Bat research efforts in the Philippines: a post-millennium review to identify future research prospects and priorities

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Abstract

Empirical evidence is important to develop effective conservation policies. The documentation and assessment of the status and threats towards a species and its habitat are essential steps toward developing appropriate policies to protect its population and mitigate existing to prevent future extinction. Bats are the example of taxa imperilled with the changing environment coupled with continuous human encroachment on its known habitats. Here, we summarize recent bat research in the Philippines using a bibliographic approach to assess progress and gaps both in different bat research areas and efforts towards each species in the post-millennia period (2000-2017). We examined 145 reports and peer-reviewed articles, including species records and research types. Our analysis revealed that regardless that most of the bat research in the Philippines are directed towards surveys in a certain geographic area, which generally limited in species inventories. Numerous species remain understudied and taxonomically unresolved. While other aspects of bat research especially on bat ecology and ecosystem services are not well understood. Remarkably, there is a growing effort in bat conservation initiatives in the Philippines involving the academe, NGO's, and conservationists aiming to protect threatened population and habitats.

Keywords: Conservation, Islands, Philippine bats, Priorities, Research effort

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1. Introduction

The Philippines has over seventy known species of bat belonging to seven families (Ingle & Heaney 1992; Heaney et al. 2010), and the majority of bat species are found in tropical rainforests (Heaney et al. 2002; Heaney et al. 2006) and around thirty species are cave-dwellers (Ingle et al. 2011; Sedlock et al. 2014). Ingle and Heaney (1992) pioneered the comprehensive listing and inventory of bats in the Philippines and the first to provide a taxonomic key. At present, as a result of continuous expeditions and inventories from different islands and provinces in the country, there are now 78 known species in the Philippines (Heaney et al. 2010). Approximately half of known bat species in the Philippines are Old-World Fruitbats (Family: Pteropodidae) and the remainder is insectivorous and echolocating bats. Insectivorous species include Vespertilionidae 32% (n= 25), Rhinolophidae (10 species), Hipposideridae (n=9), and other insectivorous species (Mollosidae (n=1), Megadermatidae (n=2), and Emballonuridae (n=3). In terms of endemism, 35% (n=27) are endemic in the country, and higher endemism can be found among Old-world fruitbats (Pteropodidae) which 60% are endemic in the country, restricted to Islands or single locality. In contrast to this, insectivorous families have a very low endemism (12%), though this may be due to under-description of species present. Many Protected areas in the country have high diversity, high endemism, and many rare species (Heaney et al. 2006). Flying foxes (*Acerodon* and *Pteropus*), for example, are highly selective and only thrive in primary to secondary forests (Van Weerd et al. 2003; Mildenstein et al. 2005; Stier and Mildenstein 2005).

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Although species richness is high, monitoring of populations and the understanding ecosystem interactions among bat species and their habitats is very limited in the country as evidenced numerous areas left unsurveyed (Mould 2012) and undescribed species for example from the complex groups of *Hipposideros* (Esseltsyn et al. 2012; Heaney et al. 2010; Murray et al. 2012), *Rhinolophus* (Sedlock & Weyandt 2009), *Cynopterus* (Campbell et al. 2004), *Macroglossus* (Vijayaraj, personal communication). Bats are important ecosystem health indicators since many species are localized in specific habitat types (Jones et al. 2009), for example, they serve as an umbrella species in caves by supporting other cave-dwelling invertebrates (Iskali & Zhang 2015). Frugivorous and nectarivorous bats provide vital ecosystem services including plant pollination (Acharya et al. 2015; Thavry et al. 2017) and seed dispersal which aids restoration of degraded habitats (Ingle 2003). Apart from this, insectivorous bats contribute in the reduction arthropod populations in agricultural lands (Jones et al. 2009; Kunz et al. 2011; Wanger et al. 2014). Hence, aside from elucidating species diversity patterns, the understanding of ecosystem function of bats is crucial in mainstreaming species value for effective conservation (Kunz et al. 2011; Olander & Maltby 2014). Island ecosystems such as the Philippines are dependent upon bats for pollination and seed dispersal, as bat mediated pollination and seed dispersal ensures gene flow across large and fragmented systems (Cox & Elmquist 2000).

Around 30% of bat species in the Philippines are pteropodids (fruitbats and nectarbats) distributed throughout the Philippines (Heaney et al. 2010). Among these are *Rousettus amplexicaudatus* and *Eonycteris spelaea* are likely to be some

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of the most important bat species in pollination and seed dispersers; however, both are locally threatened by hunting and habitat destruction. There are also endemic and threatened species in the country that needs to be protected before they go extinct. The endemic fruit bat, *Acerodon jubatus* is one of the most important forest species in the Philippines, was previously documented as seed disperser of many endemic and important plant species in the country (Mildenstein et al. 2005). Despite the importance of the bats in the ecosystem, there is little information on bat ecosystem services such as pollination, seed dispersal, and pest-reduction across the region.

The diversity of Philippine bats is undeniably high. However, unprecedented environmental change and increasing human population in the Philippines 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 has also meant ever increasing demands on land areas. The increasing use of land for agriculture and commercial plantations has been associated with 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). Furthermore, according to Hughes et al. (2012), a significant change in the diversity and species richness of Southeast Asian bats is projected in the next decades as a response to different land-use and climate change in the future.

