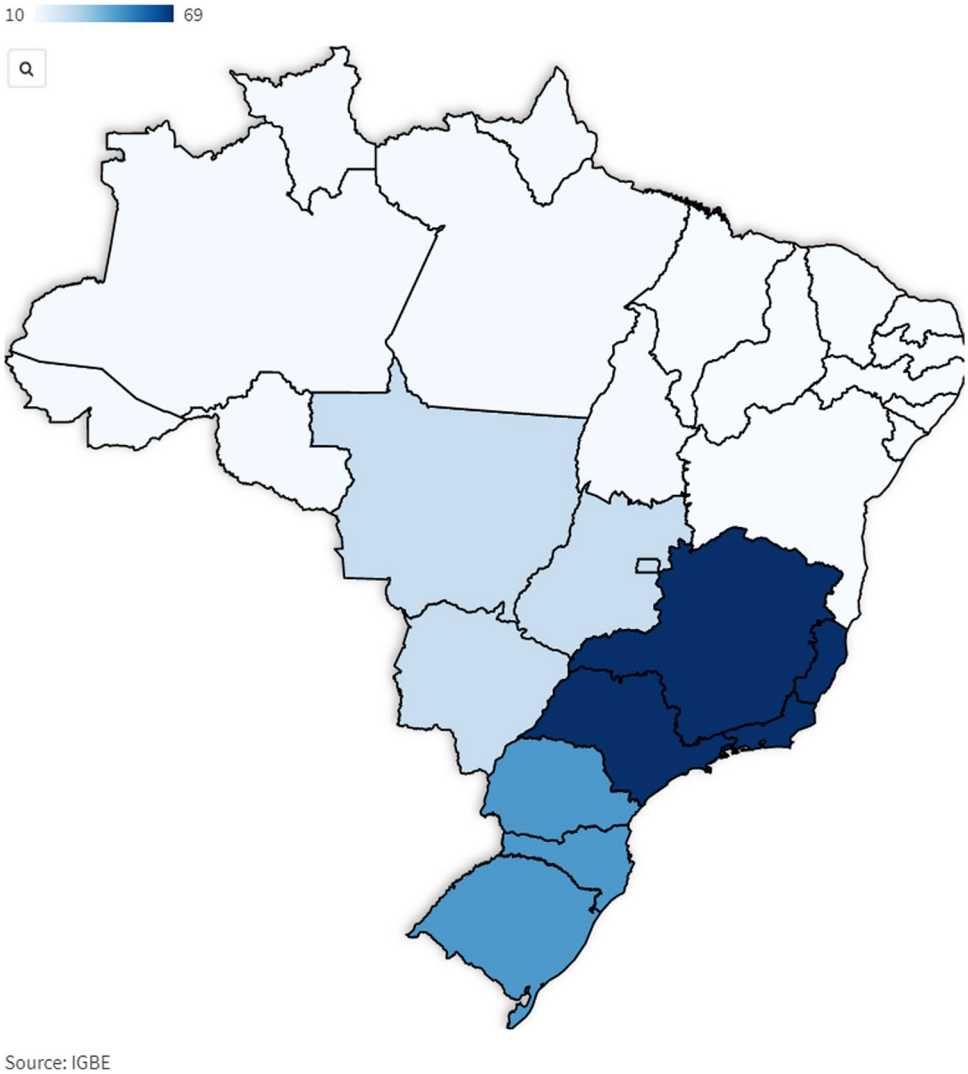

Fig. 1 The map of Brazil showing the numerical disparity in the ophiophagy records of the WikiAves database per geographic region. The dark blue indicates the most recorded region (> 69 records), the south-eastern region, followed by the southern, midwest, north, and northeast

2% during the night (after 19:01 h). In most cases, the events were caught while the bird was landed, either on the ground (41%) or on tree trunks, electrical wires, or fences (37%). The other records were made with the animal in flight (14%), in flooded environments (6%), or water (2%).

