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Review Article

Ecological and Economic Importance of Bats (Order Chiroptera)

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Order Chiroptera is the second most diverse and abundant order of mammals with great physiological and ecological diversity. They play important ecological roles as prey and predator, arthropod suppression, seed dispersal, pollination, material and nutrient distribution, and recycle. They have great advantage and disadvantage in economic terms. The economic benefits obtained from bats include biological pest control, plant pollination, seed dispersal, guano mining, bush meat and medicine, aesthetic and bat watching tourism, and education and research. Even though bats are among gentle animals providing many positive ecological and economic benefits, few species have negative effects. They cause damage on human, livestock, agricultural crops, building, and infrastructure. They also cause airplane strike, disease transmission, and contamination, and bite humans during self-defense. Bat populations appear to be declining presumably in response to human induced environmental stresses like habitat destruction and fragmentation, disturbance to caves, depletion of food resources, overhunting for bush meat and persecution, increased use of pesticides, infectious disease, and wind energy turbine. As bats are among the most overlooked in spite of their economical and ecological importance, their conservation is mandatory.

1. Introduction

The order Chiroptera is the second most diverse among mammalian orders, which exhibits great physiological and ecological diversity [1]. They form one of the largest nonhuman aggregations and the most abundant groups of mammals when measured in numbers of individuals [2]. They evolved before 52 million years ago and diversified into more than 1,232 extant species [3]. They are small, with adult masses ranging from 2 g to 1 kg; although most living bats weigh less than 50 g as adults [4]. They have evolved into an incredibly rich diversity of roosting and feeding habits. Many species of bats roost during the day time in foliage, caves, rock crevices, hollows of trees, beneath exfoliating bark, and different man-made structures [2]. During night, they become active and forage on diverse food items like insects, nectar, fruits, seeds, frogs, fish, small mammals, and even blood [3].

The forelimb of a bat is modified into a wing with elongated finger bones joined together by a thin and large (85% of the total body surface area) membrane with rich blood flow [5]. Their wing is an unusual structure in mammals enabling for active unique powered flight. Skin covering the wings of bats not only constitutes a load-bearing area that enables flying but also performs multiple functions like providing a protective barrier against microbes and parasites, gas exchange, thermoregulation, water control, trapping of insects, and food manipulation and for swimming [6]. The powerful flight of bats plays the most important role for their widespread distribution and diversity. This helps in the occurrence of bats in all continents except Antarctica, some Polar Regions, and some isolated oceanic islands. It has also contributed a lot for their extraordinary feeding and roosting habits, reproductive strategies, and social behaviors [2].

Although all bats do not echolocate, in general echolocation is considered as one of the major characteristics of bats. Even if the role of echolocation for plant-visiting bats is not clear, they use wide range (10–200 kHz) of ultrasonic frequencies during foraging. The availability of commercially produced bat detectors contributed a lot in linking data of echolocation with the biology of bats [3].

Bats are an essential natural resource that play great role in providing many ecological and economic services [7]. However, the determination of the ecological and economic values provided by bats is extremely challenging except from the studies on ecosystem services provided directly to the production of goods and services consumed by humans [3, 7].

2. Ecological Importance of Bats

Bats have long been postulated to play important ecological roles in prey and predator, arthropod suppression, seed dispersal, pollination, material and nutrient distribution, and recycle [3].

2.1. As Predators. Bats have diverse patterns of feeding in which some select among available prey while others are generalist predators, feeding on a wide diversity of taxonomic groups. They also opportunistically consume appropriately sized prey depending on availability within a preferred habitat [8]. Their prey size can vary from 1 mm (midges and mosquitoes) to as large as 50 mm long (beetles and large moths) based on the species of bat [8, 9].

Remains of 12 orders or classes of prey belonging to 18 taxonomic families of insects were reported in the diet of bats [10]. The prey items include Acari, Arachnida, Coleoptera, Diptera, Hemiptera, Homoptera, Hymenoptera, Isoptera, Lepidoptera, Neuroptera, Orthoptera, and Trichoptera. They also predate on frogs, fish, small mammals, and even blood of mammals and birds [3]. Some species also eat unusual prey items such as scorpions and spiders [11]. Bats exhibit high species diversity with multiple species forage sympatrically to avoid competition. A resource partition is possible through the use of diverse mechanism like difference in wing shape, body size, and sensory cues [12].

