NeoBat Interactions: a data set of bat-plant interactions in the Neotropics

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INTRODUCTION

Open access to primary scientific data is fundamental to enforce the social contract that governs scientific publishing (Vision 2010). This contract relies on transparency and reproducibility, including independent verification and reuse of published data (Costello 2009). This way, data access has been facilitated in the information age through important frameworks for the production, storage, curation, and sharing of data. These frameworks aim to preserve data in the long term, even beyond the life of their initial compilers and curators (Chavan and Ingwersen 2009).

One major framework for making data available are data papers, which optimize efforts in the discovery, organization, and availability of information (Chavan and Penev 2011). They have the potential to offer highly reliable data sources, as they have been subjected to quality control protocols, such as peer review and editorial inspection of data and metadata (Costello *et al.* 2013). By introducing additional incentives related to publication and citation, this new kind of publication has revolutionized contemporary biology by making decades of naturalistic information widely available in highly accessible and comprehensive formats.

Recently, the data paper revolution has also reached mammalogy. Data papers on mammal communities are growing in number. There are, for instance, data papers on non-volant mammals on a global scale (Thibault *et al.* 2011). Another important source is the BioTIME database of biodiversity time series for the Anthropocene (Dornelas *et al.* 2018). Others have larger scope, such as the global database for metacommunity ecology, integrating species, traits, environments, and space (Jeliazkov *et al.* 2020). Others attempt to harmonize and curate all main data sets for mammal traits, phyllogeny, and viral sharing (https://github.com/viralemergence/clover).

In Brazil, the most famous mammalogical data papers were produced by the ATLANTIC Series and NEOTROPICAL Series, which contain information about the biodiversity of the Atlantic Forest of South America and the Neotropics, respectively. This series includes data papers on plant-frugivore interactions (Bello *et al.* 2017), rodents and marsupials: (Bovendorp *et al.* 2017), bats (Muylaert *et al.* 2017), primates (Culot *et al.* 2019), and medium- and large-sized mammals (Souza *et al.* 2019). Many other data papers were produced by other research groups outside the ATLANTIC Series, focusing on groups such as small mammals (Figueiredo *et al.* 2017). Nevertheless, only a few of them covered larger spatial scales, such as Neotropical xenarthrans (Santos *et al.* 2019) and Neotropical Carnivores (Nagy-Reis *et al.* 2020). In addition, most of them, particularly in the Atlantic Forest and Cerrado, are based on abundance-incidence data whereas species interactions received much less attention.

Mutualistic interactions between animals and plants are a cornerstone of terrestrial ecosystems. Almost 94% of plants in neotropical communities are pollinated by animals (Ollerton *et al.* 2011), while 70–94% have their seeds dispersed by vertebrates (Jordano 2013). Bats are especially important in this context, as they represent the second largest group of seed dispersers in the Neotropics, after birds (Bello *et al.* 2017). On the other hand, even though insects pollinate most flowering plants, bats are also the second group of pollinating vertebrates since they pollinate about 2% of the extant plant genera (Sekercioglu 2006). Bat-plant interactions also generate ecosystem services, such as the pollination of economically important plants and the dispersal of seeds from pioneer plants that are key to habitat regeneration (Kunz *et al.* 2011).

Therefore, bats and their food-plants are the focus of our data paper. We compiled a georeferenced database of 2571 interaction records of frugivory and nectarivory between 93 bat species and 501 plant species. The data came from 169 studies covering 200 locations in 16 countries all over the Neotropical region (Figure 1). The database compiled by Geiselman and Younger (2002) was used as a starting point and was filtered, revised, and updated. We added mainly new literature, specially from South America.

After this update, NeoBat Interactions is so far the most extensive bat-plant interaction database both in geographic and taxonomic terms. Most sampling sites are georeferenced with high coordinate accuracy. All records came from primary sources and were taxonomically verified and updated. Besides, our database

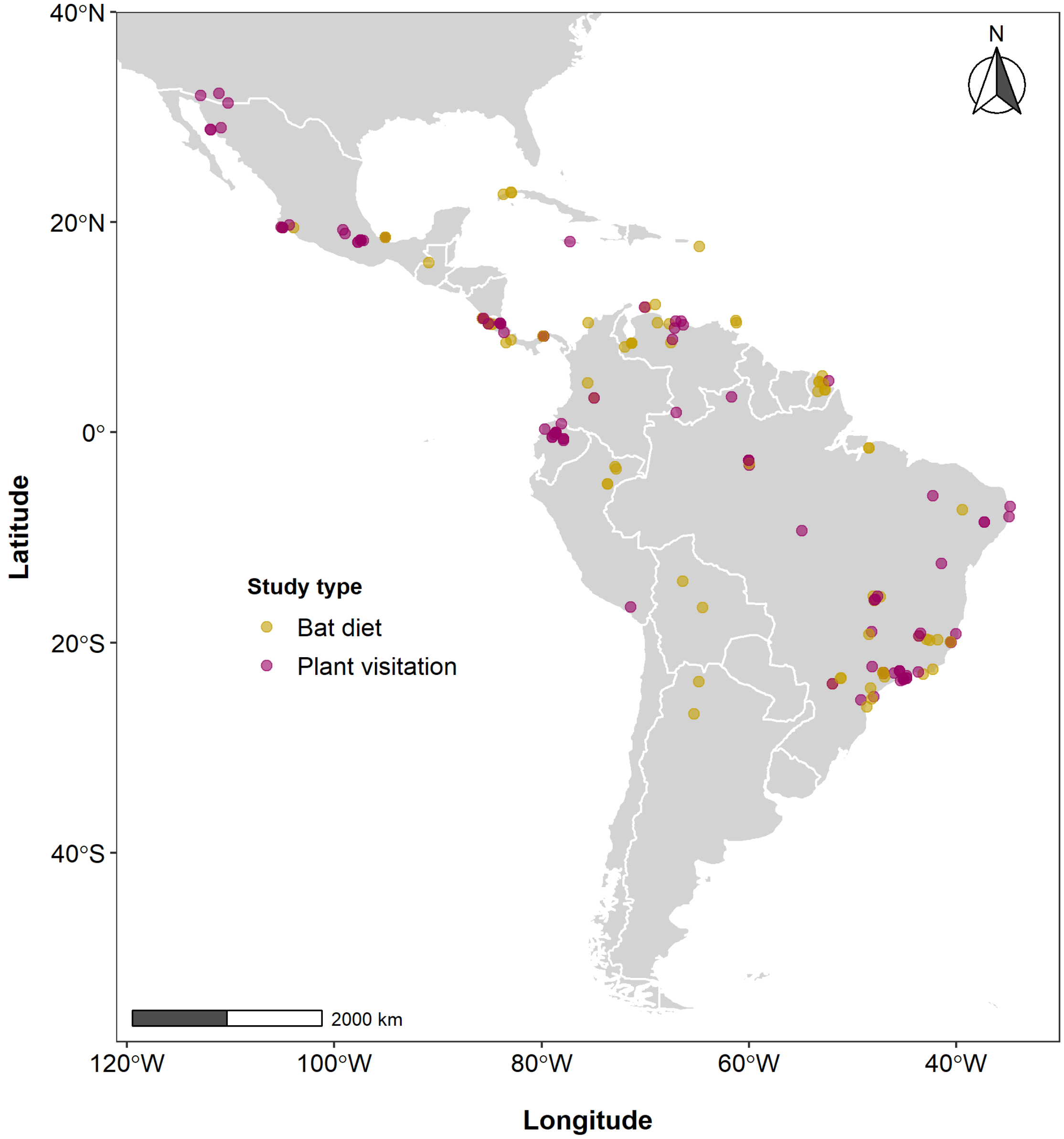

Figure 1: Distribution of sampling sites included in NeoBat Interactions. Dots show the location of original studies focused on plant visitation (purple) and bat diet (yellow). White lines show country borders. We included only studies with records of bat-plant interactions that were confirmed either by indirect or direct observation.

includes some geographic and abiotic information of study sites such as vegetation type and rainfall. Our database also includes ecological information for most species, such as a life form and successional stage of plants, and trophic guild of bats. The data are organized and standardized at different levels of ecological complexity and temporal and geographic scales, which allows using them in a variety of studies with different scopes.

