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An Assessment on Bat Diversity in Curitiba, Paraná State, Subtropical Brazil

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HIGHLIGHTS

- 29 species (five of them threatened with extinction) in 17 genera and four families.
- Insectivorous bats represent 62.1% of the species recorded.
- Frugivorous bats (Phyllostomidae) represent 24.1% of the species recorded.
- This high-growth potential diversity bears both a numerical and ecological relevance.

Abstract: Urbanization changes natural environments making them inhospitable to autochthonous fauna. However, studies have shown that certain groups and animal species tolerate urban habitat or even benefit from it as is the case of some bats. This study assesses the diversity of bats in Curitiba, Southern Brazil, providing a basis for the discussion on their conservation, management, ecological services provide, and the critical evaluation of their role in the zoonoses of interest for public health. The data was compiled from a combination of museum, historical and recent literature (1824 to 2020), records to identify which bat species have actually been captured or recorded in Curitiba. The results indicate 29 species (five of them threatened with extinction) from four families: Phyllostomidae, Noctilionidae, Molossidae and Vespertilionidae. Insectivorous bats (Molossidae and Vespertilionidae) represent 62.1% of the species recorded; and the primarily frugivorous (Phyllostomidae) 24.1%, followed by nectarivorous/polinivorous species (6.9%), insectivorous/frugivorous (ca. 3.4%) and piscivorous/insectivorous (ca. 3.4%). Fruit-eating bats seem to prefer urban green areas while insectivores tend to occupy human-made structures. Our results show that this high-growth potential diversity bears both a numerical and ecological relevance. It is worth remembering that Curitiba is in Brazil's subtropical area, where the richness of bat species is lower, and the predominant species are different from those in the tropical region of the country. Finally, studies on the natural history of bats (feeding, reproduction, roosting, etc.) in Curitiba are scarce and urgently necessary given to the current pandemic scenario where these traditionally stigmatized animals have been even more depreciated by public opinion.

Keywords: Atlantic Forest; urban biodiversity; araucaria forest; steppes; ecosystem services; subtropics; fragmentation; habitat loss; coronaviruses; human-wildlife interfaces.

INTRODUCTION

Urbanization is a process that results in the widespread loss, or fragmentation, of the natural habitat which affects animal communities [1]. Several organisms are vulnerable to these changes in their habitat [2]; however, the urbanization process seems to benefit some groups and animal species that apparently are better adapted to deal with new opportunities because of their greater phenotypic plasticity or evolutionary processes [3-6].

Bats are a fine example of this situation. In a recent review of the sensitivity of bats to urbanization, Russo and Ancillotto [6] demonstrate that while some species show a strong degree of adaptation, tolerating the urban habitat or even taking advantage of the availability of roosts and foraging opportunities, others are affected by the loss or fragmentation of their main natural habitat, or by the physical and chemical pollution associated with urbanization. The same can be said of fragmented forest habitats where the resilience to disturbances found in bats varies among the taxa according to their characteristics (e.g., dispersion capacity, specialized diet, foraging patterns, roosting requirements, etc.), and the landscape structure and composition [7-10]. However, variations in the composition of the phyllostomid bat communities can be better explained by spatial processes [11].

In the past, biologists neglected the work in cities because they considered the urban environment would have little to offer their research [12], and it was only in the last few decades that urban ecology, a branch of traditional ecology, showed a significant expansion and consolidation of its research [13,14]. Thus, regardless of the theory and praxis underlying their research, the human effects on the environment were rarely studied and monitored, causing the active processes to be generally ignored and leaving no bionomic data on fauna and flora preceding and succeeding the urbanization process of most cities in the Neotropical region, as is the case with Curitiba. For Brazilian bats in urban areas, for example, the number of studies has noticeably increased since 2005 up to now [15].

Very few studies have specifically investigated bats diversity and biology in Curitiba. Most of the information available is in partially disclosed museum records (e.g., [6]), unpublished academic studies [17], grey literature (see Miretzki [18] for a review), few academic publications/articles [16,19,20] and numerous municipal and state governments reports and databases with restricted access (see Bianconi [19], Pacheco [20]). The absence of such studies has led to inaccurate estimates of bat diversity in Curitiba. This kind of knowledge gap can have a negative impact on bats, contributing to stigmatize these animals that were held responsible for the origin of Covid-19 pandemic [21] and reinforcing the negative public opinion worldwide about them.