Obtaining accurate estimates of the amount of prey consumed by bats is challenging. However, its amount and type are confirmed as it varies with prey availability, time during night, species, sex, age, and the reproductive status of bats [13, 14]. Variety of approaches like direct observation [15], comparison of pre- and postflight body mass [14], and fecal sample analysis [16] have been used to estimate the amount and type of prey consumed by bats. Results of studies carried out on insectivorous bats indicated that they consume more than 25% of their body mass of insects each night [17]. At the peak night of lactation, a 7.9 g little brown bat (*Myotis lucifugus*) needs to consume 9.9 g of insects which is over 100% of its body mass [18]. At peak lactation, a female Brazilian free-tailed bat (*Tadarida brasiliensis)* consumes insects up to 70% of the body mass each night. It frequently selects nutrient-rich abdomen of moths while discarding the wings, head, and appendages, which greatly increases feeding efficiency and the quantity of insects consumed [14]. This can indicate that maternity colony of one million Brazilian free-tailed bats weighing 12 g each could prey up to 8.4 metric tons of insects in a single night. These studies hint at the immense capability of insect consumption and the potential role of bats in the suppression of arthropod populations [3]. Based on fecal sample analyses, a colony of 300 evening bats (*Nycticeius humeralis*) and 150 big brown bats in Indiana was estimated to consume 6.3 and 1.3 million insects per year, respectively [16, 19].

In this way, an estimated 99% of potential crop pests are limited by natural ecosystems of which some fraction can be attributed to predation by bats [7]. Predation of bats can have direct effects on herbivore communities and indirect effects on plant communities through both density mediated (consumption) and trait-mediated (behavioral) interactions and for nature balance [20].

2.2. Prey for Vertebrates. Although there are relatively few observations of animals feeding on bats, a number of vertebrate predators like fish, amphibians, birds, reptiles, and mammals prey on bats throughout the world [21, 22]. The main bat predators are owls, hawks, falcons, snakes, and mammals such as raccoons, ringtails, and opossums. In some countries like New Zealand, forest-floor dweller bats are frequently predated by the introduced rats, feral cats, and weasel [23]. The larger phyllostomid bats (*Vampyrum spectrum*, *Chrotopterus auritus*, and *Phyllostomus hastatus*) are known to eat smaller bats [24].

Bats generally comprise a relatively small proportion of the diet of most predators. Bats represented only 0.003% of the diet of small falcons and hawks and 0.036% of the diet of owls in Great Britain [21]. Although diurnal raptors feed on bats during twilight hours in some parts of the world [25], nocturnal predation by owls is the most significant predation pressure on bats in temperate regions [21].

Most of the bats are predated on roosting or when they emerge from roosts although sometimes predated during foraging or flying. Large concentrations of bats at roost sites and the relatively predictable patterns of their emergence from roosts, provide significant opportunities for predators to prey on bats [25]. However, strategies like low dependability to roost sites, selection of time, and patterns of emergence from roosts and nocturnal activity are used to minimize the risk of predation [21].

2.3. Hosts for Parasite. Numerous haematophagous ectoparasites live such as bat fleas (Ischnopsyllidae), bat flies (Nycteribiidae), bat mites (Spinturnicidae), and bugs (Cimicidae) on the skin surface and in the fur of bats. These obligate ectoparasites are specialized to their hosts [26]. The skin and hair morphology play important roles in affecting the parasite's life style in terms of adaptation, feeding, movement and egg laying resulted in morphological adaptations with coevolution of both species [5].

The hair density as well as surface structures of bat hairs and the distribution of mast cells are very important for the host defense against parasite infestation. Although the hair density of bats primarily provides protection against unfavorable microclimatic conditions, it also serves as passive antiparasitic defense. The high hair density prohibits infestation by large parasites. However, dense fur in some parts of the host's body may provide a suitable shelter for specialized small parasites [5].

