Bats of the Philippine Islands –a review of research directions and relevance to national-level priorities and targets

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Abstract

Effective science-based conservation priorities and policies are crucially important to effectively maintain biodiversity into the future. For many threatened species and systems insufficient information exists to generate priorities, or the mechanisms needed to effectively conserve species into the future, and this is especially important in megadiversity countries like the Philippines, threatened by rapid rates of development and with few overarching strategies to maintain their biodiversity. Here, using a bibliographic approach to indicate research strengths and priorities, we summarised scientific information on Philippine bats from 2000-2017. We examine relationships between thematic areas and effort allocated for each species bat guild, and conservation status. We found that an average of 7.9 studies was published annually with the majority focused on diversity and community surveys. However, research effort is not even between taxonomic groups, thematic areas or species, with disproportionate effort focusing on 'taxonomy and systematics' and 'ecology'. Species effort allocation between threatened and less threatened species does not show a significant difference, though this may be because generalist species are found in many studies, whereas rarer species have single species studies devoted to them. A growing collaborative effort in bat conservation initiatives in the Philippines has focused on the protection of many endemic and threatened species (e.g., flying foxes) and their habitats. The implementation of conservation relevant policies, outreach programs, capacity building, and mainstreaming of evidence-based conservation are encouraged to strengthen bat conservation in the Philippines.

Keywords: Conservation, Islands, National red list, Priorities, Research efforts

1. Introduction

The 7000+ islands of Philippine archipelago hosts over 70 bat species belonging to seven families (Ingle and Heaney, 1992; Heaney et al., 2010) (Fig. 1). Ingle and Heaney (1992) pioneered a comprehensive assessment of bats in the Philippines and developed the first taxonomic key, which has become fundamental to most bat studies in the country.

Approximately 32% bat species in the Philippines are frugivorous or nectarivorous and the remainder is predominantly insectivorous (Fig. 1). Insectivorous species include Vespertilionidae (33%, n= 26), Rhinolophidae (13%, n=10), Hipposideridae (11%, n=9), and other insectivorous species (Mollosidae (6%, n=5), Megadermatidae (1%, n=1), and Emballonuridae (4%, n=3) (Heaney et al., 2010). In terms of endemism, 35% (n=27) of species are known to be endemic to the country, with the highest described endemism in the Old-world fruit bats (Pteropodidae), with 60% endemic in the country, and often restricted to Islands or single localities. In contrast to this, insectivorous families have relatively low described endemism (12%), though this is likely due to under-description of species present and large numbers of 'cryptic' species i.e., the case of Hipposideros groups (Esselstyn et al., 2012; Murray et al., 2012).

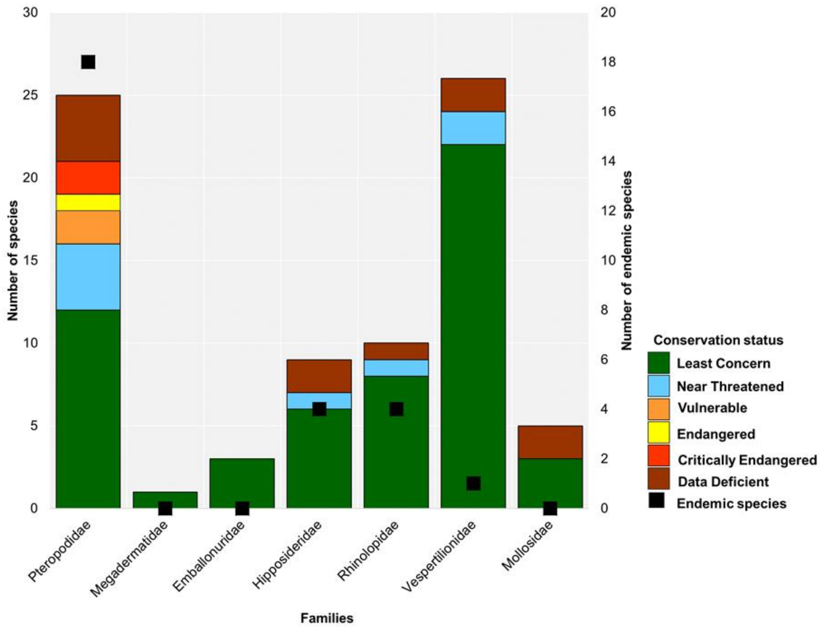

Figure 1. The distribution of species from seven bat families in the Philippines (bars) where fruit bats (Pteropodidae) and evening bats (Vespertilionidae) are of the similar proportion in the terms of species richness. Species endemism (in black squares) is relatively higher among fruit bat family compared to other families.

A high proportion of Philippine bats rely on primary forests (Heaney et al., 2006; Sedlock et al., 2008). Flying foxes (bats of the genus *Acerodon* and *Pteropus*), for example, selectively roost, and forage, in primary to secondary forests (Van Weerd et al., 2003; Mildenstein et al., 2005; Stier and Mildenstein, 2005). While, around thirty species roost in caves and underground habitats (Ingle et al., 2011; Sedlock et al., 2014). However, unprecedented environmental change poses a threat to many bat populations and their habitats (Posa et al., 2008; Wiles et al., 2010). Intensification of agriculture and other land-use changes

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have also meant ever-increasing pressure on native habitats. The increasing conversion of natural habitats into agricultural areas has driven extensive loss and fragmentation of natural habitats and frequently the degradation of remaining habitats in the Philippines (Carandang, 2005; Posa et al., 2008; Apan et al., 2017). Additionally, land-use change combined with climate change is projected to significantly alter species richness and range of most Southeast Asian bats in the future and have an important implication in the Philippine bat biodiversity (Hughes et al., 2012).

Thus, to facilitate future conservation and management, bat research in the Philippines should clearly set its national-level priorities according to gaps and best knowledge available to provide a clear understanding of (1) species diversity, population patterns, and tolerance to varying habitat conditions (2) accurate taxonomy and systematics (3) the role of bats in providing ecosystem services, (4) effects of current environmental changes to design effective conservation measures in the future and avoid mismatch of priorities. Heaney et al. (2002) emphasized that though basic information on the diversity and distribution of Philippine mammals has been collated further information is needed to develop effective priorities and action plans (i.e., species ecology, the extent of distributional range). The most recent and comprehensive review of Philippine bats was detailed in the 'Synopsis of the Philippine Mammals' by Heaney et al. (1998) which was updated in 2010. In addition, Ingle et al. (2011) reviewed the status of cave bats including known roosting cave and karst ecosystems. Their reviews have provided essential information on conservation status and threats; however, the reviews largely focus the distribution of species and diversity patterns, and further reviews are needed to identify conservation gaps in Philippine bat biodiversity. The synthesis from this review aims to assess recent bat research directions in the Philippines in order to match priorities according to gaps and guide future bat research and conservation efforts in the Philippines.

