

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

Guillermo L. Florez-Montero<sup>1\*</sup>, Renata L. Muylaert<sup>2</sup>, Marcelo R. Nogueira<sup>3</sup>, Cullen Geiselman<sup>4</sup>, Sharlene E. Santana<sup>5</sup>, Richard D. Stevens<sup>6</sup>, Marco Tschapka<sup>7, 8</sup>, Francisco A. Rodrigues<sup>9</sup> and Marco A. R. Mello<sup>10</sup>

1 *Universidade Federal do ABC. Centro de Ciências Humanas e Naturais. 09210-580 Santo André, SP, Brazil.*

2 *Massey University. Molecular Epidemiology and Public Health Laboratory, Hopkirk Research Institute. 4442. Palmerston North, New Zealand.*

3 *Universidade Federal Rural do Rio de Janeiro. Instituto de Biologia, Laboratório de Mastozoologia. 23890-000 Seropédica, RJ, Brazil.*

4 *Bat Eco-Interactions Project, Houston, TX, USA.*

5 *Department of Biology and Burke Museum of Natural History and Culture, University of Washington, Seattle, WA, 98195, USA.*

6 *Department of Natural Resources Management and Natural Science Research Laboratory of the Museum of Texas Tech University, Lubbock, TX, USA.*

7 *Institute of Evolutionary Ecology and Conservation Genomics, Ulm University, Ulm, Germany.*

8 *Smithsonian Tropical Research Institute, Panamá City, Panamá.*

9 *Universidade de São Paulo. Departamento de Matemática Aplicada e Estatística, Instituto de Ciências Matemáticas e de Computação. 13560-970 São Carlos, SP, Brazil.*

10 *Universidade de São Paulo, Instituto de Biociências, Departamento de Ecologia. 05508-090 São Paulo, SP, Brazil.*

\*Corresponding author: Guillermo L. Florez-Montero (gflorezmontero@gmail.com)\*

# INTRODUCTION

*“We dedicate this work to the memory of our loving friend and mentor, Prof. Elisabeth Kalko, who we lost ten years ago and told us the value of sharing and caring”.*

Science is based on ideas, data, and trust. Trust comes from social contracts, which are enforced by directives and initiatives. One fundamental initiative proposed to enforce the social contract that governs scientific publishing is open access to primary data (Vision 2010). Open data initiatives foment transparency and reproducibility, as they are based on independent verification and reuse of published data (Costello 2009). Those goals are facilitated in the age of information through concrete frameworks for the production, storage, curation, and sharing of data. In addition, those frameworks aim to preserve data in the long term, beyond the life of their initial creators and curators (Chavan and Ingwersen 2009).

One major framework for making data available are data papers, which optimize efforts in discovery, organization, and availability of information (Chavan and Penev 2011). Data papers have the potential to offer highly reliable sources of information, as they are subjected to quality control protocols, such as peer review and editorial inspection of data and metadata (Costello *et al.* 2013). Furthermore, by introducing additional incentives related to publication and citation, this new type of publication has revolutionized contemporary biology. It made decades of natural history 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). Other important sources are the BioTIME database of biodiversity time series for the Anthropocene (Dornelas *et al.* 2018), and the Neotoma Paleoecology Database (<http://www.neotomadb.org>), a database of palaeobiological information of the recent geological past that contains ecological information on different levels of organization and taxa (Williams *et al.* 2018). Others have larger scope, such as the Global Database for Metacommunity Ecology (CESTES), integrating species, traits, environments, and spatial information (Jeliazkov *et al.* 2020). Other attempts have been made to harmonize and curate the largest data sets for mammal traits, phylogeny, viral sharing and other interactions, even attempting automatic incorporation of new data

and updates such as Virion (<https://www.viralemergence.org/virion>) and GloBI (<https://www.globalbioticinteractions.org/about>).

In Brazil, some of the most important mammalogical data papers were produced by the ATLANTIC and NEOTROPICAL series, which contain information about the biodiversity of the Atlantic Forest and the Neotropics, respectively. These series include static 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 have covered larger spatial scales, such as the Neotropical xenarthrans (Santos *et al.* 2019) and Neotropical carnivores (Nagy-Reis *et al.* 2020) data papers. In addition, most of these data sets, particularly from the Atlantic Forest and Cerrado, are based on abundance-incidence data, whereas species interactions received much less attention.