METADATA

CLASS I. DATA SET DESCRIPTORS

A. Data set identity

Title: NeoBat Interactions: a data set of bat-plant interactions in the Neotropics

B. Data set identification

Data set identity codes:

NeoBat_Interactions_References.csv

NeoBat_Interactions_Sites.csv

NeoBat_Interactions_Records.csv

C. Data set description

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Abstract:

Data papers and open databases revolutionized contemporary science, as they provide the long-needed incentive to collaborate in large international teams and make naturalistic information widely available. Nevertheless, most of them focus on occurrence or abundance, while species interactions received much less attention. To help fill this gap, we compiled a georeferenced data set of interactions between 93 bat species of the family Phyllostomidae (Chiroptera) and 501 plant species of 68 families. Data came from 169 studies published from 1957 to 2007 in the entire Neotropical Region, with most records from Brazil (34.5% of all study sites), Costa Rica (16%), and Mexico (14%). Our data set includes 2571 records of frugivory (75.1% of all records) and nectarivory (24.9%). The best represented bat genera are *Artibeus* (28% of all records), *Carollia* (24%), *Sturnira* (10.1%), and *Glossophaga* (8.8%). *Carollia perspicillata* (187), *Artibeus lituratus* (125), *Artibeus jamaicensis* (94), *Glossophaga soricina* (86), and *Artibeus planirostris* (74) are the bat species with the broadest diets recorded in number of plant species. Among plants, the best represented families are Moraceae (17%), Piperaceae (15.4%), Urticaceae (9.2%), and Solanaceae (9%). Plants of the genera *Cecropia* (46), *Ficus* (42), *Piper* (40), *Solanum* (31), and *Vismia* (27) hold the largest number of interactions. These data are stored as arrays (records, sites, and studies) organized by logical keys and rich metadata, which helps compile the information at

different ecological and geographic scales, according to how they should be used. Our data set on bat-plant interactions is so far the most extensive both in geographic and taxonomic terms, and also includes some abiotic information of study sites and ecological information of plants and bats. It has already helped us develop several studies and we hope it will stimulate novel analyses and syntheses, in addition to pointing out to important gaps in knowledge.

D. Key words

Databases, frugivory, mutualism, nectarivory, networks, pollination, seed dispersal, species interactions.

E. Description

This database includes 2571 records of interactions involving the consumption of nectar and fruits by bats, taken from studies focused on bat diets or plant visitation by bats across the Neotropics (Figure 1). The information came from 16 countries, from southwestern United States of America to northwestern Argentina. We have compiled 169 scientific papers carried out over 50 years, in 200 study locations. The spatial and temporal distribution of the studies is not heterogeneous.Brazil (69), Costa Rica (32), Mexico (28) and Venezuela (16) are the countries where most studies have been carried out (Figure 2A). Likewise, the number of studies on frugivory and nectarivory was low between the 1950s and the 1970s, peaking between the 1980s and the 2000s (Figure 2B).

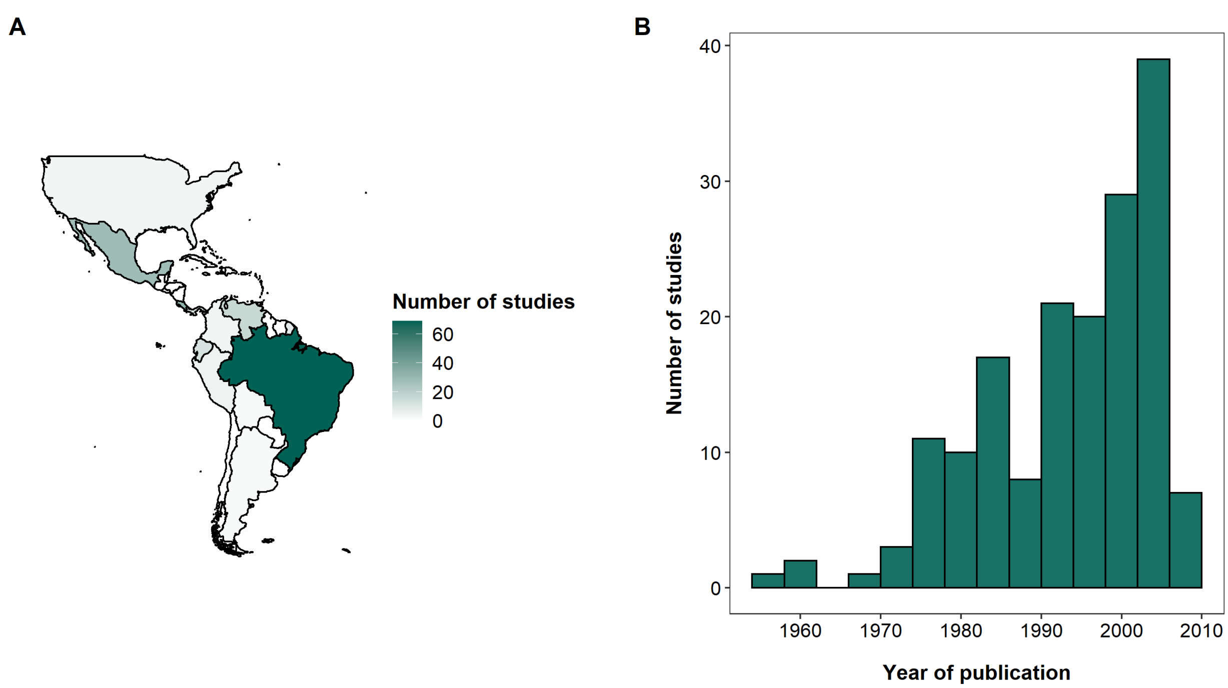

Figure 2: Distribution of the number of studies on frugivory and nectarivory by bats, published by country (A) and throughout the recorded period (B).

The best represented interaction type was frugivory (75.1% of all records) while nectarivory came second (24.9% of all records). Although most data come from primarily fruit- and nectar-feeding bats, there are also interaction records of species from other trophic guilds that occasionally feed on fruit or nectar. Likewise, this database includes information mainly on trees and shrubs, although it also contains other plant life forms such as vines and herbs. Several plant species have no information on successional stage, but there are many classified as early successional species (Table 1).

We have also included information about interaction strength, nevertheless 44.5% of the records have no such data, mainly because strengths were not reported in the source papers. Regarding their conservation status, 8.6% of the bat species and 2.8% of the plant species are listed in some category of threat according to the IUCN (Table 2). However, most plant species (59.9%) and some bat species (17.2%) have not been listed in any category.

