

# Foraging-dependent ecosystem services

# 15

Rieka Yu, Nathan Muchhala

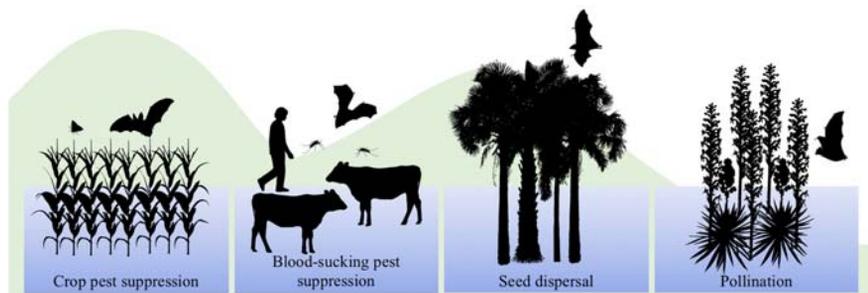
*Department of Biology, University of Missouri – St. Louis, St. Louis, MO, United States*

## Introduction

Healthy ecosystems deliver regulatory and supporting processes as well as provisions and cultural benefits that sustain all life, including human beings. These are considered ecosystem services (United Nations Millennium Ecosystem Assessment, 2005). Regulatory processes include insect suppression, pollination, seed dispersal, water, and air purification. These support nutrient cycling, soil formation, and primary production as well as providing food, fuel, and medicines. Cultural benefits include any aesthetic, spiritual, educational, or recreational contributions that improve human life (Kunz et al., 2011). Here, we focus on the ecosystem services provided by bats, specifically through their foraging behaviors.

Bats (Chiroptera) are the second largest order of mammals. The first fossils are over 50 million years old (Rietbergen et al., 2023). The over 1400 extant species (Simmons and Cirranello, 2023) are classified in two suborders, Yinpterochiroptera and Yangochiroptera (Simmons and Cirranello, 2023). Insectivory is the most common diet, but other foods include other animals as well as plants (Kunz et al., 2011). Within Yinpterochiroptera, most species feed primarily on fruit and nectar. Yangochiroptera include species that primarily eat nectar, fruits, frogs, fishes, birds, arthropods, small mammals, and blood (Fleming and Muchhala, 2008; Hall et al., 2021; Muscarella and Fleming, 2007; Rojas et al., 2012).

With this large variety of dietary guilds, combined with consuming large amounts of food relative to their body size, bats contribute to insect suppression, seed dispersal, and pollination. These important ecological processes translate into ecosystem services (Fig. 15.1). About 2/3 of bat species eat mainly insects, some of which are pests of plants and animals (Kunz et al., 2011). By their diet, insectivorous bats may minimize pest damage to crops, leading to higher yields and lower costs for pest control (Russo et al., 2018; Tuneu-Corral et al., 2023). Frugivorous and nectarivorous bats pollinate over 500 species of angiosperms and disperse the seeds of more than 500 plant species, many of which are economically important and provide provisions such as fruit or timber (Fleming and Muchhala, 2008; Lobova et al., 2009). Frugivorous and nectarivorous bats also disperse pioneer species, supporting forest regeneration. They may also be important in maintaining



**FIGURE 15.1**

Bats provide direct benefits by eating insects, fruits, and nectar. Insectivorous bats consume crop pests, minimizing economic losses from crop damage and also feed blood-sucking pests that are harmful to both livestock and humans. Frugivorous bats disperse seeds, aiding in dispersal of forest regeneration and connectivity. Nectarivorous bats are important pollinators for many flowering plants, facilitating plant mating and genetic diversity.

genetic diversity of plant populations through pollination and seed dispersal (Biscaia de Lacerda et al., 2008; Law and Lean, 1999; Muscarella and Fleming, 2007).

Unfortunately, many anthropogenic activities threaten bats and the ecosystem services they provide. Bats are too often perceived as vectors of diseases, such as rabies, or even as supernatural vampire-like creatures, contributing to the intentional killing of bats (Frick et al., 2020; Tuttle, 2013). Hunting bats for food has led to the decline and local extinction of many species (Mickleburgh et al., 2009). Habitat destruction and land-use change have led to greater bat mortality by removing foraging and roosting habitats and causing declines in prey abundance (Frick et al., 2020; Muylaert et al., 2016; Russo and Ancillotto, 2015). In Canada and the United States, 12 bat species are declining due to white-nose syndrome, a fungal infection that causes hibernating bats to arouse more frequently than normal, provoking an often fatal physiological cascade (Hoyt et al., 2021). Here, we examine the direct and indirect benefits that bats provide to ecosystems and humans by consuming arthropods, fruits, and nectar. We briefly touch on ecosystem disservices and conclude with conservation recommendations to maintain and protect the ecosystem services provided by bats.

## Arthropod suppression

Insectivorous bats have a significant impact in ecosystems, with more than half of bat species eating mainly insects. These bats forage by gleaning insects from vegetation and water bodies or by hunting insects in open areas such as grasslands, agricultural fields, and forest canopy. Below, we discuss the role of bats in pest suppression in agricultural and natural systems.

Although small, insectivorous bats consume a lot of insects in terms of total biomass. In several species, individuals eat more than half of their body weight each night (Kunz et al., 1995; Russo et al., 2018). There are estimates that the little brown bat (*Myotis lucifugus*) daily can consume more than 100% of its body mass, and the Brazilian free-tailed bat (*Tadarida brasiliensis*) may consume up to 70% of its body mass each night (Kurta et al., 1989). A dietary analysis of the common big-eared bat (*Micronycteris microtis*) shows that daily, it can eat up to 84% of its own body mass of 5–7 g, with a population of 600 individuals in Barro-Colorado Island eating at least 700 kg of insects per year (Kalka and Kalko, 2006). One colony of one million female Brazilian free-tailed bats is estimated to consume at least eight tonnes of insects in one night (Kalka and Kalko, 2006; Kunz et al., 2011).

As generalist predators, insectivorous bats eat a range of insects, largely of the orders of Lepidoptera, Coleoptera, Diptera, Homoptera, and Hemiptera (Black, 1974; Kunz, 1974; Kunz et al., 1995; Kurta and Whitaker, 1998; Lee and McCracken, 2002; Leelapaibul et al., 2005; Whitaker, 1972). These arthropod orders include agricultural pests such as June beetles, click beetles, leafhoppers, plant hoppers, spotted cucumber beetles, Asiatic oak weevils, green stinkbugs, cotton bollworm, and pest moths (Baroja et al., 2021; Brown et al., 2015; Cohen et al., 2020; Des Marais et al., 1980; Froidevaux et al., 2017; Jay et al., 2012; Kolkert et al., 2021; Mizutani et al., 1992; Rodríguez-San Pedro et al., 2020; Taylor et al., 2018; Whitaker, 1972; Williams-Guillén et al., 2008; Tuneu-Corral et al., 2023).