Despite having received much less attention in data papers, mutualistic interactions between animals and plants are a cornerstone of terrestrial ecosystems. Almost 94% of all 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 (Muscarella and Fleming 2007). In addition, even though insects pollinate most flowering plants, bats are also the second largest group of pollinating vertebrates since they pollinate about 2% of extant plant genera (Fleming *et al.* 2009). Bat-plant interactions therefore generate essential ecosystem services, such as the pollination of economically important plants and the dispersal of seeds from pioneer plants that are key to habitat maintenance and regeneration (Kunz *et al.* 2011). Interactions between frugivorous vertebrates and fruit-bearing plants were the focus of only one data paper so far (Bello *et al.* 2017).

In the present data paper, we have also compiled information on plant-animal interactions by focusing on frugivorous and nectarivorous bats and their food-plants. Other compilations with similar scope have been made in previous studies (Almeida and Mikich 2018), but none had been made publicly available in a curated database so far. We have put together a georeferenced database with 2,571 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 and spans the entire Neotropical region (Figure 1). The database compiled by Geiselman *et al.* (2004) was used as a starting point and was filtered, revised, and updated. We added mainly new literature, especially 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 accuracy. It is important to note that our database was compiled from trophic interactions. Only part of the original studies investigated the outcome of those interactions, either mutualistic or antagonistic. Therefore, we cannot state for sure that these interactions between bats and plants result in true seed dispersal or pollination in each case recorded.

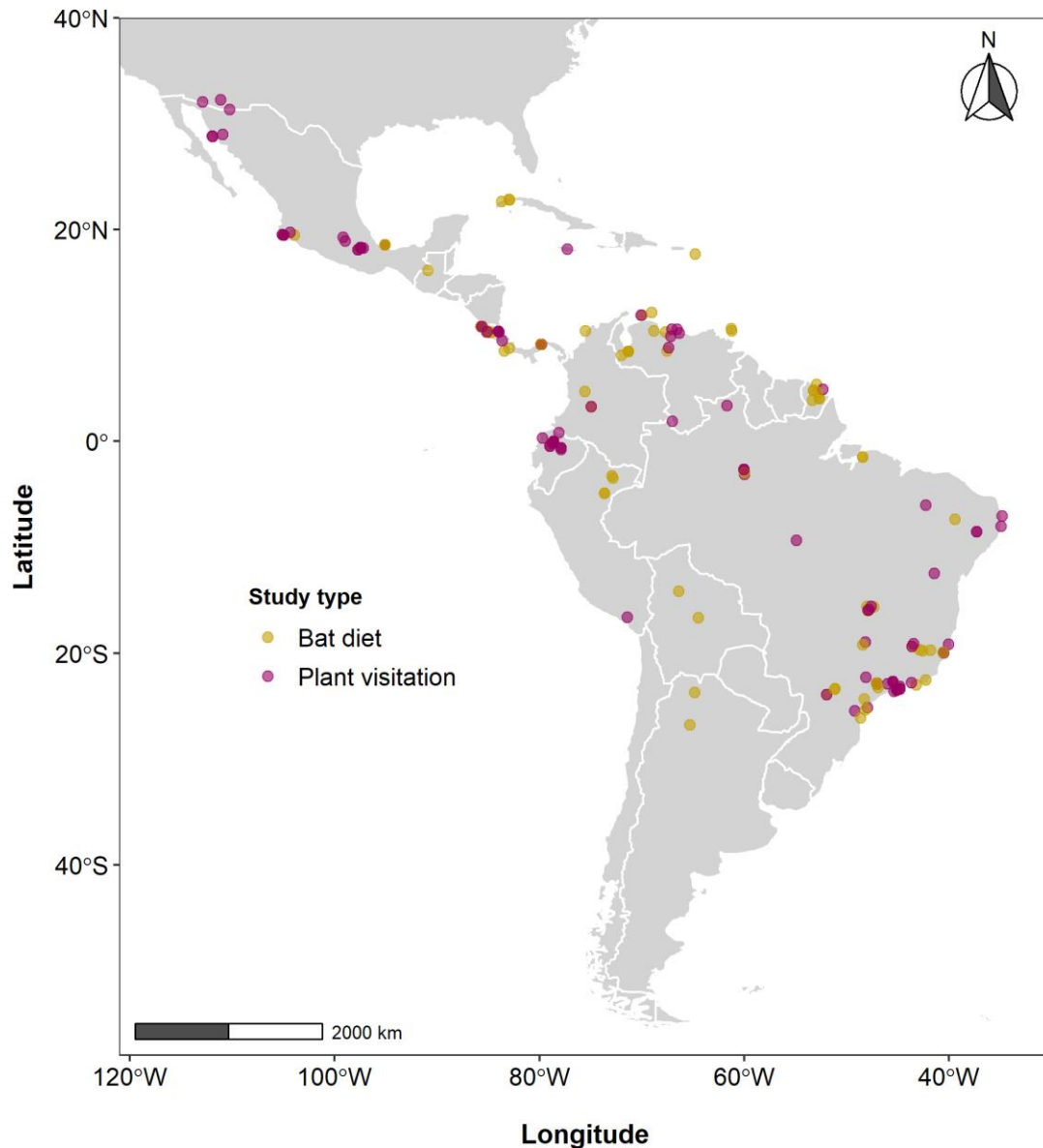


Figure 1: Distribution of sampling sites included in NeoBat Interactions. Dots show the location of original studies focused on plant visitation (purple) and bat diet (yellow). White lines show country borders. We included only studies with records of bat-plant interactions that were confirmed either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