Table 1: Ecological information of bat and plant species recorded in the NeoBat Interactions database

Ecological trait	**Class**	**Number of species**	**%**
Trophic guild of bats	Foliage gleaner	5	5.4
	Frugivore	55	59.1
	Nectarivore	27	29.0
	Omnivore	6	6.5
Succesional stage of plants	Early	152	29.8
	Late	112	22.0
	Not information	246	48.2
Life form of plants	Herb	52	10.1
	Palm-tree	8	1.6
	Shrub	135	26.3
	Succulent	25	4.9
	Tree	231	45.0
	Vine	36	7.0
	Not information	26	5.1

The taxonomic scope of this data paper encompasses 93 species and 40 genera of bats of the family Phyllostomidae, and 501 species, 189 genera, and 68 families of plants. The most frequently recorded bat was *Carollia perspicillata*, followed by *Artibeus lituratus*, which have been also reported as hyper-dominant species in other community-focused databases (Muylaert *et al.* 2017) as they are cosmopolitan species, widely distributed across the neotropical region (Gardner 2008). Only seven species were responsible for almost 50% of records: *Carollia perspicillata* (16.49%), *Artibeus lituratus* (9.3%), *Artibeus jamaicensis* (7.62%), *Glossophaga soricina* (5.6%), *Artibeus planirostris* (3.89%), *Carollia castanea* (3.46%) and *Carollia castanea* (3.46%). In contrast, most of bats species are infrequent, 67 species have a relative frequency $\leq 1\%$ (Figure 3A). *Chiroderma gorgasi*, *Choeroniscus godmani*, *Choeroniscus minor*, *Glossophaga leachii*, *Glyphonycteris sylvestris*, *Lampronycteris brachyotis*, *Lionycteris spurrelli*, *Lonchophylla bokermanni*, *Lonchophylla inexpectata*, *Micronycteris megalotis*, *Phyllostomus latifolius*, *Platalina genovensium*, *Platyrrhinus brachycephalus*, *Pygoderma bilabiatum*, *Sturnira aratathomasi* and *Tonatia bakeri* were the rarest species, representing 0.64% of all records.

Plants of the genera *Piper* (15.17% of the records), *Ficus* (15.13%), *Cecropia* (9.02%) and *Solanum*

Table 2: IUCN conservation status of animals and plants species reported in the NeoBat Interactions database

Group	IUCN Status	Number of species	%
Plants	Critically Endangered (CR)	1	0.2
	Endangered (EN)	4	0.8
	Vulnerable (VU)	5	1.0
	Near Threatened (NT)	4	0.8
	Least Concern (LC)	183	36.5
	Conservation Dependent (CD)	1	0.2
	Data Deficient (DD)	3	0.6
	Not Evaluated (NE)	300	59.9
Bats	Endangered (EN)	3	3.2
	Vulnerable (VU)	2	2.2
	Near Threatened (NT)	3	3.2
	Least Concern (LC)	67	72.0
	Data Deficient (DD)	2	2.2
	Not Evaluated (NE)	16	17.2

(6.81%) were the most abundant in this database, as they represent the main food source for bats of the genera *Carollia*, *Artibeus,* and *Sturnira*, which are abundant groups (Fleming 1982). Several species are recorded as unidentified (6.22%) which reflects the difficulty of identifying plants from seed samples, which was the principal sampling method used in the studies (Figure 3C). Plants of the genera *Acacia, Adenocalymma, Aechmea, Alexa, Aureliana, Bakeridesia, Beilschmiedia, Bombax, Calliandra, Calycolpus, Capsicum, Chelonanthus, Clarisia, Cobaea, Copaifera, Cucurbita, Cynometra, Cynophalla, Elizabetha, Emmotum, Encholirium, Eriolarynx, Genipa, Gustavia, Harpochilus, Heisteria, Hesperalbizia, Hillia, Karwinskia, Lecythis, Livistona, Mimosa, Myrcia, Nectandra, Oenocarpus, Phenakospermum, Phytolacca, Praecereus, Protium, Prunus, Pseudolmedia, Randia, Ruellia, Schultesianthus, Siparuna, Socratea, Souroubea, Symphonia, Tabernaemontana, Thespesia, Thunbergia, Tovomita, Turpinia, Weberbauerocereus, Xanthosoma* and *Zapoteca* were the less represented in this database, accumulating the 2.24% of all records.

Carollia perspicillata (187 species of plants), *Artibeus lituratus* (125), *Artibeus jamaicensis* (94) and *Glossophaga soricina* (86) were the species with highest number of interactions as they also were very abundant species (Figure 3B). Most of species of bats 55 interact with at least five species of plants. The species with only one interaction recorded in this database were: *Anoura fistulata, Chiroderma gorgasi, Choeroniscus godmani, Choeroniscus minor, Glossophaga leachii, Glyphonycteris sylvestris, Lampronycteris brachyotis, Lionycteris spurrelli, Lonchophylla bokermanni, Lonchophylla inexpectata, Micronycteris megalotis, Musonycteris harrisoni, Phyllostomus latifolius, Platalina genovensium, Platyrrhinus brachycephalus, Pygoderma bilabiatum, Sturnira aratathomasi, Tonatia bakeri* and *Vampyressa pusilla.*

On the contrary, most of plants recorded (430 species) interact with less than five bat species. *Ficus sp.* (31 species), *Cecropia sp.* (23) and *Piper sp.* (23) hold the highest number of interactions. The rest of plant species (68) interact with between 6 and 16 bat species (Figure 3D).

Each species of plant interacts with a relatively small number of bat species and the range of the number of interactions varies considerably ($\bar{x}$ = 3, range=1-23). Most of species of trees hold the a large num-

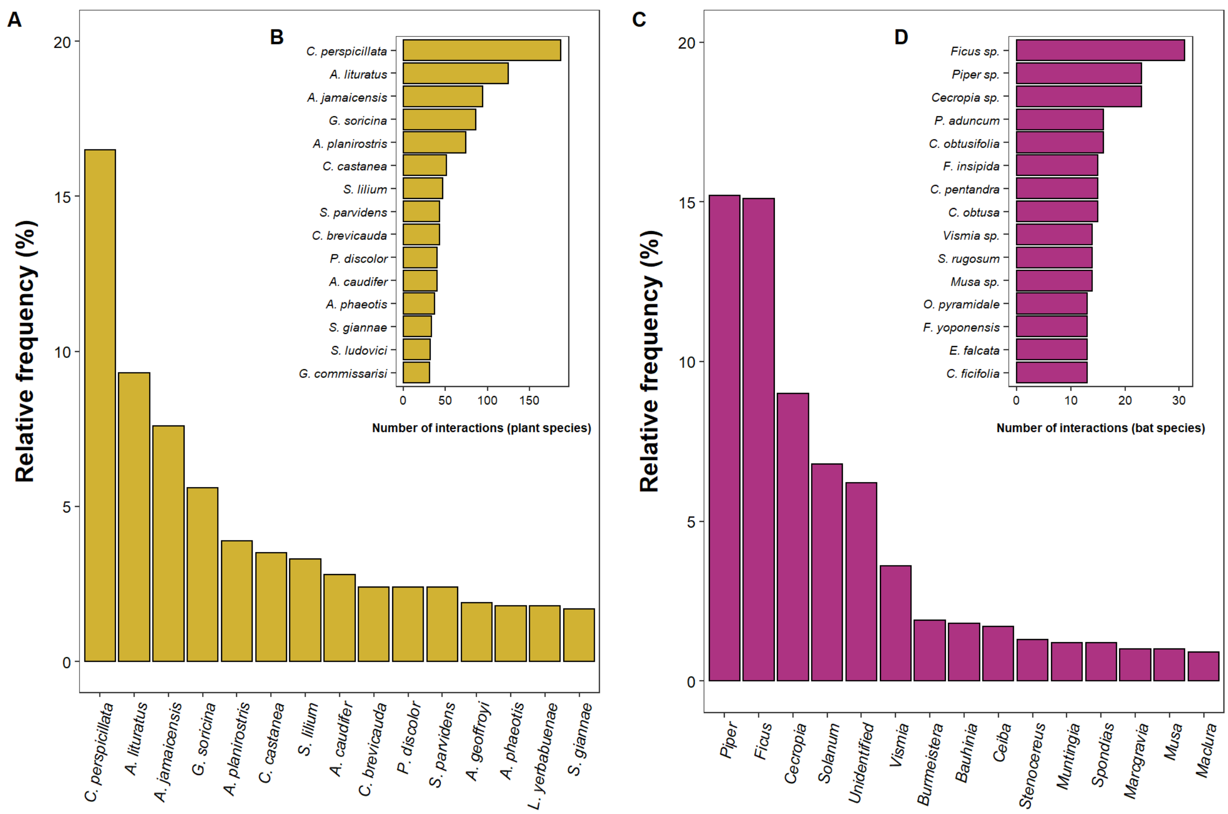

Figure 3: Ranking of frequency of the 15 most abundant bat species (A) and plant genera (C). Internal plots represent the number of each one of the 15 species of bats (B) and plants (D) with most interactions recorded in the NeoBat Interaction database