In December 2019, cases of pneumonia epidemiologically linked to the Huanan (Southern China) Seafood Wholesale Market [22] prompted local health authorities to issue an epidemiological alert. The etiologic agent of the pneumonia cases was designated SARS-CoV-2 by a study group of the International Committee on Taxonomy of Viruses (ICTV) [23]. By mid-January 2020, the virus had spread far and wide in Hubei Province and in early March the World Health Organization [24] declared a SARS-CoV-2 pandemic. Coronavirus has claimed over 4,137,000 human lives in about 210 countries according to <https://www.worldometers.info/> (July 21, 2021).

Bats have been historically stigmatized for their appearance or associated negatively with blood-feeding and rabies, and consequently victimized, mistreated and often killed [25,26]. Since the first news about SARS-CoV-2 pandemic came out, bats have been blamed for the disease current outbreak although no consensus has been reached on significant evidence that would justify such responsibility [27-29]. Concurring and more strongly backed up proposals put pangolins (*Manis javanica* Desmarest, 1822) as a potential intermediate species for the emergence of SARS-CoV-2 (e.g., [27,30]).

Amid the rush to hold some animal group responsible for COVID-19 pandemic, the aversion to bats took a further dimension in the public opinion worldwide [29,31,32], which is completely unjustified in the light of what this animal group represents in terms of ecosystem services provided (e.g., environmental restoration through pollination, seed dispersal, and natural pest control) and also diverts the attention they should been given from the conservational point of view [33,34]. As recently alerted by Fenton *et al.* [31], the International Union for the Conservation of Nature Red List [35] put 77 species of bats under the Endangered category. Equally serious is the Brazilian report on the assessment of threatened species that categorized six species of bats as Vulnerable, one Endangered, and 42 as Data Deficient [2,36], whereas a Paraná state report listed

14 species of bats in the Vulnerable category, two in Endangered, and other 17 in Data Deficient [37]. Today, the bat specialists have concerned [29] that all the speculation about bats being the source of Covid-19 could drive people, or public authorities, to exterminate them. The concern is not to be disregarded at all; for example, after 2004 SARS outbreak, civets (a group of small feliform carnivores) were killed en masse [38].

Therefore, we believe it is particularly important to better understand bats in terms of their diversity in an urban system. In this respect, we present here a synthesis of all the data we collected from museum records and scientific literature on the chiropterans in the city of Curitiba. In addition, we bring forward a proposal to discuss ecological and public health aspects related to the species and/or genera in the city of Curitiba which also outlines a more comprehensive view of the ecological roles played by bats in urban ecosystems to object the general idea formed during the critical times we live in that these animals are the villains of COVID-19 pandemic [21,29].

MATERIAL AND METHODS

Study area

Founded in 1693, Curitiba is the capital of Paraná State. The city's total area is 430 km² (ca. 43,000 hectares) (~25°30'S e 49°15'W) and it is situated in South Brazil subtropical region. To the east, the city is limited by Serra do Mar and to the west by Escarpa Devoniana, with altitudes varying from 908 to 948 m height above mean sea level [39]. The climate is humid subtropical, Köppen's Cfb, with an average annual temperature of 16 to 17 °C, annual rainfall between 1400-1500 mm and relative humidity between 80-85% [40]. The vegetation is composed of the Araucaria Forest (Mixed Ombrophilous Forest), in the north and west, Campos (Steppes) that are predominant in the central and eastern portions, and southern Edaphic Fields, Floodplains and Riparian Forests (Fluvial-influenced Pioneer Formations).

Curitiba is the core city of the Metropolitan Region (CMR) that extends over an area of 15,622.33 km² and is composed of 29 cities [41]. According to the Brazilian Institute of Geography and Statistics (IBGE), the population estimate for the CMR is 3,693,891 inhabitants and for Curitiba 1,948,626 inhabitants, which makes it the most populous city in southern Brazil and the eighth in the country [42].

Regarding the legal preservation of urban forest fragments, Curitiba has 91 conservation units, including 27 parks, 24 woodlands, two Environmental Protection Areas, two Ecological Stations, a Wildlife Refuges, a Botanical Garden [41], besides 34 private reserves (Private Reserves of Natural Heritage - RPPN) [43]. Currently, nearly 18% of the city's total area is covered with trees [44] following a tendency to increase its vegetation coverage that has been observed since 1987 [45]. Furthermore, the diverse vertebrate fauna accounts for at least 25 terrestrial mammal species [46,47], 389 bird species [48], 35 reptile species, 21 amphibian species [49] and 37 fish species [46].