All records in the NeoBat Interactions dataset came from primary literature sources and were taxonomically verified and updated. In addition, our database includes geographic and abiotic information such as vegetation type and rainfall for some study sites. Our database also includes ecological information for most species, such as a life form and successional stage of plants, and trophic guild of bats. Data are organized and standardized at different levels of ecological complexity and temporal and geographic scales, which will allow 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**

**Principal Investigator(s):**

1. Guillermo L. Florez-Montero. Universidade Federal do ABC. Centro de Ciências Humanas e Naturais. 09210-580 Santo André, SP, Brazil.
2. Marco A. R. Mello. Universidade de São Paulo, Instituto de Biociências, Departamento de Ecologia. 05508-090 São Paulo, SP, Brazil.

## Abstract:

Data papers and open databases have revolutionized contemporary science, as they provide the long-needed incentive to collaborate in large international teams and make natural history information widely available. Nevertheless, most data papers focus on species occurrence or abundance, while interactions have 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 and from 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) were the bat species with the broadest diets recorded based on number of plant species. Among plants, the best represented families were 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) exhibited 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 by far the most extensive both in geographic and taxonomic terms, and includes abiotic information of study sites, and ecological information of plants and bats. It has already facilitated several studies and we hope it will stimulate novel analyses and syntheses, in addition to pointing out important gaps in knowledge.

## D. Key words

Bats, Chiroptera, chiropterophily, chiropterochory, databases, data science, frugivory, mutualism, nectarivory, networks, Phyllostomidae, pollination, seed dispersal, species interactions.

## E. Description

This data set includes 2,571 records of interactions involving the consumption of nectar and fruits by bats, taken from studies focused on diets or plant visitation across the Neotropics between 1957 and 2007 (Figure 1). The information came from 16 countries, from the 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 homogeneous. Brazil (69 studies), Costa Rica (32), Mexico (27) 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, then increased steadily towards the 2000s (Figure 2B).