In this review, using a bibliographic review approach, we quantified recent information on bat research and effort directions in the Philippines focusing on species (1) diversity, (2) taxonomy and systematics, (3) ecology, (4) disease, and (5) conservation. This kind of approach has been shown to be effective measure of allocation of national, global, or regional conservation efforts and resources (de Lima et al., 2011; Ress et al., 2016; for example, Conenna et al., 2017 on insular bat species; Vincenot et al., 2017 on Island flying foxes).

2. Methods

2.1. Data search and limitations

Published literature was searched between January 25 and April 20, 2017. A dataset was created based on the literature published obtained from Web of Science (®Thompson Reuters), Google Scholar (https://scholar.google.com), self-archived ResearchGate (https://www.researchgate.net) and personal communications with bat experts working in the Philippines. We used the following keywords to screen the literature: (bat* OR Chiroptera) AND (Philippine* OR Luzon OR Visayas OR Mindanao). To maximize the output for our dataset, we included studies published online from conference proceedings from biodiversity societies in the Philippines (e.g. Biodiversity Conservation Society of the Philippines [formerly Wildlife Conservation Society of the Philippines], Philippine Society for Study of Nature, Philippine Society of Taxonomy and Systematics, etc.). Technical reports published online from NGO's and Government offices were also included. To avoid incomplete and biased data sampling, unpublished theses were excluded from the review, as most universities in the Philippines do not have an online library or accessible thesis repository.

All publications from our search results were categorized according to the year it was published, geographic focus, target habitat, thematic areas, and bat guild (e.g., species level, family level, diet-group level, conservation status). To assess the distribution of studies geographically, we classified each research based on their geographical focus based on main islands Philippines (*viz.* Luzon, Visayas, and Mindanao) and refined the distribution by reclassifying each study according to thematic areas by provinces (listed here http://nap.psa.gov.ph/activestats/psgc/listreg.asp). We then visualised the geographical distribution and proportion using the diagram function of QGIS 2.18.15 Las Palmas (QGIS Development Team, 2017). Research papers were also classified based on target habitat in order to assess the distribution and gaps of research allocation based on main terrestrial habitat types in the Philippines, which includes (1) forest, (2) caves & karst, (3) forest vs. caves, (4) land-use & urban, and (5) forest vs. land-use types. We excluded in the count those papers that do not clearly state the geographic location and target habitat i.e., museum-based examinations.

In order to assess bat research attention across different areas, all the papers, proceedings, and reports we collated were screened according to main thematic areas that include (1) Diversity, (2) Taxonomy and Systematics, (3) Ecology, (4) Disease, and (5.) Conservation. To refine and differentiate all studies to a more specific area, we divided each main thematic areas into secondary thematic areas described in Table 1. To assess the equitability of research in, between bat groups (*viz.* frugivorous bats and insectivorous bats), and among main thematic areas, we applied Pielou's evenness index (*J'*), where the value of *J'* is constrained between 0 and 1, which is interpreted as values approaching 1 indicates equal proportion of research allocated (Pielou, 1966). Furthermore, we used the Pearson's chi-squared test of independence (χ^2) to test the difference in the proportion of studies between main thematic areas (Diversity, Taxonomy and Systematics, Ecology, Disease, and Conservation) and bat groups (frugivorous and insectivorous bats).

Table 1 (Box 1). Thematic areas of research identified in the review

Main research areas	Secondary research areas	Scope and description
Diversity	Community composition	Purely aims to identify species composition in a specific site or different habitat types. Findings resulting from species inventories, rapid-assessments, biodiversity surveys, results of observations and sightings.
	Conservation	Diversity surveys that focus on the endemism and conservation status patterns of bats.
Taxonomy & Systematics	Species	Studies resulting in describing new species.
	Phylogenetic	Studies using principles of genetics or molecular biology to assess evolutionary processes to understand bat taxonomy and systematics.
Ecology	Roosting	Ecological studies that include the observation of bat roosting habits, preferences, and movement.
	Foraging	Bat research focused on the diet and foraging habits of different bat communities.
	Ecosystem Function	Studies focused on the ecological services of bats including pest control, pollination, seed dispersal, nutrient transfer.
	Reproductive	Studies on the reproductive biology, phenology, patterns of bats. It may also include anatomical and physiological studies relating to bat reproduction or reproductive parts.
	Genetics/Molecular	Studies using concepts of genetics or molecular biology to elucidate ecological function or processes of bat species (i.e. diet, movement, and disease transfer).
Diseases	Parasites	Studies encompassing all inventories of ectoparasite, endoparasite of bats. All studies concerning bat-parasite relationships including parasite taxonomy and distribution.
	Virus, Bacterial, and Fungal associations (microbes)	Studies concerning the bat-borne diseases or emerging diseases related to bats including detection of virus, bacteria, and fungi among bat species.
Conservation	Species and threats	Studies or programs that aim to assess species, threats, and human-bat interactions that directly leads to the conservation of the species or population. Studies designed to understand the human-bat conflicts.
	Habitat and ecosystems	Studies that concern the conservation bat species/population habitat or hotspot.

2.2. Species-Research Effort Allocation (SREA)

In order to quantify research efforts among species temporally and to determine which species (or any taxonomic group) requires higher attention, we developed the Species-Research Effort Allocation (SREA) metric. A simplified metric that allows identifying species or taxonomic groups that received adequate attention in a certain period of time i.e., 18-year period in the case of this review. Ideally, SREA metric is effective in a review covering a longer period of time (e.g., more than 10 years). Species-Research Effort Allocation (SREA) can be expressed using the equation:

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$$\textbf{SREA (x)} = R^{o}/y$$

Where:

SREA	=	Species-Research Effort Allocation
x	=	Species or taxonomic group
R^{o}	=	Number of times species or taxonomic group **(x)** was recorded from publications/reports
y^{o}	=	Number of years covered by the review or assessment

Species-Research Effort Allocation (SREA) value can be interpreted as species or taxonomic group with a value equal to 1.00 indicates an average effort per year relative to all species, while >1.00 values indicate that higher effort is given to the species, and <1.00 indicates lower effort is provided. Using Mann-Whitney *U*-test (Fowler et al. 1998), we then tested the difference between overall Species-Research Effort Allocation (SREA), in among bat groups (diet groups: frugivorous bats and insectivorous bats), in main thematic areas, in between conservation status (*viz.* non-threatened (least concern) and threatened (Near Threatened, Vulnerable, Endangered, Critically-endangered). We also included 'Data deficient' species in the analysis as they are possibly equally or more threatened species (Bland et al., 2015; Tanalgo et al., 2018).