Ophiophagous birds

There were 31 bird species recorded preying on or consuming snakes (Table 1). Most species (61.3%) represent birds of prey: Accipitridae, Falconidae, and Strigidae. The families

Table 1 Bird species recorded eating snakes. Bird species are listed by family, and families are listed in alphabetic order. The numbers in columns indicate the total number of observed instances per bird species (*N* obs) and the number of observed instances per snake family

	N obs	Dipsadidae	Colubridae	Viperidae	Boidae	Anomalepididae	Others/unkown
Accipitridae							
Rupornis magnirostris	17	10	0	0	0	0	7
Heterospizias meridionalis	9	5	0	0	0	0	4
Urubitinga urubitinga	9	3	1	2	1	0	2
Urubitinga coronata	3	0	0	2	0	0	1
Busarelus nigricollis	2	1	0	0	0	0	1
Leptodon cayanensis	2	0	1	0	0	0	1
Pseudastur albicollis	1	1	0	0	0	0	0
Buteo nitidus	1	0	1	0	0	0	0
Buteo platypterus	1	0	0	0	0	0	1
Gampsonyx swainsonii	1	0	1	0	0	0	0
Ardeidae							
Syrigma sibilatrix	2	2	0	0	0	0	0
Cariamidae							
Cariama cristata	7	3	0	0	0	0	4
Ciconiidae							
Ciconia maguari	5	3	0	0	0	0	2
Jabiru mycteria	4	2	0	0	0	0	2
Mycteria americana	2	0	0	0	0	0	2
Corvidae							
Cyanocorax chrysops	1	1	0	0	0	0	0
Cuculidae							
Guira guira	16	10	0	0	0	1	5
Falconidae							
Herpetotheres cachinnans	24	12	8	1	0	0	4
Caracara plancus	20	7	2	1	1	0	9
Milvago chimachima	5	2	0	1	1	0	1
Falco sparverius	3	1	0	0	0	0	2
Milvago chimango	2	1	0	0	0	0	1
Micrastur semitorquatus	1	1	0	0	0	0	0
Phalacrocoracidae							
Nannopterum brasilianus	1	1	0	0	0	0	0
Strigidae							
Athene cunicularia	6	4	0	0	0	0	2
Megascops choliba	1	1	0	0	0	0	0
Bubo virginianus	1	1	0	0	0	0	0
Thamnophilidae							
Batara cinerea	1	0	0	1	0	0	0
Threskiornithidae							
Plegadis chihi	2	2	0	0	0	0	0
Theristicus caudatus	2	1	0	0	0	0	1
Tyrannidae							
Pitangus sulphuratus	1	1	0	0	0	0	0

Ciconiidae and Threskiornithidae represent 16% of recorded species, and other species belonged to Ardeidae, Cuculidae, Cariamidae, Corvidae, Phalacrocoracidae, Thamnophilidae, and Tyrannidae. The laughing falcon (*H. cachinnans*) was the most frequent species in records ($n = 24$), followed by southern caracara (*Caracara plancus*; $n = 20$), roadside hawk (*Rupornis magnirostris*; $n = 17$), guira cuckoo (*Guira guira*; $n = 16$), and both great black hawk (*Urubitinga urubitinga*) and savanna hawk (*Heterospizias meridionalis*) with nine records each. We register new ophiophagous habits for one species of the family Threskiornithidae, the white-faced ibis (*Plegadis chihi*), which had two records preying on the water snake *Helicops infrataeniatus* during daytime in a flooded area.

Snakes preyed or consumed by birds

Considering the total number of preyed and consumed snakes ($n = 111$), most records belonged to the Dipsadidae ($n = 76$), followed by Colubridae ($n = 14$), Viperidae ($n = 8$), Boidae ($n = 3$), and Anomalepididae ($n = 1$). We could not identify the family of nine specimens. We did not observe any species of the family Elapidae in the analyzed images.

Among the 40 identified species or genus of preyed and consumed snakes recorded in this study, most have diurnal activity, are primarily terrestrial, and use open habitats. The most frequent species belong to the genus *Erythrolamprus* ($n = 16$), followed by *Philodryas* ($n = 14$), *Oxyrhopus* ($n = 12$), *Helicops* ($n = 10$), and *Chironius* ($n = 7$) (Fig. 2).