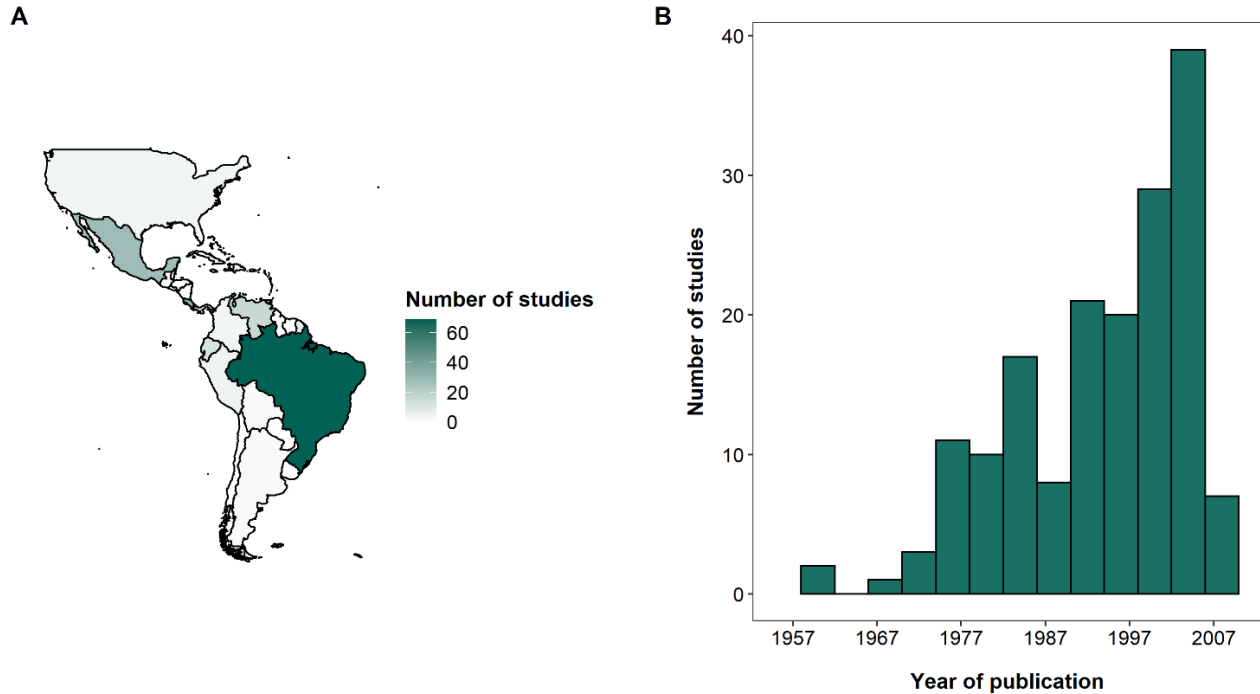


Figure 2: Distribution of studies on frugivory and nectarivory by bats by country (A) and throughout the recorded period (B).

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. For almost half of the plants there is 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
Successional stage of plants	Early	152	29.8
	Late	112	22.0
	No 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
	No 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 also been reported as hyper-dominant species in other community-focused databases (Muylaert *et al.* 2017) as they are cosmopolitan species, widely distributed



across the Neotropics (Gardner 2008). Only seven widely distributed species were responsible for nearly 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 *Sturnira lilium* (3.27%). In contrast, most bat species are infrequent. Sixty-seven species have a relative frequency  $\leq 1\%$  (Figure 3A). *Chiroderma gorgasi*, *Choeroniscus godmani*, *Choeroniscus minor*, *Glossophaga leachii*, *Glyphoncycteris sylvestris*, *Lamproncycteris 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.

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

Plants of the genera *Piper* (15.17% of the records), *Ficus* (15.13%), *Cecropia* (9.02%), and *Solanum* (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, representing 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 largest number of interactions as they can be very abundant and are also geographically widely distributed (Figure 3B). Most of the bat species (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*, *Lampronnycteris 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 the 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 interaction partners. The remaining plant genera (68) interact with between 6 and 16 bat species (Figure 3D).