To assess the percentage (%) of research literature appeared or recorded, we used the equation below derived from SREA:

$$R^{\%}(x) = (R^{o}/\Sigma R) \times 100$$

R%	=	Percentage of literature where the taxa or species appeared or recorded.
x	=	Species or taxonomic group
R^{o}	=	Number of times species or taxonomic group **(x)** was recorded from all publications/reports over a certain period of time.
ΣR	=	Total number of research assessed in y^{o}

All statistical and diversity analyses were performed using Statistica v 10 (StatSoft Inc., 2011) and PAST v 3.18 (updated version 2018) (Hammer et al., 2011) respectively. Significance was set at P=0.05.

3. Bat research allocation and gaps

3.1. Distribution of bat research in the Philippines and target habitats

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Our search returned 142 studies (Published article =93, Proceedings of conferences=30, Technical Reports =19) from 2000 to 2017 (complete list of studies archived in https://tropibats.com/philippine-bat-references/). Our analysis of bat research effort from 2000-2017 revealed that there are an average of 7.9 (±4.53) bat studies reported per year (Fig. 2). The majority of the bat research is from Islands of Luzon (n= 53, 37 %), followed by Mindanao (n=49, 35 %), Visayas (n= 34, 24 %) and very few studies were conducted at a national level (n=6, 4%) (Fig. 2; visualised proportions according to regions is showed in Fig. 3a). Yet a much lower number of studies have occurred in the southwestern part of Southern Philippines (e.g., Sulu, Tawi-Tawi).

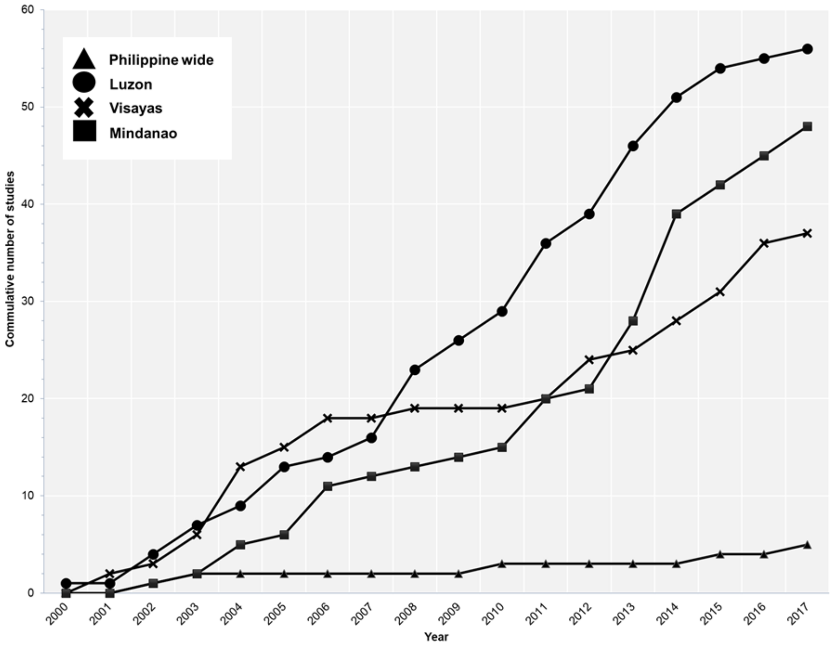

Figure 2. The number of research (in bars) and a cumulative number of bat publications in the Philippines from 2000-2017 (in lines) based on the number of published journal articles, technical reports (online), and conference proceedings from three main Islands of the Philippines.

The distribution of bat research based on target habitat showed that more than half the studies focused on forest habitats (n=77, 54%), of which the majority were from Luzon Island (n=40, 28%) particularly from mountain ranges of the Sierra Madre, Mt. Makiling in Laguna, and Polilio Island. In Mindanao, most research on forest bats is concentrated in Northern Mindanao (e.g., Mt. Kitanglad, Camiguin Island) and SOCSARGEN (e.g., Mt. Apo National Park). While in the Visayas, most of the forest research is on the islands of Bohol, Negros, and Panay. In caves and karst habitats, the majority of the studies were from Mindanao (n=19) and Visayas (n=14) (Fig. 3b). In Mindanao, recent bat surveys and inventories (e.g., Nuneza et al., 2010; Quibod et al., 2012, Tanalgo & Tabora, 2015) have established new knowledge and information on cave-dwelling bat species in the Island as well as in countrywide. Notably, on the Island of Samal, the world's largest cave colony of the frugivorous *Rousettus amplexicaudatus* with approximately 2.3 million individuals was recently discovered and studied (Carpenter et al., 2014). In the Visayas, numerous studies have been conducted in wide karst areas of Bohol Island (i.e., the comprehensive ecological studies of Sedlock et al., 2014 and Phelps et al., 2016) and coastal areas of Panay Island (Mould, 2012), which have contributed new relevant information on the ecology and distribution of cave-dwelling bats in the Philippines, particularly species roosting preferences. There are an estimated 1500 caves known in the Philippines however only four caves are under protection of the National Integrated Protected Areas System (NIPAS) act (PAWB-DENR, 2008). Remarkably, 221 caves in karst systems were reported to house bat fauna excluding unreported sites (Philippine Bat Cave Committee, 2012). While, many roosting caves are properly managed regionally many caves remains to lack the effective management and protection as a consequence of the absence of standardised and effective conservation prioritisation (Tanalgo et al. 2018, in press). Nevertheless, there is a limited number of comparative studies on bat diversity across different habitat types (i.e., forest, vs. karst, vs. different land-use types), which are equally important to ascertain the impacts of land-use and environmental changes to bat communities.

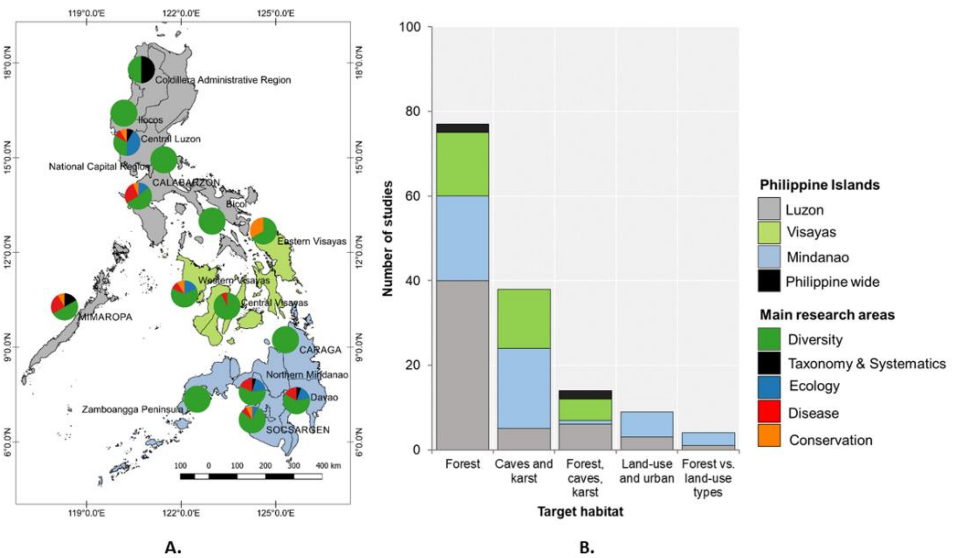

Figure 3. The geographical distribution of bat research based on (a) political region (provinces), (b) target terrestrial habitats.