Therefore, it is imperative that bat research in the Philippines is line up to answer and generate diverse information relevant to understanding the (1) species diversity and population patterns of bats in the country, (2) interactions in different

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ecosystems (3) role of bats in providing ecosystem services, (4) effects of current environmental changes to design effective conservation measures. The most recent review of Philippine bats was based on the 'Synopsis of the Philippine Mammals' by Heaney et al. (1998) and was updated in 2010. In 2011, Ingle et al. reviewed the current status of cave bats including known roosting caves and karsts ecosystems. Even if these reviews have provided essential information on conservation status and threats, it only focused the distribution of species and diversity patterns, and further reviews are needed to identify conservation gaps in bat ecology and conservation in the Philippines. The synthesis from this review would not only allow researchers to identify future research prospects but also will serve as a guide in a national and regional research allocation.

In this review, we applied a bibliographic approach to assess recent bat studies in the Philippines. Here we provide quantified information on research effort towards species diversity, ecology, taxonomy, disease, and conservation using data from research publications and reports published since 2000. Using this approach is essential to quantify allocation of global or regional conservation efforts and resources (de Lima et al. 2011; for example, Conenna et al. 2017 on insular bat species; Vincenot et al. 2017 on Island flying fox).

2. Review Approach

The search for literature took place from January 25 to April 20, 2017. A dataset was created based on the literature published from 2000-2017 obtained from Web of Science (Thompson Reuters), Google Scholar (https://scholar.google.com), and 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 from 2000-2017: (bat* OR Chiroptera) AND (Philippine* OR Luzon OR Visayas OR Mindanao) AND (Species OR diversity OR Taxonomy OR species composition OR conservation* OR threat* OR ecosystem service* seed dispers* OR pollinat* OR parasite* OR disease*) AND (Threat* OR Hunting OR trade OR bushmeat*) AND (Land-use* OR Plantation* OR Oil Palm OR Rubber*). To maximize the output for our dataset, we included studies published online from conference proceedings from biodiversity societies in the Philippines (i.e. 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 bias data sampling, the unpublished thesis was excluded from the review (Appendix A). Since most universities in the Philippines do not have an online library of the thesis to access, we excluded thesis and dissertation from the review.

Initially, our search has returned a total of 145 studies (Published article =91, Proceedings in conferences=34, Technical Reports =20). We screened these papers for the following criteria: (1) Research areas, (2) Distribution of research efforts per Island and per study site, (3) Habitat type where the study was conducted, and (4) Number of studies which recorded the species.

To quantify research efforts by research areas, five categories were set: Diversity, Conservation, Ecology, Diseases, and Taxonomy and Systematics. Each category was divided into sub-areas to differentiate each research to a more specific area (Table 1-Box 1). We counted the number of studies conducted within each main and subarea and the distribution of bat research was quantified based on where the study was conducted in the main Islands of the Philippines (Luzon, Visayas, and Mindanao) and we assessed the distribution of studies based on habitat type. Five habitat types were set according to Philippine settings including caves and karst, forest, forest and cave, forest and land-use types, land-use and urban sites.

Table 1 (Box 1). Classification of bat research based on diversity, ecology, conservation, and taxonomy and systematics

Research Area	Sub-area	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 concern with the endemism and conservation status patterns of bats.
Ecology	Roosting	▪ Ecological studies that include the observation of bat roosting habits, preferences, and movement.
	Foraging	▪ Bat research that concerns the diet and foraging habits of different bat communities.
	Ecosystem Function	▪ Studies that concerns 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).
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.

	Habitat and ecosystems	▪ Studies that concerns with the conservation bat species/population habitat or hotspot.
Taxonomy & Systematics	Species	▪ Studies resulting to describing new species.
	Phylogenetic	▪ Studies using principles of genetics or molecular biology to assess evolutionary processes to understand bat taxonomy and systematics.
Diseases	Parasites	▪ Studies encompassing all inventories of ectoparasite, endoparasite of bats. All studies concerning bat-parasite relationship including parasite taxonomy and distribution.
	Virus, Bacterial, and Fungal associations	▪ Studies concerning the bat-borne diseases or emerging disease related to bats including detection of virus, bacteria, and fungi among bat species.

Lastly, we quantified research efforts per species by evaluating every study and the target species including those species listed and surveyed. This is to assess the attention and research effort given to each species, therefore we set criteria to determine priority species. The frequency of Philippines bats records in studies dated from 2000 to present was assessed and used to rank species effort allocation. Species were ranked using a simplified method using the equation Species Effort Allocation (x) = f / y (where: x= species; f= frequency of species records; y= number of years or coverage of the review). A species with a value equal to 1.00 indicates an average effort per year, while <1.00 indicates that higher effort is given to the species, and >1.00 means lower effort is provided. Nevertheless, we did not integrate species conservation status and endemism in the ranking yet we carefully noted each species endemism patterns in the discussion. To avoid bias and inconsistency or repetitions of records, we only examined peer-reviewed published articles and technical reports and excluded review papers and reports from conference proceedings from the datasets.

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3. Results

3.1. Research effort allocation towards bats in the Philippines

Our analysis on research effort from 2000-2017 revealed that there is an average of 7.5 bat studies conducted per year, where only an average of 5.4 is published in peer-reviewed journals. The majority of the bat research is from Luzon (n= 55, 38%), followed by Mindanao (n=48, 33%), Visayas (n= 37, 26%) and very least number of studies was conducted in a country-wide level (n=5, 3%) (Figure 2; Figure 3). Most of the bat studies focused on forest habitats (Figure 4), of which the majority is from Luzon Island (n=42) especially from mountain ranges of the Sierra Madre, Mt. Makiling in Laguna, and Polilio Island. In caves and karst ecosystems, the majority of the studies were from Mindanao (n=17) and Visayas (n=15). In Mindanao, important bat surveys and inventories were made in the recent years increasing the number of known cave-dwelling species in the Philippines (see Nuneza et al. (2014), Quibod et al. (2013), Warguez et al. (2013), and Tanalgo and Tabora (2015)). In the Visayas, major studies were conducted in karst areas of the Island especially on the Island of Bohol (see Sedlock et al. 2013; Phelps et al. 2016) and coastal areas of Panay Island (Mould 2012). Nevertheless, there is a low number of comparative studies on bat diversity across different habitat types, which is important to understand the impacts of land-use and environmental changes to bat communities.