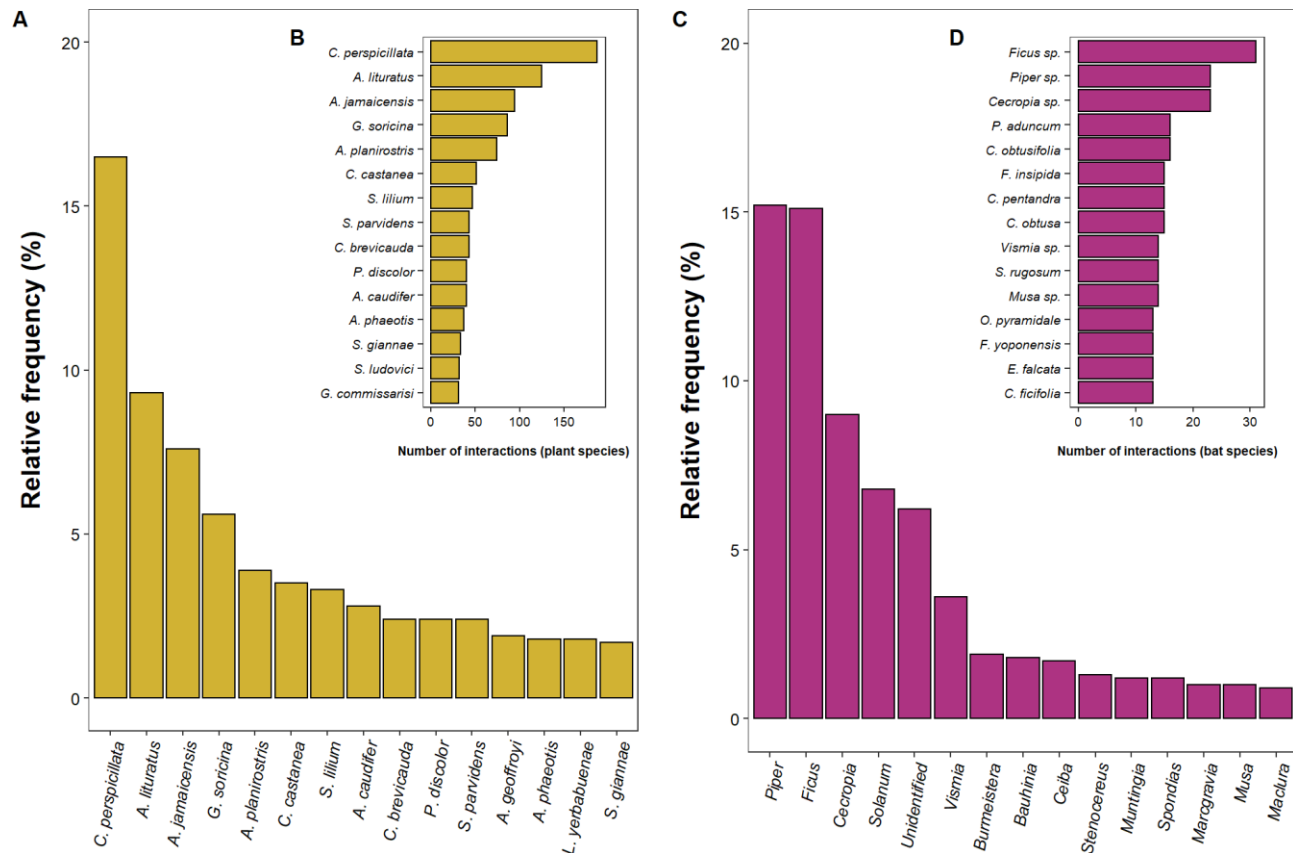


Figure 3: Ranking of frequency of the 15 most abundant bat species (A) and plant genera (C). Internal plots represent the number of each one of the 15 species of bats (B) and plants (D) with most interactions recorded in the NeoBat Interaction database.

Each species of plant interacts with a relatively small number of bat species and the number of interactions varies considerably ( $\mu=3$ , range=1-23). Most tree species account for most frugivory interactions (176 species, range=1-20 interactions) and the largest number of nectarivory interactions (68 species, range=1-15 interactions). Many shrubs (121 species) have interactions of frugivory (range=1-23 interactions), while only few species (18) interact with nectarivores (range=1-6 interactions). Despite trees and shrubs being the plant life form with the highest 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 observed for early successional plants (145 species) that interact with 1 to 20 bat species, while late successional plants (80 species) interact with 1 to 15 bat species. Conversely, nectarivory interactions came more from late successional plants (39 species) than early successional ones (13 species). The range of

interactions accounted by both groups of plants is 1-15 bat species (Figure 4B).

Most records in NeoBat Interactions come from fruit-eating bats. Frugivorous bats consume fruits of many plant species (range=1-188 interactions). Some species (18) may also eat nectar of a considerably wide number of plants (range=1-34 interactions). Nectarivorous bats eat nectar from 1 to 68 species and fruits from 1 to 28 species of plants. Species of omnivorous bats can consume fruits and nectar of up to 32 plant species. Finally, the database also contains records of a few mainly animalivorous bats of the genera *Lamproncycteris*, *Glyphonycteris*, *Trinycteris*, and *Micronycteris* that occasionally eat fruits and nectar of up to nine species of plants (Figure 4C).