Insectivorous bats track arthropod abundance, as seen by the temporal correlation between bat and prey activity on annual and daily bases (Charbonnier et al., 2014; Maine and Boyles, 2015; McCracken et al., 2012). Other studies show spatial correlations between bat and insect prey activity (Fukui et al., 2006; Müller et al., 2012). The benefits of tracking are seen in Brazilian free-tailed bats that follow corn earworm moths migrating north into the United States. Corn earworm moths (*Helicoverpa zea*) will migrate to the United States and lay eggs in silking corn (*Zea mays*) after which larvae emerge to infest surrounding crops, most notably cotton (*Gossypium* spp), and continue migrating north (Lingren et al., 1993; Westbrook et al., 1995; Wolf et al., 1990). By tracking the billions of corn earworm moths that migrate to the United States, Brazilian free-tailed bats not only prevent them from laying eggs but may avoid their migration to other agricultural settings in the country, ultimately preventing crop damage in areas far outside of their foraging range (Kunz et al., 2011; McCracken et al., 2012).

Globally, insectivorous bats are estimated to prevent the loss of up to 50% of crops by feeding on such pests (Pimentel et al., 1978) and thereby yield strong economic benefits (Table 15.1). In an Indonesian cacao (*Theobroma cacao*) plantation, bat exclusions lead to a decrease in the numbers of seeds produced and fruits harvested (Maas et al., 2013). When birds and bats are excluded, there is a 326 kg/ha loss of cacao yield, which translates to a loss of 730 USD/ha (Maas et al., 2013). For corn, pest suppression by bats is estimated to be worth more than 1 billion USD per year (Maine and Boyles, 2015). In fact, bat exclusion in cornfields lead to increased numbers of corn earworm larvae and a more than 50% increase in

**Table 15.1** Known economic evaluations of ecosystem services provided by bats. For insectivorous bats, economic values are given for specific services provided to crop plants. For nectarivorous bats, economic values are given for the commercial sale of plants. Economic values are listed per hectare when available.

Taxon	Service	Economic value (USD)/year	Geographic area	Source
Cacao <i>Theobroma cacao</i>	Pest suppression	\$730/ha	Napu Valley, Sulawesi, Indonesia	Maas et al. (2013)
Corn <i>Zea mays</i> (non-Bt)	Pest suppression	\$851 million	Global	Maine and Boyles (2015)
	Pest suppression with pesticide spray	\$886/ha	Winter Garden Region, Texas, USA	Federico et al. (2008)
Corn <i>Zea mays</i> (Bt)	Pest suppression	> \$1 billion	Global	Maine and Boyles (2015)
	Pest suppression with pesticide spray	\$214/ha	Winter Garden Region, Texas, USA	Federico et al. (2008)
Cotton <i>Gossypium</i>	Reduced pesticide use	\$200,000	Winter Garden Region, Texas, USA	Cleveland et al. (2006)
Cotton <i>Gossypium</i>	Reduced public health and environmental costs of pesticide use	\$6000	Winter Garden Region, Texas, USA	Cleveland et al. (2006)
Cotton <i>Gossypium</i>	Pest suppression	\$12.24 million	Southwestern USA	López-Hoffman et al. (2014)
All US agriculture	Pest suppression and reduced pesticide use	\$229 billion	USA	Boyles et al. (2011)
Rice <i>Oryza</i>	Pest suppression	\$1,213,997	Thailand	Wanger et al. (2014)
	Reduced pesticide use	\$22/ha	Buda Island, Ebre Delta, Iberia	Puig-Montserrat et al. (2015)
Durian <i>Durio</i>	Commercial fruit	\$117/ha	Sulawesi, Indonesia	Sheherazade et al. (2019)
	Commercial fruit	\$120 million	Southeast Asia	Myers (1985)

**Table 15.1** Known economic evaluations of ecosystem services provided by bats. For insectivorous bats, economic values are given for specific services provided to crop plants. For nectarivorous bats, economic values are given for the commercial sale of plants. Economic values are listed per hectare when available.—*cont'd*

Taxon	Service	Economic value (USD)/year	Geographic area	Source
Bitter bean <i>Parkia speciosa</i> and tree bean <i>P. javanica</i>	Commercial fruit	\$15 million	Peninsular Malaysia	Ng (1980); Fujita and Tuttle (1991)
Kapok tree <i>Ceiba pentandra</i>	Fiber	\$4.5million	Indonesia	Indonesian Bureau of Statistics (1986); Fujita and Tuttle (1991)
	Seed oil	\$500,000	Indonesia	Indonesian Bureau of Statistics (1986); Fujita and Tuttle (1991)
<i>Palaguium</i>	Timber	> \$5 million	Malaysia	Fujita and Tuttle (1991)

the number of damaged kernels per ear of corn (Maine and Boyles, 2015). Bats also suppress pests in pine (*Pinus* spp) plantations, where higher bat activity has been correlated with a decrease in colonies of the pine processionary moth (*Thaumetopoea pityocampa*), a major defoliator of pines (Charbonnier et al., 2014).

By eating crop pests, bats help farmers reduce their expenditures on insecticides. Insectivory by Brazilian free-tailed bats allows cotton growers to reduce the frequency of insecticide applications (Federico et al., 2008), minimizing costs and negative ecological impacts such as pollinator declines and pollution of aquatic ecosystems (Potts et al., 2016; Stoler et al., 2017).

Bats can also reduce crop damage by pests even when not directly feeding on them; some insects with bat-detecting ears avoid areas where bats are active, creating a “soundscape of fear” (Russo et al., 2018). In the evolutionary arms race between bats and moths, crop pest moths have evolved tympanic organs that allow them to hear echolocation calls (ter Hofstede and Ratcliffe, 2016). When these tympanate moths are exposed to broadcast bat echolocation calls in agricultural landscapes, there is lower pest infestation and a disruption of moth mating behaviors (Acharya and McNeil, 1998; Belton and Kempster, 1962; Huang et al., 2003; Huang and Subramanyam, 2004).

As pests damage leaves of crop plants, fungal infections and their mycotoxins and metabolic byproducts increase (Diekman and Green, 1992; Fennell et al., 1975). In corn, fungi such as *Aspergillus flavus* and *Fusarium graminearum* commonly infect ears damaged by corn earworm moths (Fennell et al., 1975). Fumosin (a fungal mycotoxin) can make livestock vomit and eat less feed, while other mycotoxins can disrupt the reproduction of livestock (Diekman and Green, 1992). Mycotoxin contamination has large economic costs, with one estimate of 197 million USD in losses due to contaminated corn (Shane, 1984). By feeding on corn earworm moths, bats indirectly suppress these fungal infections and mycotoxins (Maine and Boyles, 2015), thereby rendering a critical ecosystem service to livestock producers and crop farmers (Diekman and Green, 1992).

Bats also consume blood-sucking pests, with DNA analysis of fecal samples show that bats eat mosquitos and biting midges, which can be harmful to human and nonhuman animals (Cohen et al., 2020; Puig-Montserrat et al., 2020). Although there is no study to our knowledge that has directly examined the effect of bat insectivory on cattle, foraging on blood-sucking pests can potentially minimize weight loss and reduction in milk production in cattle (Ancillotto et al., 2017). Although we found no studies that directly examined the effect of bat insectivory on human health, bats eating mosquitos may bring direct benefits, as half the world is at risk of mosquito-borne diseases (Aguiar et al., 2021; World Health Organization, 2014).