Species assessment

To trace back the history of bat research in Curitiba, we used the bibliographical review and compilation of the data obtained from specimens archived in scientific collections, highlighting chronologically the main events and the researchers involved in the studies. To assemble the list of species, the information was obtained from the consolidated literature, search both in scientific collections databases and those available online, and other public databases.

The following bibliographic indexes and databases were referred to carry out the bibliographical research: Google Scholar (<https://scholar.google.com>); PubMed (<https://pubmed.ncbi.nlm.nih.gov/>); Scielo (<https://scielo.org/>); Redalyc (<https://www.redalyc.org/>); Scopus (<https://www.scopus.com/home.uri>); self-archived ResearchGate (<https://www.researchgate.net/>); Web of Science (<http://apps.webofknowledge.com>); and Lattes Platform (<http://lattes.cnpq.br/>) for researchers from Paraná state; and two additional Paraná state mammals bibliographies [18,50].

We searched the records of specimens kept in the scientific collections composing the archives of Capão da Imbuia Natural History Museum (MHNCI) and University of São Paulo Zoology Museum (MZUSP). The other following Brazilian collections were referred online: "SiBBr" (<http://www.sibbr.gov.br>); "TaxOnLine" (<http://www.taxonline.ufpr.br>), in "GBIF" (Global Biodiversity Information Facility databases, <https://www.gbif.org/>); on "Species link" (<http://splink.cria.org.br/>), in species list database; on "Táxeus" (<https://www.taxeus.com.br>) species list database; and the Taxonomic Catalog of the Brazilian Fauna (<http://fauna.jbrj.gov.br/fauna/faunadobrasil/>); and information provided in partnership with Paraná State Health Department (Division of Surveillance in Zoonoses and Intoxications - DVZI) which directed their efforts

to the correct identification of the chiropterans sent for the diagnosis of rabies in the state of Paraná in the period from 2002 to 2009, on a non-continuous basis.

The inclusion of species for this diagnosis considered only those with a reliable record of their occurrence in Curitiba, preferably mentioning where the related study and capture had taken place. Therefore, species reported only as 'for the Curitiba region' and 'Curitiba Metropolitan Region (CMR)' were not included in this study. CMR is very extensive (29 cities and over 15,000 km²) and encompasses important biotopes for bats which are either not found in Curitiba (e.g., caves) or are scarcely described in the studies.

We classified the species according to the IUCN Red List of Threatened Species [35] and/or the Brazilian list [2,36] and/or the regional list [37]. The taxonomic arrangement follows Gardner [51], modified according to Paglia [52] e Quintela [53]. And although the feeding data indicated here is a synthesis of several studies, it roughly follows Eiseberg and Redford [54] and Kunz and Fenton [55].

RESULTS

History

The settlement of Curitiba began in the 17th century and the existing collection of scientific writing on natural history of mammal fauna before and during the occupation process is limited to the occasional accounts by a very few naturalists who traveled to Paraná during the 19th century. Among them, the most famous was undoubtedly the French botanist Auguste de Saint-Hilaire, and his passage through Paraná in 1820 marked a milestone for the scientific exploration in the state [56].

The first records of chiropterans in Curitiba are from 1824 with a description by Isidore Geoffroy Saint-Hilaire of two species of bats collected by A. Saint-Hilaire: *Plecotus velatus* (= *Histiotus velatus*) and *Nyctinomus brasiliensis* (= *Tadarida brasiliensis*), and the description of the latter was based on the material obtained in Curitiba, then Paraná Province, and Misiones in Argentina [57,58]. In his revision of the genus *Tadarida*, Shamel [59] determines Curitiba is a type locality for *T. brasiliensis*.

It took 157 years before new information about bat fauna in Curitiba could emerge. While analyzing comparatively the bionomy of the barn owl, *Tyto alba* (Gray, 1829) (recently *T. furcata* (Temminck, 1827)), both in urban environments and the 'countryside' (rural area around Curitiba), Lange [60] observed a predominant predation of bats in the urban environment, two-and-one-half times greater, when compared with the rate observed in the 'countryside'.