Studies to understand species distributions and tolerance to different habitat types or land-use are relatively lower (n=3, 2.11%). Although, previous studies in the country showed that disturbed habitats (e.g., agricultural and mined areas) have lower bat diversity compared to undisturbed habitats (e.g., protected areas and pristine forest) (Sedlock et al., 2008; Phelps et al., 2016; Tanalgo et al., 2017; Relox et al., 2017). The impacts of various land conversions and land-use types in Philippine bats are poorly understood and warrants more comprehensive and long-term monitoring of seasonal variations in population and species richness as a response to threats. The understanding of effects of forest fragmentation, agriculture conversion, and other land-use coupled with current rapid rate of destruction of remaining forest cover (i.e., about 6% of country's old-growth forest remains), studies on the tolerance and response of bats from threats of habitat destruction calls for urgent further investigation (Heaney et al., 2002).

3.2. Bat research allocation based on thematic areas and species literature

Five main thematic areas were assessed in this review (Fig. 4). The majority of the bat studies and records (the number of times the species appeared across main thematic areas) focus on "Diversity" (n=90, 64 %). Bat guilds (frugivorous vs. insectivorous) showed equitability among main thematic areas (J'<0.900) except 'Taxonomy and Systematics' (J'=0.544). While there was uneven research effort distribution between frugivorous (J'= 0.683) and insectivorous (J'= 0.447) species. Although more "Diversity" studies have been conducted on insectivorous bats (n=263) than frugivorous bats (n=229), other thematic areas has focused primarily on frugivorous bats ((Taxonomy and Systematics (n=14, 88%), Ecology (n=42, 75%), Disease (n=39, 50%), Conservation (n=27, 69%)). Consequently, the proportion of studies among thematic areas across bat groups differed significantly (χ^2 test of independence, P<.05).

3.2.1. Species diversity and effort allocation (SREA)

The majority of bat research in the Philippines focused on the thematic area of 'Diversity' (n=90, 63%) where 56% (n=79) were directed on 'community composition' research (Fig. 4). While, in general, there are an average of 2.10 (±0.59) studies published per species annually (species effort/year). The number of 'diversity' studies between frugivorous and insectivorous bats did not significantly differ (Mann-Whitney U-test, P >.05), however, the overall SREA values (combining values from all main thematic areas) showed a significant difference (Mann-Whitney U-test, P<0.05) between bat groups. Despite the fact that insectivorous bats are more specious (n=54) than frugivorous bats (n=25) in the Philippines, the latter showed higher species-research effort allocation among species with some species has beyond average effort per year (SREA values >1.00) (Table 2). For example, *Rousettus amplexicaudatus* (SREA value=2.89), *Ptenochirus jagori* (SREA value=2.67) and *Cynopterus* *brachyotis* (SREA value=2.61) have had above average effort and these species appeared or were recorded in 30% of the studies from 2000 to present (Appendix S1).

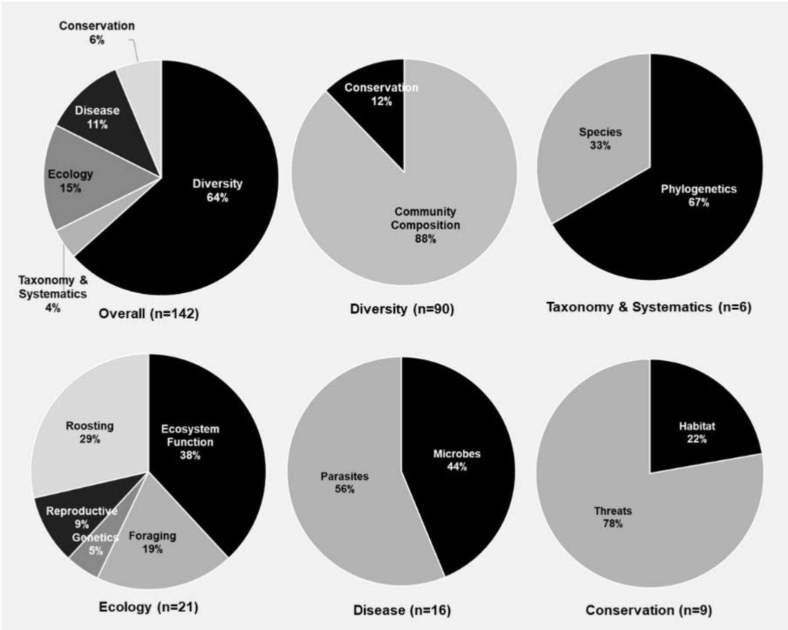

Figure 4. The proportion of research effort allocation in five main thematic areas based on number of studies from 2000-2017.

Of the 79 species, only 10 species (13%) have greater than average Species-Research Effort Allocation values indicating higher attention given within 18years (see Appendix S1) and the remaining percentage are understudied. The majority of the Philippine bats (45% of the species) were recorded in studies more than 5 times in 18 years (SREA>0.28) (Fig. 5) while, 15% of the species were studied or recorded in a single study only (SREA=0.013), and three species (*Myotis ater*, *Pipistrellus stenopterus*, and *Cheiromeles parvidens*) (3.75 %,) have not been documented in the country for the past 18 years (SREA=0.000), though these species are recorded in pre-millennia surveys (Heaney et al., 1998). Island endemic species with a narrow distribution also showed to be understudied such as *Acerodon leucotis* (SREA=0.05), *Desmalopex microleucopterus* (SREA=0.16), *Pteropus speciosus* (SREA=0.05), *Styloctenium mindorensis* (SREA=0.05), (Table 2) which occurs only in less than 1% of the studies included in this review. While the rediscovered species and EDGE listed *Dobsonia chapmani* (SREA=0.16 effort/year) in Cebu and Negros Island are also among the most understudied species (Alcala et al., 2004; Paguntalan et al., 2004).