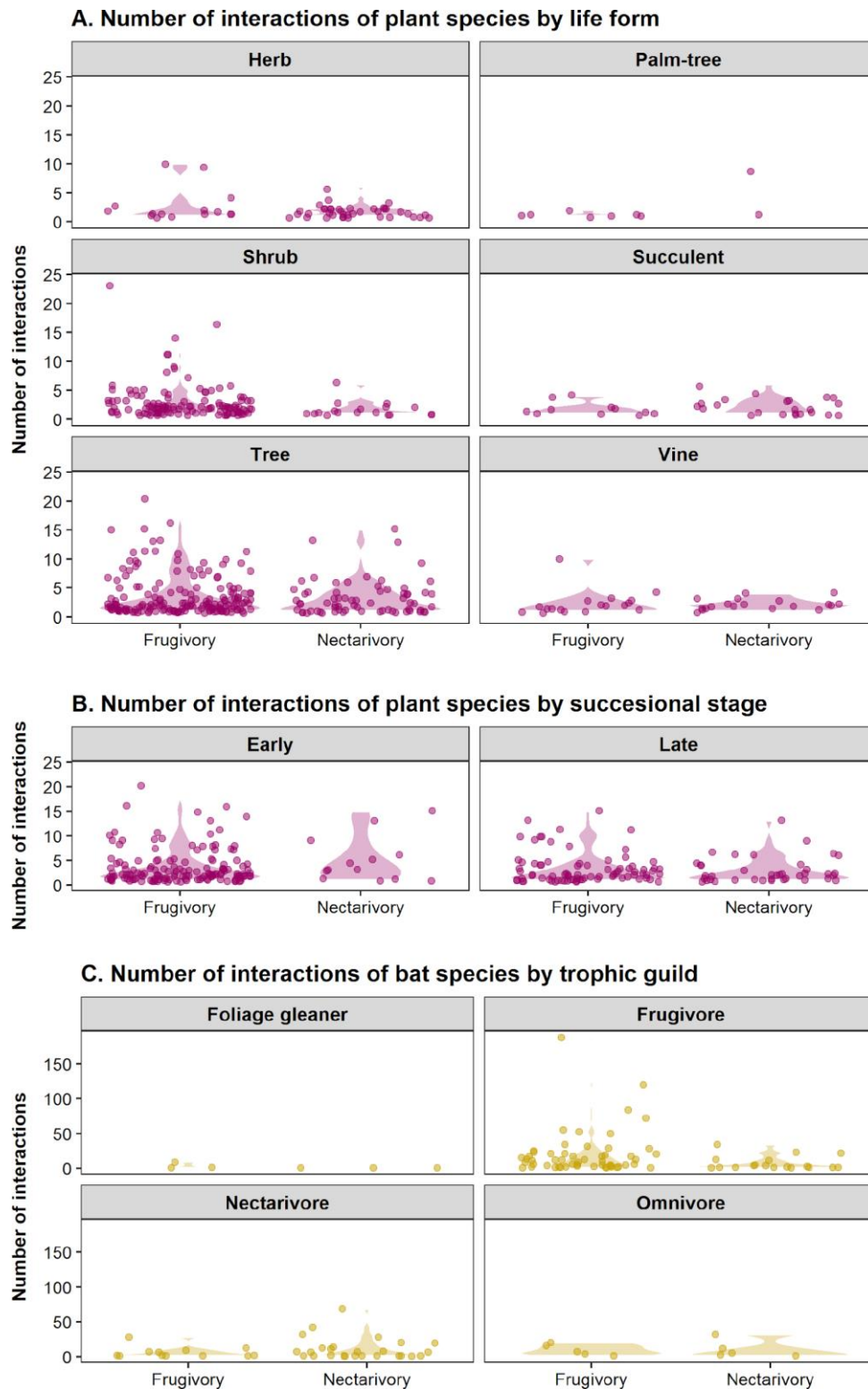


Figure 4: Number of interactions made by plant and bat species according to their ecological traits: A) Life form of plants, B) Successional stage of plants and C) Trophic guild of bats. Each violet point on A and B represents one plant species, each yellow point on C represents one bat species.

## CLASS II. RESEARCH ORIGIN DESCRIPTORS

### A. Overall project description

**Identity:** A compilation of bat-plant interactions in the Neotropics.

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

**Objectives:** We aimed (1) to summarize and make available 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 knowledge about bat-plant interactions (Eltonian shortfalls) to direct future research and sampling effort. This data set represents the most extensive and complete catalogue of bat-plant interactions in the Neotropics.

**Abstract:** Same as above.

**Source of funding:** This study was financed by the Brazilian Coordination for the Improvement of Higher Education Personnel (CAPES, grad 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 Neotropics 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 comprises 17 phytogeographic domains divided into 96 ecoregions including the Nearctic Mexico Domain (Oliveira-Filho 2017). The vegetation of the region is very diverse, including xeric and thorny shrub lands, 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, Caribbean 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 Inter- action Database (Geiselman *et al.* 2004), currently known as Bat Eco-Interactions (Geiselman and Younger 2020). We have also carried out a bibliographic search of different sources: (1) the online databases Web of Knowledge, Scopus, Scielo, and Google Scholar; (2) references cited in the literature; and (3) direct communication 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 technical reports, books chapters, and unpublished data. For each sampling site we collected information about vegetation type, mean temperature, rainfall, elevation, potential evapotranspiration, and an aridity index (see Table 4).

**Research methods:** We included studies that reported interactions of frugivory or nectarivory on native plants in the field, through the analysis of bat diets, observation of plant visitation, and captive 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 published between 1957 and 2007 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), Bizerril 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), Ippolito 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 *et al.* (2001a), Herrera *et al.* (2001b), Kay (2001), Varassin *et al.* (2001), Banack *et al.* (2002), Coelho and Marinho-Filho (2002), Godínez-Alvarez *et al.* (2002), Helversen *et al.* (2002), 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- Cáyotl *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 collected 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 the 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 were 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), Catzefflis (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 *Royal Botanic Garden Edinburgh* (<https://data.rbge.org.uk/>) and the *Smithsonian Museum of Natural History* (<https://collections.nmnh.si.edu/>). 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 a temporal bias. Although our database encompasses 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 using common and abundant bat species, and plant species with small-seeded fruits that are swallowed and show up in fecal samples as a model system. Thus, our database represents only a small subset of all bat-plant interactions that 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).