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3.1.1. Species Diversity

Our analysis on research allocation per research areas showed that the majority of the studies were conducted towards "Diversity/Community composition", accounting for the 46% (n=67) of researches conducted and published since 2000 (Figure 3; Figure 5). Despite the high number of species inventories and adding the factor of the archipelagic settings of the Philippines, there are only three newly described species (viz. *Desmalopex microleucopterus, Styloctenium mindorensis*, and *Dyacopterus rickarti*) for the past 18 years and this is relatively lower compared to the numbers of new species from other countries in the mainland Southeast Asia.

3.1.2. Research allocation per species and understudied taxa

Our present review showed that an average of 2.2 published studies per species per year (species effort/year) from 2000 to present. Regardless of a large number of studies aiming to assess species and community composition, there are still species that remains understudied for the past 18 years (Table 2). The three Philippine bat species (*Myotis ater*, *Pipistrellus stenopterus, Cheiromeles parvidens*) had no records or studies for almost past two decades documenting their occurrence in the country. These three species were recorded (pre-millennia) in the Philippines but their taxonomy and assessment were not clear until the present, yet these species are considered least concern and were recorded in few localities in other Southeast Asia countries. For example, *Myotis ater* was not recorded since

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2000 but a specimen collected in Bukidnon (Mindanao Island) might represent the species but remains unconfirmed until present (Heaney et al. 2005).

Island endemic species, which are only recorded in small Islands, such as *Acerodon leucotis, Desmalopex microleucopterus, Pteropus speciosus, Styloctenium mindorensis* are among the most understudied species in the Philippines with an average of 0.05 study/year. The recently described pteropodid *S. styloctenium mindorensis* and *D. microleucopterus* were discovered last 2007 in Mount Siburan, Mindoro Island. Both species are understudied or Data Deficient since their discovery (IUCN Redlist, 2017). Other Island bat species can only be found or have been recorded from few isolated localities, hence, most are Data Deficient until present. The previously thought extinct species, *Dobsonia chapmani* (SEA=0.16 effort/year) is also among the most understudied species. It is fairly common in early 1940's to 1960's and was presumed to be extinct in 1990's to 2000's. But, it was recently rediscovered in few localities in Carmen and Catmon on Cebu Island last 2001, and in Negros Occidental, the southwest of Negros Island, in 2003 (Alcala et al. 2004) but was never recorded again despite rigorous fieldworks were conducted after the rediscovery (Paguntalan, pers.comm 2015-Kuching, Malaysia). Another understudied bat species that needs higher attention is the threatened and endemic *Nyctimene rabori* (SEA=0.11 effort/year).

Remarkably, granting there are species currently classified threatened (under IUCN Redlist standards) but are not considered understudied in terms of research allocation per species. The number of studies and records towards large flying foxes *Acerodon jubatus* (SEA=.83 effort/year) and *Pteropus vampyrus*

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(SEA=1.00 effort/year) may have increased due to large funding allocation and monitoring in the past decades and have become significant ground work to the protection of many of their roosting sites in the Philippines especially in Visayas and Luzon (i.e. Mildenstein et al. 2005). In contrary to least studied groups, species including *Rousettus amplexicaudatus, Ptenochirus jagori,* and *Cynopterus brachyotis* are the most studied species in the Philippines with beyond the average effort per year scores (SEA values <1.00). These species occur in most of the studies conducted and has least habitat preference and high tolerance to degradation and human-disturbance in the country (Heaney et al. 2010; Tanalgo et al. 2017).

3.2. Ecological Studies

In terms of studies in bat 'Ecology', there are 27 (21 published) (19%) out of 145 studies published or report on bat roosting, feeding, ecosystem function, and reproductive. Most of the bat studies in the Philippines are in the areas of 'community composition'. These studies are limited in to providing baseline information with no further explorations of other aspects of bat biology, and many 'unresolved' species left understudied especially those echolocating groups (i.e. Sedlock et al. 2011). Hence, studies on bat ecology and ecosystem interactions are scarcely available in the country (Table 3; Figure 3; Figure 5). An evidence to this is the existence of very little data and information towards bat interactions to its environment. Based on our analysis, there is a scarce information on bat response to destruction and fragmentation of their natural habitat and on the value of different

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spatial arrangements of remnant forests and man-made vegetation for bat persistence in the Philippines (Figure 3; Figure 5).

Majority of bat ecological studies focused on the seed dispersal ecology of frugivorous bats. Ingle (2003) investigated seed dispersion of frugivorous bat along different landscape in lowland montane in Mindanao and Gonzales et al. (2004) in the lower successional area in Luzon. In Subic, 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 area since the early 2000s (Stier and Mildenstein, 2005; Mildenstien et al., 2005; Mildenstein et al. 2014). While there is a substantial number of studies on the role of the endemic *Ptenochirus jagori* as a seed disperser in the forest in the central Philippines (i.e. Curio et al. 2002; Reiter 2002; Reiter et al. 2004; Reiter et al. 2006). All of the studies mentioned above provided substantial evidence on the ecosystem services provided by frugivorous as seed dispersers of many endemic plant species in the Philippines. However, no studies ever published in the past and recently and only observational records on the flower visitation of nectarivorous bats. While in other Southeast Asian countries, bat ecology is diverse and well-explored from studies published. For example, there are numerous recent findings published on plant-bat interactions in Thailand paving way to a better understanding of the roles of bats in the ecosystem. Bat Biologists from Thailand have clearly documented the ecosystem function of the Old-world fruit bats as pollinator (i.e. *Eonycteris spelaea*) to many economically important plant species from Thailand and across Southeast Asia such as Durian and Petai (Bumrungsri et al. 2013; Acharya et al.