ber of interactions of frugivory (176species, range=1-20interactions) and the largest number of nectarivory (68species, range =1-15interactions). A large number of shrubs (121species) holds interactions of frugivory (range=1-23interactions), and a very small number of species (18) of nectarivory (range=1-6 interactions). Despite trees and shrubs are the life form of plants with most number of records, this database also includes information of nectarivory and frugivory of vines, succulents (Cactaceae) and palm-trees (Figure 4A).

Most frugivory interactions were made with early succesional plants (145 species), holding interactions with between 1 and 20 bat species while late successional plants (80 species) interact with between 1 and 15 bat species. Otherwise, nectarivory interactions came from late succesional plants (39 species) against Early (13 species). Both groups interacting with between 1 and 15 bat species (Figure 4B). Most of the records in NeoBat Interactions come from fruit eating bats. Frugivorous can eat fruits of a large number of plant species (range = 1 - 188 interactions). Some species (18) also can eat nectar of a considabel wide number of plants (range = 1 - 34 interactions). Nectarivorous bats eat nectar from 1 - 68 species and fruits from 1 - 1 species of plants. Species of omnivorous bats interact with fruits and nectar of up to 32 plant species. Finally, this database also contains information of foliage gleaner bats of the genus *Lampronycteris, Glyphonycteris, Trinycteris,* and *Micronycteris* eating fruits and nectar of up to nine species of plants (Figure 4C).

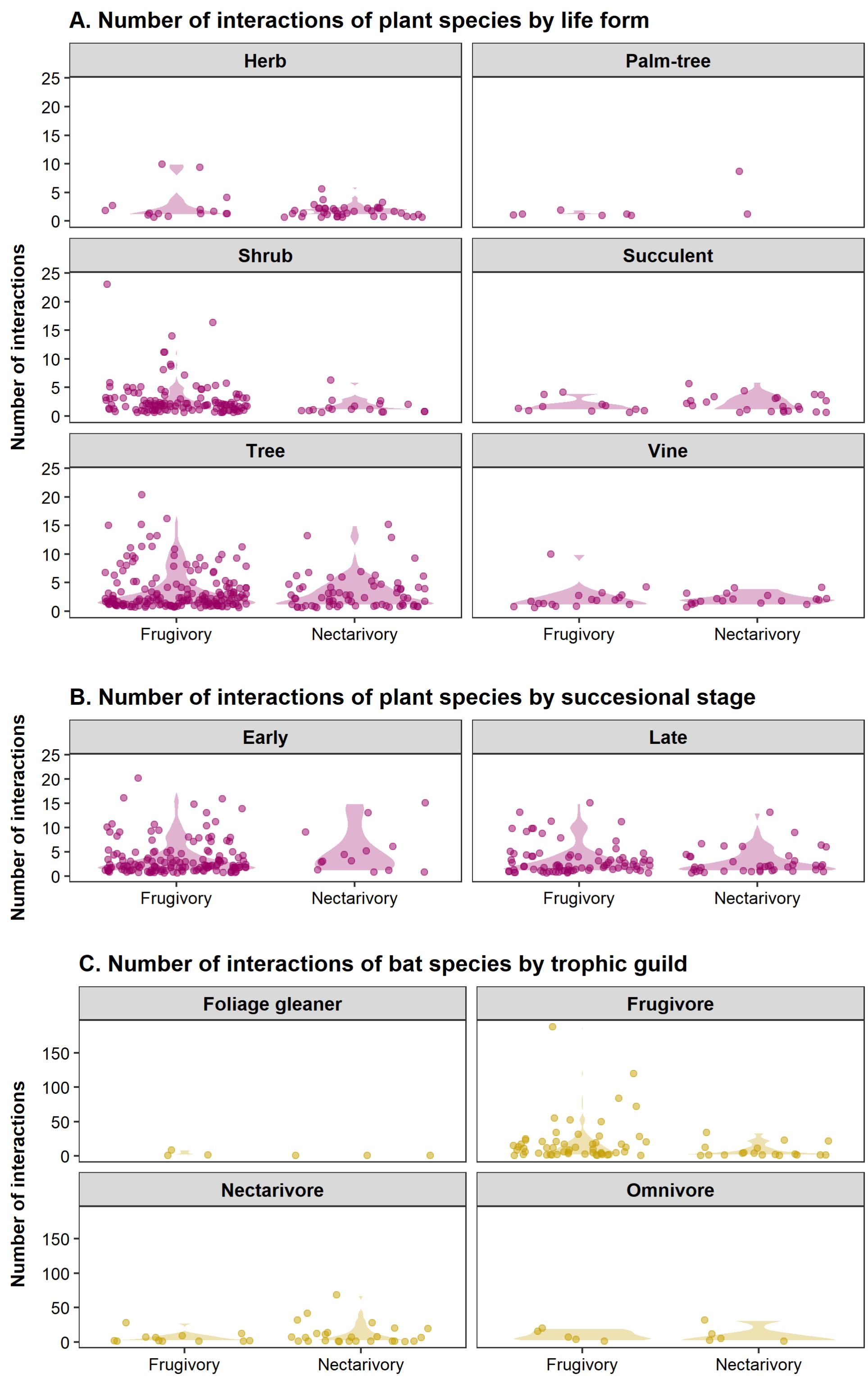

Figure 4: Number of interactions holds by plant and bat species according to their ecological traits: A) Life form of plants, B) Successional stage of plants and C) Trophic guild of bats. Each violet point on A and B represents one plant species, each yellow point on C represents one bat species.

CLASS II. RESEARCH ORIGIN DESCRIPTORS

A. Overall project description

Identity: A compilation of bat-plant interactions in the neotropical region.

Period of study: Dates of source publications range from 1957 to 2007.

Objectives: We aimed (1) to sumarize and make available the information about frugivory and nectarivory interactions between bats and plants in the Neotropics, as well as some ecological information to be used in studies of community ecology, ecological networks, and macroecology; and (2) to identify gaps in knowldge about bat-plant interactions (Eltonian shortfalls) to direct future reseach and sampling effort. This data set represents the most extensive and complete cataloge of bat-plant interactions in the neotropical region.

Abstract: Same as above.

Source of funding: This study was financed by the Brazilian Coordination for the Improvement of Higher Education Personnel (CAPES, student scholarships), the São Paulo Research Foundation (FAPESP, grant 2018/20695-7), Brazilian Council for Scientific and Technological Development (CNPq, grants 302700/2016-1, 304498/2019-0, and PEC-PG doctoral scholarship 190585/2017-0), Alexander von Humboldt Foundation (AvH, grants 1134644, 3.4-8151/15037, and 3.2-BRA/1134644) and Dean of Research of the University of São Paulo (PRP-USP, grant 18.1.660.41.7).

