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Bats and Ecosystem Management

Kareem M. Soliman and Wiame W. Emam

Abstract

Bats are among the most misperceived and undervalued animals on the planet. For wildlife ecologists, they are wonderful and incredibly fascinating creatures, but people's feelings about bats are often negative, perhaps because bats are so mysterious. Unfortunately, these fears and myths about bats threaten conservation, biodiversity, and the entire ecosystem. Bats are among the most diverse and geographically dispersed group of living mammals. They contribute to several ecosystem services and act as biological pest crop control agents. Their abundance may reflect changes in populations of arthropod prey species. Also, bats have significant potentials as bioindicators that demonstrate measurable responses to climate change and habitat loss and that induce large-scale impacts on the biota. Indeed, bat conservation is fundamental not only for biodiversity, but also because these flying mammals provide essential ecological and economic services to humans.

Keywords: agricultural pests, ecosystem services, bioindicators, environmental stressors

1. Introduction

Many ecosystems worldwide have become more threatened than ever before through many anthropogenic activities such as urbanization, deforestation and different kinds of pollution. Healthy ecosystems are crucial for human wellbeing improvement, since they provide various ecological services (e.g., insect suppression, pollination, seed dispersal, water and air purification, stabilization of soils, decomposition of wastes, binding of toxic substances, mitigation of diseases, mitigation of floods, and regulation of climate, etc.), many provisions (e.g., food, fuel, fiber, and medicines), and cultural benefits (e.g., esthetic, spiritual, educational, and recreational) [1]. These processes and products are commonly referred to as ecosystem services [2, 3] and have been duly recognized by the United Nations Millennium Ecosystem Assessment [4, 5].

Furthermore, ecosystem services mainly depend on the type of ecosystem as well as the organisms that they constitute. In this chapter, the ecosystem services provided by bats are considered. Bats have been on Earth for over 52 million years [6], with over 1400 species worldwide. They are classified as the second-largest mammalian order with great physiological and ecological diversity [7]. Due to their diverse behavioral, roosting, and feeding habits, many species of bats roost during the daytime in foliage, caves, rock crevices, hollows of trees, beneath exfoliating bark, and different manmade structures [8–11]. While during the night, bats fill the sky to forage on a variety of food items ranging from insects, nectar, and fruit, to seeds, frogs, fish, small mammals, and even blood.

2. Bat: human interaction

Bat-human interrelationships are probably as old as humanity itself. However, the oldest bat fossils are estimated to date back to the Eocene, exceeding 50 million years ago [6]. These nocturnal, fast-flying, and secretive mammals may have been as enigmatic to human ancestors as they are to most of us today. The ancient coexistence of people and bats has been translated into enormous historical and contemporary cultural representations of bats in local folklore [12–14]. This ancient connection exquisitely celebrated in abundant reddish-terracotta rock paintings of bats was made by hunter-gatherer colonizers of the northwest Amazon during the Late Pleistocene/Early Holocene transition [15]. Human still considers bats to be loathsome and fearful creatures, despite the countless research investigating the contributions of bats to the ecosystem and the benefits they provide to human wellbeing [16–21].

2.1 Bat's negative stigma

Contrary to popular belief, bats do not attack people; they do not get tangled in people's hair; and even vampire bats are not real vampires (vampire bats lick blood but do not suck blood). Underlying these negative sentiments are relatively pervasive associations between bats and death [22, 23], witchcraft [24–26], vampires [27–29], malevolent spirits [30–32], and evil [33, 34].

Across much of Europe, disdain and fear of bats are largely embroiled in Church doctrine, where bats are often used to symbolize Satan [35]. However, elsewhere (particularly throughout Southeast Asia, China, and Japan), bats are also associated with luck and good fortune [13, 36] and used as spiritual totems [37, 38]. Among several indigenous groups in Mexico, bats have been considered messengers from the underworld and important symbols of fertility [39].

Furthermore, as human numbers increase and people encroach deeper into the remaining natural habitats, human-bat interactions are becoming more frequent, often with undesirable consequences for both humans and bats.

Human-bat conflicts often arise from damage to buildings or as a result of noise/smelly caused by synanthropic species [14, 40] or due to fruit crop invasion by frugivorous species [21, 41]. These are other key areas in which ethnobiological work can substantially contribute to support evidence-based and culturally sensitive strategies aimed at reducing negative feelings toward bats.

2.2 Ecosystem services

An ecosystem is a system consisting of biotic and abiotic components that function together as a unit. The biotic components include all the living things whereas the abiotic components are the non-living things. Thus, an ecosystem science definition entails an ecological community consisting of different populations of organisms that live together in a habitat. Ecology, which is the scientific study of the interactions between populations or between organisms and the environment, can be viewed at the level of an individual, population, community, or ecosystem. Ecology at the level of individuals is mainly concerned with the physiology, reproduction, and development of an organism. At the level of population, ecology deals primarily with the attributes and the various factors affecting the population. At the level of community, ecology investigates the interactions between populations and community patterns. At the ecosystem level, ecology brings them all together to understand how the system functions as a unit [42].