---

## Pollination and seed dispersal

All members of the family Pteropodidae are phytophagous, and most of them are frugivorous (Muscarella and Fleming, 2007). Within Pteropodidae, 15 species are morphologically adapted to drink nectar with elongated snouts and tongues. The rest are mainly frugivorous with some opportunistically visiting flowers (Kunz et al., 2011; Nogueira et al., 2009). Over half of phyllostomids are plant-visitors, with 52 species specializing in nectar (Muchhala and Tschapka, 2020) and ca. 90 species primarily eating fruits (Kunz et al., 2011). Unlike insectivorous bats, plant-visiting bats may provide ecosystem services through mutualistic interactions, moving plant gametes and propagules in return for fruit and nectar.

These mutualistic interactions may provide benefits for humans as well since many plants that are dispersed and pollinated by bats are eaten by humans (Table 15.1). Bats frequently visit plants that are cultivated and traded for the production of fruits, seeds, and nuts (Aziz et al., 2021). However, there has been limited research evaluating the economic value of fruit crops dispersed by bats. This difficulty arises from challenges in accurately identifying and quantifying the economic values of locally sold crops (Kunz et al., 2011).

Other plants visited by bats have provisional values, such as having oil for scented items, being used as pulp or timber, or being cultivated as ornamentals (Gardner, 1977; Lobova et al., 2009). In the neotropics, the five plant families (Cactaceae, Arecaceae, Sapotaceae, Moraceae, Myrtaceae) dispersed by the greatest number of

phyllostomid genera include 1.6% by volume of exported timber (Muscarella and Fleming, 2007). In tropical Asia and Australia, the five plant families (Sapotaceae, Anacardiaceae, Meliaceae, Arecaceae, Rubiaceae) dispersed by the greatest number of pteropodid genera includes 3.7% by volume of exported timber. In tropical Africa, the five plant families dispersed by the greatest number of pteropodid species include 34.3% by volume of exported timber (Muscarella and Fleming, 2007). Some nectarivorous bats are the sole or major pollinators for plants with economic and provisional benefits such as *Agave* (Rocha et al., 2005; Trejo-Salazar et al., 2016) and two species of columnar cacti, *Carnegiea gigantea* and *Stenocereus thurbei* (Fleming and Valiente-Banuet, 2002).

Pollination and seed dispersal by bats indirectly benefit humans as well through the maintenance of healthy and biodiverse ecosystems. Many people value conservation of certain habitats or species that are dependent on bats (Oguh et al., 2021). Healthy ecosystems also allow recreational activities and benefit ecotourism and are the foundation of regulating services humans depend on for clean air and water (Oguh et al., 2021).

Nectarivorous bats are particularly effective at promoting genetic connectivity between plant populations because they can fly long distances. For instance, in the Brazilian Amazon, bat pollinators of West Indian locust (*Hymenaea courbaril*) move pollen up to 18 km (Biscaia de Lacerda et al., 2008), while in the Australian rain forest, the common blossom bat (*Syconycteris australis*) can fly 6 km when foraging for nectar (Law and Lean, 1999). In Mexico, both Pallas's long-tongued bat (*Glossopahaga soricina*) and the southern long-nosed bat (*Leptonycteris curasoae*) visit flowers of isolated *Ceiba grandiflora* in agricultural fields and pastures (Quesada et al., 2004).

In frugivorous bats, long distance seed dispersal is partially mediated by feeding behaviors. Those that contribute to long distance seed dispersal are "fast feeders," and consume fruits within a few minutes, swallow most or all of the seeds, and defecate them within 30 min (Dumont, 2003). These bats include the genus *Carollia*, with some species traveling 1–2 km between foraging areas (Dumont, 2003). "Slow feeders" will eat fibrous fruits, chewing on them and swallowing the juices before spitting out the seeds (Dumont, 2003) but still swallow and defecate fig (*Ficus* spp) seeds (Tang et al., 2007). The Jamaican fruit bat (*Artibeus jamaicensis*), a "slow feeder," can carry figs up to 250 m away before feeding again, and within a single night will visit trees 1 km apart from each other (Morrison, 1978; Tang et al., 2007). The Jamaican fruit bat and the great fruit-eating bat (*A. lituratus*) have even been found to consume up to 200% of their body mass in pulp each day, dispersing a large number of seeds daily (Charles-Dominique, 1991; Morrison, 1978). The Egyptian fruit bat (*Rousettus aegyptiacus*) facilitates asynchronous germination, which increases the probability in unpredictable environments, by either spitting out or digesting and passing seeds (Izhaki et al., 1995). Behaviors also vary among individuals, as pregnant and lactating females have higher energy requirements and will increase fruit consumption while foraging over shorter distances (Charles-Dominique, 1991; Korine et al., 2013; Morrison, 1978).

Pteropodids are key seed dispersers in Old World tropical islands due to their flying distances (Oleksy et al., 2015). The Mauritian flying fox (*Pteropus niger*) is an important disperser on Mauritius, traveling 6–9 km between forest fragments (Oleksy et al., 2019). In the case of the greater short-nosed fruit bat (*Cynopterus sphinx*), they can digest fig seeds for more than 12 h, potentially aiding dispersal across islands (Shilton et al., 1999). In fact, pteropodid-dispersed *Ficus* were early colonists on islands, attracting other frugivores that sequentially brought seeds from other species, leading to forest regeneration (Kunz et al., 2011; Muscarella and Fleming, 2007; Shilton and Whittaker, 2009).

In the New World tropics, frugivorous bats are critical for tropical succession because they are the most abundant seed-dispersers (Medellin and Gaona, 1999). Volant vertebrates (bats and birds) are responsible for more than 80% of seed rain in the neotropics (Galindo-González et al., 2000). Although not all phyllostomids are primarily frugivorous, all species that do eat fruit include at least one of five main neotropical plant genera in their diet (*Cecropia*, *Ficus*, *Piper*, *Solanum*, *Vismia*) (Lobova et al., 2009), of which *Cecropia*, *Solanum*, and *Vismia* are dominant pioneer species (Foster et al., 1986; Mesquita et al., 2001; Oleksy et al., 2017; Saldarriaga et al., 1988; Toledo and Salick, 2006; Uhl, 1987). Bats also forage relatively frequently in forest fragments in lowland tropics (Arteaga et al., 2006; Estrada et al., 1993; Schulze et al., 2000), minimizing habitat fragmentation by dispersing seeds under isolated trees in abandoned agricultural lands or defecating seeds mid-flight in open areas (Duncan and Chapman, 1999; Galindo-González et al., 2000; Muscarella and Fleming, 2007).

Long distance seed dispersal can be critical because seeds dispersed too close to parent plants may suffer increased mortality from predation, pathogens, and intra-specific competition (Harms et al., 2000). It is important to acknowledge that while bats contribute to seed dispersal, the ecosystem services derived from frugivory rely on the successful germination of dispersed seeds. This successful germination is contingent not only upon seed viability but also habitat quality of the locations where the seeds are deposited (Chan et al., 2021).

Plant pollinated and dispersed by bats are also important for community structure and ecosystem function. One classic example is the dispersal of tropical figs, which are considered keystone species (Shanahan et al., 2001). Bats pollinate mangroves, which are involved in many ecosystem functions (Coupland et al., 2006), providing habitats for diverse assemblages of plants and animals, as well as reproductive habitats and shelter, and play important roles in nutrient cycling and water purification (Barbier et al., 2011). Mangroves are crucially important to humans, serving as a vital source of physical protection against storms, flooding, and tsunamis (Barbier et al., 2011). These ecosystems play a significant role in mitigating the destructive impacts of natural disasters, providing valuable coastal defense and safeguarding coastal communities and infrastructure.