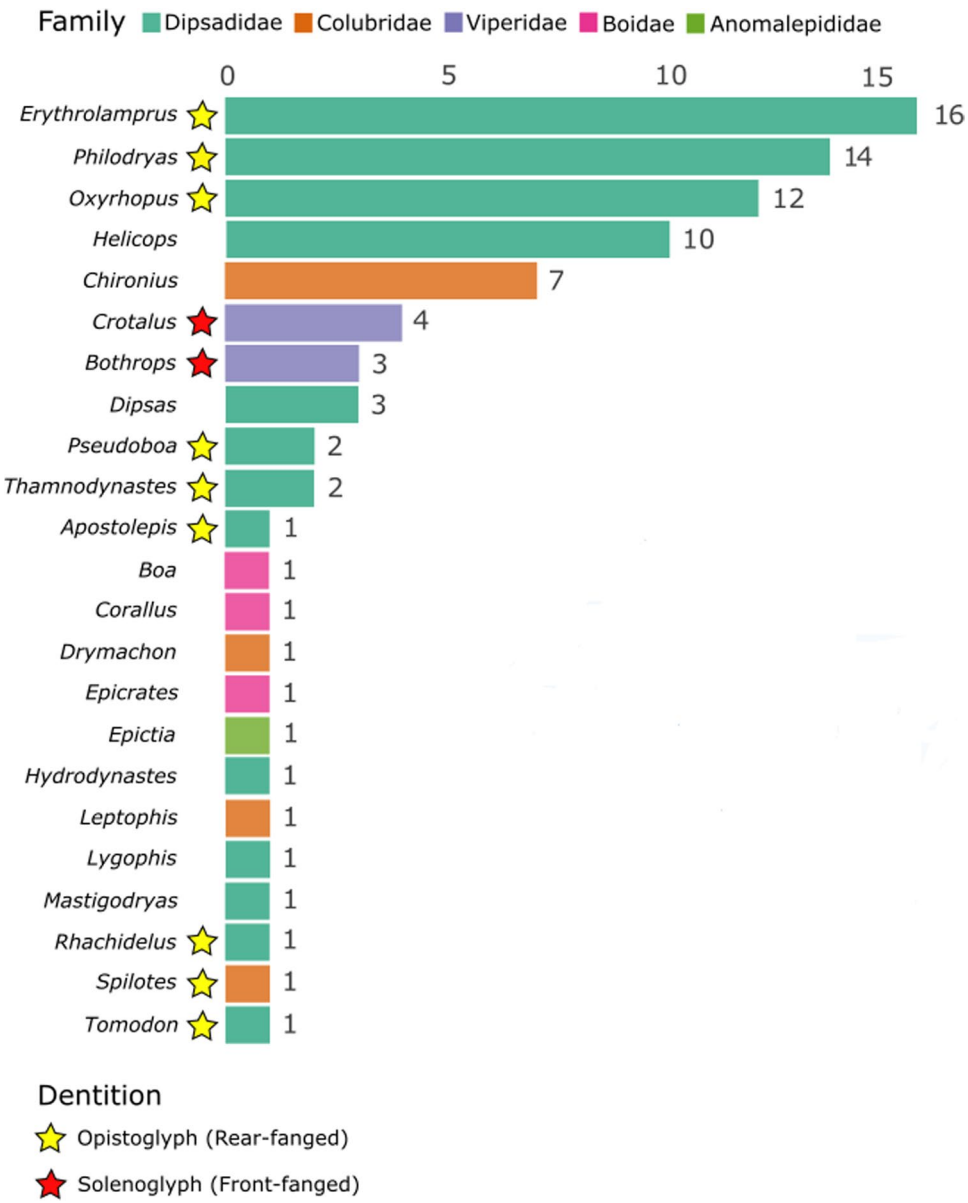

Fig. 2 Identified families and genera of snakes that are eaten by birds. The numbers at the end of the bars indicate the number of records, the colours indicate the snake family, and the stars indicate the snakes' dentition