However, only in 1995 the first estimate of the composition of Curitiba's chiropterans came out. Initially the composition was estimated in 10 species, which would represent 3% of all vertebrate fauna and 28.5% of Curitiba mammals, highlighting that among the four most common species of mammals two were bats, *A. lituratus* e *T. brasiliensis* [18]. In the following year, two more species were added to the list, increasing the number of Curitiba species to twelve [18]. The preliminary analysis indicated a low representativeness of frugivorous species of the Phyllostomidae family (n = 3; 25%) and a predominance of insectivorous taxa from the families Vespertilionidae and Molossidae (n = 9; 75%) [61]. Afterwards, Cáceres and Moura [62,63] captured two specimens of *Pygoderma bilabiatum*, observed consuming *Solanum* fruits (jurubeba), increasing the diversity of bats in Curitiba to 13 species. In 2008, the urban ecology study with bats by Pulchério-Leite [17] added more three species to Curitiba list: *Anoura geoffroyi*, *Myotis ruber* and *Myotis levis*. This elevated the number of Curitiba's confirmed species to 16.

The Paraná State Health Department analyzes many bats annually to diagnose the rabies virus. This analysis material from 2002 to 2009 was used in partnership with G. V. Bianconi to enhance the knowledge of species which are difficult to sample by traditional methods. This allowed to register 15 species from 11 genera in Curitiba city, including the southernmost record for a Peale's Free-tailed Bat *Nyctinomops aurispinosus* (Molossidae) in Brazil [19].

Additionally, the first assessment of bat diversity in the Curitiba Metropolitan Region (CMR) was carried out by Lorini and Morais [64]. This study reported the occurrence of 17 species of chiropterans distributed in four families, with the prevalence of *Artibeus lituratus*, *Sturnira liliium*, *Carollia perspicillata*, *Tadarida brasiliensis*, and *Histiotus velatus*. Lima [65] enumerated the species of bats in Brazilian urban parks and the 21 species categorized in "the region of Curitiba" are not distinguished from those occurring in exclusively in Curitiba. Finally, Pacheco and coauthors [20] described 36 species for the Curitiba Metropolitan Region (CMR), and like Lima [65], they did not report which species were observed in the city of Curitiba and incorporate the records from the neighboring cities in their work. Along with these inventories, other four studies contributed with information to enrich our data on bat diversity in the CMR, which now, according to our research, has increased to 43 species. Three of them are associated with the caves in the CMR: Trajano

[66], Sipinski and coauthors [67], Oliveira and Sipinski [68] and one study on communities: Arnone and Passos [69].

This bibliographic information combined with the scientific (e.g., [16]) and governmental (e.g., [19]) databases has oriented the writing of this article.

Bat diversity in Curitiba

We conducted an analysis of all bat species documented for Curitiba between 1824 and 2020. This revealed that the taxocenosis is represented by 29 species belonging to 17 genera and four families (Table 1). Insectivorous bats from the Molossidae and Vespertilionidae families were the most related species, totaling 62.1% of the observed diversity (18 species), followed by frugivores from the subfamilies Stenodermatinae and Carollinae, accounting for 24.1% (7 species). Finally, other four species were listed: two of them present a preference for the consumption of nectar and pollen (*Anoura caudifer* and *A. geoffroyi*) (6.9% of the total); one is insectivorous/frugivorous (*Mimon bennettii*); and the last is piscivorous/insectivorous, *Noctilio leporinus* (ca. 3.4% each).

Five of the 29 species listed for Curitiba (ca. 17.2%) rank in two categories of the threatened species list (Vulnerable - VU and Endangered - EN) at regional level (Paraná, 2010), and other four (ca. 14%) lack sufficient information for a proper assessment of their conservation status, and therefore are classified as Data Deficient (DD) at global (IUCN, 2020), national (Brazil, 2014; ICMBIO, 2018), or regional level (Paraná, 2010) (Table 1). Regionally, apart from *Lasiurus ega* in DD category, the other species (22, ca. 75.8%) are classified as Least Concern (LC).

Table 1. List of the bat species in Curitiba displaying the records source, diet, and conservation status according to the IUCN Red List of Threatened Species (IUCN, 2020) and/or the Brazilian list (Brazil, 2014; ICMBIO, 2018) and the regional list (Paraná, 2010).