---

## Ecosystem disservices

Although bats provide many benefits through foraging, their behaviors may also adversely affect ecosystem services. For example, insectivorous bats also feed on predatory arthropods, which may lead to a release of pest suppression at a lower trophic level (Maas et al., 2013). Experimental bat exclusions in agriculture show an increase in predatory spiders and ants in agriculture (Maas et al., 2013); however, some evidence suggests this does not affect yield (Denmead et al., 2017). In the case of frugivory, bats also consume commercial fruits, such as lychee (*Litchi chinensis*), arecanut (*Areca catechu*), and sapota (*Achras zapota*), leading to economic losses (Chakravarthy and Girish, 2015; Oleksy et al., 2019). Finally, in some cases, bats disperse and pollinate exotics plants, particularly in urban areas (Chan et al., 2021; Corlett, 2005).

---

## Conservation recommendations

A key tool for effective conservation is raising awareness about the economic advantages that bats bring. However, the scarcity of studies focusing on the monetary value of bats' ecosystem services is apparent. To address this gap, this review presents a compilation of diverse valuations related to bat's ecosystem services (Table 15.1). Effective valuation of ecosystem services requires understanding not only the structure and function of the natural system but also its link with human systems, and how both affect consumptive (e.g., agriculture) and nonconsumptive (e.g., recreation) uses (National Research Council, 2005). Despite the availability of site-level analyses of economic contributions, there is difficulty in scaling those up to a global level as the value of ecosystem services varies spatially (Plummer, 2009). Although it is difficult to estimate economic values from a comprehensive analysis, effort should be directed to collecting detailed data on bats and the organisms they interact with, as well as other factors that influence ecosystem services (National Research Council, 2005).

In this review, we have shown that, through foraging, bats play critical roles in ecosystem services, benefitting both natural processes and human well-being. Insectivorous bats are important arthropod suppressors, especially in agricultural systems where they minimize crop damage, saving millions in USD each year. Through seed dispersal and pollination, frugivorous and nectarivorous bats not only maintain genetic diversity of plant populations but also sustain ecologically and economically important plant species.

The International Union for Conservation of Nature (IUCN) considers 80% of bat species as threatened, data deficient, or suffering from decreased populations (IUCN; Frick et al., 2020). Major threats include logging, agriculture, and the combination of hunting and persecution, with some hunting driven by public fears and

misconceptions of bats (Frick et al., 2020; Tuttle, 2013). In light of these threats, addressing research gaps will aid in managing natural and altered environments to support biodiversity and ecosystem processes. For many plant species, we do not know the fate of seeds dropped and defecated by bats, and future work should investigate the germination and survival rates to determine bats' true contributions to seed dispersal (Chan et al., 2021). This can help devise strategies to prioritize which plant species require conservation efforts. We also must understand how urbanization is affecting bat communities and in turn the ecosystem services they provide. The changes in habitat composition and food availability, introduction of nonnative plant and animal species, as well as light, noise, and chemical pollution are all factors in urban areas that can influence bat behaviors and their services. We can then better support bats in urban areas by managing green spaces, pollutants, and the presence of nonnative species.

---

## References

- Acharya, L., McNeil, J.N., 1998. Predation risk and mating behavior: the responses of moths to bat-like ultrasound. *Behav. Ecol.* 9 (6), 552–558. <https://doi.org/10.1093/beheco/9.6.552>.
- Aguiar, L.M.S., Bueno-Rocha, I.D., Oliveira, G., Pires, E.S., Vasconcelos, S., Nunes, G.L., Frizzas, M.R., Togni, P.H.B., 2021. Going out for dinner—the consumption of agriculture pests by bats in urban areas. *PLoS One* 16 (10), e0258066. <https://doi.org/10.1371/journal.pone.0258066>.
- Ancillotto, L., Ariano, A., Nardone, V., Budinski, I., Rydell, J., Russo, D., 2017. Effects of free-ranging cattle and landscape complexity on bat foraging: implications for bat conservation and livestock management. *Agric. Ecosyst. Environ.* 241, 54–61. <https://doi.org/10.1016/j.agee.2017.03.001>.
- Arteaga, L.L., Aguirre, L.F., Moya, M.I., 2006. Seed rain produced by bats and birds in forest islands in a neotropical savanna. *Biotropica* 38 (6), 718–724. <https://doi.org/10.1111/j.1744-7429.2006.00208.x>.
- Aziz, S.A., McConkey, K.R., Tanalgo, K., Sritongchuay, T., Low, M.-R., Yong, J.Y., Mildenstein, T.L., Nuevo-Diego, C.E., Lim, V.-C., Racey, P.A., 2021. The critical importance of Old World fruit bats for healthy ecosystems and economies. *Front. Ecol. Evolut.* 9, 1–29. <https://doi.org/10.3389/fevo.2021.641411>.
- Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C., Silliman, B.R., 2011. The value of estuarine and coastal ecosystem services. *Ecol. Monogr.* 81 (2), 169–193.
- Baroja, U., Garin, I., Vallejo, N., Aihartza, J., Rebelo, H., Goiti, U., 2021. Bats actively track and prey on grape pest populations. *Ecol. Indicat.* 126, 107718. <https://doi.org/10.1016/j.ecolind.2021.107718>.
- Belton, P., Kempster, R.H., 1962. A field test on the use of sound to repel the European corn borer. *Entomol. Exp. Appl.* 5 (4), 281–288.
- Biscaia de Lacerda, A.E., Kanashiro, M., Sebbenn, A.M., 2008. Long-pollen movement and deviation of random mating in a low-density continuous population of a tropical tree *Hymenaea courbaril* in the Brazilian Amazon. *Biotropica* 40 (4), 462–470. <https://doi.org/10.1111/j.1744-7429.2008.00402.x>.