Table 2. Top five group of understudied in the Philippines since post-millennia period (2000-2017), ranked in order of average number species records in studies. The conservation status and endemism of the species were not included in the ranking and solely based

on records from published studies. The full-list of other species is provided in appendix A. Conservation status are DD, Data Deficient; LC, Least Concern; NT, Near Threatened; VU, Vulnerable; EN, Endangered; CE, Critically-endangered. Species Endemism are PE, Philippine Endemic; IE, Island Endemic or in the single locality; WS, Widespread. SEA values closer to 1.00 indicates that species is averagely studied over the period of the review. Complete list of Species Allocation Effort in Appendix S1.

Rank	**Species**	**Species Effort Allocation (SEA)**	**Conservation Status**	**Endemism**
	Myotis ater		LC	NE
1	*Pipistrellus stenopterus*	0.000	LC	NE
	Cheiromeles parvidens		LC	NE
	Acerodon leucotis		VU	IE
	Desmalopex microleucopterus		NA	IE
	Pteropus speciosus		DD	IE
	Styloctenium mindorensis		DD	IE
	Hipposideros lekaguli		NT	NE
	Rhinolophus borneensis		LC	NE
2	*Rhinolophus creaghi*	.056	LC	NE
	Glischropus tylopus		LC	NE
	Murina suilla		LC	NE
	Nyctalus plancyi		LC	NE
	Phoniscus jagorii		LC	NE
	Cheiromeles torquatus		LC	NE
	Mops sarasinorum		DD	NE
	Nyctimene rabori		EN	IE
	Pteropus dasymallus		NT	IE
	Hipposideros coronatus		DD	IE
	Rhinolophus acuminatus		LC	NE
3	*Falsistrellus petersi*	0.111	DD	NE
	Kerivoula papillosa		LC	NE
	Kerivoula pellucida		LC	NE
	Pipistrellus tenuis		LC	NE
	Tylonycteris pachypus		LC	NE
	Tylonycteris robustula		LC	NE
	Desmalopex leucopterus		LC	PE
	Dobsonia chapmani		CE	IE
4	*Saccolaimus saccolaimus*	0.167	LC	NE
	Hipposideros cervinus		LC	NE
	Kerivoula hardwickii		LC	NE
	Otomops sp.		UA	UA
5	*Dyacopterus spadiceus*	.222	NT	NE

Dyacopterus rickarti	DD	IE
Coelops hirsutus	NA	IE
Rhinolophus macrotis	LC	NE
Harpiocephalus harpia	LC	NE
Philetor brachypterus	LC	NE
Chaerephon plicatus	LC	NE

We also assessed how frequently different species appeared in papers, four species appeared in above 20% of papers. *Rousettus amplexicaudatus* has the highest record in all literature reviewed at 37%, which means this species appeared in 52 out of 142 papers included in this review. Surprisingly, some 'rare' species i.e., endemic with a narrow distribution, for example, *Acerodon jubatus* and *Pteropus vampyrus*, which we presumed to have lower $R^{\%}$ value we found to have the comparable appearance as those to commonly recorded species. This is associated with the number of papers that are focused only on one or two species, often larger and more endangered species.

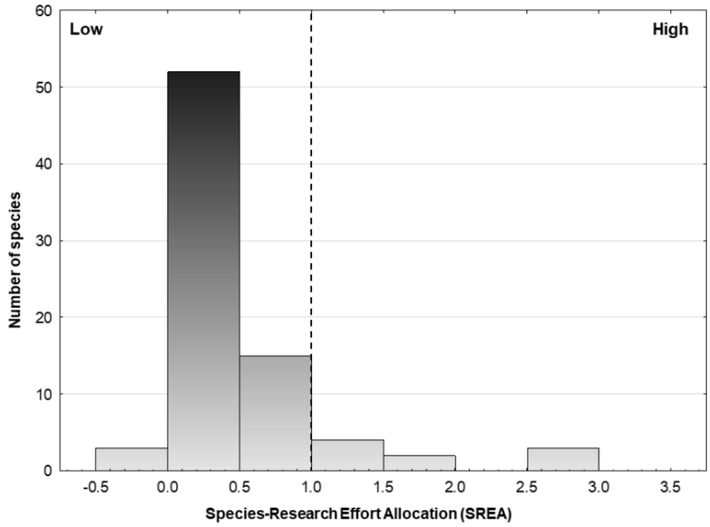

Figure 5. Species-Research Effort Allocation (SREA) of 79 bat species from the Philippines showing that majority of the species are below the average (dash line) SREA suggesting that many species lacks scientific information.

The strength of Philippine bat research relies on diversity studies across landscapes. However, despite the high percentage of studies on 'diversity', understanding of species distribution and tolerance between habitat types are relatively lower in number. However, fundamental studies to develop spatial-conservation priorities such as comparative studies in pristine and non-pristine habitats, effects of climate and land-use changes to species distribution are still lacking. These studies are important to construe species, endemism patterns, and tolerance to varying habitats and are an important step towards developing a concrete basis for species and habitat conservation.

3.2.2. Taxonomy and systematics of Philippine bats

The endemism pattern of species in the Philippines is relatively high (n=27, 34%) (see Fig 1.). In total, six (n=6, 4%) papers focused on 'Taxonomy & Systematics' research with 16 (20%) species (14 frugivorous and two insectivorous). SREA values in this thematic area showed a significant difference (Mann-Whitney *U*-test, *P*<.05) between bat groups. Considering that there have been many recent species inventories conducted across the country (see Fig. 4), there are only three newly described frugivorous species (*viz. Desmalopex microleucopterus*, *Styloctenium mindorensis*, and *Dyacopterus rickarti*) and two new records of insectivorous bats, *Falsistrellus petersi* (Heaney et al., 2012) and *Kerivoula papillosa* (Duya et al., 2007) over the last 18 years. Rigorous taxonomic work is needed to delineate and resolve species nested within complexes (e.g., families of Hipposideridae and Rhinolophidae) and unresolved groups as many species from these groups remain undetermined and are, therefore, Data Deficient (Sedlock et al., 2008;). The taxonomy and systematics of Philippine bats are challenging, but an open-door for research opportunities as many species are potentially yet to be described. The recent increase in taxonomic studies leading to the description of new bat species from mainland Southeast Asia (e.g., Thailand, Vietnam, and Cambodia indicates the need to explore different taxonomic facets of Philippines diversity. It is important to take note that the accurate taxonomic examination or identification of species is essential to assess the state of biodiversity as well as the assigning correct conservation status (Dubois, 2003; Tsang et al., 2016) and hence it is a foundation of all bat research and conservation initiatives. Furthermore, the advancement and integration of various techniques and the use of novel technologies (i.e., bat detectors, bat call libraries, DNA metabarcoding) to enhance detection and improve discovery and description of new species are pivotal in future conservation efforts in the country.