TÁXON	FOOD	SOURCE	STATUS
Family Phyllostomidae (6 genera, 10 species)			
Subfamily Phyllostomina			
<i>Mimon bennettii</i> (Gray, 1838)	insects and fruits	2	-
Subfamily Glossophaginae			
<i>Anoura caudifer</i> (É. Geoffroy, 1818)	pollen, nectar, fruits, and insects	1	-
<i>Anoura geoffroyi</i> Gray, 1838	pollen, nectar, fruits, and insects	1	-
Subfamily Carollinae			
<i>Carollia perspicillata</i> (Linnaeus, 1758)	fruits and insects	1	-
Subfamily Stenodermatinae			
<i>Artibeus fimbriatus</i> Gray, 1838	fruits	1	-
<i>Artibeus lituratus</i> (Olfers, 1818)	fruits	1	-
<i>Artibeus obscurus</i> (Schinz, 1821)	fruits	1	-
<i>Artibeus planirostris</i> (Spix, 1823)	fruits	1	-
<i>Pygoderma bilabiatum</i> (Wagner, 1843)	fruits	1	-
<i>Sturnira lilium</i> (É. Geoffroy, 1810)	fruits	1	-
Family Noctilionidae (1 genus, 1 species)			
<i>Noctilio leporinus</i> (Linnaeus, 1758)	fish and insects	1	PR-VU

TÁXON	FOOD	SOURCE	STATUS
Family Molossidae (6 genera, 9 species)			
Subfamily Molossinae			
<i>Cynomops abrasus</i> (Temminck, 1826)	insects	1	IUCN-DD; PR-VU
<i>Eumops bonariensis</i> (Peters, 1874)	insects	1	BR-DD; PR-EN
<i>Eumops hansae</i> Sanborn, 1932	insects	1	PR-VU
<i>Molossus molossus</i> (Pallas, 1766)	insects	1	-
<i>Molossus rufus</i> É. Geoffroy, 1805	insects	1	-
<i>Nyctinomops aurispinosus</i> (Peale, 1848)	insects	5	-
<i>Nyctinomops laticaudatus</i> (É. Geoffroy, 1805)	insects	1	-
<i>Promops nasutus</i> (Spix, 1823)	insects	1	PR-VU
<i>Tadarida brasiliensis</i> (L. Geoffroy, 1824)*	insects	1	-
Family Vespertilionidae (4 genera, 9 species)			
Subfamily Vespertilioninae			
<i>Eptesicus brasiliensis</i> (Desmarest, 1819)	insects	1	-
<i>Eptesicus furinalis</i> (d'Orbigny & Gervais, 1847)	insects	1	-
<i>Histiotus velatus</i> (L. Geoffroy, 1824)*	insects	1	IUCN-DD
<i>Lasiurus blossevillii</i> [Lesson, 1826]	insects	1	-
<i>Lasiurus cinereus</i> (Palisot de Beauvois, 1796)	insects	1	-
<i>Lasiurus ega</i> (Gervais, 1856)	insects	3	PR-DD
Subfamily Myotinae			
<i>Myotis levis</i> (L. Geoffroy, 1824)	insects	1	-
<i>Myotis nigricans</i> (Schinz, 1821)	insects	1	-
<i>Myotis ruber</i> (É. Geoffroy, 1806)	insects	4	-

Legend: (*) species whose type locality is Curitiba [57,58,59]; Source: 1) MHNCl; 2) MZUSP; 3) SpeciesLink (DZUP - Mammalia, UFPR); 4) Pulchério-Leite (2008) [17]; 5) Bianconi and coauthors (2009) [19].

DISCUSSION

Bats are considered one of the most diverse groups of mammals in urban areas [71,72] and the literature is replete with studies that report marked changes in species assemblies within cities in different parts of the world (e.g., [20,71,73]).