Ecosystem services are the benefits obtained from the environment that increase human well-being. Economic valuation is conducted by measuring the human welfare gains or losses resulting from changes in the provision of ecosystem services. Bats, which live on all continents except Antarctica, are essential members of many types of ecosystems, ranging from rainforests to deserts. By fulfilling their ecosystem roles, bats promote biodiversity and support the health of their ecosystems. Due to the rich diversity of dietary habits of bats, ranging from species that feed on insects and other arthropods to those that feed on fruit, nectar, and flowers, they have long been postulated to play important roles in ecological and economic services. Moreover, other species that feed on seeds, frogs, fish, small mammals, and even blood also play important roles in ecosystems as predators or prey in ecosystems sustainability. Modifying ecosystems to facilitate socioeconomic development is necessary but how can we avoid damaging important ecosystem services? As a prerequisite, we need to understand how ecosystem services contribute to people's livelihoods and well-being.

2.2.1 Ecological services

Bats have long been known as the main contributor to remarkable ecosystem benefits, are significant suppressors of agricultural pests [43–46], consume important disease vectors, such as malaria-bearing mosquitos [47], with an important role in seed dispersal, pollination, material and nutrient distribution, and recycle [48].

One of the most troubling problems of the farming industry is insect pests, which affect crop production worldwide. Inhibitors of natural insect pests such as bats, as major predators of arthropods, provide valuable ecosystem benefits for crops cultivation [48, 49]. Indeed, herbivorous arthropods destroy approximately 25–50% of crops worldwide [50, 51], in response to these threats, it is clear that the application of synthetic pesticides has increased which in turn has led to several unintended consequences including human health risks, degradation of ecosystem function, evolved toxicity resistance by pests, and severe alterations in the agribusiness dynamics [50, 52, 53].

Indeed, the elimination of beneficial vertebrate predators that act as biocontrol of insects, such as bats, insect species that are not normally considered pests are often elevated to pest status [53, 54]. Thus, the promotion of biological controls can reduce the widespread and indiscriminate use of chemical pesticides [55]. About 99% of potential crop pests are limited by natural ecosystems [53, 56] of which some fraction can be attributed to predation by bats [57]. For example, a colony of 150 big brown bats (*Eptesicus fuscus*) in the midwestern United States annually consume approximately 600,000 spotted cucumber beetles (*Diabrotica undecimpunctata*), 194,000 June beetles (Scarabidae), 158,000 leafhoppers (Cicadellidae), and 335,000 stinkbugs (Pentatomidae), which are severe crop pests [58]. A Brazilian free-tailed bat (*Tadarida brasiliensis*) can eat up to 20 females of corn earworm moth (*Helioverpa zea*), one of the costliest agricultural pest insects in one night [59]. In fact, each moth can potentially produce 10,000 crop-damaging caterpillars each night [60]. Bats are just one of several groups of animals that naturally prey on mosquitoes. A Florida colony of 30,000 southeastern myotis (*Myotis austroriparius*) eats 50 tons of insects annually, including more than 15 tons of mosquitoes (**Figure 1**) [61, 62].

Therefore, insectivorous bat species, which largely feed on airborne insects and other arthropods, considerably contribute to the suppression of insects that harm the agricultural industry or transmit specific pathogens to humans, consequently contributing to the maintenance of ecosystem stability.

Figure 1. Insectivorous bat species (a) big brown bats (*Eptesicus fuscus*); (b) Southeastern myotis (*Myotis austroriparius*); (c) Brazilian free-tailed bat (*Tadarida brasiliensis*): photos by Merlin Tuttle's Bat Conservation/MerlinTuttle.org.

Figure 2. A lesser long-nosed bat (*Leptonycteris yerbabuenae*) feeding on a cross-sectioned saguaro cactus flower: photo by Merlin Tuttle's Bat Conservation/MerlinTuttle.org.

Another important ecosystem service provided by bats is pollination. Although, bat pollination is relatively uncommon when compared with bird or insect pollination, it involves an impressive number of economically and ecologically important plants [63]. Plant-visiting bats play a remarkable role in facilitating reproductive success and the recruitment of new seedlings [48]. For instance, bat-pollinated columnar cacti (Cactaceae) and agaves (Asparagaceae) are among the most important species as dominant vegetation elements in arid and semiarid habitats (Figure 2) [48].

Furthermore, seed dispersal is a major way in which animals contribute to ecosystem succession by depositing seeds from one area to another [64]. Frugivorous bats play a tremendous role in dispersing the seeds of tropical trees and shrubs to produce fleshy fruits as 50–90% of these trees are adapted to the consumption of vertebrates [65]. Generally, frugivorous bats help maintain the diversity of forests by dispersing seeds across different ecosystems, often introducing novel plant species into previously disturbed landscapes [64].

In contrast to predation, which is an antagonistic population interaction, pollination, and seed dispersal are mutualistic population interactions in which plants provide a nutritional reward (nectar, pollen, and fruit pulp) for a beneficial service [48]. Indeed, frugivorous bats as well as nectarivorous bats provide valuable ecosystem services by pollinating plants, dispersing pollen, and thus helping to maintain the genetic diversity of flowering plants.

Bats offer an important multisensory role in assessing ecosystem health either by directly contributing to regulating services to agricultural production or indirectly

by providing forage and nesting habitat for pollinators and seed dispersers. To some extent, bat guano has great ecological potential for soil fertility and nutrient distribution, as bats sprinkle them over the landscape overnight, they facilitate nutrient redistribution within ecosystems [66]. In other words, bat guano supports a great diversity of organisms including arthropods, fungi, bacteria, and lichens representing different trophic levels by supporting their ecosystems [67].