2.4. Pollination. In addition to insect suppression through predation, some bat species primarily the two families of bats (Pteropodidae in the Old World and Phyllostomidae in the New World) play important roles in plant pollination [3]. Although bat pollination is relatively uncommon when compared with bird or insect pollination, it involves an impressive number of economically and ecologically important plants [27]. Particularly, beyond the economic value of plant pollination and seed dispersal services, plant-visiting bats provide important ecological services by facilitating the reproductive success and the recruitment of new seedlings [3]. Many of these plants are among the most important species in terms of biomass in their habitats. For instance, bat-pollinated columnar cacti and agaves are dominant vegetation elements in arid and semiarid habitats of the New World [3].

Bat pollination occurs in more than 528 species of 67 families and 28 orders of angiosperms worldwide [28]. Pteropodid bats are known to pollinate flowers of about 168 species of 100 genera and 41 families and phyllostomid bats pollinate flowers of about 360 species of 159 genera and 44 families [28]. As feeding on nectar and pollen requires relatively specialized morphology (e.g., elongated snout and tongue), relatively few members of these families are obligate pollinators. Unlike 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 [3].

2.5. Seed Dispersal. Seed dispersal is a major way in which animals contribute for ecosystem succession by depositing seeds from one area to another [29]. As 50–90% of tropical trees and shrubs produce fleshy fruits adapted for consumption by vertebrates, the role played by frugivorous bats in dispersing these seeds is tremendous [30].

Countless tropical trees and understory shrubs are adapted for seed dispersal by animals, primarily by bats and birds. Particularly, night-foraging fruit bats are more compliant than birds by covering long distances each night, defecating in flight, and scattering far more seeds across cleared areas [31]. Unlike most seed dispersal by vertebrates that dispersed close to parent plants with only 100–1,000 m away, the seeds dispersed by frugivorous bats were relatively far away (1-2 km) [31]. Furthermore, the flying fox migration for more than 1,000 km across the central belt of the African continent helps to scatter huge numbers of seeds along the way. Unlike birds, bats tend to defecate or spit out seeds during flight and hence facilitate seed dispersal in clear-cut strips [32]. In addition to their tendency to defecate seeds in flight, many bats use one or more feeding roosts each night where they deposit the vast majority of seeds ingested far away from fruiting plants.

Many bat-dispersed seeds are from hardy pioneer plants, the first to grow in the hot, dry conditions of clearings with up to 95% chance of germination. As these plants grow, they provide shelter that helps other, more delicate plants to grow [33]. Fruit-eating bats play an extremely important role in forest regeneration. Tropical frugivorous bats also facilitate tropical forest regeneration and help to maintain species diversity by introducing seeds from outside disturbed areas, whereas the neotropics frugivorous bats play important role in the early stages of forest succession [32].

The dispersed seeds of palms and figs by bats are also common in many tropical forests. Because they are also eaten by many birds and mammals, figs often act as keystone species in tropical forests [34].

2.6. Soil Fertility and Nutrient Distribution. Bats play an important ecological role in soil fertility and nutrient distribution due to their relatively high mobility and the use of different habitats for roosting and foraging, which facilitates nutrient transfer within ecosystems [35, 36]. However, the suspected importance of nutrient transfer by bats in overall ecosystem function is probably relatively low when compared with microhabitat conditions [36]. For soil fertility and nutrient distribution, bat guano has a great ecological potential as bats sprinkle it over the landscape throughout the night. Thus, bats contribute a lot in nutrient redistribution, from nutrient-rich sources (e.g., lakes and rivers) to nutrient-poor regions (e.g., arid or upland landscapes) [35]. For instance, a colony of one million Brazilian free-tailed bats (*T. brasiliensis*) in Texas can contribute to 22 kg of nitrogen in the form of guano.

Bat guano in turn supports a great diversity of organisms including arthropods, fungi, bacteria, and lichens that represent different trophic levels [37]. The diversity of organisms living on guano differs depending on the species and their diet. For example, guano from insectivorous bats is typically inhabited by mites, pseudoscorpions, beetles, thrips, moths, and flies, whereas the guano of frugivorous bats is inhabited by spiders, mites, isopods, millipedes, centipedes, springtails, barklice, true bugs, and beetles [38]. As bats regularly or occasionally roost in caves, bat guano provides the primary organic input to cave ecosystems, which are inherently devoid of primary productivity. They provide essential organic input that supports assemblages of different endemic cave flora and fauna. For example, cave-dwelling salamander and fish populations and invertebrate communities are also highly dependent upon nutrients from bat guano. However, little consideration has been given to the role of bats in supporting entire cave ecosystems [39].