The richness of bat species in Curitiba corroborates with these findings. According to our research, the exact diversity figures are ca. 70% higher than the 17 species underrepresented in the literature, accounting for 67% of the diversity found in the CMR (43 species) and about 43% of the species reported for Paraná state (68 species) [16,19,74,75,76,77,78]. The predominance of the molossid bats over phyllostomids and of the insectivorous species over the frugivorous ones is also relevant. This aspect seems to reflect the condition of the urban fauna, which suffers not only a loss in its richness but also undergoes changes in the dominant groups or species. In this regard, it is also observed that species considered generalist and flexible, as the essentially frugivorous members of the Phyllostomidae family, prevail, whereas the more sensitive or specialized representatives, as is the case with many bats of the subfamily Phyllostominae, taken as

indicators of environmental quality [79,80], are represented by a single species: *Mimon bennetti*, out of at least other seven that were described for Paraná [16,75]. The inclusion of *Mimon bennetti* in our list is supported by the specimen collected by the naturalist Rudolf Bruno Lange from the Museu Paranaense [18] preserved in the collection of the University of São Paulo Zoology Museum. Although the collection date is uncertain, it is estimated to somewhere around 1940s, nearly 80 ago.

Fruit-eating bats of the genera *Artibeus*, *Sturnira* and *Carollia*, which account for six species in Curitiba, are noteworthy for the way they interact with fragmented forest landscapes demonstrating tolerance to the edge effect and high mobility [8,81,82,83,84,85]. The persistence of the representatives of these genera in the city seems to be possibly linked to the distribution and density of resources in green areas, especially food and daytime roosts in forest fragments such as parks and woodlands [17,86,87]. In addition, new opportunities for roosting and feeding are provided when exotic or native trees are planted in private areas or in connection with some urban afforestation plan [88].

Molossidae and Vespertilionidae alone accounted for 18 species for Curitiba. These families demonstrate greater adaptability to urban environments, notably the molossids, which are known for foraging in open spaces above the treetops when in natural areas and seem to benefit from urbanized landscapes [72]. These bats also benefit from the variety of roosts (19 according to Pacheco [20]) arising from the urbanization process. Artificial roosts have acquired great value for bats because they emulate the structural and functional properties of the natural ones which are critical to the survival and reproductive success of many species (e.g., structure, microclimate, protection from predators) [89].

In Curitiba, the main artificial roosts used by molossids are found in the residences' attics, under roofs/inside ceilings and in the expansion joints of buildings [20], and the use of these structures by *Molossus molossus* and *Tadarida brasiliensis* has been commonly reported. For Vespertilionidae, *Eptesicus brasiliensis*, *Histiotus velatus* and *Myotis nigricans* have been frequently reported roosting in spacious areas such as residences' attics and under roofs/inside ceilings, sometimes sharing the same roost [90]. Although artificial roosts potentially mean a crucial resource for Vespertilionidae in the urban area, green areas are essential for the maintenance of many groups roosting in the denser foliage of trees, hanging stems of epiphytes and palm trees, as is the case with *Lasiurus* spp. [90].

Despite the diversity of bat species in Curitiba described here is relatively low for the subtropical region, we emphasize here the importance it assumes to ecology at an urban level as it corresponds to the interactions that are fundamental to the ecosystems functioning, such as the spread of propagules (pollen grains and seeds) and control of insect populations [55], which enhances its value in terms of conservation.

Studies have reported that phyllostomid bats are visitors of about 360 species in 159 genera of 44 plant families [91]. The Brazilian list of actual and potential mammal pollinators includes 48 species of bats [92]. This list includes two species of nectar-feeding bats (*Anoura caudifera* and *A. geoffroyi*) and at least seven species of fruit-eating bats (all Phyllostomidae), all reportedly inhabitants of the city of Curitiba (Table 1). Unlike insects, bats deposit large amounts of pollen in plant stigmas over longer distances every night, ensuring the exchange of genetic material [33,34,91].

The excellent seed dispersers *Artibeus* spp. and *Sturnira liliium* have been historically and frequently reported in studies conducted in Curitiba [17,63]. These phyllostomids, alongside *Carollia perspicillata* (less frequent in the city of Curitiba), have a mostly frugivorous diet and show a consistent preference for the consumption of the native fruits available in urban forest fragments, although they can also benefit from the exotic fruit plants used in urban landscaping as we mentioned earlier here. Authors have emphasized the behavioral flexibility of some of these species when in fragmented landscapes [80,82,83,93], and such reasoning can be at least hypothetically expanded to the forest remnants found similarly fragmented within Curitiba's urban environment. There is a vast number of reports on the long-distance travels the individuals of these species make (v. Bianconi [8]), which would be sufficient to make the production of fruits and the exchange of genetic material among the urban green areas of the capital viable. Furthermore, the value of seed dispersal ecosystem services provided by some of these species may be estimated between U\$ 509.84 ha⁻¹day⁻¹ (value corresponding to *S. liliium*) and U\$ 22,033.77 ha⁻¹day⁻¹ (for *C. perspicillata*), according to the data obtained from a case study of Atlantic Forest in the state of Paraná [94].