Moreover, bats have enormous potential as bioindicators of both disturbance and the existence of contaminants [68]. They show taxonomic stability, trends in their populations can be monitored, short- and long-term effects on populations can be measured and widely distributed worldwide [68–70]. Since insectivorous bats occupy high trophic levels, they are sensitive to the accumulations of pesticides and other toxins, and changes in their abundance may reflect changes in populations of arthropod prey species [71]. In particular, changes in bat numbers or activity can be related to climate change, deterioration of water quality, agricultural intensification, loss and fragmentation of habitats, fatalities at wind turbines, disease, pesticide use, and overhunting [68], and hence bat populations are affected by a wide range of stressors that affect many other taxa. Overall, there is an urgent need to implement a global effort for monitoring bat populations, to ensure that their role as bioindicators can be used to their full potential.

2.2.2 Economic services

Estimating the economic importance of bats in agricultural systems is challenging; however, the bats value in pest suppression illustrates an important agricultural service by increasing the monetary gain of farmers, and consequently supporting food security [49]. They consume enormous quantities of insect pests that cost farmers and foresters billions of dollars annually [59]. In USA, due to the fact of insect pests are eliminated by bat predation, the estimated value of bats as a result of reduced costs of pesticide applications is in the range of \$3.7–\$53 billion per year [66]. These estimates include the reduced costs of unnecessary pesticide applications to suppress insects consumed by bats [72].

Bats provide substantial ecosystem services worldwide, and their benefits to human economies are not limited to agricultural pest control. For example, pioneering research in tropical ecosystems shows the importance of plant-visiting bats in the pollination of valuable fruit crops [73, 74]. There are 289 Old World tropical plant species, which rely on pollination and seed dispersal services by bats for their propagation, providing human with about 448 products in a variety of categories, for instance, wood products (23%); food, drinks and fresh fruit (19%); medicine (15%); dye, fiber, animal fodder, fuel wood, and others (43%) [57]. In addition to some cash crops such as wild bananas (*Musa acuminata*), mangos (*Mangifera indica*), breadfruits (*Artocarpus altilis*), agave (*Agave* spp.), and durians (*Durio* spp.) they rely on bats for pollination [57]. Durian, a wildly popular fruit worth more than \$230 million per year in Southeast Asia, opens its flower at dusk and relies almost exclusively on fruit bats for pollination [57]. In general, according to the vital role that bats play in the global pollination services, their total economic value is up to \$200 billion [75]. Furthermore, bats have a tremendous economic value in maintaining forests through dispersing the seeds of crucial plants for forest reemerging [76]. For instance, the estimated economic value of bat seed dispersal services to giant oak (*Quercus virginiana*) is \$212,000 for acorn seeding and \$945,000 for planting saplings [77].

Bats provide some of the world's finest natural fertilizers known as Guano [78]. Since there are high concentrations of nitrogen and phosphorous in guano [79], it provides some of the world's finest natural fertilizers [78]. For instance, in Texas the

Brazilian free-tailed bat guano has been extracted for fertilizer in thousands of tons from Bracken Cave alone with the current retail sales ranging from \$2.86 to \$12.10 per kilogram [78].

Finally, it is important to recognize the extraordinary value of bats to ancient and contemporary traditions and science. Recently, bats provide esthetic contributions through cave visits, nocturnal tours in national parks, and educational nature programs. Like other wildlife recreational activities, bat watching is considerably growing [80]. Besides providing adventure and life memories to the public, it generates income for the communities and companies involved [80]. For instance, Congress Avenue Bridge, one of the largest urban bat colonies in the USA, is visited by 200–1500 visitors every evening with a value of \$3 million per year [80, 81]. Bats also commonly appear as symbols or logos in popular movies (e.g., Batman), products (e.g., Bacardi rum), and holidays (e.g., Halloween), and all major revenue-generating endeavors [82]. Moreover, many novel technological advances have been inspired by bat echolocation and locomotion, such as sonar systems, biomedical ultrasound, sensors for autonomous systems, wireless communication, and BATMAVs (bat-like motorized aerial vehicles) [83]. Also, in the medical sector, the saliva of vampire bats with its anticlotting chemicals has been investigated as a potential anticoagulant for people who are at high risk of blood clots and strokes [84].

Although, some of these services provide direct benefits to humans (e.g., food, fuel, fiber, and fertilizer), most ecosystem services offer indirect benefits (e.g., pest suppression, seed dispersal, and pollination). Often, little attention is paid to “free” services provided by ecosystems either because the benefits of the services are not fully understood by decision makers or because the benefits accrue to non-owners of the ecosystem providing the service [48]. Information on nonmarket values of ecosystem services can be used to inform decisions regarding whether to protect existing ecosystem services, improve the current provision of ecosystem services, or restore previously lost ecosystem services [4, 85].

Finally, although much of the public and some policy makers may view the precipitous decline of bats worldwide as only of academic interest, the economic and ecological consequences of losing so many bats could be substantial. Thus, a deeper understanding

Figure 3. Ecosystem services provided by bats by Ramírez-Fráncel [86].

of bat-human inter-relationships, the importance of bat diversity, and ecosystem management is crucial for healthy ecosystems and human well-being (**Figure 3**).

3. Ecosystem management

The management and protection of ecosystems are essential to the functioning of ecosphere processes and for the well-being of the biotic and abiotic components of the Earth. Different sectors of society view ecosystem management in terms of their own economic, cultural and societal needs. Management should involve all stakeholders and balance local interests with the broader public interest. Effective ecosystem management depends on both cultural and biological diversity, the dynamic relationship within a species, among species and between species and their abiotic environment, as well as the physical and chemical interactions within the environment [87].