In addition to those two biases, the lack of standardization of sampling methods across studies makes it difficult to acquire interaction data in the field. Sampling methods vary significantly between studies focused on plants or bats. On the one hand, studies focused on plants are sampled primarily through the observation of a single species and its floral visitors or fruit removers. Moreover, studies focused on bats are made mainly by the analysis of fecal samples from one species or an entire local sub-assemblage of species that are more readily caught. In those 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). Nevertheless, the bias caused by mist-netting is more severe for studies focused on sampling entire bat assemblages. In the case of studies on bat-plant interactions, almost all species from this small world belong to the family Phyllostomidae, which is the least affected by the mist-netting bias. Other 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 identification of which bat species each fecal sample belongs to, and therefore are not useful for recording pairwise interactions.

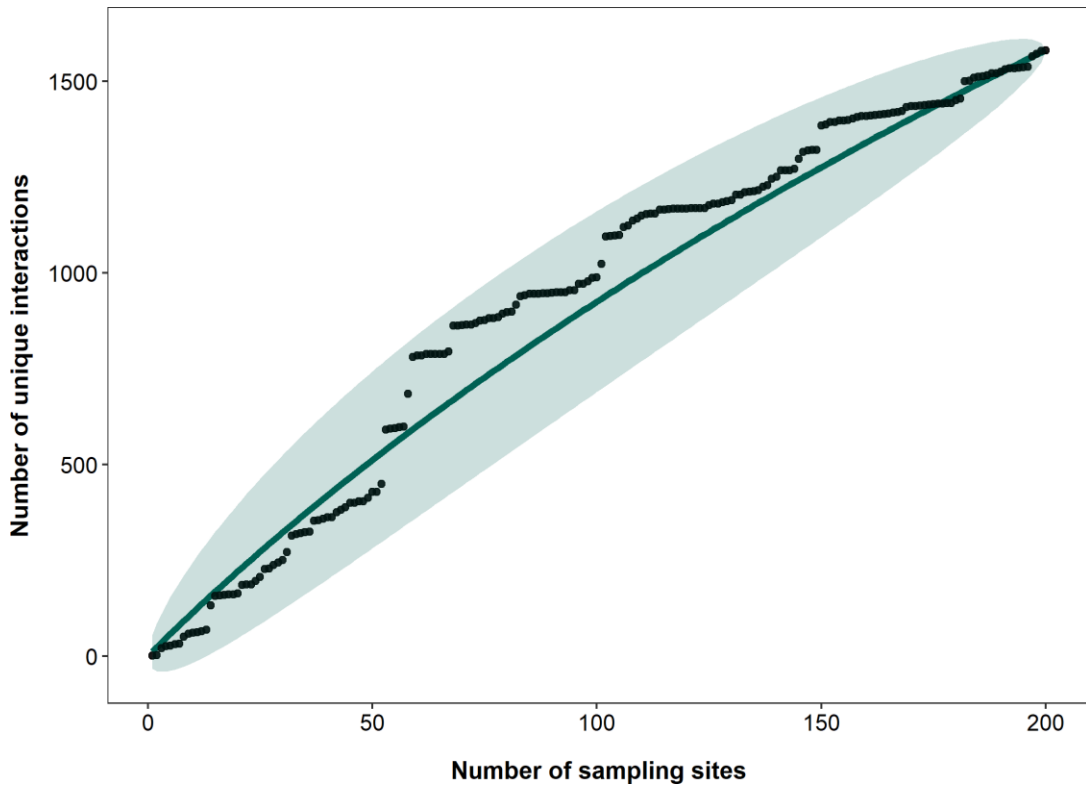


Figure 5: Interaction accumulation curve by sampling site. Black dots represent the empirical accumulation data, green line represents the rarefaction curve based on Chao2 non-parametric estimator and green polygon is the 95% confidence interval of the rarefaction curve.

We also have identified some shortfalls in large-scale knowledge about bat-plant interactions in the Neotropics (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 in the literature, mainly in the identification of plants. In 707 out of 2,571 records, plants are identified only to the genus, and in 160 they are recorded as “unidentified genus”, and in 116 of those records they 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 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 of plant identification from biological samples, it is necessary

to build reference collections of seeds and pollen over long periods for a given study site. Increasingly, molecular techniques, such as DNA barcoding are used to identify diet items (González-Varo *et al.* 2014; Lim *et al.* 2018). If reference sequences for plant taxa are available (e.g., from a reference library, or in GenBank), these techniques can improve the taxonomic resolution of the data. However, there is a lack of reference sequence libraries that enable the correct identification by DNA of the species present in the diet. Furthermore, researchers must also lead with an increase in operating costs, which makes these techniques almost inaccessible in Latin-American 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 solve identification issues, when voucher specimens cannot be collected.