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2015; Sritongchuay et al. 2016; Stewart et al. 2016) and as seed disperser in degraded habitats (Sritongchuay et al. 2014). In Malaysia, nectarivorous bats are also documented as pollinators of mangrove species (Mohamed et al. 2016), and Abdul-Aziz et al. (2016) utilized a molecular approach to understanding the pollination roles of Island flying fox in wild durian. All of these studies from neighbouring territories have clearly highlighted the significant role of bats in sustaining ecosystem process and have become important in the protection of populations and their habitat.

Bat foraging studies concerning the insect-pest consumption of insectivorous bats also share scarcity on a number of bat-plant interaction studies in the Philippines. There are only two studies (out of 6 ecological studies) focused on the foraging ecology of species other than Pteropids. Balete (2010) investigated the diet and foraging behaviour of false vampire bat *Megaderma spasma* in Mt. Makiling, revealing this species consumed at least 10 insect orders, though almost 90% comprised of the Orders Coleoptera, Hemiptera, and Orthoptera. While, Sedlock et al. (2014) explored the diet of *Rhinolophus inops, R. arcuatus, R. virgo,* and *Hipposideros pygmaeus* using molecular techniques and found the complex diet relationship among taxa.

Studies on the reproductive ecology of bats are also deficient. There are only 2 papers studied the reproductive phenology of only three species (out of 78): *Eonycteris spelaea, Macroglossus minimus,* and *Rousettus amplexicaudatus* (Heideman and Utzurrum 2003; Delpopolo et al. 2014). The reproductive phenology and its relationship to foraging and environment have been widely

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explored in other Southeast Asian countries. Nurul-Ain et al. (2017) comprehensively documented the reproductive patterns of 11 Malaysian bat species and the ecological factors such as diet and climate affecting it. Furey et al. (2011), in Vietnam, has pioneered the documentation of the reproductive patterns of cave-dwelling bats in relation to cave conditions and climate. Both studies have shown the relationship of reproductive phenology on climatic patterns and availability of food resources.

3.3. Disease and Parasites

Although there are several studies on disease associated with Philippine bats, unlike in temperate region disease such as white-nose syndrome is not widely causing declines to many populations. The diversity of disease occurrence in bats has been recently explored in Philippine bat population. Arguin et al. (2002) pioneered to study Lyssavirus infections among bats in the Philippines. Jayme et al. (2015) revealed that Reston ebolavirus virus (RESTV) is present in multiple bat taxa. At the same time, the presence of anti-RESTV antibodies was found from the Philippine endemic *Acerodon jubatus*. However, the low prevalence and low viral load based on findings suggest broader investigations assess the geographic occurrence of ebolavirus groups in Philippine bats. Recently, Taniguchi et al. (2017) isolated and characterized Pteropine orthoreovirus (PRV) from four Philippine fruitbats (all are non-endemic). In humans, this virus causes respiratory tract illness (RTI) and alike. Their findings showed that roughly 90% of the bats sampled have tested positive with neutralizing antibodies to PRVs. Furthermore,

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the risks of PRVs to infect human remains vague and further surveillance is necessary.

Aside from virus-associated to bats, the presence of other microbes (bacteria and fungi) were also studied in selected bat species. Hatta et al. (2016) detected the presence of *Campylobacter jejuni,* bacteria that causing diarrheal illness in human (CDC, 2017), were detected from rectal swabs from *Rousettus amplexicaudatus.* On the other hand, Jumao-as et al. (2017) revealed the presence of important agro-economic fungi (i.e. Aspergillus, Penicillium) from fruitbats common to orchards.

While studies in ectoparasites in bats are relatively higher on Luzon Island. For example, Alvarez et al. (2015) contributed new host and distribution records of batflies from Mt. Makiling and Mindoro Island (Alvarez et al. 2016), and Amarga et al. (2017a; 2017b) recorded batflies from cave-dwelling bats from Marinduque Island with new records in the Philippines.

3.4. Conservation Research and initiatives

Alongside with the increasing number of bat research, the efforts to conserve bat populations and their ecosystems have been implemented and currently widely growing successfully in different regions in the Philippines. A very good and well-organized project in the Philippines dedicated to conserving bats and its habitat is the flying fox species conservation in the initiated in the late 1990's, the "Bat Count Philippines" aimed to provide baseline information and capacity building towards the conservation of flying foxes particularly *A. jubatus*

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and *Pteropus vampyrus*, which piloted in the Northern Part of the Philippines and later in the central Philippines (Mildenstein 2002; Mildenstein et al. 2012). In 2012, the 'Filipinos for Flying Fox' project was initiated by the same investigators and new collaborators (i.e. Philippine Biodiversity Foundation Inc., Mabuwaya Foundation Inc., Bat Conservation, Save our Species). Similar project initiatives have also expanded to different areas in Luzon and Visayas (viz. Friends of the Flying Fox Boracay) which aims to intensify information on the distribution range of the species for conservation and to develop more researcher interests in the country. Currently, the project is on-going in areas Northern and Central Philippines and very few areas have been covered from Mindanao Island (south Philippines) despite the fact that there are numerous sightings of the species and its roosting sites (Cayunda et al. 2004; Carino pers.com; Tanalgo pers.obs). Project expansion in Mindanao is still a challenge and may be due to the lack of research capacity, access (i.e., security and safety of fieldwork), the existence of initial communicated information, and concrete evidence of their occurrence to the areas where flying foxes were thought to exist.