2.7. Bioindicators. The earth is now subject to climate change and habitat deterioration on a large scale. Monitoring of climate change and habitat loss alone is insufficient to understand the effects of these factors on complex biological communities [40]. Ecosystems are geographically variable and inherently complex whereas responses to anthropogenic changes are in a nonlinear and scale dependent manner. Thus, a broad-scale network of monitoring that captures local, regional, and global components of the earth's biota is critical for understanding and forecasting responses to climate change and habitat conversion [2]. It is therefore important to identify bioindicator taxa that show measurable responses to climate change and habitat loss and that reflect wider-scale impacts on biodiversity [2].

There are three types of bioindicators (biodiversity, ecological, and environmental indicators) [41]. Biodiversity indicators capture responses of a range of taxa and reflect components of biological diversity such as species richness and species diversity. Ecological indicators consist of taxa or assemblages that are sensitive to identified environmental stress factors that demonstrate the effect of those stress factors on biota. Environmental indicators respond in predictable ways to specific environmental disturbances [41].

Biodiversity indicator species have characteristics that can be used as an index of attributes (e.g., presence/absence, population density, and relative abundance) of other species comprising the biota of interest [42]. Thus, these species collectively must have characteristics that make them easily identifiable (stable taxonomy), easy to sample, and show graded responses to habitat degradation that correlate with the responses of other taxa [43]. In addition, as environmental degradation can occur over a variety of scales, monitoring the impacts of such threats through indicator species requires the species that have broad geographic ranges. Bats, as volant taxa, fulfill this criterion better than most other taxa [2].

Bats are excellent ecological indicators of habitat quality. They have enormous potential as bioindicators to both disturbance and the existence of contaminants due to a combination of their size, mobility, longevity, taxonomic stability, observable short and long term effects, trends of populations, and their distribution around the globe [2, 4, 44].

Bat populations are affected by a wide range of stressors that affect many other taxa. In particular, changes in bat numbers or activity can be related to climate change (including extremes of drought, heat, cold, precipitation, cyclone, and sea level rise), deterioration of water quality, agricultural intensification, loss and fragmentation of habitats, fatalities at wind turbines, disease, pesticide use, and overhunting [2]. The magnitude of changes around the globe is quite variable as is the nature of the human activities that alter and fragment landscapes differs from one place to another [45]. As insectivorous bats occupy high trophic levels, they are sensitive to accumulations of pesticides and other toxins, and changes in their abundance may reflect changes in populations of arthropod prey species [1]. High fatalities observed in bats associated with diseases, may provide an early warning of environmental links among contamination, disease prevalence, and mortality. Increased environmental stress can suppress the immune systems of bats and other animals and thus one might predict that the increased prevalence of diseases is a consequence of altered environments [2].

3. Economic Importance of Bats

3.1. Biological Pest Control. Among the estimated 1,232 extant bat species, over two-thirds are either obligate or facultative insectivorous mammals. They consume nocturnal and crepuscular species of insects from different habitats as such forests, grasslands, agricultural landscapes, aquatic, and wetland habitats [3].

Various species of prominent insect pests have been found in the diet of bats based on identification of insect fragments in fecal samples and stomach contents. They consume enormous quantities of insect pests that cost farmers and foresters billions of dollars annually [46]. These insects include, June beetles (Scarabidae), click beetles (Elateridae), leafhoppers (Cicadelidae), plant hoppers (Delphacidae), the spotted cucumber beetle (Chrysomelidae), the Asiatic oak weevil (Curculionidae), and the green stinkbug (Pentatomidae) [3].