**Wallacean Shortfall:** The lack of information about species geographic distributions is a worldwide issue (Lomolino 2004). Despite the increasing effort to sample animals and plants independently in studies about interactions, we need a stronger effort to reduce this shortfall. Inferring ecological interactions only from co-occurrence data sometimes is not appropriate since interactions can be conditioned by biotic and abiotic processes, which are more complex 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 a 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 provides insight into the complex structure of mutualistic networks, which is not possible when only binary data are available (Fründ *et al.* 2016). 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 total 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. Yet, 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. Bats are very opportunistic and flexible animals with high energy requirements and may use besides their co-evolved plant partners alternative food sources. Nectarivorous bats can visit flowers with other pollination syndromes (Tschapka and Helversen 1999) and may even accept artificial nectar feeders (Maguiña and Muchhala 2017). Among frugivorous phyllostomids, the genus *Chiroderma* is known to feed destructively on seeds of *Ficus* spp. (Nogueira and Peracchi 2003, Wagner *et al.* 2015). Therefore, assumptions about mutually beneficial relationships are fragile without additional information (Tschapka 2003). 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 and alternative resources (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 also be met, depending on the plant's floral biology (King *et al.* 2013). Consequently, benefits can be measured in many 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 interaction frequency, as well as modern techniques that improve the taxonomic resolution of species identification. Although bats are recognized for delivering vital ecological services to plants, we suggest caution in labeling all bat-plant interactions as mutualistic, as the outcome of each interaction event is conditioned by several factors. We need more natural history data and experiments to unveil complex cases, such as dual relationships (Genrich *et al.* 2017). 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 May 2021, version submitted.

**Data verification:** Data were compiled as presented 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](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. Sarmiento, 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. 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. *Nature Ecology and Evolution* 3: 1525–1532.



## ACKNOWLEDGMENTS

First, we thank Mauro Galetti and Milton Ribeiro, from the State University of São Paulo, Brazil, who started the Atlantic Series of data papers and so sparked a revolution that inspired our community to take their data out of their drawers. Our lab mates, colleagues, and institutions helped us at different stages of this project. Coauthors of previous publications derived from these data helped us polish our data set. Our sponsors, especially the Alexander von Humboldt Foundation (AvH), German Academic Exchange Service (DAAF), Brazilian Council of Scientific and Technological Development (CNPq), Brazilian Coordination for the Improvement of Higher Education Personnel (CAPES), São Paulo Research Foundation (FAPESP), and Research Dean of the University of São Paulo (PRP-USP), supported our research with grants, fellowships, and scholarships. Last, but not least, we thank the Stack Overflow Community, where we solve most of our coding dilemmas.

## 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 <i>et al.</i>	...	Hernández-Conrique <i>et al.</i>
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. <i>Biotropica</i> 29: 376-379

Table 4: Information about the sampling 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 sampling 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 sampling sites in the NeoBat Interactions database (continued).

<b>Variable</b>	<b>Description</b>	<b>Levels</b>	<b>Example</b>
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 sampling sites in the NeoBat Interactions database (continued).

<b>Variable</b>	<b>Description</b>	<b>Levels</b>	<b>Example</b>
StudyType	The type of study according to the focus reported in the reference paper. Bat diet refers to a 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 was more than one species of bat (when the Study type is Bat diet) or plant (when the study type is Plant visitation), we considered 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 seasons.	Dry Wet	Dry and Wet
Vegetation	Vegetation type as described in the reference paper.	...	Subtropical montane cloud forest

Table 4: Information about the sampling sites in the NeoBat Interactions database (continued).

<b>Variable</b>	<b>Description</b>	<b>Levels</b>	<b>Example</b>
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 Llano Mesoamerica Nearctic Mexico Northern Andes Southern Andes	Mesoamerica
Elevation	Meters above sea level reported in the reference paper.	2 to 2700	1900

Table 4: Information about the sampling sites in the NeoBat Interactions database (continued).

<b>Variable</b>	<b>Description</b>	<b>Levels</b>	<b>Example</b>
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 Evapotranspiration (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.	...	<i>Uroderma</i>
BatSpecies	Scientific name of the bat as reported in the reference paper.	...	<i>Uroderma bilobatum</i>
CurrentBatSpecies	Current scientific name of the bat species	...	<i>Uroderma bilobatum</i>
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.	...	<i>Piper</i>
PlantSpecies	Scientific name of the plant as reported in the reference paper.	...	<i>Photomorpha peltata</i>



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 ( <a href="http://www.theplantlist.org">http://www.theplantlist.org</a> ) and the REFLORA database ( <a href="http://reflora.jbrj.gov.br">http://reflora.jbrj.gov.br</a> ).	...	<i>Piper peltatum</i>
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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