Relationship between bird and snake habitats

Most ophiophagous birds recorded here occupy mainly open habitats and have a terrestrial habit and diurnal activity. Only two nocturnal species were observed, the owls *Bubo virginianus* and *Megascops choliba*. We also recorded five aquatic or semi-aquatic species (*Busarelus nigricollis*, *Ciconia maguari*, *Jabiru mycteria*, and *Nannopterum brasilianus*), most consuming mainly snakes of the genus *Helicops*, which also have a semi-aquatic habit (Fig. 3). Four bird species were forest-specialist (*Pseudastur albicollis*, *Cyanocorax chrysops*, *Micrastur semitorquatus*, and *Batara cinerea*), recorded preying or consuming the snakes *Oxyrhopus guibei*, *Tomodon dorsatus*, and *Bothrops jararaca* (Fig. 3), species commonly found in forest habitats. Finally, five bird species were common on both forestall and open habitats (*U. urubitinga*, *Buteo nitidus*, *H. cachinnans*, *B. virginianus*, and *Pitangus sulphuratus*).

There were eight records of birds predating or consuming venomous snakes (i.e., *Bothrops* and *Crotalus*), of which seven involved birds of prey, and one was from the passerine giant antshrike (*B. cinerea*) (Table 1; Fig. 3). The passerine bird was observed preying on an adult *B. jararaca* during daytime, repeatedly using its beak to harm the snake's head and neck while it still moved (see the video available in Supplementary Material S1). There were 23 records of birds predating or consuming coral-like snakes (i.e., *Oxyrhopus* spp., *Apostolepis assimilis*, and *Erythrolamprus poecilogyrus*), of which 17 involved birds of prey (Fig. 3).

Considering both venomous and coral-like snakes, 14 records (45%) showed that the snakes were either completely decapitated, or that the cephalic region was severely harmed. In ten records, it was not possible to observe the snake's head, and in three records, the head was intact. Considering snakes other than venomous or coral-like species, there were 11 records that show the snake was completely decapitated or with evidence that the bird attack started in the cephalic region of the snake body (see the videos and photo codes available in Supplementary Material S1).

Discussion

Our records show that approximately 60% of birds that prey or consume snakes belong to the Accipitridae, Falconidae, and Strigidae, reinforcing results from previous investigations, in which snakes are shown to compose most of the diet of birds of prey. Both in the Neotropics and the Old World, there are plenty of reports on hawks of different taxonomic clades preying on snakes (e.g. Thiollay 1994; Motta-Junior et al. 2010; Draheim et al. 2012; Chiarani and Fontana 2019), which some authors suggest it might be an example of convergent evolution (Costa et al. 2014). Unsurprisingly, the laughing falcon was the most common bird in our data, with 24 records. In a review, Costa et al. (2014) found that snakes compose more than 73% of prey items of the species, suggesting a high degree of diet specialization on snakes.