Mexican free-tailed bats (*T. brasiliensis*) feed an estimated one million kilogram of the most costly agricultural pest insects (corn earworm moth) each night [47]. One bat can eat 20 female corn earworm moths in a night and each moth can lay as many as 500 eggs, potentially producing 10,000 crop-damaging caterpillars [46]. About 150 big brown bats also consume enough adult cucumber beetles in one summer to prevent egg-laying that could produce 33 million rootworm larvae and contributing in prevention of agricultural pests damage [16]. Thus, the death of one million bats from the disease called white nose syndrome indicates 660–1,320 metric tons of insects are no longer being consumed each year in affected areas [36]. Millions of Brazilian free-tailed bats each evening consume a wide variety of prey items (12 orders, 35 families) of about 14,000 kg agricultural pests [48, 49]. Based on the dietary composition (minimum number of the total insects per guano pellet), number of specific agricultural pest species in each pellet, and the number of active foraging days per year, a colony of 150 big brown bats (*Eptesicus fuscus*) in the midwestern United States annually consume approximately 600,000 cucumber beetles, 194,000 June beetles, 158,000 leafhoppers, and 335,000 stinkbugs, which are severe crop pests [16].

Bats are just one of several groups of animals that naturally prey upon mosquitoes. A Florida colony of 30,000 southeastern myotis (*Myotis austroriparius*) eats 50 tons of insects annually, including more than 15 tons of mosquitoes [8]. It is also known that northern long-eared bats (*Myotis septentrionalis*) suppress mosquito populations through direct predation [50].

The estimation of the economic importance of bats in agricultural systems is challenging [36]. A common challenge in the study of the use of bats as pest control is the lack of basic ecological information regarding foraging behavior and diet for many species of bats. For example, traditional dietary analyses through fecal or stomach contents have only identified arthropod fragments to the ordinal or familial level, rather than to species [9, 17] and in cases where species identification is possible, it has typically been restricted to hard-bodied insects although recent novel molecular techniques have allowed detection and species identification of both hard and soft bodied insects [51, 52]. However, the value of pest suppression services provided by bats ranges from \$12 to \$173 per 0.405 ha in Texas [48]. In USA, the estimate value of bats as a result of reduced costs of pesticide applications due to insect pest suppression by bat predation is in the range of \$3.7–\$53 billion per year excluding the costs of impacts of pesticides on ecosystems [36].

3.2. Pollination. As pollinators, tropical bats provide invaluable support to many local and national economies [33]. Large-scale cash crops that are originally pollinated or dispersed by bats include wild bananas, mangos, breadfruits, agave, durians, and petai of which durians and petai currently rely on bats for pollination [7]. 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 [7].

Except the "ornamental" bananas with upright flowers that are pollinated by birds, all the rest, including the ancestors of edible bananas, that have horizontal or drooping flowers are pollinated primarily by bats [33]. Their adaptations for bat pollination include nocturnal flowering, a strong and characteristic odor that attracts bats, plus abundant and accessible nectar and pollen. The coevolution of bananas and bats over 50 million years also resulted in adaptations for effective seed dispersal even if other mammals like monkeys feed on fruits and disperse seeds [33]. Although bats are no longer needed to pollinate flowers or disperse the seeds of edible bananas, the ecological services bats provide for their wild relatives are important for conserving its genetic diversity [3].

Agave macroacantha is extremely dependent on nocturnal pollinators for its reproductive success of which bats are especially important for its successful pollination [53]. Some of these pollinators (bats) are migratory, and have been reported to be steadily declining. A continuing decline in the populations of pollinators may hamper the successful sexual reproduction of the plant host and may put its survival under risk [53].

The Mahwa tree or honey tree (*Madhuca indica*) is pollinated by bats. These pollination services highlight one of the highly valued ecosystem services provided by plant-visiting bats both culturally and economically. The timber of this tree is used for making farm cart wheels in India. The flowers are used as food and for preparing a distilled spirit and its sun-dried fruits for human consumption and the oil extracted from flowers and seeds as ingredients for soaps, candles, cosmetics, lubricants, and medicines [54].

Similarly, there are 289 Old World tropical plant species that rely on pollination and seed dispersal services by bats for their propagation [7]. These plants, in turn, contribute to the production of 448 bat-dependent products in a variety of categories such as timber and other wood products (23%); food, drinks and fresh fruit (19%); medicine (15%); dye, fiber, animal fodder, fuel wood, ornamental plants, and others (43%). However, because bat-provided services represent one input within a multi-input production process, only a portion of the total value of the end product can be attributed to bats [7].

The pollination services of bats for 100 food crops by combining the pollination dependence ratios with regional crop production and its prices was determined [55]. Of these, 46 crops depended to some degree on animal pollinators (6 essentially dependent, 13 highly dependent, 13 moderately dependent, and 14 slightly dependent) accounting for 39% of world production value.