There are different perspectives of environmental management, one of which deals with human needs as central such as protecting a young forest because it may be able to be logged in the future which is known as anthropocentric perspective. While the egocentric perspective deals with the needs of environments as central, for example allowing farmers to extract less water from the river to permit more water to flow downstream [88]. Thus, we must appropriately value and manage ecosystems because of their multiple values to humanity and/or because of their value to other ecosystems and both scenarios lead to a healthier environment and more human well-being.

As human numbers increase and people encroach deeper into the remaining natural habitats, human-bat interactions are becoming more frequent, with often undesirable consequences for both humans and bats [14]. However, bats are often considered keystone species, as they play an important role in many ecosystem services [89], bat populations are declining worldwide mainly because of habitat destruction [90] and increased population control [91, 92]. Additionally, the lack of knowledge about bats makes them an easy target for disease-related fears [93–95] and a potential target for persecution [28, 96].

Indeed, bat management requires a comprehensive approach that must consider the development of culturally appropriate strategies that minimize zoonotic health risks and support bat diversity and its associated ecosystem services [97]. However, even with some communities expressing positive attitudes toward bats, bat control efforts and roost destruction are significant threats to the taxon. Thus, healthy comprehensive management depends on a robust understanding of the importance of bat diversity and emphasizes the non-lethal actions by the general public, health officials, and pest/wildlife managers [98]. It is essential to document people's relationship with bats and to incorporate these perceptions into educational efforts and management decisions, consequently increasing the potential for successful conservation efforts. While comprehensive management can be more costly in the short term (compared to typical pest control efforts), the long-term results should provide the best sustainable outcomes that are satisfactory to people, bats, and the environment [99].

The key to sustainable development is to strike a balance between the exploitation of natural resources for socio-economic development and the preservation of ecosystem services. In other words, healthy ecosystems are a prerequisite for sustainable development and all ecosystem services provided by different vertebrate animals, such as bats, compromise options for present and future generations. Hence, it is important to demonstrate that undervaluing one ecosystem service is likely to lead to the loss of many.

4. Conclusion

In conclusion, for the benefit of present and future generations, bat management by governmental agencies and NGOs needs to be evaluated. Additionally, more understanding is needed of how ecosystem services provided by bats contribute to livelihoods and how far the benefits provided by bats elevate their detrimental impact. Furthermore, in the context of accelerating environmental change, there is an urgent need to identify ecosystem conservation, restoration, and management strategies that are likely to support biodiverse and adaptive ecosystems in the future. We hope that increased awareness about these nocturnal, fast-flying, and secretive mammals can help build synergies between international scientific knowledge, conservation priorities, and local cultural values, which together can promote the benefits of the ecosystem services provided by bats (Video 1, <https://www.merlintuttle.org/video/the-importance-of-bats/>).

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References

- [1] Chivian E, Bernstein A, editors. Sustaining life. In: How Human Health Depends on Biodiversity. New York: Oxford University Press; 2008
- [2] Daily GC, editor. Nature's Services. Societal Dependence on Natural Ecosystems. Washington, DC: Island Press; 1997
- [3] Daily GC, Söderqvist T, Aniyar S, Arrow K, Dasgupta P, Ehrlich PR, et al. The value of nature and the nature of value. *Science*. 2000;**289**(5478):395-396. DOI: 10.1126/science.289.5478.395
- [4] Joseph A, Neville JA, Colin DB, Doris C, Stephen RC, Juan CC, et al. Millennium ecosystem assessment. In: *Ecosystems and Human Well-Being: A Framework for Assessment*. Washington, DC: Island Press; 2003
- [5] Walter VR, Harold A M, Angela C, Doris C, Stephen RC, Kanchan C, et al. Millennium ecosystem assessment. In: *Ecosystems and Human Well-Being: Synthesis*. Washington, DC: Island Press; 2005
- [6] Simmons NB, Seymour KL, Habersetzer J, Gunnell GF. Primitive early eocene bat from Wyoming and the evolution of flight and echolocation. *Nature*. 2008;**451**:U818-U816. DOI: 10.1038/nature06549
- [7] Simmons NB, Cirranello AL. Bat Species of the World: A Taxonomic and Geographic Database [web page]. 2021. Available from: <https://batnames.org/>
- [8] Patterson BD, Willig MR, Stevens RD. Trophic strategies, niche partitioning, and patterns of ecological organization. In: Kunz TH, Fenton MB, editors. *Bat Ecology*. Chicago: University of Chicago Press; 2003. pp. 536-579
- [9] Simmons NB, Conway M. Evolution and ecological diversity of bats. In: Kunz TH, Fenton MB, editors. *Bat Ecology*. Chicago: University of Chicago Press; 2003. pp. 493-535
- [10] Kunz TH. *Ecology of Bats*. 1st ed. Vol. XVIII. Boston, MA: Springer; 1982. p. 450. DOI: 10.1007/978-1-4613-3421-7
- [11] Chaverri G, Kunz TH. Ecological determinants of social systems: Perspectives on the role of roosting ecology in the social behavior of tent-roosting bats. In: Macedo R, editor. *Behavioral Ecology of Tropical Animals, Advances in the Study of Behavior*. Vol. 42. New York: Academic Press; 2010. pp. 275-318. DOI: 10.1016/S0065-3454(10)42009-4
- [12] Lawrence EA. The sacred bee, the filthy pig, and the bat out of hell: Animal symbolism as cognitive biophilia. In: Kellert SR, editor. *The Biophilia Hypothesis*. Washington, D.C: Island Press; 1993. pp. 301-341
- [13] Low M, Hoong WZ, Shen Z, Murugavel B, Mariner N, Paguntalan LM, et al. Bane or blessing? Reviewing cultural values of bats across the Asia-Pacific region. *Journal of Ethnobiology*. 2021;**41**(1):18-34. DOI: 10.2993/0278-0771-41.1.18
- [14] Rocha R, Fernández-Llamazares A, López-Baucells A, Andrimatandrina SFM, Andriatafika ZE, Burgas D, et al. Human-bat interactions in rural southwestern Madagascar through a biocultural lens. *Journal of Ethnobiology*. 2021;**41**(1):53-69. DOI: 10.2993/0278-0771-41.1.53
- [15] Morcote-Ríos G, Aceituno FJ, Iriarte J, Robinson M, Chaparro-Cárdenas JL. colonisation and early peopling of the colombian amazon during the late pleistocene and the early holocene: New evidence from La Serranía La Lindosa. *Quaternary International*. 2021;**578**:5-19. DOI: 10.1016/j.quaint.2020.04.026