There are also policies which enforce bat conservation in the Philippines, for instance for bat caves there is National Cave Committee which functions to identify and protect important caves based on biodiversity and geological importance. However, this policy often overlooked because to the lack of bat cave biologist working with the committee and it focuses more on caves' potential for tourism and economic purposes (Tanalgo pers. observation) as evident to the current number of cave bats under protection by the policy (Philippine Bat Cave

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Committee, 2010; Ingle et al. 2011). To address the current situation in bat cave conservation in the Philippines as well as in a larger region of Southeast Asia, the Bat Cave Vulnerability and Conservation Mapping Initiative (https://tropibats.com/about-the-bcvi/) was initiated to develop standardized and easy-to-use strategy for cave conservation and to identify important bat cave hotspots in the tropics (Tanalgo and Hughes, 2017).

4. Future priorities in bat research in the Philippines: Addressing current issues

In spite of the high diversity and significance of bats in the Philippines, most of the bat habitats are still facing counts of threats due to lack of specific statutory protection. Thus, it is essential that bat biologists working in the country should be steered of which research priorities they should work on and focus in the future to build strong conservation evidence in order to protect many important bats species and their habitats. Even with the numerous studies conducted and published in the recent decades, the diversity and proportionality of studies by areas and priorities are lacking. The findings of this review suggest that bat biologists and conservationists in the country should be encouraged to diversify bat research work and publish their data and findings even though personal compensation in publishing research work in the majority of institutions is relatively low (Abritis et al. 2017). In the Philippines, there are many studies that have been carried out but many may have remain as a report, Masters, or Ph.D. theses, and others are in local journals, which is different to access online. Within this review, we have excluded records from unpublished reports to avoid unequal data sampling. Due to this,

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global species assessment (i.e. IUCN redlist) of Philippine bats have become challenging especially the assessment of threat intensity per species (Mildenstein et al. 2016).

Future prospects for bat research should not only focus on 'community-compositions' or inventories but should dig further to explore the taxonomy and systematic of different species, especially those species that belongs complex and unresolved groups (i.e. families Hipposideridae and Rhinolophidae) as many insectivorous bats remain undetermined and Data Deficient (i.e. Sedlock et al. 2008). The accurate taxonomic examination or identification of a species is essential in assessing the state of biodiversity as well as the assigning correct conservation status (Dubois 2003) and hence it is the foundation of every bat research and conservation initiatives. Additionally, it is important to properly apposite conservation measures of the species or of the population in terms of its ecological status and endemism. Monitoring of species population not only those charismatic groups (i.e. Flying foxes) should be prioritized in the region, especially for those common yet vulnerable to threats and disturbance (i.e. cave bats *Rousettus amplexicaudatus* hunted in massive amount).

The elucidation of bat ecosystem services from different ecosystem types in the country should be another top priority in Philippine bat research. This another important step to enforce a concrete basis for the species and habitat conservation. The impacts of deforestation and other land-use changes to bat population and their ecological dynamics should also be explored alongside. For example, the impacts of oil palm and rubber plantations, two of the fast-growing agricultural crops in the

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Philippines and currently expanding to most forested areas, however, its impact on bats and other wildlife (including vegetation) is still unclear in the Philippines. Moreover, the threat from changing climate always remain and may exacerbate species extinction in Southeast Asia in the near decade. Regional studies on the implication of climate change on current and future distribution of Philippine bats especially those with very narrow distribution are also imperative in order to heads-up conservation actions and mitigation.

The interactions of human and bats including its habitat is also an interesting aspect of bat research to explore in the region. Illegal hunting and trade of bats from forests and caves for food, bush meat, and trade is an emerging threat to bats in many regions especially protected areas but the lack of quantitative information warrants rigorous investigations (Scheffers et al. 2012; Tanalgo et al. 2016; Tanalgo 2017). While, consumption of bat meat is quite common across the country and although studies on disease associated with bats were studied in some species in the Philippines, investigations on the risk of disease spill overs from bat species remain unexplored.

The involvement of academe, NGO's, and funding agencies should also be highlighted and strengthened across different regions. The role of local researchers and NGO's are an important key factor to attain effective and sustainable conservation especially in biodiversity hotspots for bats (Racey 2013).

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5. Synthesis

Consequently, based on the information gathered and synthesized from different studies from 2000 to present. Here, we provide key recommendations to address different concerns towards bat research and conservation in the Philippines. The following were recommended for future work and directions:

1. Increase bat studies and field surveys in the region with special attention to conservation areas, the forest remains, and in caves and underground habitats.
2. Increase taxonomic studies on cryptic, data deficient, and revisit unresolved Philippine bat species especially on complex groups of *Hipposideros, Rhinolophus*, *Macroglossus,* and *Cynopterus*.
3. Enhance and standardize sampling techniques to adequately assess bat assemblage and activities in varying ecosystems. For example, simultaneously using traps and bat detectors to assess echolocating species (i.e. Hughes et al. 2010; Hughes et al. 2011).
4. Locate and identify areas with possible roosting sites of flying foxes in the southern region of the Philippines.
5. Diversify the proportion of bat studies especially in ecological aspects such as pest control services, pollination, and seed dispersal, and interactions among species and its habitat.
6. Provide quantified evidence on the ecosystem provision of bats to different ecosystems using a different approach, models, and projections (i.e. Wanger et al. 2014).