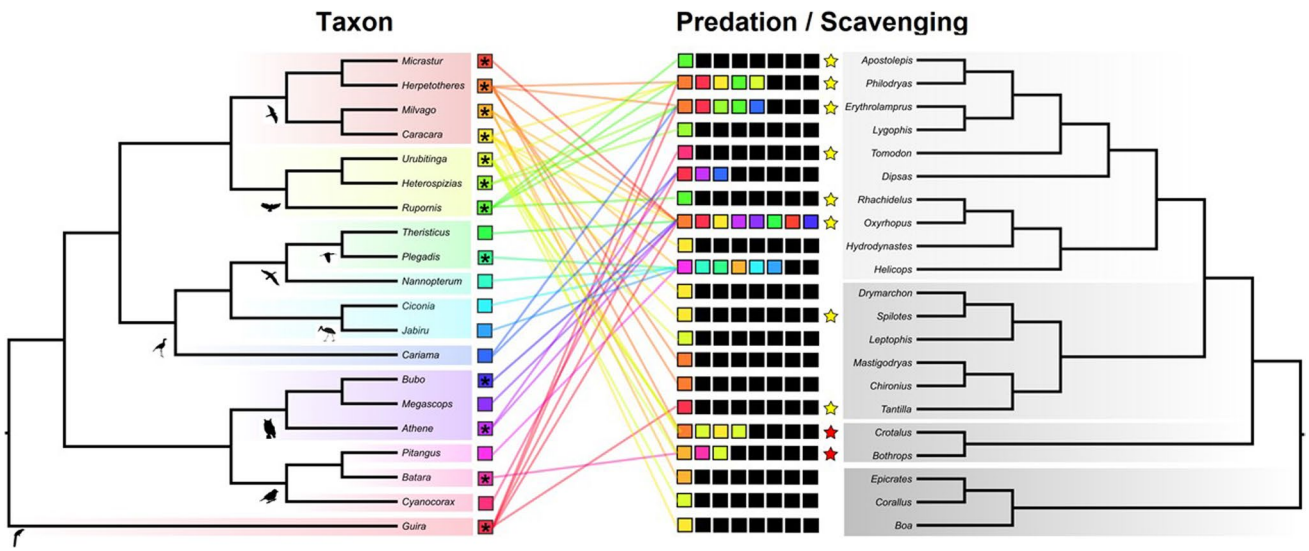

Fig. 3 Relationship between bird and snake involved in feeding interactions. The colours on the left side represent genera of birds, and the coloured squares on the right side represent the type of prey each bird consumed. Asterisks = birds that exhibited behavioural strategies to avoid envenomation (e.g. attack on the snake's cephalic region); yellow stars = opisthoglyphous (rear-fanged) snakes; red stars = solenoglyphous (front-fanged) snakes

We added a new vertebrate item to the diet of the white-faced ibis, a water snake of the genus *Helicops*. In previous studies, the food items identified for *P. chihi* were mainly composed of invertebrates (Bray and Klebenow 1988; Soave et al. 2006). However, there are a few records of *P. chihi* predating vertebrates, particularly amphibians (Soave et al. 2006; Salvador et al. 2017) and a teiid lizard *Teius oculatus* (Salvador et al. 2017).

We noticed an absence of Elapidae species predated or consumed by birds. The conspicuous coloration of coral snakes may act as a warning signal to avoid predators, as indicated in other studies (e.g. Brodie-III and Janzen 1995). Although observations on *Micrurus* predation by birds are relatively scarce (Pough 1988), coral snake avoidance is not completely corroborated. In an experimental work using plasticine replicas, the coral snake replicas received fewer attacks by avian predators, but only when replicas were set upon white backgrounds (Banci et al. 2020). There are several records of the laughing falcon and the burrowing owl preying on coral or coral-like snakes (e.g. Brugger 1989; Sazima and Abe 1991; DuVal et al. 2006; Santos et al. 2021; this work). In addition, there is a record of a *Micrurus frontalis* preyed on by the red-legged seriema, *Cariama cristata* (Pueta 2002). In our study, all venomous snakes predated or consumed belong to the family Viperidae, genera *Bothrops* and *Crotalus*, of which most records involve birds of prey.

It seems that there is a behaviour pattern associated with venomous snake predation. Previous studies of birds preying on venomous or coral-like snake report that the prey was commonly found decapitated before being consumed (e.g. Battstrom 1955; Howell 1957; Smith 1975; Pueta 2002; Medrano-Vizcaíno 2019; Santos et al. 2021). This behaviour possibly happens because birds are not able to resist envenomation. A red-tailed hawk (*Buteo jamaicensis*) died showing typical symptoms of neurotoxic envenomation after landing with a decapitated *Micrurus fulvius* (Brugger 1989). Indeed, even without identifying any specimen of the genus *Micrurus*, we noticed that many records of *Oxyrhopus*, *Bothrops*, and *Crotalus* showed decapitated snakes. This behaviour was not exclusive to birds of prey. Even the guira cuckoo and the giant antshrike primarily attacked the snakes' cephalic region. Our findings and previous studies suggest that birds do not avoid the conspicuous coloration of coral snakes or other venomous snakes, but rather deploy behaviour strategies to avoid envenomation.

Previous studies report vertebrate predation by passerines (see a review in Lopes et al. 2005). In our data set, we report non-venomous snakes predated by passerine species, such as *P. sulphuratus* and *C. chrysops*. In addition, the passerine giant antshrike predated an adult *B. jararaca* during the daytime. Possibly opportunistic, our data show that this bird is capable of predating large snakes, including venomous. The bird repeatedly strikes the snakes' head and neck with the beak before consuming it. Whether this trait is shared with other Neotropical passerines is still unknown. However, the behavioural repertoire used by the bird may suggest that predating large vertebrates by Neotropical passerines can be more widespread than previously thought.