- Black, H.L., 1974. A North temperate bat community: structure and prey populations. *J. Mammol.* 55 (1), 138–157.
- Boyles, J.G., Cryan, P.M., McCracken, G.F., Kunz, T.H., 2011. Economic importance of bats in agriculture. *Science* 332 (6025), 41–42. <https://doi.org/10.1126/science.1201366>.
- Brown, V.A., Braun de Torrez, E., McCracken, G.F., 2015. Crop pests eaten by bats in organic pecan orchards. *Crop Protect.* 67, 66–71. <https://doi.org/10.1016/j.cropro.2014.09.011>.
- Chakravarthy, A.K., Girish, A.C., 2015. Crop protection and conservation of frugivorous bats in orchards of hill and coastal regions of Karnataka. *Zoos' Print J.* 18 (8), 1169–1172. <https://doi.org/10.11609/JoTT.ZPJ.18.8.1169-71>.
- Chan, A.Q., Aziz, S.A., Clare, E.L., Coleman, J.L., 2021. Diet, ecological role and potential ecosystem services of the fruit bat, *Cynopterus brachyotis*, in a tropical city. *Urban Ecosyst.* 24, 251–263. <https://doi.org/10.1007/s11252-020-01034-x>.
- Charbonnier, Y., Barbaro, L., Theillout, A., Jactel, H., 2014. Numerical and functional responses of forest bats to a major insect pest in pine plantations. *PLoS One* 9 (10), e109488. <https://doi.org/10.1371/journal.pone.0109488>.
- Charles-Dominique, P., 1991. Feeding strategy and activity budget of the frugivorous bat *Carollia perspicillata* (Chiroptera: phyllostomidae) in French Guiana. *J. Trop. Ecol.* 7 (2), 243–256. <https://doi.org/10.1017/S026646740000540X>.
- Cleveland, C.J., Betke, M., Federico, P., Frank, J.D., Hallam, T.G., Horn, J., López, J.D., McCracken, G.F., Medellín, R.A., Moreno-Valdez, A., Sansone, C.G., Westbrook, J.K., Kunz, T.H., 2006. Economic value of the pest control service provided by Brazilian free-tailed bats in south-central Texas. *Front. Ecol. Environ.* 4 (5), 238–243. [https://doi.org/10.1890/1540-9295\(2006\)004\[0238:EVOTPC\]2.0.CO;2](https://doi.org/10.1890/1540-9295(2006)004[0238:EVOTPC]2.0.CO;2).
- Cohen, Y., Bar-David, S., Nielsen, M., Bohmann, K., Korine, C., 2020. An appetite for pests: synanthropic insectivorous bats exploit cotton pest irruptions and consume various deleterious arthropods. *Mol. Ecol.* 29 (6), 1185–1198. <https://doi.org/10.1111/mec.15393>.
- Corlett, R.T., 2005. Interactions between birds, fruit bats and exotic plants in urban Hong Kong, South China. *Urban Ecosyst.* 8, 275–283.
- Coupland, G.T., Paling, E.I., McGuinness, K.A., 2006. Floral abortion and pollination in four species of tropical mangroves from northern Australia. *Aquat. Bot.* 84 (2), 151–157. <https://doi.org/10.1016/j.aquabot.2005.09.003>.
- Denmead, L.H., Darras, K., Clough, Y., Diaz, P., Grass, I., Hoffmann, M.P., Nurdiansyah, F., Fardiansah, R., Tschardtke, T., 2017. The role of ants, birds and bats for ecosystem functions and yield in oil palm plantations. *Ecology* 98 (7), 1945–1956. <https://doi.org/10.1002/ecy.1882>.
- Des Marais, D.J., Mitchell, J.M., Meinschein, W.G., Hayes, J.M., 1980. The carbon isotope biogeochemistry of the individual hydrocarbons in bat guano and the ecology of the insectivorous bats in the region of Carlsbad, New Mexico. *Geochem. Cosmochim. Acta* 44 (12), 2075–2086. [https://doi.org/10.1016/0016-7037\(80\)90205-7](https://doi.org/10.1016/0016-7037(80)90205-7).
- Diekman, M.A., Green, M.L., 1992. Mycotoxins and reproduction in domestic livestock. *J. Anim. Sci.* 70 (5), 1615–1627. <https://doi.org/10.2527/1992.7051615x>.
- Dumont, E.R., 2003. Bats and fruit: an ecomorphological approach. In: Kunz, T.H., Fenton, M.B. (Eds.), *Bat Ecology*. University of Chicago Press, pp. 398–429.
- Duncan, R.S., Chapman, C.A., 1999. Seed dispersal and potential forest succession in abandoned agriculture in tropical Africa. *Ecol. Appl.* 9 (3), 998–1008. [https://doi.org/10.1890/1051-0761\(1999\)009\[0998:SDAPFS\]2.0.CO;2](https://doi.org/10.1890/1051-0761(1999)009[0998:SDAPFS]2.0.CO;2).

- Estrada, A., Coates-Estrada, R., Merritt, D.J., 1993. Bat species richness and abundance in tropical rain forest fragments and in agricultural habitats at Los Tuxtlas, Mexico. *Ecography* 16 (4), 309–318.
- Federico, P., Hallam, T.G., Mccracken, G.F., Purucker, S.T., Grant, W.E., Correa-Sandoval, A.N., Westbrook, J.K., Medellín, R.A., Cutler, J., Sansone, C.G., Lopez, J.D., Betke, M., Valdez, A.M.-V., Kunz, T.H., 2008. Brazilian free-tailed bats as insect pest regulators in transgenic and conventional cotton crops. *Ecol. Appl.* 18 (4), 826–837.
- Fennell, D.I., Lillehoj, E.B., Kwolek, W.F., 1975. *Aspergillus flavus* and other fungi associated with insect-damaged field corn. *Cereal Chem.* 52 (3), 314–321.
- Fleming, T.H., Muchhala, N., 2008. Nectar-feeding bird and bat niches in two worlds: pantropical comparisons of vertebrate pollination systems. *J. Biogeogr.* 35 (5), 764–780. <https://doi.org/10.1111/j.1365-2699.2007.01833.x>.
- Fleming, T.H., Valiente-Banuet, A., 2002. *Columnar Cacti and Their Mutualists: Evolution, Ecology, and Conservation*. University of Arizona Press.
- Foster, R.B., Arce, J., Wachter, T.S., 1986. Dispersal and the sequential plant communities in Amazonian Peru floodplain. In: Estrada, A., Fleming, T.H. (Eds.), *Frugivores and Seed Dispersal*. Dr. W. Junk Publishers.
- Frick, W.F., Kingston, T., Flanders, J., 2020. A review of the major threats and challenges to global bat conservation. *Ann. N. Y. Acad. Sci.* 1469 (1), 5–25. <https://doi.org/10.1111/nyas.14045>.
- Froidevaux, J.S.P., Louboutin, B., Jones, G., 2017. Does organic farming enhance biodiversity in Mediterranean vineyards? A case study with bats and arachnids. *Agric. Ecosyst. Environ.* 249, 112–122. <https://doi.org/10.1016/j.agee.2017.08.012>.
- Fujita, M.S., Tuttle, M.D., 1991. Flying foxes (Chiroptera: pteropodidae): threatened animals of key ecological and economic importance. *Conserv. Biol.* 5 (4), 455–463. <https://doi.org/10.1111/j.1523-1739.1991.tb00352.x>.
- Fukui, D., Murakami, M., Nakano, S., Aoi, T., 2006. Effect of emergent aquatic insects on bat foraging in a riparian forest. *J. Anim. Ecol.* 75 (6), 1252–1258. <https://doi.org/10.1111/j.1365-2656.2006.01146.x>.
- Galindo-González, J., Guevara, S., Sosa, V.J., 2000. Bat- and bird-generated seed rains at isolated trees in pastures in a tropical rainforest. *Conserv. Biol.* 14 (6), 1693–1703. <https://doi.org/10.1046/j.1523-1739.2000.99072.x>.
- Gardner, A.L., 1977. Feeding habits Pt. 2. In: Baker, R.J., Jones, J.K., Carter, D.C. (Eds.), *Biology Of Bats of the New World Family Phyllostomatidae*. Texas Tech Press.
- Hall, R.P., Mutumi, G.L., Hedrick, B.P., Yohe, L.R., Sadier, A., Davies, K.T.J., Rossiter, S.J., Sears, K., Dávalos, L.M., Dumont, E.R., 2021. Find the food first: an omnivorous sensory morphotype predates biomechanical specialization for plant based diets in phyllostomid bats. *Evolution* 75 (11), 2791–2801. <https://doi.org/10.1111/evo.14270>.
- Harms, K.E., Wright, S.J., Calderón, O., Hernández, A., Herre, E.A., 2000. Pervasive density-dependent recruitment enhances seedling diversity in a tropical forest. *Nature* 404 (6777), 493–495. <https://doi.org/10.1038/35006630>.
- Hoyt, J.R., Kilpatrick, A.M., Langwig, K.E., 2021. Ecology and impacts of white-nose syndrome on bats. *Nat. Rev. Microbiol.* 19 (3), 196–210. <https://doi.org/10.1038/s41579-020-00493-5>.
- Huang, F., Subramanyam, B., 2004. Behavioral and reproductive effects of ultrasound on the Indian meal moth, *Plodia interpunctella*. *Entomol. Exp. Appl.* 113 (3), 157–164. <https://doi.org/10.1111/j.0013-8703.2004.00217.x>.