- [16] Polák J, Rádlová S, Janovcová M, Flegl J, Landová E, Frynta D. Scary and nasty beasts: Self-reported fear and disgust of common phobic animals. *British Journal of Psychology*. 2020; **111**(2):297-321. DOI: 10.1111/bjop.12409
- [17] Todd J. Dreaming the bat out of the shadow. *Psychological Perspectives*. 2016; **59**(2):219-241. DOI: 10.1080/00332925.2016.1170566
- [18] Deshpande K, Kelkar N. How do fruit bat seed shadows benefit agroforestry? Insights from local perceptions in Kerala, India. *Biotropica*. 2015; **47**(6):654-659. DOI: 10.1111/btp.12275
- [19] Fagan KE, Willcox EV, Willcox AS. Public attitudes toward the presence and management of bats roosting in buildings in Great Smoky Mountains National Park, Southeastern United State. *Biological Conservation*. 2018; **220**(1):132-139. DOI: 10.1016/j.biocon.2018.02.004
- [20] Lim VC, Wilson JJ. Public perceptions and knowledge of, and responses to, bats in urban areas in Peninsular Malaysia. *Anthrozoös*. 2019; **32**(6):825-834. DOI: 10.1080/08927936.2019.1673063
- [21] Shapiro HG, Willcox AS, Ader DR, Willcox EV. Attitudes towards and relationships with cave-roosting bats in northwest Cambodia. *Journal of Ethnobiology*. 2021; **41**(1):87-104. DOI: 10.2993/0278-0771-41.1.87
- [22] Fernández-Llamazares Á, Cabeza M. Rediscovering the potential applications of indigenous storytelling for conservation practice. *Conservation Letters*. 2018; **11**(3):e12398. DOI: 10.1111/conl.12398
- [23] Kingston T. Cute, creepy, or crispy—How values, attitudes and norms shape behavior toward bats. In: Voigt CC, Kingston T, editors. *Bats in the Anthropocene: Conservation of Bats in a Changing World*. Springer International Publishing; 2015. pp. 571-595. DOI: 10.1007/978-3-319-25220-9_18
- [24] Lunney D, Moon C. Blind to bats. In: Law B, Eby P, Lunney D, Lumsden L, editors. *The Biology and Conservation of Australasian Bats*. Mosman, NSW, Australia: Royal Zoological Society of NSW; 2011. pp. 44-63. DOI: 10.7882/FS.2011.008
- [25] Musila S, Prokop P, Gichuki N. Knowledge and perceptions of, and attitudes to, bats by people living around Arabuko-Sokoke Forest, Malindi-Kenya. *Anthrozoös*. 2018; **31**: 247-262. DOI: 10.1080/08927936.2018.1434065
- [26] Tuttle MD. Fear of bats and its consequences. *Journal of Bat Research and Conservation*. 2017; **10**(1):66-69. DOI: 10.14709/BarbJ.10.1.2017.09
- [27] Prokop R, Tunncliffe SD. “Disgusting” animals: Primary school children’s attitudes and myths of bats and spiders. *Eurasia Journal of Mathematics, Science & Technology Education*. 2008; **4**(2):87-97. DOI: 10.12973/ejmste/75309
- [28] Prokop P, Fančovičová J, Kubiato M. Vampires are still alive: Slovakian students’ attitudes toward bats. *Anthrozoös*. 2009; **22**:19-30. DOI: 10.2752/175303708X390446
- [29] Rydell J, Eklöf J, Riccucci M, du Père-Lachaise C. Bats and vampires in French romanticism. *Journal of Bat Research & Conservation*. 2018; **11**:83-91. DOI: 10.14709/BarbJ.11.1.2018.10
- [30] Tanalgo KC. Wildlife hunting by indigenous people in a Philippine protected area: A perspective from Mt. Apo National Park, Mindanao Island. *Journal of Threatened Taxa*. 2017; **9**: 10307-10313. DOI: 10.11609/jott.2967.9.6.10307-10313