A higher number of predation records upon dipsadid and colubrid taxa were also observed in our sample. Several reasons might be attributable to this numerical disparity. Dipsadidae and Colubridae represent a large portion of the snake diversity within the sampled area; Costa and Bérnils (2018) report 258 dipsadid and 35 colubrid species for Brazil, out of a total 405 snake species recorded for this country. Conversely, this overrepresentation might also be attributable to observation biases, once that most observations were performed during daytime and in open areas. Birdwatchers generally collect data in areas easily accessible, such as urban green areas (Tulloch et al. 2013), and early in the morning, when birds are more active. Indeed, the two most commonly observed preyed genera (*Erythrolamprus* and *Philodryas*) have most species with diurnal habits (Marques et al. 2019), which might be more frequently observed by humans and preyed upon by birds. Both *Erythrolamprus* and *Philodryas* also have been reported to be commonly encountered within urbanized environments (Entiauspe-Neto et al. 2016), which might further enhance their possibilities to be spotted both by birds and humans.

Zoologists, and especially ornithologists, are increasingly using innovative resources, such as data-driven methods and large data set exploration, to better understand animals' natural history (Kitchin 2014; La Sorte et al. 2018). In this sense, citizen science platforms can provide some insights. In 2017, eBird presented over 30 million checklists and compiled more than 423 million observations (La Sorte et al. 2018), constantly growing numbers. However, some observational bias is still common in collaborative platforms. For instance, we have more records in southern and south-eastern Brazil, regions that are residence for more than 70% of WikiAves users (Barbosa et al. 2021). Even north and northeast regions of Brazil being more populous than the midwest and south, respectively (Instituto Brasileiro de Geografia e Estatística -IBGE 2020), these later regions comprise more WikiAves users than the former. This bias may also be an indirect result of the investment of time and equipment by birdwatchers (Scott et al. 2005). Birdwatchers can be classified alongside a continuum ranging from casual to experienced birder (Harshaw et al. 2020). The specialization reflects directly on their data contribution on citizen science platforms, in which higher specialized birdwatchers contribute with more data than casual birdwatchers (Randler 2021).

Here, we used 15 years of photographs shared in a Brazilian citizen science platform to better understand patterns relating to snake predation and consumption by birds. Most of these birds belong to Accipitridae, Falconidae, and Strigidae;

however, even passerines were observed preying on large snakes, including venomous. Birds that prey upon large or venomous snakes usually deploy behaviour strategies to avoid injuries, attacking the snakes' cephalic region. Because this behaviour was observed in different bird clades, this might be an example of convergent evolution. However, further studies should elucidate the extent of this shared trait. Snakes commonly predated by birds belong to Dipsadidae and Colubridae, and this numerical disparity might be attributable to the diurnal habits of the majority of the species in both families or due to species richness. Finally, we described a new prey record for the white-faced ibis. Therefore, we show here that citizen science (or community science) platforms are an important tool to help understand patterns of the natural world. However, scientists willing to use these tools should be aware of the biases that can influence the observational patterns, such as the discrepancies observed here between the number of records from different regions of Brazil, times of day, and between open and forested observation sites. In addition, we suggest that birdwatchers should describe as best as possible the event they are witnessing to help scientists interpret ecological processes such as predation.

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Author contribution Conceptualization and methodology: Matheus Moraes dos Santos, Paulo Roberto de Moura, and Erika Hingst-Zaher; formal analysis and investigation: Eletra de Souza, Jade Lima-Santos, and Matheus Moraes dos Santos; writing—original draft preparation: Eletra de Souza; writing—review and editing: Eletra de Souza, Jade Lima-Santos, Omar Entiauspe-Neto, and Erika Hingst-Zaher; figures: Omar Entiauspe-Neto; resources: none; supervision: Erika Hingst-Zaher.

Data availability The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

Declarations

Ethics approval Not applicable.

Conflict of interest The authors declare no competing interests.

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