- Huang, F., Subramanyam, B., Taylor, R., 2003. Ultrasound affects spermatophore transfer, larval numbers, and larval weight of *Plodia interpunctella* (Hübner) (Lepidoptera: pyralidae). *J. Stored Prod. Res.* 39 (4), 413–422. [https://doi.org/10.1016/S0022-474X\(02\)00035-8](https://doi.org/10.1016/S0022-474X(02)00035-8).
- Indonesian Bureau of Statistics, 1986. Indonesia Foreign Trade Statistics.
- IUCN. (n.d.). Red List of Threatened Species. <http://www.iucnredlist.org>.
- Izhaki, I., Korine, C., Arad, Z., 1995. The effect of bat (*Rousettus aegyptiacus*) dispersal on seed germination in eastern Mediterranean habitats. *Oecologia* 101, 335–342.
- Jay, M., Roince, C.B., de, Ricard, J.M., Garcin, A., Mandrin, J.F., Lavigne, C., Bouvier, J.C., Tupinier, Y., Puechmaille, S., 2012. Functional biodiversity in apple orchards: are the bats eating the pests? *Infos-Ctifl* 286, 28–34.
- Kalka, M.B., Kalko, E.K.V., 2006. Gleaning bats as underestimated predators of herbivorous insects: diet of *Micronycteris microtis* (Phyllostomidae) in Panama. *J. Trop. Ecol.* 22 (1), 1–10. <https://doi.org/10.1017/S0266467405002920>.
- Kolkert, H., Smith, R., Rader, R., Reid, N., 2021. Insectivorous bats provide significant economic value to the Australian cotton industry. *Ecosyst. Serv.* 49, 101280. <https://doi.org/10.1016/j.ecoser.2021.101280>.
- Korine, C., Daniel, S., Pinshow, B., 2013. Roost selection by female Hemprich's long-eared bats. *Behav. Process.* 100, 131–138. <https://doi.org/10.1016/j.beproc.2013.08.013>.
- Kunz, T.H., 1974. Feeding ecology of a temperate insectivorous bat (*Myotis velifer*). *Ecology* 55 (4), 693–711.
- Kunz, T.H., de Torrez, E.B., Bauer, D., Lobova, T., Fleming, T.H., 2011. Ecosystem services provided by bats. *Ann. N. Y. Acad. Sci.* 1223 (1), 1–38. <https://doi.org/10.1111/j.1749-6632.2011.06004.x>.
- Kunz, T.H., Whitaker, J., Wadanoli, M.D., 1995. Dietary energetics of the insectivorous Mexican free-tailed bat (*Tadarida brasiliensis*) during pregnancy and lactation. *Oecologia* 101 (4), 407–415. <https://doi.org/10.1007/BF00329419>.
- Kurta, A., Bell, G.P., Nagy, K.A., Kunz, T.H., 1989. Energetics of pregnancy and lactation in free-ranging little brown bats (*Myotis lucifugus*). *Physiol. Zool.* 62 (3), 804–818. <https://doi.org/10.1086/physzool.62.3.30157928>.
- Kurta, A., Whitaker, J.O., 1998. Diet of the endangered Indiana bat (*Myotis sodalis*) on the northern edge of its range. *Am. Midl. Nat.* 140 (2), 280–286. <https://doi.org/10.2307/2426441>.
- Law, B.S., Lean, M., 1999. Common blossom bats (*Syconycteris australis*) as pollinators in fragmented Australian tropical rainforest. *Biol. Conserv.* 91 (2–3), 201–212. [https://doi.org/10.1016/S0006-3207\(99\)00078-6](https://doi.org/10.1016/S0006-3207(99)00078-6).
- Lee, Y.-F., McCracken, G.F., 2002. Foraging activity and food resource use of Brazilian free-tailed bats, *Tadarida brasiliensis* (Molossidae). *Ecoscience* 9 (3), 306–313.
- Leelapaibul, W., Bumrungsri, S., Pattanawiboon, A., 2005. Diet of wrinkle-lipped free-tailed bat (*Tadarida plicata* Buchannan, 1800) in central Thailand: insectivorous bats potentially act as biological pest control agents. *Acta Chiropterol.* 7 (1), 111–119. [https://doi.org/10.3161/1733-5329\(2005\)7\[111:DOWFBT\]2.0.CO;2](https://doi.org/10.3161/1733-5329(2005)7[111:DOWFBT]2.0.CO;2).
- Lingren, P.D., Bryant, V.M., Raulston, J.R., Pendleton, M., Westbrook, J., Jones, G.D., 1993. Adult feeding host range and migratory activities of corn earworm, cabbage looper, and celery looper (Lepidoptera: noctuidae) moths as evidence by attached pollen. *J. Econ. Entomol.* 86 (5), 1429–1439. <https://doi.org/10.1093/jee/86.5.1429>.
- Lobova, T.A., Geiselman, C.K., Mori, S.A., 2009. Seed dispersal by bats in the Neotropics. In: *Memoirs of the New York Botanical Garden*. New York Botanical Garden Press.