- [31] Tanalgo KC, Teves RD, Salvaña FRP, Baleva RE, Tabora JAG. Human-bat interactions in caves of south-central Mindanao, Philippines. *Wildlife Biology in Practice*. 2016;**12**:1-14
- [32] Tatai E. An iconographical approach to representations of the devil in medieval Hungary. *Christian Demonology and Popular Mythology*. 2006;**2**:54
- [33] Charro M. Murciélagos: Principes de las Tinieblas. *Revista Folklore*. 1999;**19**:111-118
- [34] Frembgen JW. Embodying evil and bad luck: Stray notes on the folklore of bats in southwest Asia. *Asian Folklore Studies*. 2006;**65**(2):241-247. Available from: <https://www.jstor.org/stable/30030400>
- [35] Eklöf J, Rydell J. Attitudes towards bats in swedish history. *Journal of Ethnobiology*. 2021;**41**:35-52. DOI: 10.2993/0278-0771-41.1.35
- [36] Pham HMA, Yonn-Soon L. A study on the classifications and symbolic meanings of Vietnamese traditional patterns. *International Journal of Human Ecology*. 2008;**9**(1):29-40
- [37] Hall LS, Richards G. *Flying Foxes: Fruit and Blossom Bats of Australia*. Sydney: UNSW Press; 2000
- [38] Hadnes M, Schumacher H. The Gods are watching: An experimental study of religion and traditional belief in Burkina Faso. *Journal for the Scientific Study of Religion*. 2012; **51**(4):689-704. DOI: 10.1111/j.1468-5906.2012.01676.x
- [39] Retana-Guiascón OG, Navarijo-Ornelas ML. Los valores culturales de los murciélagos. *Revista Mexicana de Mastozoología*. 2012;**2**(1): 18-26. DOI: 10.22201/ie.20074484e.2012.2.1.19
- [40] Voigt CC, Phelps KL, Aguirre LF, Corrie Schoeman M, Vanitharani J, Zubaid A. Bats and buildings: The conservation of synanthropic bats. In: Voigt CC, Kingston T, editors. *Bats in the Anthropocene: Conservation of Bats in a Changing World*. Cham, Switzerland: Springer; 2016. pp. 427-462. DOI: 10.1007/978-3-319-25220-9_14
- [41] Aziz SA, Clements GR, Giam X, Forget PM, Campos-Arceiz A. Coexistence and conflict between the island flying fox (*Pteropus hypomelanus*) and humans on Tioman Island, Peninsular Malaysia. *Human Ecology*. 2017;**45**:377-389. DOI: 10.1007/s10745-017-9905-6
- [42] The Concept of the Ecosystem. Umich. Edu. 2017. Available from: <https://globalchange.umich.edu/globalchange1/current/lectures/kling/ecosystem/ecosystem.html>
- [43] Maas B, Karp DS, Bumrungsri S, Darras K, Gonthier D, Huang JC, et al. Bird and bat predation services in tropical forests and agroforestry landscapes. *Biological Reviews*. 2016;**91**:1081-1101. DOI: 10.1111/brv.12211
- [44] Puig-Montserrat X, Torre I, López-Baucells A, Guerrieri E, Monti MM, Ràfols-García R, et al. Pest control service provided by bats in mediterranean rice paddies: Linking agroecosystems structure to ecological functions. *Mammalian Biology*. 2015;**80**:237-245. DOI: 10.1016/j.mambio.2015.03.008
- [45] Puig-Montserrat X, Flaquer C, Gómez-Aguilera N, Burgas A, Mas M, Tuneu C, et al. Bats actively prey on mosquitoes and other deleterious insects in rice paddies: Potential impact on human health and agriculture. *Pest Management Science*. 2020;**76**:3759-3769. DOI: 10.1002/ps.5925
- [46] Wanger TC, Darras K, Bumrungsri S, Tschardt T, Klein AM. Bat pest control contributes to food security in Thailand. *Biological*

Conservation. 2014;**171**:220-223.
DOI: 10.1016/j.biocon.2014.01.030

[47] Kemp J, López-Baucells A, Rocha R, Wangenstein OS, Andriatafika Z, Nair A, et al. bats as potential suppressors of multiple agricultural pests: A case study from Madagascar. *Agriculture, Ecosystems & Environment*. 2019;**269**: 88-96. DOI: 10.1016/j.agee.2018.09.027

[48] Kunz TH, de Torrez EB, Bauer D, Lobova T, Fleming TH. Ecosystem services provided by bats. *Annals of the New York Academy of Sciences*. 2011;**1223**:1-38. DOI: 10.1111/j.1749-6632.2011.06004.x

[49] de Groot R, Brander L, van der Ploeg S, Costanza R, Bernard F, Braat L, et al. Global estimates of the value of ecosystems and their services in monetary units. *Ecosystem Services*. 2012;**1**:50-61. DOI: 10.1016/j.ecoser.2012.07.005

[50] Pimentel D, Krummel J, Gallahan D, Hough J, Merrill A, Schreiner I, et al. Benefits and costs of pesticide use in the US food production. *Bioscience*. 1978;**28**:778-784. DOI: 10.2307/1307251

[51] Pimentel D, McLaughlin L, Zepp A, Lakitan B, Kraus T, Kleinman P, et al. Environmental and economic effects of reducing pesticide use. *Agriculture, Ecosystems & Environment*. 1993; **46**:1-4. DOI: 10.1016/0167-8809(93)90030-S

[52] Benbrook CM. Pest management at the crossroads. New York: Consumers Union (1996). *The Journal of Agricultural Science*. 1998;**130**:119-123. DOI: 10.1017/S0021859697245120