3.2.3. Bat ecology and ecosystem function

Twenty-one (15%) out of 142 studies focused on bat ecology and ecosystem function (Fig. 4). Ecological studies measured by SREA are significantly higher among frugivorous bats compared to insectivorous bats (Mann-Whitney *U*-test, *P*<.05) where the majority of bat ecological studies are focused on the seed dispersal ecology of frugivorous bats (6%). Frugivorous bats constitute a large proportion of bat species in the Philippines. The role and importance of frugivorous bats in neighbouring countries has been documented in numerous studies (i.e., Fruitbats are important pollinators in Thailand (Sritongchuay et al., 2016) and mangroves in Malaysia (Nor Zalipah et al., 2016), and flying fox pollinate durian in Malaysia, Abdul-Aziz et al., 2017), there is little information and key studies on ecosystem service provision across the Philippines. The role and contribution of frugivorous bats as effective seed dispersers was previously documented in primary forests, lowland montane forests, and successional areas (Curio et al., 2002; Ingle, 2003; Reiter, 2002; Reiter et al., 2004; Reiter et al., 2006; Gonzales et al., 2009). The roosting and foraging ecology of flying foxes (*Acerodon jubatus* and *Pteropus vampyrus*) are well understood through series of surveys and radio-tracking studies conducted in the early 2000s (Stier and Mildenstein, 2005; Mildenstein et al., 2005; Mildenstein et al., 2014).

There are a number of studies (n=6, 4.22%) on the role of the frugivorous bats as seed dispersers in pristine ecosystems within the Philippines (i.e., Ingle, 2003; Gonzales et al., 2009). Yet, there are no documented studies on the flower visitation and pollination role of nectarivorous bats, unlike in many other Southeast Asian countries (e.g., Bumrungsri et al., 2013, Acharya et al., 2015; Stewart et al., 2015; Abdul-Aziz et al., 2017; Lim et al., 2017). Only two studies focused on the foraging ecology of species other than Pteropids. The false vampire bat, *Megaderma spasma* was revealed to forage in at least ten insect orders in Mt. Makiling, where almost 90% of the diet is madeup of Coleoptera, Hemiptera, and Orthoptera (Balete, 2010). While using molecular techniques, high overlapping degree among diets of insectivorous species (e.g., *Rhinolophus inops*, *R. arcuatus*, *R. virgo*, and *Hipposideros pygmaeus*) was revealed although they differ in body size and call frequency (Sedlock et al., 2014). Lastly, there are only two papers (1.4%) on the reproductive phenology of Philippine bats. Three frugivorous species of the 79 (3.8%) species in the Philippines (viz. *Eonycteris spelaea*, *Macroglossus minimus*, and *Rousettus amplexicaudatus*) showed a highly seasonal reproductive pattern but with varying birth peaks associated to the availability of food resources (Heideman and Utzurrum, 2003).

Little is known about the ecology and ecosystem services of Philippine bats since there have been few studies and there are still knowledge gaps on the understanding ecosystem services of bats in different ecosystems, for example, evidence on how fruitbats facilitate seed dispersal, pollination of important plant species, and insectivorous bats as a pest-control agent in agroecosystems. A better understanding of bat ecosystem function, in addition to responses to environmental change, is needed to ensure adequate conservation initiatives are enacted.

3.2.4. Disease and Parasites

Disease studies are significantly higher among insectivorous versus frugivorous (Mann-Whitney *U*-test, $P<.05$). In total, 16 (11%) studies focused on bat disease and parasites, of which seven (5%) studies focused on microbial associations (e.g. viruses, bacteria, and fungal) (Fig. 4). Lyssavirus (Arguin et al., 2002) and Reston ebolavirus virus (RESTV) (Jayme et al., 2015) have been found in many bat species. Recently, Pteropine orthoreovirus (PRV) from Philippine fruitbats and roughly 90% of bats tested positive for neutralizing antibodies to PRV's (Taniguchi et al., 2017). Aside from viruses associated with bats, the presence of other microbes (bacteria and fungi) has also been studied in selected bat species. *Campylobacter jejuni* was detected from rectal swabs from *Rousettus amplexicaudatus* (Hatta et al., 2006). Furthermore, Jumao-as et al. (2017) revealed the association of agro-economic fungi (e.g. Aspergillus, Penicillium) in frugivorous bats common to orchards and agricultural areas.

The detection of wildlife emerging infectious disease is relevant for public and human health and conservation of wildlife species (Daszak et al. 2000; Belant and Deese, 2010), however, there is a lack of emphasis on the importance of disease research to species protection and conservation bats in the country. Studies exploring disease association to bats have increased over decades and have driven a negative public perception to bats and have resulted in the execution of many roosting colony sites. Therefore scientists must carefully present their findings to prevent negative outcomes for conservation and highlight the ecosystem importance of bats (Lopez-Baucells et al., 2017). Another concern based on disease studies is the apparent overcollection of bat killed to study diseases (Russo et al., 2017). In the Philippines, for example, a single study has collected 917 individuals from 13 species, another one has collected 403 individuals (20 species) to isolate, and study virus associated with bats.

Studies on bat ectoparasites (n=9, 6%) are increasing and most common on Luzon Island, relative to the rest of the Philippines. Alvarez et al. (2015) contributed new findings and records of host and distribution of batflies from Mt. Makiling and Mindoro Island, and other studies (Alvarez et al., 2016), and Amarga et al. (2017a; 2017b) recorded batflies from cave-dwelling bats from Marinduque Island with new records for the Philippines. The study of ectoparasite association to bat are an important indicator to understand bat behaviour and habitat quality selection (Ter Hofstede and Fenton, 2005).