- López-Hoffman, L., Wiederholt, R., Sansone, C., Bagstad, K.J., Cryan, P., Diffendorfer, J.E., Goldstein, J., LaSharr, K., Loomis, J., McCracken, G., Medellín, R.A., Russell, A., Semmens, D., 2014. Market forces and technological substitutes cause fluctuations in the value of bat pest-control services for cotton. *PLoS One* 9 (2), e87912. <https://doi.org/10.1371/journal.pone.0087912>.
- Maas, B., Clough, Y., Tschardtke, T., 2013. Bats and birds increase crop yield in tropical agroforestry landscapes. *Ecol. Lett.* 16 (12), 1480–1487. <https://doi.org/10.1111/ele.12194>.
- Maine, J.J., Boyles, J.G., 2015. Bats initiate vital agroecological interactions in corn. *Proc. Natl. Acad. Sci. U. S. A.* 112 (40), 12438–12443. <https://doi.org/10.1073/pnas.1505413112>.
- McCracken, G.F., Westbrook, J.K., Brown, V.A., Eldridge, M., Federico, P., Kunz, T.H., 2012. Bats track and exploit changes in insect pest populations. *PLoS One* 7 (8), e43839. <https://doi.org/10.1371/journal.pone.0043839>.
- Medellin, R.A., Gaona, O., 1999. Seed dispersal by bats and birds in forest and disturbed habitats of Chiapas, Mexico. *Biotropica* 31 (3), 478–485. <https://doi.org/10.1111/j.1744-7429.1999.tb00390.x>.
- Mesquita, R.C.G., Ickes, K., Ganade, G., Bruce Williamson, G., 2001. Alternative successional pathways in the Amazon basin. *J. Ecol.* 89 (4), 528–537. <https://doi.org/10.1046/j.1365-2745.2001.00583.x>.
- Mickleburgh, S., Waylen, K., Racey, P., 2009. Bats as bushmeat: a global review. *Oryx* 43 (2), 217–234. <https://doi.org/10.1017/S0030605308000938>.
- Mizutani, H., McFarlane, D.A., Kabaya, Y., 1992. Nitrogen and carbon isotope study of bat guano core from Eagle Creek Cave, Arizona, U.S.A. *J. Mass Spectrom. Soc. Jpn.* 40 (1), 57–65.
- Morrison, D.W., 1978. Foraging Ecology and Energetics of the frugivorous bat *artibeus jamaicensis*. *Ecology* 59 (4), 716–723. <https://doi.org/10.2307/1938775>.
- Muchhala, N., Tschapka, M., 2020. The ecology and evolution of nectar-feeding phyllostomids. In: Fleming, H., Davalos, L., Mello, M. (Eds.), *Phyllostomid Bats, a Unique Mammalian Radiation*. University of Chicago Press.
- Müller, J., Mehr, M., Bässler, C., Fenton, M.B., Hothorn, T., Pretzsch, H., Klemmt, H.J., Brandl, R., 2012. Aggregative response in bats: prey abundance versus habitat. *Oecologia* 169 (3), 673–684. <https://doi.org/10.1007/s00442-011-2247-y>.
- Muscarella, R., Fleming, T.H., 2007. The role of frugivorous bats in tropical forest succession. *Biol. Rev.* 82 (4), 573–590. <https://doi.org/10.1111/j.1469-185X.2007.00026.x>.
- Muylaert, R.L., Stevens, R.D., Ribeiro, M.C., 2016. Threshold effect of habitat loss on bat richness in cerrado-forest landscapes. *Ecol. Appl.* 26 (6), 1854–1867. <https://doi.org/10.1890/15-1757.1>.
- Myers, N., 1985. *The Primary Source*. W.W. Norton and Co.
- National Research Council, 2005. *Valuing Ecosystem Services: Towards Better Environmental Decision-Making*. National Academies Press.
- Ng, F.S.P., 1980. Legumes in forestry. In: *Proceedings of Legumes in the Tropics*. Faculty Agricultural University Pertanian Malaysia, pp. 449–456.
- Nogueira, M.R., Peracchi, A.L., Monteiro, L.R., 2009. Morphological correlates of bite force and diet in the skull and mandible of phyllostomid bats. *Funct. Ecol.* 23 (4), 715–723. <https://doi.org/10.1111/j.1365-2435.2009.01549.x>.
- Oguh, C.E., Obiwulu, E., Jennifer, U.O., Ameh, S.E., Ugwu, C., Sheshi, I.M., 2021. Ecosystem and ecological services; need for biodiversity conservation-A critical review. *Asian J. Biol.* 11 (4), 1–14. <https://doi.org/10.9734/AJOB/2021/v11i430146>.

- Oleksy, R., Ayady, C.L., Tatayah, V., Jones, C., Howey, P.W., Froidevaux, J.S.P., Racey, P.A., Jones, G., 2019. The movement ecology of the Mauritian flying fox (*Pteropus niger*): a long-term study using solar-powered GSM/GPS tags. *Move. Ecol.* 7, 1–12. <https://doi.org/10.1186/s40462-019-0156-6>.
- Oleksy, R., Giuggioli, L., McKetterick, T.J., Racey, P.A., Jones, G., 2017. Flying foxes create extensive seed shadows and enhance germination success of pioneer plant species in deforested Madagascan landscapes. *PLoS One* 12 (9), e0184023. <https://doi.org/10.1371/journal.pone.0184023>.
- Oleksy, R., Racey, P.A., Jones, G., 2015. High-resolution GPS tracking reveals habitat selection and the potential for long-distance seed dispersal by Madagascan flying foxes *Pteropus rufus*. *Global Ecol. Conservat.* 3, 678–692. <https://doi.org/10.1016/j.gecco.2015.02.012>.
- Pimentel, D., Krummel, J., Gallahan, D., Hough, J., Merrill, A., Schreiner, I., Vittum, P., Koziol, F., Back, E., Yen, D., Fiance, S., 1978. Benefits and costs of pesticide use in the U.S. food production. *Bioscience* 28 (12), 772–784.
- Plummer, M.L., 2009. Assessing benefit transfer for the valuation of ecosystem services. *Front. Ecol. Environ.* 7 (1), 38–45. <https://doi.org/10.1890/080091>.
- Potts, S.G., Imperatriz-Fonseca, V., Ngo, H.T., Aizen, M.A., Biesmeijer, J.C., Breeze, T.D., Dicks, L.V., Garibaldi, L.A., Hill, R., Settele, J., Vanbergen, A.J., 2016. Safeguarding pollinators and their values to human well-being. *Nature* 540. <https://doi.org/10.1038/nature20588>.
- Puig-Montserrat, X., Flaquer, C., Gómez-Aguilera, N., Burgas, A., Mas, M., Tuneu, C., Marquès, E., López-Baucells, A., 2020. Bats actively prey on mosquitoes and other deleterious insects in rice paddies: potential impact on human health and agriculture. *Pest Manag. Sci.* 76 (11), 3759–3769. <https://doi.org/10.1002/ps.5925>.
- Puig-Montserrat, X., Torre, I., López-Baucells, A., Guerrieri, E., Monti, M., Ràfols-García, R., Ferrer, X., Gisbert, D., Flaquer, C., 2015. Pest control service provided by bats in Mediterranean rice paddies: linking agroecosystems structure to ecological functions. *Mamm. Biol.* 80 (3), 237–245. <https://doi.org/10.1016/j.mambio.2015.03.008>.
- Quesada, M., Stoner, K.E., Lobo, J.A., Herrerías-Diego, Y., Palacios-Guevara, C., Munguía-Rosas, M.A., Salazar, O., Rosas-Guerrero, K.A.V., 2004. Effects of forest fragmentation on pollinator activity and consequences for plant reproductive success and mating patterns in bat-pollinated Bombacaceous trees. *Biotropica* 36 (2), 131–138. <https://doi.org/10.1646/q1571>.
- Rietbergen, T.B., van den Hoek Ostende, L.W., Aase, A., Jones, M.F., Medeiros, E.D., Simmons, N.B., 2023. The oldest known bat skeletons and their implications for Eocene chiropteran diversification. *PLoS One* 18 (4), 20283505. <https://doi.org/10.1371/journal.pone.0283505>.
- Rocha, M., Valera, A., Eguiarte, L.E., 2005. Reproductive ecology of five sympatric *Agave littaea* (Agavaceae) species in central Mexico. *Am. J. Bot.* 92 (8), 1330–1341. <https://doi.org/10.3732/ajb.92.8.1330>.
- Rodríguez-San Pedro, A., Allendes, J.L., Beltrán, C.A., Chaperon, P.N., Saldarriaga-Córdoba, M.M., Silva, A.X., Grez, A.A., 2020. Quantifying ecological and economic value of pest control services provided by bats in a vineyard landscape of central Chile. *Agric. Ecosyst. Environ.* 302, 107063. <https://doi.org/10.1016/j.agee.2020.107063>.
- Rojas, D., Vale, Á., Ferrero, V., Navarro, L., 2012. The role of frugivory in the diversification of bats in the Neotropics. *J. Biogeogr.* 39 (11), 1948–1960. <https://doi.org/10.1111/j.1365-2699.2012.02709.x>.