[53] Naylor RL, Ehrlich PR. Natural pest control services and agriculture. In: Daily GC, editor. *Nature's Services. Societal Dependence on Natural Ecosystems*. Washington, DC: Island Press; 1997. pp. 151-176

[54] National Research Council. *Alternative Agriculture*. Washington, DC: National Academies Press; 1989

[55] United States Environmental Protection Agency. *Integrated Pest Management (IPM) Principles*. 2009. Available from: <http://www.epa.gov/opp00001/factsheets/ipm.htm>

[56] Debach P, Rosen D. *Biological Control by Natural Enemies*. 2nd ed. London: Cambridge University Press; 1991. SB975.D39 1991

[57] Fujita MS, Tuttle MD. Flying foxes (Chiroptera: Pteropodidae): Threatened animals of key ecological and economic importance. *Conservation Biology*. 1991;**5**:455-463. DOI: 10.1111/j.1523-1739.1991.tb00352.x

[58] Whitaker JO. Food of the big brown bat *Eptesicus fuscus* from maternity colonies in Indiana and Illinois. *American Midland Naturalist*. 1995;**134**: 346-360. DOI: 10.2307/2426304

[59] Keeley BW, Tuttle MD. *Bats in American Bridges*. Resource Publication #4. Austin, Tex.: Bat Conservation International, Inc.; 1999

[60] McCracken GF. Bats aloft: A study of high-altitude feeding. *Bats*. 1996;**14**:7-101

[61] Anthony ELP, Kunz TH. Feeding strategies of the little brown bat (*Myotis lucifugus*) in southern New Hampshire. *Ecology*. 1977;**58**:775-786. DOI: 10.2307/1936213

[62] Reiskind MH, Wund MA. Experimental assessment of the impacts of northern long-eared bats on ovipositing *Culex* (Diptera: Culicidae) mosquitoes. *Journal of Medical Entomology*. 2009;**46**:1037-1044. DOI: 10.1603/033.046.0510

[63] Fleming TH, Muchhala N. Nectar-feeding bird and bat niches in two

- worlds: Pantropical comparisons of vertebrate pollination systems. *Journal of Biogeography*. 2008;**35**:764-780. DOI: 10.1111/j.1365-2699.2007.01833.x
- [64] Duncan RS, Chapman CA. Seed dispersal and potential forest succession in abandoned agriculture in tropical Africa. *Ecological Applications*. 1999;**9**:998-1008. DOI: 10.1890/1051-0761
- [65] Howe HF, Smallwood J. Ecology of seed dispersal. *Annual Review of Ecology and Systematics*. 1982;**13**:201-228. DOI: 10.1146/annurev.es.13.110182.001221
- [66] Boyles JG, Cryan PM, McCracken GF, Kunz TH. Economic importance of bats in agriculture. *Science*. 2011;**332**:41-42. DOI: 10.1126/science.1201366
- [67] Polis GA, Anderson WB, Holt RD. Toward an integration of landscape and food web ecology: The dynamics of spatially subsidized food webs. *Annual Review of Ecology and Systematics*. 1997;**28**:289-316. DOI: 10.1146/annurev.ecolsys.28.1.289
- [68] Jones G, Jacobs D, Kunz TH, Wilig MR, Racey PA. CarpeNoctem: The importance of bats as bioindicators. *Endangered Species Research*. 2009;**8**: 93-115. DOI: 10.3354/esr00182
- [69] Fenton MB. Science and the conservation of bats: Where to next? *Wildlife Society Bulletin*. 2003;**31**:6-15. DOI: 10.2307/3784355
- [70] Fenton MB, Acharya L, Audet D, Hickey MBC, Merriman C, Obrist MK, et al. Phyllostomid bats (Chiroptera: Phyllostomidae) as indicators of habitat disruption in the neotropics. *Biotropica*. 1992;**24**:440-446. DOI: 10.2307/2388615
- [71] Hutson AM, Mickleburgh SP, Racey PA. Microchiropteran Bats: Global Status Survey and Conservation Action Plan. Gland, Switzerland: IUCN/SSC chiroptera specialist group, IUCN; 2001. DOI: 10.2305/IUCN.CH.2001.SSC-AP.1.en
- [72] Cleveland CJ, Betke M, Federico P, Frank JD, Hallam TG, Horn J, et al. Economic value of the pest control service provided by Brazilian free-tailed bats in south-central Texas. *Frontiers in Ecology and the Environment*. 2006;**4**:238-243. DOI: 10.1890/1540-9295
- [73] Bumrungsri S, Sripaoraya E, Chongsiri T, Sridith K, Racey PA. The pollination ecology of durian (*Durio zibethinus*, Bombacaceae) in southern Thailand. *Journal of Tropical Ecology*. 2009;**25**:85-92. DOI: 10.1017/S0266467408005531
- [74] Bumrungsri S, Harbit A, Benzie C, Carmouche K, Sridith K, Racey PA. The pollination ecology of two species of Parkia (Mimosaceae) in southern Thailand. *Journal of Tropical Ecology*. 2008;**24**:467-475. DOI: 10.1017/S0266467408005191
- [75] Gallai N, Salles JM, Settele J, Vaissière BE. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological Economics*. 2009;**68**:810-821. DOI: 10.1016/j.ecolecon.2008.06.014
- [76] Buddenhagen IW. Bats and disappearing wild bananas: Can bats keep commercial bananas on supermarket shelves? *Bats*. 2008;**26**:1-6
- [77] Hougner C, Colding J, Söderqvist T. Economic valuation of a seed dispersal service in the Stockholm National Urban Park, Sweden. *Ecological Economics*. 2006;**59**:364-374. DOI: 10.1016/j.ecolecon.2005.11.007
- [78] Tuttle MD, Moreno A. Cave-Dwelling Bats of Northern Mexico: Their Value and Conservation Needs.