The predominance of insectivorous species belonging to the families Molossidae and Vespertilionidae in Curitiba we verify here can also be thought in terms of value. Widely distributed all over the world, these families have received great recognition for the significant number of insects they consume, including flies, beetles, moths, cicadas, aphids, mealybugs, and many other arthropods, making them unarguably important and valuable to the provision of services of natural control of pest that otherwise would cause crop losses,

and thus reducing costs with pesticides [34,95]. Therefore, the direct and indirect benefits of these bats to humans are immeasurable.

For urban environments, we see a considerable potential of this group in the large-scale control of insect vectors of diseases which is justified by the fact some genera, usually well represented in large cities (*Myotis*, *Eptesicus*, *Lasiurus*, *Tadarida*), can consume 25 up to 70% of its own weight in insects every night, with an increase of these figures during their reproductive period [34,96,97]. In addition, experimental studies have shown that bats can cause a substantial reduction in the profusion of varied diseases within a locality by preying *Culex* (Diptera: Culicidae) mosquitoes [98], which hypothetically reinforces the group's character as aerial predators of urban pathogens.

The benefits associated with the existence of these animals and their high value for conservation are unarguably, yet bats have had an unfavorable reputation in the eyes of public opinion, worsened by the COVID-19 pandemic [31,32]. Such animosity can be partially explained by the fact they are natural reservoir and sources of potential infections by microorganisms, including some pathogens that can cause human diseases, such as bacteria, fungi, and viruses, which have already been found in the individuals themselves or in deposits of their feces [99,100].

The most iconic zoonoses associated with the group are viruses, once bats have been reported as important reservoirs of some families of viruses emerging as human pathogens, such as Ebola and Marburg viruses, Severe Acute Respiratory Syndrome (SARS) and Middle East Respiratory Syndrome (MERS) coronaviruses [99], and more recently SARS-CoV-2, the virus responsible for the COVID-19 pandemic [23].

In Brazil, apart from the rabies virus (family Rhabdoviridae, genus *Lyssavirus*) and some zoonoses associated with fungi attacks, the involvement of bats in the epidemiology (incidence and distribution) of other diseases is rare yet little studied. The coefficient of rabies incidence in Brazil for all mammals in the 2012-2017 period was 0.0098/100,000 inhabitants [101]. In large Brazilian capitals, the positivity rates for rabies vary between 0.5% and 0.8%, which is considered normal according to the indicators established by the World Health Organization [20]. For Curitiba, this rate within the 2007-2015 period was 0.21%, below the national rate, but only 0.95% of the bats were tested [102]. Morikawa and coauthors [103] report the case of contamination in Curitiba caused by the contact of non-blood-feeding bats with a domestic cat (*Felis catus*) after almost three decades with no records of the disease. The authors of this study warn that monitoring bats is necessary even in areas historically free from rabies.

Rabies affects all mammals (including domestic) [104], and it is monitored by city and state public health agencies. As a result, the understanding of each bat species role in the epidemiology of rabies has expanded, promoting the development of strategies for its control. In Paraná, the Environmental Health Center (Division of Zoonoses) of the State Department of Health has directed their efforts to the correct identification of the chiropterans sent for the diagnosis of rabies, as well as to obtain and analyze biological and distribution data of these individuals in the cities. The correct identification of bat species is a simple yet not common practice in the public health agencies and the lack of this information hinders (or stops altogether) not only subsequent analyzes but also the prophylactic measures (see Ribeiro and coauthors [102]), which can lead to conflicts between the implementation of sanitary measures and the need for biodiversity conservation.

About 40 species of Brazilian bats have been reported as carriers of the rabies virus or rabies-related viruses (emerging 'lyssavirus') [105, 106], and 20 of them are reported for Curitiba: *Anoura caudifer*, *A. geoffroyi*, *Carollia perspicillata*, *Artibeus fimbriatus*, *A. lituratus*, *A. planirostris*, *Sturnira lilium*, *Cynomops abrasus*, *Molossus molossus*, *M. rufus*, *Nyctinomops laticaudatus*, *Tadarida brasiliensis*, *Eptesicus brasiliensis*, *E. furinalis*, *Histiotus velatus*, *Lasiurus blossevillii*, *L. cinereus*, *L. ega*, *Myotis levis* and *M. nigricans*, and some of these species tested positive for rabies in Curitiba in the 2006-2010 period [103].