B. Specific subproject description

Site description: The neotropical region is one of the eight biogeographic realms of the world and extends from southeastern United States to Patagonia, including the Caribbean and some pacific islands (Olson *et al.* 2001). The region is comprised by 17 Phytogeographic Domains divided in 96 ecoregions including the Nearctic Mexico Domain (Oliveira-Filho 2017). The vegetation of the region is very diverse, including xeric and thorny shrubs, open fields, sandy and rocky vegetation, woodlands, savannas, deciduous and semideciduous forest, rainforest, cloud forest, dwarf forest, and floodplains.

The Neotropics is the most species-rich realm in the world and has high levels of endemism (Ulloa *et al.* 2017). Due to this high level of endemism and the number of threats in some areas, seven of the 25 hotspots of biodiversity are in the neotropical region: Mesoamerica, Caribean Islands, Tumbes-Choco-Magdalena, Tropical Andes, Cerrado, Atlantic Forest, and Chilean Winter Rainfall and Valdivian Forests (Mittermeier *et al.* 2011), beside the Amazon Forest, the most biodiverse ecoregion in the world (Hoorn *et al.* 2010).

Data compilation: The present database was originally compiled from the Bat-Plant Interaction Database, currently known as Bat Eco Interactions (Geiselman and Younger 2002). We have also carried out a bibliographic search of different sources: (1) the online databases Web of Web of Knowledge, Scopus, Scielo and Google Scholar; (2) references cited in the literature;

and (3) direct comunication with local experts. The bibliographic search was performed using the keywords: bat-plant interactions; bat(s) diet + frugivory; bat(s) diet + nectarivory; plant visitation + bat(s), bat(s) pollination, bat(s) seed dispersal. The search was conducted in English, Spanish, Portuguese, and French. We compiled information from 169 references, mainly papers but also tecnical reports, books chapters, and unpublished data. For each sampling site we collected information about vegetation type, mean temperature, rainfall, altitude, potential evapo-transpiration, and aridity index (see Table 4).

Research methods: We included studies that reported interactions of frugivory or nectarivory in the field, through the analysis of tbat diets, observation of plant visitation, and cafeteria experiments. We excluded records from secondary references or unconfirmed potential interactions. When available, interaction strength was reported as the number of bat fecal samples containing the seeds of a given plant species for frugivory, and the number of visits of each bat species to each plant species per sampling unit for nectarivory. Missing information was coded as NA. We also included geographic information of the study sites (latitude, longitude, locality, state, and country). Geographic information was manually curated for all sites using Google Maps and clues from each publication.

We compiled information of bat-plant interactions from Greenhall (1957), Alcorn *et al.* (1961), Carvalho (1961), Jimbo and Schwassmann (1967), Wilson (1971), Heithaus *et al.* (1974), Howell and Burch (1973), Heithaus *et al.* (1975), Sazima and Sazima (1975), Janzen *et al.* (1976), Sazima (1976), Fleming *et al.* (1977), Nellis and Ehle (1977), Sazima and Sazima (1977), Heithaus and Fleming (1978), Morrison (1978a), Morrison (1978b), Sazima and Sazima (1978), Bonaccorso (1979), Morrison (1980), Sazima and Sazima (1980), Voss *et al.* (1980), August (1981), Fleming (1981), McCracken and Bradbury (1981), Uhl *et al.* (1981), Heithaus *et al.* (1982), Sazima *et al.* (1982), Dos Reis and Guillaumet (1983), Steiner (1983), Foresta *et al.* (1984), Estrada *et al.* (1984a), Estrada *et al.* (1984b), Helversen and Reyer (1984), Hopkins (1984), Lemke (1984), Ramirez *et al.* (1984), Fleming (1985), Fleming *et al.* (1985), Uieda and Vasconcellos-Neto (1984), Charles-Dominique (1986), Coates-Estrada and Estrada (1986), Dinerstein (1986), Fleming and Heithaus (1986), Herbst (1986), Bonaccorso and Gush (1987), Eguiarte *et al.* (1987), Sazima and Sazima (1987), Palmeirim *et al.* (1989), Sazima *et al.* (1989), Fleming and Williams (1990), Hokche and Ramirez (1990), Charles-Dominique (1991), Handley Jr and Leigh Jr (1991), Handley *et al.* (1991), Marinho-Filho (1991), Soriano *et al.* (1991), Ascorra and Wilson (1992), Buzato and Franco (1992), Fischer (1992), Hernandez and Martinez del Rio (1992), Muller and Reis (1992), Ascorra *et al.* (1993), Gribel and Hay (1993), Kress and Stone (1993), Sosa and Soriano (1993), Willig *et al.* (1993), Buzato *et al.* (1994), Galetti and Morellato (1994), Marinho-Filho and Vasconcellos-Neto (1994), Sazima *et al.* (1994a), Sazima *et al.* (1994b), Zortéa and Chiarello (1994), Cunningham (1995), Engriser (1995), Gorchov *et al.* (1995), Silva and Peracchi (1995), Figueiredo (1996), Sahley (1996), Sosa and Soriano (1996), Valiente-Banuet *et al.* (1996), Bizerríl and Raw (1997), Hernandez-Conrique *et al.* (1997), Iudica and Bonaccorso (1997), Locatelli *et al.* (1997), Nassar *et al.* (1997), Pedro and Taddei (1997), Petit (1997), Ruiz *et al.* (1997), Valiente-Banuet *et al.* (1997), Lppolito and Suarez (1998), Kalko and Condon (1998), Machado *et al.* (1998), Casas *et al.* (1999), Gastal and Bizerril (1999), Giannini (1999), Gibbs *et al.* (1999), Gribel *et al.* (1999), Sazima *et al.* (1999), Tschapka and Helversen (1999), Tschapka *et al.* (1999), Arizaga *et al.* (2000), Garcia *et al.* (2000), Godínez-Alvarez and Valiente-Banuet (2000), Ruiz *et al.* (2000), Slauson (2000), Soriano *et al.* (2000), Wendeln *et al.* (2000), Charles-Dominique and Cockle (2001), Herrera M *et al.* (2001a), Herrera M *et al.* (2001b), Kay (2001), Varassin *et al.* (2001), Banack *et al.* (2002), Coelho and Marinho-Filho (2002), Godínez-Alvarez *et al.* (2002), von2002glossophagine, Martino *et al.* (2002), Mikich (2002), Muchhala and Jarrin-V (2002), Stoner *et al.* (2002), Aguirre *et al.* (2003), Cáceres and Moura (2003), Lobo *et al.* (2003), Lobova *et al.* (2003), Mikich *et al.* (2003), Molina-Freaner and Eguiarte (2003), Naranjo *et al.* (2003), Nogueira and Peracchi (2003), Passos and Passamani (2003), Passos *et al.* (2003), Sazima *et al.* (2003), Giannini and Kalko (2004), Lima and Reis (2004), Lobova and Mori (2004), Lopez and Vaughan (2004), Machado and Vogel (2004), Mello *et al.* (2004), Passos and Graciolli (2004), Quesada *et al.* (2004), Thies and Kalko (2004), Tschapka (2004), Valiente-Banuet *et al.* (2004), Vogel *et al.* (2004), Aguiar (2005), Delaval *et al.* (2005), Ibarra-Cerdeña *et al.* (2005), Korine and Kalko (2005), Lobo *et al.* (2005), Mancina *et al.* (2005), Mello *et al.* (2005), Sanmartin-Gajardo and Sazima (2005), Tschapka (2005), Vogel *et al.* (2005), Acosta and Aguanta (2006), Arias-Cóyotl *et al.* (2006), Mancina *et al.* (2002), Muchhala (2006a), Muchhala (2006b), Tschapka *et al.* (2006), Aguiar and Marinho-Filho (2007), Estrada-Villegas *et al.* (2007), Lopez and Vaughan (2007), Mancina *et al.* (2007), Olea-Wagner *et al.* (2007), Oria and Machado (2007), and Tavares *et al.* (2007).