7. Integrate novel technologies to increase ecological and taxonomic studies (i.e. Russo et al. 2017; Lim et al. 2017 in Malaysian bats). For example, using metabarcoding techniques to identify diet to elucidate species ecosystem services (Sedlock et al. 2009; Abdul-Aziz et al. 2016), detect disease.
8. Assess species distribution in the current and future scenario using models based on climate and land-use change (i.e. Hughes et al. 2012).
9. Engage partnerships and increase research capacities and collaboration among the students, academes, Department of Environment and Natural Resources, NGO's and locals; Establish a more interactive and localized bat research networks, collaborative science, and linkages among regional/national researchers and international researchers and organizations.
10. Develop effective conservation-education programs especially in areas with known high bat diversities.
11. Encourage and train young bat researchers in the region to sustain the need for conservationists and advocates in the region.

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Figures

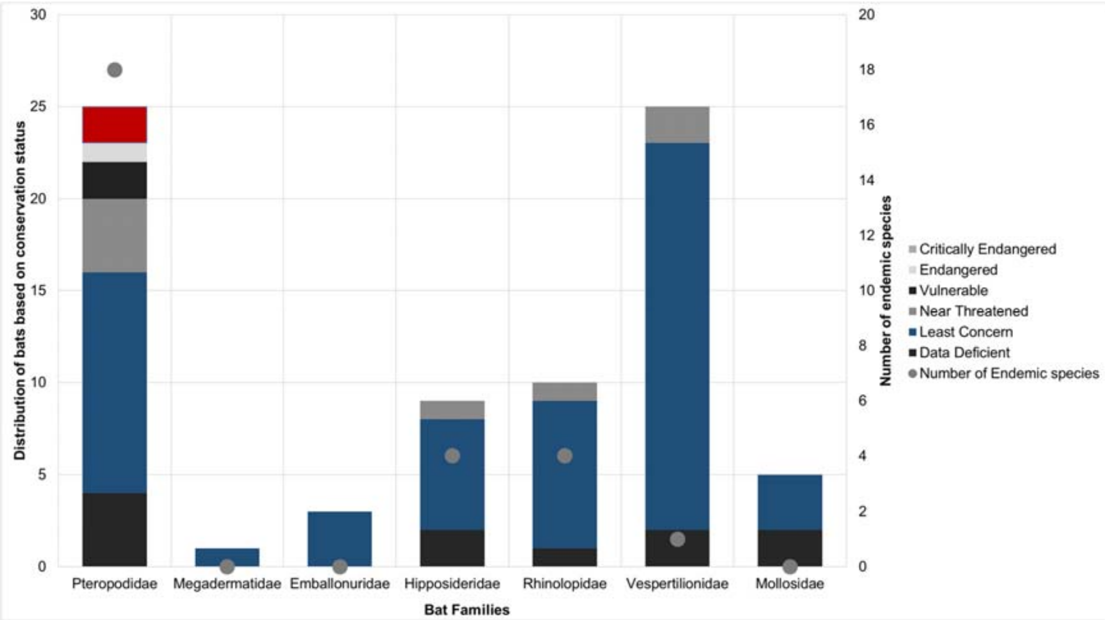

Figure 1. *The distribution of species from seven bat families in the Philippines (bars) where fruitbats and evening bats shares a same proportion in the terms of species richness. Species endemism (grey dots) is higher among fruitbats.*

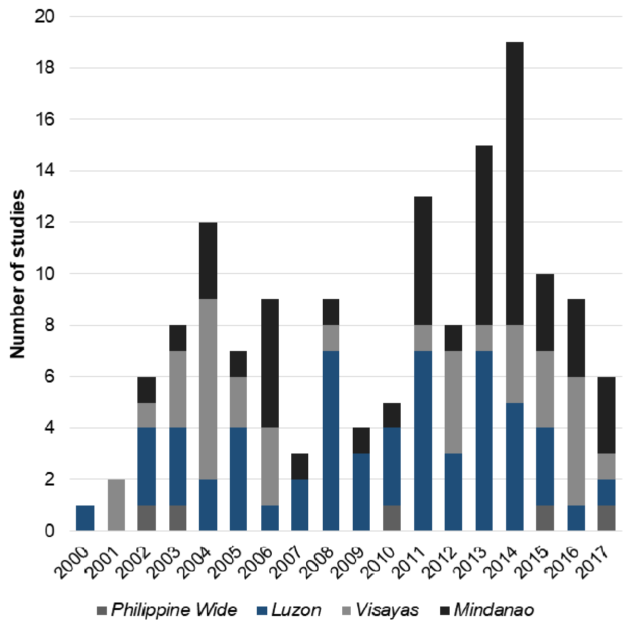

Figure 2. *Number bat research per year based on the number of published journal articles, technical reports (online), and conference proceedings from three main Islands in the Philippines from 2000-2017.*

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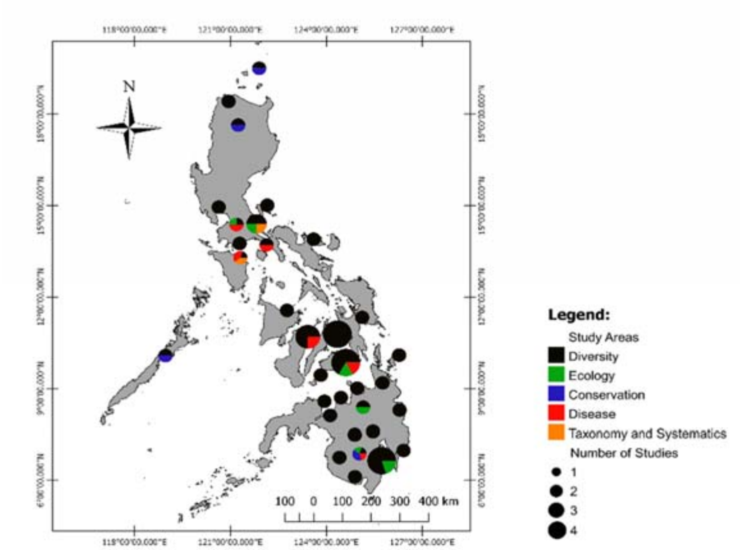