Austin, Texas, USA: Bat Conservation International, Inc.; 2005

[79] Hutchinson GE. Survey of existing knowledge of biogeochemistry: The biogeochemistry of vertebrate excretion. *Bulletin of the American Museum of Natural History*. 1950;**96**:1-554. Available from: <http://hdl.handle.net/2246/918>

[80] Tapper R. *Wildlife Watching and Tourism: A Study on the Benefits and Risks of a Fast Growing Tourism Activity and Its Impacts on Species*. Bonn, Germany: UNEP/CMS Secretariat; 2006

[81] Pennisi LA, Holland SM, Stein TV. Achieving bat conservation through tourism. *Journal of Ecotourism*. 2004;**3**:195-207. DOI: 10.1080/14664200508668432

[82] Brown DE. *Vampiro: The Vampire Bat in Fact and Fantasy*. 1st ed. Silver City, NM: High-Lonesome Books; 1994

[83] Bunget G, Seelecke S. BATMAV: A 2-DOF bio-inspired flapping flight platform. *The International Society for Optics and Photonics*. 2010;**7643B**:1-11. DOI: 10.1117/12.853398

[84] Schleuning WD. Vampire bat plasminogen activator DSPAalpha-1 (desmoteplase): A thrombolytic drug optimized by natural selection. *Pathophysiology of Haemostasis and Thrombosis*. 2000;**31**:118-122. DOI: 10.1159/000048054

[85] National Research Council. *Valuing Ecosystem Services: Towards Better Environmental Decision-Making*. Washington, DC: National Academies Press; 2005

[86] Ramírez-Fráncel LA, García-Herrera LV, Losada-Prado S, Reinoso-Flórez G, Sánchez-Hernández A, Estrada-Villegas S, et al. Bats and their vital ecosystem services: A global

review. *Integrative Zoology*. 2021;**0**:1-22. DOI: 10.1111/1749-4877.12552

[87] Bellera EE, McClenachan L, Zavaleta ES, Larsen LG. Past forward: Recommendations from historical ecology for ecosystem management. *Global Ecology and Conservation*. 2020;**21**:e00836. DOI: 10.1016/j.gecco.2019.e00836

[88] Rülke J, Rieckmann M, Nzau JM, Teucher M. How ecocentrism and anthropocentrism influence human–environment relationships in a Kenyan biodiversity hotspot. *Sustainability*. 2020;**12**:8213. DOI: 10.3390/su12198213

[89] Ghanem SJ, Voigt CC. Increasing awareness of ecosystem services provided by bats. *Advances in the Study of Behavior*. 2012;**44**:279-302. DOI: 10.1016/b978-0-12-394288-3.00007-1

[90] Elliot WR. Protecting caves and cave life. In: Culver DC, White WB, editors. *Encyclopedia of Caves*. Amsterdam: Elsevier; 2014. pp. 458-467

[91] Reid JL. Knowledge and experience predict indiscriminate bat-killing intentions among Costa Rican men. *Biotropica*. 2016;**48**:394-404. DOI: 10.1111/btp.12279

[92] Frick WF, Kingston T, Flanders J. A review of the major threats and challenges to global bat conservation. *Annals of the New York Academy of Sciences*. 2020;**1469**:5-25. DOI: 10.1111/nyas.14045

[93] Olival KJ, Hosseini PR, Zambrana-Torrel C, Ross N, Bogich TL, Daszak P. Host and viral traits predict zoonotic spillover from mammals. *Nature*. 2017;**546**:646-650. DOI: 10.1038/nature22975

[94] López-Baucells A, Rocha JR, Fernández-Llamazares Á. When bats go viral: Negative framings in virological

research imperil bat conservation.
Mammal Review. 2018;**48**:62-66.
DOI: 10.17863/CAM.21045

[95] Centers for Disease Control and Prevention (CDC). Coronavirus disease 2019 (COVID-19). Atlanta, Georgia, USA: Centers for Disease Control and Prevention; 2020. Available from: <https://www.cdc.gov/coronavirus/2019-ncov/cases-updates/summary.html#emergence>

[96] Dickman AJ, Hazzah L. Money, myths and man-eaters: Complexities of human– wildlife conflict. In: Angelici FM, editor. *Problematic wildlife*. Springer; 2016. pp. 339-356. DOI: 10.1007/978-3-319-22246-2_16

[97] MacFarlane D, Rocha R. Guidelines for communicating about bats to prevent persecution in the time of COVID-19. *Biological Conservation*. 2020;**248**:108650. DOI: 10.1016/j.biocon.2020.108650

[98] Fagan KE, Willcox EV, Willcox AS. Public attitudes toward the presence and management of bats roosting in buildings in Great Smoky Mountains National Park, Southeastern United States. *Biological Conservation*. 2018;**220**:132-139. DOI: 10.1016/j.biocon.2018.02.004

[99] Frantz SC, Laniewicz BR. Comprehensive management of commensal bats. In: Brittingham MC, Kays J, McPeake R, editors. *The Ninth Wildlife Damage Management Conference Proceedings*. PA, USA: State College; 2000. Available from: <http://wildlifedamage.unl.edu>