The interaction records of Giannini and Kalko (2004) do not appear in the original article as the information colected in that study were identified, reviewed, and manually added. The rest of the information can be verified in the original articles.

Taxonomic information: For bat species, we followed de taxonomic arrangement in Simmons and Cirranello (2020). We added a column with the current bat species name following verification of the taxonomy and geographic distribution. Taxonomic verification was conducted by Marcelo Nogueira. Taxonomic changes in the current name of species and geographic distribution was checked in Cole and Wilson (2006), Solari and Baker (2006), Mantilla-Meluk *et al.* (2009), Velazco *et al.* (2010), Mantilla-Meluk (2014), Nogueira *et al.* (2014), Tavares *et al.* (2014), Velazco and Patterson (2014), Velazco and Patterson (2019), Basantes *et al.* (2020), Catzeflis (2020), Lim *et al.* (2020), Ramírez-Chaves *et al.* (2020), Siles and Baker (2020), Tirira *et al.* (2020), Turcios-Casco *et al.* (2020), Vargas-Arboleda *et al.* (2020), and Velazco (2020). For plant taxonomy, we updated taxonomy and corrected for synonyms following The Plant List (2013) and REFLORA (2020).

Functional traits information: We reported the life form and the successional stage of plant species. We compiled this information from the literature (Dinerstein 1986; Galindo-González *et al.* 2000; Garcia *et al.* 2000, 2011; Kammesheidt 2000; Lopez and Vaughan 2004; Mantovani *et al.* 2005; Oatham and Ramnarine 2006; Olea-Wagner *et al.* 2007; Marimon *et al.* 2008; Fleming *et al.* 2009; Gusson *et al.* 2009; Ramos *et al.* 2011; Swanson *et al.* 2011; Sampaio *et al.* 2012; Condé and Tonini 2013; Paolucci *et al.* 2019; Aximoff *et al.* 2020), and also from the species information of the REFLORA (2020), and the virtual herbarium of the *Smithsonian Museum of Natural History* (https://collections.nmnh.si.edu/search/botany/) and the *Royal Botanic Garden Edinburgh* (https://data.rbge.org.uk/). The trophic guild classification of bat species was made following Gardner (1977), Willig (1986) and Soriano (2000).

C. Data limitations and potential enhancements

The NeoBat Interactions Database has some limitations, first of all a temporal bias. Although our database includes 50 years of publications on bat-plant interactions, it already has a delay of 14 years. This delay will be reduced in future updates, as our database has a live online version on GitHub. The second bias is related to representativeness: our database is clearly biased towards frugivory studies of common and abundant bat species. Thus, our database represents only a small subset of all bat-plant interactions that actually occur in the neotropical region. The rarefaction curve shows that despite having registered 1,581 interactions in 200 sampling sites, the curve is far from reaching an asymptote (Figure 5).

The lack of standardization of sampling methods makes it difficult to acquire interaction data in the field. Sampling methods vary significantly between studies focused on plants or bats. Studies focused on plants are sampled primarily through the observation of a single species and its floral visitors or fruit removers. On the other hand, studies focused on bats are made mainly by the analysis of fecal samples from one species or an entire local sub-assemblage of net-happy species. In these studies, capture is carried out mainly with mist nets, which adds a bias towards animals that fly in the understory and do not easily detect the nets (Tschapka 1998). Some studies used seed traps to sample the seed rain under the canopy (Medellin and Gaona 1999; Arteaga *et al.* 2006). However, these methods do not allow to identify which bat species each fecal sample belongs to, and therefore are not useful for recording pairwise interactions.

We also have identified some shortfalls in large-scale knowledge about bat-plant interactions in the region (Hortal *et al.* 2015), which we discuss in the following sections.

Linnean Shortfall: Identifying species is a great challenge for studying ecological interactions. Our database presents some gaps mainly in the identification of plants. 707 records of 2571 are identified only to the genus, 160 are recorded as "unidentified genus" of which only 116 are not even identified to the family. Nevertheless, bat taxonomy is better resolved, as only 57 records of *Platyrrhinus* from the Amazon and Venezuela and some small-sized *Artibeus* were not identified to the species. Most studies on frugivory and some on nectarivory come from the analysis of bat diets. This represents a great issue since identifying plant species from seeds and pollen is remarkably difficult. Carrying out diet studies involves a much greater effort than simply collecting and identifying biological samples. To improve the precision in plant identification from biological samples, it is necessary to make reference collections of seeds and pollen over long periods for a given study site. Some studies have chosen to use more advanced techniques, such as DNA barcoding, to identify diet items (González-Varo *et al.* 2014; Lim *et al.* 2018). These techniques can improve the taxonomic resolution of the data but lead to an increase in operating costs, which makes them almost inaccessible in many neotropical countries. On the other hand, studies on floral visitation and fruit removal carried out based on direct observation or photographic records can also lead to misidentification of bat species. In this sense, combining photographic records with mist-netting and other techniques can help researchers to solve identification issues, when voucher specimens cannot be collected.

Wallacean Shortfall: The lack of information about species geographic distributions is a worldwide

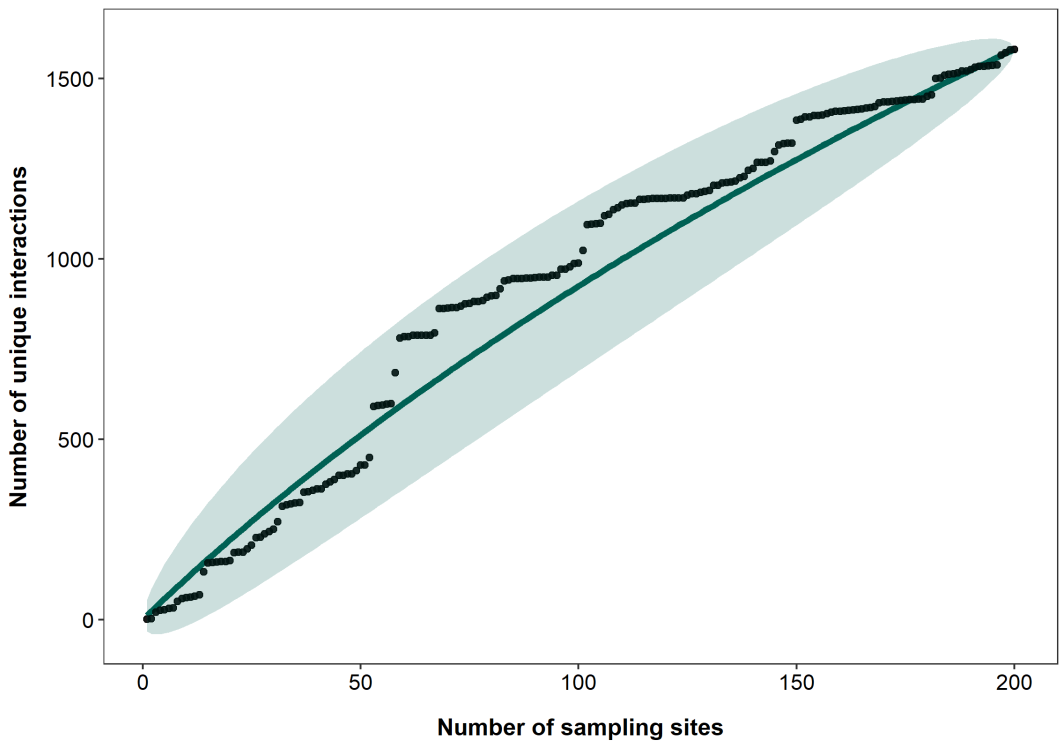

Figure 5: Interactions accumulation curve by sampling site. Black dots represent the empirical accumulation data, green line represents the rarefaction curve based on Chao2 non-parametric estimator and green polygon is the 95% confidence interval of the rarefaction curve.