As the highest concentration of the virus is in saliva, the bite is the most effective means of the transmission. Thus, while feeding on other mammals' blood, the vampires are more likely to effectively transmit the virus than any other species. Although the common vampire bat (*Desmodus rotundus*, the main involved in the epidemiology of rabies) has been reported for some Brazilian cities (São Paulo, Belo Horizonte, Rio de Janeiro, Salvador, Olinda) [107,108], the accidents generally occur in poor regions (vulnerable housing) where there is a limited availability of large prey (cattle, horses), with the highest incidence of cases involving bats in rural areas in the North and Northeast of the country [101]. Vampires bats are occasionally seen in urban areas, most frequently in the outskirts where the creation of unconfined animals and landscapes offer potential feeding and roosting opportunities. There are no records supporting the evidence of *D. rotundus* in the urban area of Curitiba, although they do exist for several neighboring cities in the metropolitan region (e.g., Campo Largo, Bocaiúva do Sul, Tunas do Paraná, Rio Branco do Sul) [16,67,69,109].

Bat feces (likewise that of birds) when accumulated in unventilated roosts may contain fungal spores associated with respiratory problems like histoplasmosis. It is a mycotic infection caused by *Histoplasma capsulatum*, a dimorphic pathogenic fungus to mammals, which may evolve to a pulmonary infection in humans. Although bats are reported as the main reservoirs and dispersers of this fungus in the environment, their role in spreading out *H. capsulatum* has not been fully elucidated [99].

Emerging infectious diseases are correlated with socioeconomic, environmental, and ecological factors and their impacts on public health, daily life and the world economy are undoubtedly considerable [99]. However, the problem seems not to lie with the animals, but with our contact with them [21]. That is what the urbanization process exactly does. And the remaining fauna in the cities and the human population [104] are increasingly coming into contact as the populational density rates go up, accelerating the fusion of these two worlds.

Our discussion here concludes that the maintenance of the diversity of bats in urban areas depends on the species' potential to tolerate changes in urban habitat. Cities seriously impact resources availability, accentuating declines, or fluctuations in bat populations [71,73], which is often reflected in the classifications of the threatened fauna lists. About 76% of the species reported for Curitiba are classified regionally as Least Concern (LC). In principle, this may seem to reflect the adaptability and tolerance of bats; however, according to what Lacher and coauthors [110] recently highlighted for rodents in Brazil, high percentages of LC reported may also reflect the application of the data as many species have gaps in the distribution of samples or do not have adequate population data that would allow an assessment of trends, resulting in an overestimation of the dispersion of risk. Therefore, bat research needs to be continuously improved to refine the assessments of species that are now considered LC or even Data Deficient (DD).

CONCLUSION

Urbanization presents indisputably one of the most significant threats to biological diversity and this will challenge the viability of many animal populations and communities as it becomes more and more intense particularly in developing countries like Brazil.

Bats represent an extremely significant portion of mammals in our country (181 species in 68 genera and 9 families) [111] and some species endure in many Brazilian cities due to their behavior, morphology, and diet, using strategically urban landscapes to foraging and roosting.

For frugivores with high mobility (e.g., *Artibeus*, *Sturnira*, *Carollia*), urban afforestation emulates structurally the corridors of vegetation in natural areas, functioning as the linear green rows that connect the animals with the isolated forest remnants that protect essential resources (daytime roosts and food). Insectivores from some families (e.g., Molossidae, Vespertilionidae), accounting for more than 62% of the species in Curitiba, show a consistently close connection with urban areas wide and far in its geographical distribution, finding roosting opportunities in human-made structures (e.g., attics, roofs/ceilings, and buildings expansion joints). In Curitiba, the species *Tadarida brasiliensis* and *Molossus molossus* are noteworthy in this regard.

We believe that expanding our knowledge of the urban ecology of bat species is perhaps the most effective conservation effort we can launch in favor of this group that has traditionally been held in the lowest esteem by the public opinion, which has now been made worse by COVID-19. This can be achieved by understanding the real dimension of the impacts of urbanization on species, the ecosystem services they provide and public health issues involving the group.

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