Figure 3. *Distribution of research conducted in four themes (Diversity, Ecological, Disease, Taxonomy & Systematics, and Conservation, see Box 1. for definition and scope) throughout the Philippines from 2000-present. This data is based only from published studies and data. Projects and initiatives towards conservation is not included in the map.*

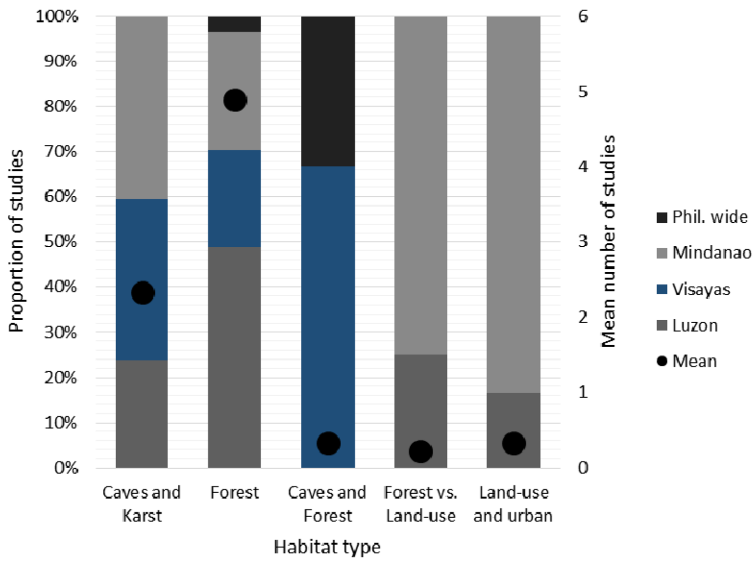

Figure 4. *Distribution of bat research according to habitat type across the Philippines.*

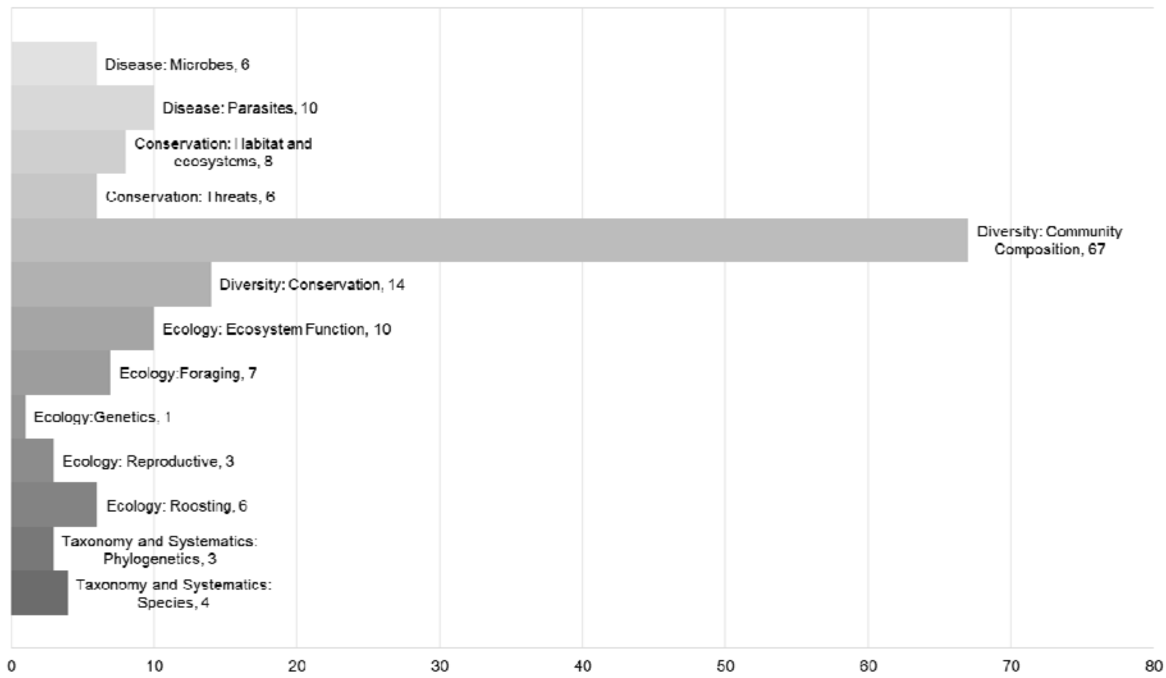

Figure 5. *Proportion of research effort allocation towards bats classified into five main themes: Diversity, Ecology, Conservation, Disease, and Taxonomy and Systematics. This figure shows that the majority of the studies on Philippines in the post-millennia period were highly concentrated on Community-Composition studies, this include rapid inventories, species counting, and population monitoring.*

Tables

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 values of SEA per species in listed in Appendix B.*