issue (Lomolino 2004). Despite the increasing effort to sample animals and plants independently in studies about interactions, this effort is not enough to reduce this shortfall. Inferring ecological interactions only from co-occurrence data is not correct since interactions can be conditioned by other biotic and abiotic processes, more than the simple presence of the two species in the same place at the same time (Blanchet *et al.* 2020). In this database we have only compiled verified interactions, but there is clearly a large gap in sampling and publishing about bat-plant interactions in the region (Figure 1). There is huge amount of gray literature (especially theses) on bat-plant interactions produced by neotropical universities and research institutes. However, most of those grey sources are not digitally available or cannot be freely used, which makes it even harder to fill the gaps in knowledge about the geographic distribution of bat-plant interactions.

Prestonian Shortfall: This shortfall concerns the gap in knowledge about species abundance (Cardoso *et al.* 2011). Most papers compiled in our database (55.5% of records) provide information on the presence of each interaction, but they include no abundance data. Quantifying the strength of ecological interactions allows gaining insight into the complex structure of mutualistic networks, which is not possible when only binary data are available (Fründ *et al.* 2015). Due to the variety of sampling methods used, quantifying the frequency of bat-plant interactions in a comparable way is very difficult. Studies on bat diets, in which pollen or fecal samples are taken directly from the animal's body, generally report interaction frequency as the number of samples of each bat species in which pollen or seeds of each plant species were found. However, in many cases, the authors do not report the number of fecal samples collected for each bat species, and others only report the number of seeds obtained in the total samples of each bat species. Studies on plant visitation usually report the number of visits of each species of bats to each plant, and, in some cases, they report only the duration of flower visits or even the number of flowers visited. Despite being useful for studying autecology, much of these data are not useful for quantifying the strength of ecological interactions. Then, collecting and reporting data to calculate the frequency of interaction between pairs of species as a proxy for interaction strength could be an option to overcome this shortfall (Vázquez *et al.* 2005).

Eltonian Shortfall: This shortfall refers to the lack of information about species interactions (Hortal *et al.* 2015). We have extended the definition of this shortfall as the lack of verification about the type of interaction that takes place between a pair of species. Roughly, we tend to assume that frugivory necessarily implies seed dispersal, and nectarivory necessarily implies pollination. We even tend to define both interactions as mutualistic, but they are trophic in nature. Therefore, assumptions about mutually benetificial relationships are fragile without additional information. This issue gets even more complicated, when we consider that ecological interactions are not constant in time and space. The effect of one species on the fitness of another species can be modulated by intrinsic factors such as population densities, and extrinsic factors such as environmental conditions (Hernandez 1998). These conditional outcomes lead to a context-dependent transition from mutualism to antagonism (Bronstein 1994). Overcoming this shortfall for bat-plant interactions requires considerable effort. For instance, frugivory can only be assumed as mutualistic, if the balance between destruction and safe gut passage of seeds results in fitness gain for the plant (Genrich *et al.* 2017). Nectarivory can only be assumed as resulting in a mutualistic interaction of pollination, if the bat at least touches the reproductive structures of the flower. Nevertheless, many other criteria must be also met, depending on the plants floral biology. Consequently, benefits can be measured in many different ways, focusing on different stages of the reproductive cycle of each plant species (Simmons *et al.* 2018).

Our database points to the need for increasing the investment in systematic, long-term studies on bat-plant interactions. Future studies need to incorporate quantitative information about the interaction frequency, as well as modern techniques that improve the taxonomic resolution of species identification. We suggest caution in labeling bat-plant interactions as mutualistic. Potential biases derived from the shortfalls mentioned above should be taken seriously.

CLASS III. DATA SET STATUS AND ACCESSIBILITY

A. Status

Latest update: October 2020.

Latest archive date: October 2020.

Metadata status: Last updated January 2021, version submitted.

Data verification: Data were compiled as presented is in the sources. We corrected transcription errors, checked the geographic coordinates of study sites, and verified the taxonomic information.

B. Accessibility

Contact person: Guillermo Florez-Montero (gflorezmontero@gmail.com) or Marco Mello (marmello@usp.br).

Download link: https://github.com/gflorezm/NeoBat_Interactions

Copyright restrictions: Creative Commons Attribution 4.0 International License.

Proprietary restrictions: Please cite this *Ecology* data paper when the data are used in any kinds of publication, as well as research, outreach, and teaching activities.

Costs: None.

CLASS IV. DATA STRUCTURAL DESCRIPTORS

A. Data set file

Identity:

(1) NeoBat_Interactions_References.csv

(2) NeoBat_Interactions_Sites.csv

(3) NeoBat_Interactions_Records.csv

Size:

(1) NeoBat_Interactions_References.csv, 168 references, 34.9 KB

(2) NeoBat_Interactions_Sites.csv, 200 study sites, 49.4 KB

(3) NeoBat_Interactions_Records.csv, 2571 records, 402.3 KB

Format and storage mode: Data frames as comma-separated values (.csv)

Alphanumeric attributes: Mixed

Data anomalies: If no information is available for any cell, this is indicated as 'NA'.

B. Variable information

Table 3. References information

Table 4. Study sites information

Table 5. Interaction records information

CLASS V. SUPPLEMENTAL DESCRIPTORS

A. Data acquisition

1. **Data request history:** None
2. **Data set updates history:** None
3. **Data entry/verification procedures**

G. History of data set usage

The data were used in the following studies, in chronological order:

1. Mello, M. A. R., F. M. D. Marquitti, P. R. Guimarães Jr., E. K. V. Kalko, P. Jordano, M. A. M. de Aguiar, and P. R. Guimaraes.

2011. The missing part of seed dispersal networks: structure and robustness of bat-fruit interactions. PLoS One 6: e17395.

2. Mello, M. A. R., F. M. D. Marquitti, P. R. Guimarães, E. K. V. Kalko, P. Jordano, and M. A. M. de Aguiar.

2011. The modularity of seed dispersal: differences in structure and robustness between bat– and bird–fruit networks. Oecologia 167: 131–140.

3. Sarmento, R., C. P. Alves-Costa, A. Ayub, and M. A. R. Mello.

2014. Partitioning of seed dispersal services between birds and bats in a fragment of the Brazilian Atlantic Forest. Zoologia 31: 245–255.

4. Mello, M. A. R., F. A. Rodrigues, L. da F. Costa, W. D. Kissling, Ç.

H. Şekercioğlu, F. M. D. Marquitti, and E. K. V. Kalko.

2015. Keystone species in seed dispersal networks are mainly determined by dietary specialization. Oikos 124: 1031–1039.

5. Mello, M. A. R., G. M. Felix, R. B. P. Pinheiro, R. L. Muylaert, C. Geiselman, S. E. Santana, M. Tschapka, N. Lotfi, F. A. Rodrigues, and R. D. Stevens.