3.2.5. Conservation status and threats to bats

Lastly, 'Conservation' research is relatively lower compared to other thematic areas with nine (6%) studies only, and is significantly higher in frugivorous bats than insectivorous bats (Mann-Whitney *U*-test, $P<.05$), though this may be because of the medium (largely peer-reviewed papers) we were looking at. Although, scientific attention in terms of both conservation status (threatened vs. non-threatened) and endemism (endemic vs. non-endemic) do not significantly differ (Mann-Whitney *U*-test, *P*>.05) a large proportion of the species remains understudied (SREA value>1.00) across thematic areas (n=69, 87%: Fig. 5). Interestingly, some threatened species were relatively higher in species-research effort allocation compared to those with lower conservation status (e.g. Least Concern, Near Threatened) (though this may be because higher numbers of fruit bats are classed as more threatened, and fruit bats generally receive more attention). There are also increasing numbers of studies for locally threatened large flying foxes *Acerodon jubatus* (SREA=0.83 effort/year) and *Pteropus vampyrus* (SREA=1.00 effort/year) possibly due to increased funding. This, in turn, has resulted in increased levels of monitoring and the protection of many of their roosting sites (e.g., Mildenstein et al., 2005). Conversely, human-induced activities are continuously posing alarming threats to many bat population and its associated habitats despite the implementation of policies that covers Philippine bat fauna i.e., the Philippine Wildlife Act and Cave Management Act (for cave bats). Our review revealed illegal hunting and trade of bats for food, bushmeat is a prevailing conservation concern in different habitats i.e., cave bats, large-flying foxes are massively hunted from caves and forested areas, and in many regions particularly in remote areas where poverty is high (Scheffers et al., 2012; Tanalgo et al., 2016; Mildenstein et al., 2016; Tanalgo,) but sparse of quantitative information on the intensity and extent. The bat hunting and trade for bushmeat remained a significant threat, with an estimated 50% of the species are hunted in different Islands particularly in unsurveyed and unprotected areas (Mildenstein et al., 2016; Mildenstein, 2015; Tanalgo, 2017). In caves and underground areas in karst ecosystems, hunting of large cave frugivorous and insectivorous bats are common (Mould et al., 2012; Sedlock et al., 2014; Tanalgo et al., 2016). In addition, human disturbance in caves (e.g., hunting and tourism activities) may have caused some bat species to abandon their roosting colonies. For example, in 2001, there were an estimated 500,000 bats in Canlunsong cave but the population has now dropped to only 200 bats observed in most recent surveys (Sedlock et al., 2014). Habitat and fragmentation is clearly a serious conservation concern not only to bats but also to other taxa and has been poorly studied in Philippine bats. This substantiates the earlier statement (see section 3.1.) that comparable studies of diversity and species tolerance across pristine ecosystems to different land-use types have limited data and poor understanding.

In-situ conservation efforts have grown and succeeded over the past decade in many regions particularly with endemic and endangered flying foxes (genus of *Acerodon* and *Pteropus*), which are 'charismatic' and received high conservation attention gauged by funding and policies related to population and habitat protection (Bat Conservation International, 2015).

Such efforts include the "Bat Count Philippines", a conservation project initiated in the late 1990's, which aims to develop baseline information and capacity building for the conservation of flying foxes particularly *A. jubatus* and *Pteropus vampyrus* (Mildenstein, 2002, Mildenstein et al., 2012). In 2012, a similar conservation platform, the 'Filipinos for Flying Foxes' project was initiated and expanded to other regions in the country especially Northern and Central Philippines (Balbas et al., 2014). Conservation NGO's such as Philippine Biodiversity Conservation Foundation (http://pbcfi.org.ph/) and its 'sister' platform organisations have become instrumental and commendable in developing policies and successfully implementing to declare protected areas with emphasis to protect bats and their habitat

4. Synthesis

Our review revealed that more than 50% of the bat studies are focused on 'diversity' and at least half Philippine bat species are understudied based on effort allocation measures suggesting that knowledge gap in Philippine bat research across bat species, groups, geographic focus including target habitats are evident. The development of national-level research priorities led by countries' bat biologists and conservationists could be developed to target knowledge gaps in bat research and conservation, which are adaptable and achievable in a reasonable time (Gardenfor, 2001; Brito et al., 2010; Juslen et al., 2013). At a regional scale (Southeast Asia) priorities have been developed for bat research and conservation (see Kingston 2010) and downscaling these priorities to practicable regional priorities may be essential for effective regional protection. Developing regional-scale conservation priorities is essential to efficiently achieve large-scale conservation (e.g., continental-, global-scale conservation), however, a successful regional priority relies on the effective national or local implementation of the conservation management process (Kark et al. 2009; Rudd et al., 2011; Mazor et al., 2013; Beger et al., 2015).

Although research effort is well-proportioned among species in terms conservation status and endemism, a National Red list for Philippine bats (i.e., following the approach of Keller and Bollmann, 2004) is integral to the conservation management of bat species and its habitats and will redefine conservation priorities on a national scale. The global Red List, which is mainly the basis of conservation prioritisation in Philippine bats, although has been designed to indicate the risk of extinction of a species or subspecies on a global scale (IUCN 2001; Rodrigues et al., 2006) and it essentially reflects the extinction risk within the national level it inadequately set conservation priorities because the national populations including its associated threats as a whole is often missed into considerations (Keller and Bollmann, 2004).

For example less threatened species are greatly impacted by direct human threats and activities in local or national scale i.e., common species *Rousettus amplexicaudatus* are harvested in hundreds to thousands in caves despite this species is common and has wide range of distribution, but continuous hunting overtime may result in the 'Passenger pigeon's fiasco', where a common and abundant species went extinct thus conservation-oriented project should also not only target threatened species.

This review has demonstrated the effectiveness of bibliographic review approach to assay priorities in Philippine bat research and conservation. The appropriate allocation of research and conservation efforts is often dependent on the availability of information and quality of data (Ribeiro et al., 2016). In the Philippines, many studies remain as inaccessible reports, Masters, or PhD theses, and others are in local journals, which are difficult to access online. Thus, bat biologists and conservationists in the country are encouraged to diversify their bat research but also to make their information and findings accessible (e.g. publish data and findings to open access journals) to fill in many gaps in bat research in the country. Evidence-based conservation is needed to overcome 'research-implementation gaps' (Knight et al., 2008). Effective outreach programs and science communication should be promoted to educate and raise public awareness about the importance of bats and their conservation.

Consequently, to address the gaps in bat research in the Philippines research and conservation capacity among local researchers from the academia must be strengthened, NGO's and other institutions concerned to attain effective and sustainable conservation especially in bat biodiversity hotspots (Racey, 2013). Conservation-orientated studies have increased and we must encourage and involve young bat researchers in the region to develop the capacity of conservationists and advocates in the future, and continue the success of conservation programs currently in action.

Acknowledgement

We dedicate this review paper to all the bat researchers, young, and upcoming bat ecologist and conservationists in the Philippines, who in one way or another passionately pour all their efforts to conserve and protect bats and their remaining habitats through research, conservation, and outreach. May this work will inspire you to continue to explore, discover, and country's rich bat biodiversity.