Based on the crop production and animal-dependent pollination, the total economic value of bats in global pollination services is estimated to be $200 billion, representing 9.5% of the value of world food crop production in 2005 [55].

3.3. Seed Dispersal. Bats are crucial to the survival of the world's tropical forests. Enormous expanses of rain forest are cleared every year for logging, agriculture, ranching, and other uses. Fruit-eating bats are uniquely suited for dispersing the seeds of "pioneer plants" from which a diverse and healthy forest can reemerge [33]. Thus, the economic value contributed by bats in maintaining forests is tremendous. For instance, the economic value estimate for seed dispersal services provided by bats to the regeneration of giant oak is $212,000 for seeding acorns and $945,000 for planting saplings [56]. The tropical almond tree, *Terminalia catappa*, is one of the bat-dispersed trees with many human uses like shade, fuel-wood, edible nuts, timber, and tannin (extracted from the bark, leaves, roots, and the fruit shell). The large leaves are also used as wrapping material and have also many medicinal uses, including diaphoretic, anti-indigestion, antidysentery and headache [33].

3.4. Guano Mining. Guano from bats has long been mined from caves for use as fertilizer on agricultural crops due to its high concentrations of limiting nutrients like nitrogen and phosphorous [57]. It provides some of the world's finest natural fertilizers [58]. About 950 bat guano products show a market demand for the product. Prices for bat guano organic fertilizer varied from $1.25 to $12.00 per 0.5 kg depending on the size of the package (larger packages have lower unit prices) and the mix of its ingredients [3]. The Mexican free-tailed bat guano has been extracted for fertilizer in thousands of tons from Bracken Cave in Texas alone with the current retail sales ranging from $2.86 to $12.10 per kilogram [58]. In some places, guano harvesting is carried out on a sustainable basis, especially in caves where bats normally migrate elsewhere for a part of their life each year. The bacteria extracted from bat guano have also been used by some companies to improve detergents and other products of great value to humans [58].

3.5. Bush Meat and Medicine. Bats have also long been used for food and medicine [59]. They provide a direct source of human food in many countries [60]. Several anecdotal price information of bat bush meat ranges from $2.50 to $3.50 per bat in Malaysia and $0.43–$10 per bat in Jakarta. Bat bush meat has the highest nutrient (high protein, vitamin and mineral composition) with lowest cost per kg [7, 61, 62]. Several studies have reported on the overhunting of bat for bush meat indicating a need for further conservation [61].

The anticoagulant compound called salivary plasminogen activator (DSPA) found in the saliva of the common vampire bat is used to treat strokes. Unlike alternative medicines, it can be administered even much later after a stroke has occurred and still be effective [63]. Physicians used bats to treat ailments of patients ranging from baldness to paralysis [60, 63].

3.6. Aesthetic and Bat Watching Tourism. Wildlife watching is simply an activity that involves watching wildlife to identify and observe their behavior and appreciate their beauty. It differs from other forms of wildlife-based activities like hunting and fishing [49]. Although perhaps not as widely practiced as bird watching, bat watching is currently growing as a recreational activity [49]. Similar to other wildlife watching tourism, it also generates income in the form of entrance and permit fees, personal payments to the guides, drivers and scouts and payment for accommodation, and other services [49].

The majority of bat watching takes place at cave entrances where bats emergence can be viewed. For this purpose, the charge ranges from $5 to $12 per visitor. For instance, the Congress Avenue Bridge, which is the home to the largest urban bat colony of approximately 1.5 million Mexican free-tailed bats (*T. brasiliensis*) in USA is visited by 200–1,500 visitors per evening with the value of $3 million per year. The spectacular flock emergence of bats from their roost from March to November, to feed and migrate south during the winter months serves as tourist attraction [49, 64].

3.7. Education and Research. Although extremely difficult to quantify, it is important to recognize the extraordinary value of bats to ancient and contemporary traditions and science. The current study of bat echolocation and locomotion has provided inspiration for novel technological advances in biomedical ultrasound, sensors for autonomous systems, and wireless communication and BATMAVs (bat-like motorized aerial vehicles) [65, 66].