2019. Insights into the assembly rules of a continent-wide multilayer network. Nat. Ecol. Evol. 3: 1525–1532.

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TABLES

Table 3: Information about the references in the NeoBat Interactions database

Variable	Description	Levels	Example
RefCode	Identification of each reference. This code links the reference matrix to the other matrices	BPR001 to BPR168	BPR066
Author	Short name of the author(s), if there are three or more authors, we use et al.	...	Hernández-Conrique et al.
Year	Year of publication.	1957 to 2007	1997
Reference	Extended reference.	...	Hernández-Conrique, D., L.I. Iñiguez-Dávalos & J.F. Storz. 1997. Selective feeding by phyllostomid fruit bats in subtropical montane cloud forest. Biotropica 29: 376-379

Table 4: Information about the samplig sites in the NeoBat Interactions database

Variable	Description	Levels	Example
SiteCode	Identification of each sampling site. This code links the site matrix to the record matrix. In many cases, a paper can have more than one sampling site.	BPA001 to BPA200	BPA074
RefCode	Identification of each reference. This code links the reference matrix to the other matrices.	BPR001 to BPR168	BPR066

Table 4: Information about the samplig sites in the NeoBat Interactions database *(continued)*

Variable	**Description**	**Levels**	**Example**
Locality	Locality where fieldwork was carried out, based on information reported in the paper. We checked all names using the Google Earth database.	...	Sierra de Manantlan Biosphere Reserve
State	State, Department or Province of the study site based on the geographic coordinates.	...	Jalisco
Country	Country where fieldwork was carried out (English name).	Argentina Bolivia Brazil Colombia Costa Rica Cuba Curacao Ecuador French Guiana Jamaica Mexico Panama Peru Trinidad and Tobago United States Venezuela	Mexico
Latitude	Corrected latitude in decimal degrees (Projection WGS84 EPSG:4326). In studies with two or more sampling sites with less than 5 km of linear distance between them we used the centroid coordinate.	Decimal degrees	19.485675

Table 4: Information about the samplig sites in the NeoBat Interactions database *(continued)*

Variable	**Description**	**Levels**	**Example**
Longitude	Corrected longitude in decimal degrees. See Latitude for more information.	Decimal degrees	-103.950087
Precision	In some cases, papers reported the precise coordinates of each sampling site. Other papers reported only geographic references (basins, rivers, municipality, or distance from a village). In these cases, we validated these references with Google Earth satellite images. We consider Not Precise when coordinates mismatch the written information in the paper, or when the paper only reported the coordinates of the municipality or region.	Precise Not Precise	Precise
YearStart	The year in which sampling started.	1960 to 2006	1993
YearEnd	The year in which sampling ended.	1960 to 2006	1994
Duration	Unstandardized duration of the sampling period (in months).	1 to 37	7
SamplingEffort	For studies based on feces collection: Total number of fecal samples. For studies based on the observation of plant visitation events: Total number of events recorded.	6 to 6809	68

Table 4: Information about the samplig sites in the NeoBat Interactions database *(continued)*

Variable	**Description**	**Levels**	**Example**
StudyType	The type of study according to the focus reported in the reference paper. Bat diet refers to study focused on describing the diet of a bat species or assemblage. Plant visitation refers to studies aimed at describing the visitors of a plant species or assemblage.	Bat diet Plant visitation	Bat diet
EcologicalScale	The ecological scale studied. When there were more than one species of bat (when the Study type is Bat diet) or plant (when the study type is Plant visitation), we considered as Assemblage.	Population Assemblage	Assemblage
SamplingMethod	The sampling method as described in the reference paper. We have standardized the levels to five broad methods. Some studies have more than one sampling method	Direct observation Experimental Feces collection Pollen collection Roost inspection	Experimental
SamplingSeason	Climatic season in which sampling was performed. Some studies were conducted in both, dry and wet season.	Dry Wet	Dry and Wet
Vegetation	Vegetation type as described in the reference paper.	...	Subtropical montane cloud forest

Table 4: Information about the samplig sites in the NeoBat Interactions database *(continued)*

Variable	**Description**	**Levels**	**Example**
VegType	Vegetation type corrected according to Oliveira-Filho (2017).	Cloud forest Coastal sandy mosaic Deciduous forest Floodplain forest Limestone deciduous woodland Limestone Rainforest Mixed forest Montane woodland Rainforest Rocky woodland Savanna woodland Seasonal riverine forest Semi-arid thorny woodland Semi-desert and desert Semideciduous forest	Mixed forest
Ecoregion	Ecological region according to Olson et al. (2001).	...	Trans-Mexican Volcanic Belt pine-oak forests
Domain	Phytogeographic domain according to Oliveira-Filho (2017).	Amazonia Atlantic Forest Caatinga Caribbean Cerrado Los Llanos Mesoamerica Nearctic Mexico Northern Andes Southern Andes	Mesoamerica
Altitude	Meters above sea level reported in the reference paper.	2 to 2700	1900

Table 4: Information about the samplig sites in the NeoBat Interactions database *(continued)*

Variable	**Description**	**Levels**	**Example**
X1kmAlt	Meters above sea level, from the Hydro-1K dataset (United States Geological Survey-USGS, 2001. Global 30 arc-seconds Elevation (GTOPO30).	0 to 2686	2462
AnnRain	Annual Rainfall in mm from WorldClim 2.0 with 30 arc seconds resolution (Fick and Hijmans 2017).	66 to 3912	1116
MeaAnnTemp	Mean annual temperature in Celsius degrees from WorldClim 2.0 with 30 arc seconds resolution (Fick and Hijmans 2017).	10.3 to 27.9	14.2
PET	Global Potential Evapo-Transpiration (annual average in mm) from CGIAR-CSI (Trabucco and Zomer 2009), with resolution of 30 arc seconds.	1021 to 2588	1577
GAI	Global Aridity Index model from CGIAR-CSI (Trabucco and Zomer 2009), with resolution of 30 arc seconds.	0 to 3	0.7072

Table 5: Information about the interaction records in the NeoBat Interactions database

Variable	Description	Levels	Example
IDCode	Identification code of each interaction record.	BPI0001 to BPI2574	BPI0077
SiteCode	Identification of each sampling site. This code links the site matrix to the record matrix. In many cases, a paper can have more than one sampling site.	BPA001 to BPA200	BPA008
RefCode	Identification of each reference. This code links the reference matrix to the other matrices.	BPR001 to BPR168	BPR008
BatGenus	Current scientific name of the bat genus.	...	Uroderma
BatSpecies	Scientific name of the bat as reported in the reference paper.	...	Uroderma bilobatum
CurrentBatSpecies	Current scientific name of the bat species	...	Uroderma bilobatum
TrophicGuild	Trophic guild of the bat species	Foliage gleaner Frugivore Nectarivore Omnivore	Frugivore
PlantFamily	Current scientific name of the plant family.	...	Piperaceae
PlantGenus	Current scientific name of the plant genus.	...	Piper
PlantSpecies	Scientific name of the plant as reported in the reference paper.	...	Photomorpha peltata

Table 5: Information about the interaction records in the NeoBat Interactions database *(continued)*

Variable	**Description**	**Levels**	**Example**
CurrentPlantSpecies	Current scientific name of the plant, validated with The Plant List database (http://www.theplantlist.org) and the REFLORA database (http://reflora.jbrj.gov.br).	...	Piper peltatum
LifeForm	Life form of the plant species.	Herb Palm-tree Shrub Succulent Tree Vine	Shrub
SuccessionalStage	Successional stage of the plant species.	Early Late	Early
Interaction	Type of interaction described.	Frugivory Nectarivory	Frugivory
Weight	Frugivory: Number of fecal samples containing the plant seed.Nectarivory: Number of visits per sampling unit.	1 to 219	1

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