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Appendix 1. Complete list of Species SREA and $R^{\%}$ values

Species	Diet Group	Conservation Status	Endemism	SREA	$R^{\%}$
Cheiromeles parvidens	Insectivorous bats	LC	PE	0	0
Myotis ater	Insectivorous bats	LC	NE	0	0
Pipistrellus stenopterus	Insectivorous bats	NT	NE	0	0
Acerodon leucotis	Frugivorous bats	VU	IE	0.055556	0.704225
Pteropus speciosus	Frugivorous bats	LC	NE	0.055556	0.704225
Styloctenium mindorensis	Frugivorous bats	LC	NE	0.055556	0.704225
Cheiromeles torquatus	Insectivorous bats	LC	PE	0.055556	0.704225
Glischropus tylopus	Insectivorous bats	LC	NE	0.055556	0.704225
Hipposideros lekaguli	Insectivorous bats	LC	NE	0.055556	0.704225
Mops sarasinorum	Insectivorous bats	DD	PE	0.055556	0.704225
Murina suilla	Insectivorous bats	LC	NE	0.055556	0.704225
Nyctalus plancyi	Insectivorous bats	LC	PE	0.055556	0.704225
Phoniscus jagorii	Insectivorous bats	NT	NE	0.055556	0.704225
Rhinolophus borneensis	Insectivorous bats	LC	NE	0.055556	0.704225
Rhinolophus creaghi	Insectivorous bats	LC	PE	0.055556	0.704225
Pteropus dasymallus	Frugivorous bats	LC	NE	0.111111	1.408451
Falsistrellus petersi	Insectivorous bats	LC	NE	0.111111	1.408451
Hipposideros coronatus	Insectivorous bats	LC	NE	0.111111	1.408451
Kerivoula papillosa	Insectivorous bats	LC	NE	0.111111	1.408451
Kerivoula pellucida	Insectivorous bats	LC	NE	0.111111	1.408451
Nyctimene rabori	Insectivorous bats	NT	PE	0.111111	1.408451
Pipistrellus tenuis	Insectivorous bats	LC	NE	0.111111	1.408451
Rhinolophus acuminatus	Insectivorous bats	LC	NE	0.111111	1.408451
Tylonycteris pachypus	Insectivorous bats	LC	NE	0.111111	1.408451
Tylonycteris robustula	Insectivorous bats	LC	NE	0.111111	1.408451

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Desmalopex leucopterus	Frugivorous bats	LC	NE	0.166667	2.112676
Desmalopex microleucopterus	Frugivorous bats	LC	NE	0.166667	2.112676
Dobsonia chapmani	Frugivorous bats	DD	IE	0.166667	2.112676
Hipposideros cervinus	Insectivorous bats	LC	PE	0.166667	2.112676
Kerivoula hardwickii	Insectivorous bats	LC	NE	0.166667	2.112676
Saccolaimus saccolaimus	Insectivorous bats	LC	NE	0.166667	2.112676
Otomops sp.	Insectivorous bats	LC	NE	0.166667	2.112676
Alionycteris paucidentata	Frugivorous bats	LC	IE	0.222222	2.816901
Harpiocephalus harpia	Frugivorous bats	DD	IE	0.222222	2.816901
Chaerephon plicatus	Insectivorous bats	NT	NE	0.222222	2.816901
Coelops hirsutus	Insectivorous bats	LC	NE	0.222222	2.816901
Philetor brachypterus	Insectivorous bats	LC	NE	0.222222	2.816901
Rhinolophus macrotis	Insectivorous bats	LC	NE	0.222222	2.816901
Eonycteris robusta	Frugivorous bats	LC	PE	0.277778	3.521127
Hipposideros bicolor	Insectivorous bats	LC	NE	0.277778	3.521127
Myotis rufopictus	Insectivorous bats	LC	PE	0.277778	3.521127
Rhinolophus subrufus	Insectivorous bats	LC	PE	0.277778	3.521127
Kerivoula whiteheadi	Insectivorous bats	NT	NE	0.333333	4.225352
Myotis macrotarsus	Insectivorous bats	LC	NE	0.333333	4.225352
Rhinolophus rufus	Insectivorous bats	DD	PE	0.333333	4.225352
Otopteropus cartilagonodus	Frugivorous bats	DD	NE	0.388889	4.929577
Myotis muricola	Insectivorous bats	LC	NE	0.388889	4.929577
Taphozous melanopogon	Insectivorous bats	DD	IE	0.388889	4.929577
Dyacopterus rickarti	Frugivorous bats	LC	NE	0.444444	5.633803
Pteropus pumilus	Frugivorous bats	LC	NE	0.444444	5.633803
Miniopterus tristis	Insectivorous bats	EN	IE	0.444444	5.633803
Scotophilus kuhlii	Insectivorous bats	LC	NE	0.444444	5.633803
Hipposideros obscurus	Insectivorous bats	DD	NE	0.5	6.338028

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Murina cyclotis	Insectivorous bats	LC	PE	0.5	6.338028
Rhinolophus inops	Insectivorous bats	LC	NE	0.5	6.338028
Pteropus hypomelanus	Frugivorous bats	LC	PE	0.555556	7.042254
Hipposideros pygmaeus	Insectivorous bats	LC	NE	0.555556	7.042254
Megaerops wetmorei	Frugivorous bats	LC	NE	0.611111	7.746479
Ptenochirus minor	Frugivorous bats	LC	PE	0.611111	7.746479
Myotis horsfieldii	Insectivorous bats	LC	NE	0.611111	7.746479
Pipistrellus javanicus	Insectivorous bats	DD	PE	0.611111	7.746479
Miniopterus australis	Insectivorous bats	DD	PE	0.666667	8.450704
Rhinolophus philippinensis	Insectivorous bats	NT	PE	0.666667	8.450704
Harpyionycteris whiteheadi	Frugivorous bats	LC	NE	0.722222	9.15493
Hipposideros ater	Insectivorous bats	LC	NE	0.722222	9.15493
Miniopterus schreibersii	Insectivorous bats	LC	NE	0.722222	9.15493
Emballonura alecto	Insectivorous bats	LC	NE	0.777778	9.859155
Megaderma spasma	Insectivorous bats	LC	NE	0.777778	9.859155
Acerodon jubatus	Frugivorous bats	EN	PE	0.833333	10.56338
Pteropus vampyrus	Frugivorous bats	LC	NE	1	12.67606
Haplonycteris fischeri	Frugivorous bats	CE	IE	1.055556	13.38028
Rhinolophus virgo	Insectivorous bats	LC	NE	1.166667	14.78873
Hipposideros diadema	Insectivorous bats	NT	NE	1.388889	17.60563
Rhinolophus arcuatus	Insectivorous bats	LC	NE	1.5	19.01408
Eonycteris spelaea	Frugivorous bats	NA	IE	1.555556	19.71831
Macroglossus minimus	Frugivorous bats	NT	PE	1.777778	22.53521
Cynopterus brachyotis	Frugivorous bats	LC	NE	2.611111	33.09859
Ptenochirus jagori	Frugivorous bats	LC	NE	2.666667	33.80282
Rousettus amplexicaudatus	Frugivorous bats	DD	IE	2.888889	36.61972

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