Bats contributed a lot to the field of biomimetics, which is the science of modeling cutting-edge technologies based on natural forms [65]. The anticlotting chemicals in the saliva of bats are also currently being investigated as potential anticoagulant for people who are at high risk of blood clots and strokes. In addition, the development of sonar for ships and ultrasound was partly inspired from echolocation that bats use as navigation system to find and follow their prey at night without crashing on trees, buildings, or other obstructions [65, 66].

Particularly, a unique feature of bats that provides potential for future application is their flying ability by their own power. The aerodynamic range of bats includes changing flight direction by turning 180 degrees within just three wing beats while flying at full tilt. They are such quick flyers because of the quickness of their wings that are structured to fold during flight, similar to the way that a human hand folds. Also, their wings are draped by stretchy skin and are powered by special muscles. Ongoing research about the structure of bat wings and the mechanics of bat flight may ultimately lead to the development of technologies that improve the maneuver ability of airplanes [22].

3.8. Bats as Pests. Although bats are grouped among the world's gentlest animals that provide many positive ecological and economic benefits, few of them are considered as pests. They may cause damage on human, livestock, agricultural crops, airplane strike, building, and infrastructure infestation, and rarely become aggressive or bite humans during self-defense [58]. For instance, frugivorous bats that feed on some economically important fruits result in greater loss.

Three species of vampire bats that occur in the New World are major pests feeding mainly on the blood of livestock (cattle, equines, goats, sheep, and pigs), poultry and occasionally humans. They are also responsible in transmitting rabies. Populations of vampire bats have increased sharply in areas of Latin America where European livestock have been introduced [67]. Wounds caused by vampire bats may also be vulnerable to secondary infections [1].

Bat strikes to airplane have been responsible for loss of human lives and damage to materials worldwide resulting in loss of billions of dollars annually [68, 69]. For example, 821 bat strikes were reported in the USA Air Force during 1997–2007 [70] and 327 from 91 airports during 1996–2006 in Australia [71]. From less than 1% of the bat-strike reported in USA, a cumulative damage is more than $825,000 of which more than half is attributable to 5 bat-strike incidents [70]. This high damage is accredited to high body weight (up to 1 kg like flying foxes) and unlike birds, they possess none pneumatized solid and heavy bones. It results in a greater and more concentrated impact force of strike and a greater capacity to perforate an aircraft than bird strikes [69]. Australian flying foxes roost gregariously and emerge from roosts in flocks, which may include thousands of flying foxes, thus the increasing risk of multiple simultaneous strikes. Their major damage to aircraft includes breaking of windscreen, perforation of aircraft skin, and ingestion into engine [71].

Building and house infestation by bat constitutes a serious public health problem [72]. They spoil food and make ceilings, walls, and floors dirty with the accumulation of guano and urine [72]. Besides, they cause discomfort to humans by their distressing noise, offensive odors, and attraction of coprophagous insects. Potential health hazards may result from chitinous remains of finely chewed insects in guano, attack of ectoparasites, drinking water contamination by urine and feces [72].

3.9. Disease Transition and Contamination. Bats are hosts to a range of zoonotic and potentially zoonotic pathogens. They differ from other disease reservoirs because of their unique and diverse lifestyles, including their ability to fly, often highly gregarious social structures, long life spans, and low fecundity rates [73]. They represent a potential epidemiologic of several diseases that can be fatal to humans, including rabies, Ebola, leptospirosis, histoplasmosis, and pseudotuberculosis [72, 74].

Bats are reservoirs of several pathogens, whose spread may be related to physiological stress associated with habitat loss or alteration [75]. The recent die-offs of bats presenting with white nose syndrome may relate to increased levels of environmental stress that render them to be susceptible to fungal infection and viral infections like Henipaviruses, European bat lyssaviruses, rabies, and Ebola virus [74].

Human activities that increase exposure to bats will likely increase the opportunity for infections [73]. Like bird droppings, bat guano can contain a potentially infectious fungus *Histoplasma capsulatum* that causes lung infection known as histoplasmosis [58].

Bat populations appear to be declining presumably in response to human induced environmental stresses like habitat destruction and fragmentation, disturbance to caves, depletion of food resources, overhunting for bush meat and persecution, increased use of pesticides, infectious disease, and wind energy turbine. As bats are among the most overlooked in spite of their economical and ecological importance, their conservation is mandatory.

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