Rank	Species	Species Effort Allocation (SEA)	Conservation Status	Endemism
1	*Myotis ater*	0	LC	NE
1	*Pipistrellus stenopterus*	0	LC	NE
1	*Cheiromeles parvidens*	0	LC	NE
2	***Acerodon leucotis***	**0.055556**	**VU**	**IE**
2	***Desmalopex microleucopterus***	**0.055556**	**NA**	**IE**
2	***Pteropus speciosus***	**0.055556**	**DD**	**IE**
2	***Styloctenium mindorensis***	**0.055556**	**DD**	**IE**
2	*Hipposideros lekaguli*	0.055556	NT	NE
2	*Rhinolophus borneensis*	0.055556	LC	NE
2	*Rhinolophus creaghi*	0.055556	LC	NE
2	*Glischropus tylopus*	0.055556	LC	NE
2	*Murina suilla*	0.055556	LC	NE
2	*Nyctalus plancyi*	0.055556	LC	NE
2	*Phoniscus jagorii*	0.055556	LC	NE
2	*Cheiromeles torquatus*	0.055556	LC	NE
2	*Mops sarasinorum*	0.055556	DD	NE
3	***Nyctimene rabori***	**0.111111**	**EN**	**IE**
3	***Pteropus dasymallus***	**0.111111**	**NT**	**IE**
3	*Hipposideros coronatus*	0.117647	DD	IE
3	*Rhinolophus acuminatus*	0.111111	LC	NE
3	*Falsistrellus petersi*	0.111111	DD	NE
3	*Kerivoula papillosa*	0.111111	LC	NE
3	*Kerivoula pellucida*	0.111111	LC	NE
3	*Pipistrellus tenuis*	0.111111	LC	NE
3	*Tylonycteris pachypus*	0.111111	LC	NE

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3	*Tylonycteris robustula*	0.111111	LC	NE
4	*Desmalopex leucopterus*	0.166667	LC	PE
4	***Dobsonia chapmani***	**0.166667**	**CE**	**IE**
4	*Saccolaimus saccolaimus*	0.166667	LC	NE
4	*Hipposideros cervinus*	0.176471	LC	NE
4	*Kerivoula hardwickii*	0.166667	LC	NE
4	*Otomops* sp.	0.166667	UA	UA
5	***Alionycteris paucidentata***	**0.222222**	**LC**	**PE**
5	*Dyacopterus spadiceus*	0.222222	NT	NE
5	***Dyacopterus rickarti***	**0.222222**	**DD**	**IE**
5	***Coelops hirsutus***	**0.235294**	**NA**	**IE**
5	*Rhinolophus macrotis*	0.222222	LC	NE
5	*Harpiocephalus harpia*	0.222222	LC	NE
5	*Philetor brachypterus*	0.222222	LC	NE
5	*Chaerephon plicatus*	0.222222	LC	NE

Table 3. *List of bat ecological studies from 2000 to present*

Habitat Types	**Hypothesis/Findings**	**Bat Species**	**Reference**
Forest	Seed dispersal activity of a fruitbat in Philippine rainforest	*Ptenochirus jagori*	Curio et al. 2002
Forest	Differential seed ingestion of *Ptenochirus jagori* in Ficus species	*Ptenochirus jagori*	Reiter 2002
Forest	Frugivorous birds dispersed more forest seeds and species into the successional area than	*Alionycteris paucidentata, Cynopterus brachyotis, Dyacopterus spadiceus, Haplonycteris fishcheri, Harpionycteris, Harpyioncyteris whiteheadi, Ptenochirus jagori, P. minor, Pteropus vampyrus, Rousettus amplexicaudatus*	Ingle 2003

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Forest	Seed germination after ingestion of *Ptenochirus jagori*	*Ptenochirus jagori*	Reiter et al. 2004
Forest	Physiological response of flying foxes to human activities	*Acerodon jubatus, Pteropus vampyrus, P. hypomelanus*	Van der Aa et al. 2006
Forest	Tracking seed dispersal by frugivorous bats	*Ptenochirus jagori*	Reiter et al. 2006
Caves and Karst	Wing Eco morphology of bats in caves	*Cynopterus brachyotis, Rhinolophus arcuatus, Miniopterus tristis, Emballonura alecto*	Tanalgo et al. 2011
Caves and Karst	Fluctuation in bat morphology in response to disturbance	*Rousettus amplexicaudatus*	Jose et al. 2015
Forest	Seed dispersal of birds and bats in lowland successional area	*Not mentioned*	Gonzales et al. 2009
Forest	Preference of *Ptenochirus jagori* based on leaf chemical composition	*Ptenochirus jagori*	Reiter 2003
Forest	Roosting and foraging behaviour of flying foxes	*Acerodon jubatus, Pteropus vampyrus*	Stier and Mildenstein 2005
Forest	Roosting and foraging habits of *Megaderma spasma*	*Megaderma spasma*	Balete 2010
Forest	Foraging preference of fruitbats	*Cynopterus brachyotis, Haplonycteris fischeri, Megaerops wetmorei*	Relox et al. 2014
Caves and Karst	Diet overlapping among insectivorous bats	*Rhinolophus spp. and Hipposideros spp.*	Sedlock et al. 2014
Forest	Reproductive phenology of selected nectarivorous bats	*Eonycteris spelaea, Rousettus amplexicaudatus, Macroglossus minimus*	Heideman and Utzurrum. 2003
Caves and Karst	Reproductive biology of *Rousettus amplexicaudatus*	*Rousettus amplexicaudatus*	Delpopolo et al. 2014
Forest	Roosting preference and foraging behaviour of *Ptenochirus jagori*	*Ptenochirus jagori*	Reiter et al. 2001

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Forest	Roosting behaviour of *Pteropus vampyrus*	*Pteropus vampyrus*	Cayunda et al. 2004
Forest	Habitat selection flying foxes	*Acerodon jubatus, Pteropus vampyrus*	Mildenstein et al. 2005
Caves and Karst	Diurnal roosting preference of cave bats	*Rousettus amplexicaudatus, Rhinolophus arcuatus*	Warguez et al. 2013
Caves and Karst	Roosting preference of *Rousettus amplexicaudatus*	*Rousettus amplixicaudatus*	Carpenter et al. 2014

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