- Russo, D., Ancillotto, L., 2015. Sensitivity of bats to urbanization: A review. *Mamm. Biol.* 80 (3), 205–212. <https://doi.org/10.1016/j.mambio.2014.10.003>.
- Russo, D., Bosso, L., Ancillotto, L., 2018. Novel perspectives on bat insectivory highlight the value of this ecosystem service in farmland: Research frontiers and management implications. *Agric. Ecosyst. Environ.* 266, 31–38. <https://doi.org/10.1016/j.agee.2018.07.024>.
- Saldarriaga, J.G., West, D.C., Tharpt, M.L., Uhl, C., 1988. Long-term chronosequence of forest succession in the upper Rio Negro of Colombia and Venezuela. *J. Ecol.* 76 (4), 938–958. <https://doi.org/10.2307/2260625>.
- Schulze, M.D., Seavy, N.E., Whitacre, D.F., 2000. A comparison of Phyllostomid bat assemblages in undisturbed Neotropical forest in forest fragments of a slash-and-burn framing mosaic in Petén, Guatemala. *Biotropica* 32 (1), 174–184.
- Shanahan, M., Samson, S.O., Compton, S.G., Corlett, R., 2001. Fig-eating by vertebrate frugivores: A global review. *Biol. Rev. Camb. Phil. Soc.* 76 (4), 529–572. <https://doi.org/10.1017/S1464793101005760>.
- Shane, S.H., 1984. Economic issues associated with aflatoxins. In: Eaton, D.L., Groopman, J.D. (Eds.), *The Toxicology of Aflatoxins*.
- Sheherazade, Ober, H.K., Tsang, S.M., 2019. Contributions of bats to the local economy through durian pollination in Sulawesi, Indonesia. *Biotropica* 51 (6), 913–922. <https://doi.org/10.1111/btp.12712>.
- Shilton, L.A., Altringham, J.D., Compton, S.G., Whittaker, R.J., 1999. Old World fruit bats can be long-distance seed dispersers through extended retention of viable seeds in the gut. *Proc. Biol. Sci.* 266 (1416), 219–223. <https://doi.org/10.1098/rspb.1999.0625>.
- Shilton, L.A., Whittaker, R.H., 2009. The role of pteropodid bats in re-establishing tropical forests on Krakatau. In: Fleming, T.H., Racey, P.A. (Eds.), *Island Bats: Evolution, Ecology, and Conservation*. University of Chicago Press, pp. 176–215.
- Simmons, N.B., Cirranello, A.L., 2023. *Bat Species of the World: A Taxonomic and Geographic Database*. Version 1.3.
- Stoler, A.B., Mattes, B.M., Hintz, W.D., Jones, D.K., Lind, L., Schuler, M.S., Relyea, R.A., 2017. Effects of a common insecticide on wetland communities with varying quality of leaf litter inputs. *Environ. Pollut.* 226, 452–462. <https://doi.org/10.1016/j.envpol.2017.04.019>.
- Tang, Z.H., Mukherjee, A., Sheng, L.-X., Cao, M., Liang, B., Corlett, R.T., Zhang, S.-Y., 2007. Effect of ingestion by two frugivorous bat species on the seed germination of *Ficus racemosa* and *F. hispida* (Moraceae). *J. Trop. Ecol.* 23 (1), 125–127. <https://doi.org/10.1017/S0266467406003737>.
- Taylor, P.J., Grass, I., Alberts, A.J., Joubert, E., Tschardtke, T., 2018. Economic value of bat predation services – A review and new estimates from macadamia orchards. *Ecosyst. Serv.* 30, 372–381. <https://doi.org/10.1016/j.ecoser.2017.11.015>.
- ter Hofstede, H.M., Ratcliffe, J.M., 2016. Evolutionary escalation: The bat-moth arms race. *J. Exp. Biol.* 219 (11), 1589–1602. <https://doi.org/10.1242/jeb.086686>.
- Toledo, M., Salick, J., 2006. Secondary succession and indigenous management in semideciduous forest fallows of the Amazon basin. *Biotropica* 38 (2), 161–170. <https://doi.org/10.1111/j.1744-7429.2006.00120.x>.
- Trejo-Salazar, R.E., Eguiarte, L.E., Suro-Piñera, D., Medellín, R.A., 2016. Save our bats, save our tequila: Industry and science join forces to help bats and Agaves. *Nat. Area J.* 36 (4), 523–530. <https://doi.org/10.3375/043.036.0417>.

- Tuneu-Corral, C., Puig-Montserrat, X., Riba-Bertolín, D., Russo, D., Rebelo, H., Cabeza, M., López-Bauccells, A., 2023. Pest suppression by bats and management strategies to favour it: a global review. *Biol. Rev.* <https://doi.org/10.1111/brv.12967>.
- Tuttle, M.D., 2013. Threats to bats and educational challenges. In: Adams, R.A., Pedersen, S.C. (Eds.), *Bat Evolution, Ecology, and Conservation*. Springer Science and Business Media, pp. 363–391. <https://doi.org/10.1007/978-1-4614-7397-8>.
- Uhl, C., 1987. Factors controlling succession following slash-and-burn agriculture in Amazonia. *J. Ecol.* 75 (2), 377–407.
- United Nations Millennium Ecosystem Assessment, 2005. *Ecosystems and Human Well-Being: Synthesis*. Island Press.
- Wanger, T.C., Darras, K., Bumrungsri, S., Tschardtke, T., Klein, A.M., 2014. Bat pest control contributes to food security in Thailand. *Biol. Conserv.* 171, 220–223. <https://doi.org/10.1016/j.biocon.2014.01.030>.
- Westbrook, J.K., Eyster, R.S., Wolf, W.W., Lingren, P.D., Raulston, J.R., 1995. Migration pathways of corn earworm (Lepidoptera: noctuidae) indicated by tetroon trajectories. *Agric. For. Meteorol.* 73 (1–2), 67–87. [https://doi.org/10.1016/0168-1923\(94\)02171-F](https://doi.org/10.1016/0168-1923(94)02171-F).
- Whitaker, J.O., 1972. Food habits of bats from Indiana. *Can. J. Zool.* 50 (6), 877–883. <https://doi.org/10.1139/z72-118>.
- Williams-Guillén, K., Perfecto, I., Vandermeer, J., 2008. Bats limit insects in a neotropical agroforestry system. *Science* 320 (5872), 70. <https://doi.org/10.1126/science.1152944>.
- Wolf, W.W., Westbrook, J.K., Raulston, J., Pair, S.D., Hobbs, S.E., Riley, J.R., Mason, P.J., Joyce, R.J., 1990. Recent airborne radar observations of migrant pests in the United States. *Phil. Trans. Biol. Sci.* 328 (1251), 619–630.
- World Health Organization, 2014. *A Global Brief on Vector-Borne Diseases*.