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Research Article

Priority-setting for Philippine bats using practical approach to guide effective species conservation and policy-making in the Anthropocene

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Abstract

National level approaches to the development and implementation of effective conservation policy and practice are often challenged by limited capacity and resources. Developing relevant and achievable priorities at the national level is a crucial step for effective conservation. The Philippine archipelago includes over 7000 islands and is one of only two countries considered both a global biodiversity hotspot and a megadiversity country. Yet, few studies have conducted overarching synthesis for threats and conservation priorities of any species group. As bats make up a significant proportion of mammalian diversity in the Philippines and fulfil vital roles to maintain ecosystem health and services we focus on assessing the threats and priorities to their conservation across the Philippines. Habitat loss from logging and agriculture and hunting are the main threatening process to over half of the Philippine bats. Using available information on species' threats, conservation status, and endemism, we developed priority settings for Philippines bats to enable effective future decision making. We determined endemic and threatened species are the highest priority and larger bats are under more intense threat than smaller bats. Our finding further suggests that in order to bolster bat conservation and prevent future species loss, it is important to identify emerging threats and its extent, increase conservation education, develop effective policies, and forge equitable partnerships between scientists and stakeholders towards research and outreach capacity.

Introduction

Within Island tropical ecosystems such as those in the Philippines bats fulfill unique and crucial roles, and when extirpated the entire structure and function of the ecosystem is likely to alter considerably (Cox and Elmquist, 2000; Jones et al., 2009a; Wiles and Brooke, 2008; Kunz et al., 2011). Bats provide wide range of essential ecosystem services from pollination, seed dispersal, pest control, and tourism (Kunz et al., 2011; Bumrungsri et al., 2013; Wanger et al., 2014) and some sensitive species are ecosystem health indicators (Medellin et al., 2000; Russo andJones, 2015). Many bat species and their populations are threatened by a variety of threats (O'Shea et al., 2016; Voigt and Kingston, 2016). Worldwide, the principal cause of bat mortality and extinction are hunting for bushmeat and unprecedented rates of habitat loss and degradation (Mickleburgh et al., 2002; Racey, 2013; O'Shea et al., 2016; Voigt and Kingston, 2016).

In Southeast Asia, a substantial percentage of bat fauna may be dependent on intact forest (Kingston, 2010). Deforestation in the region may cause a loss of over 74% of the forest by the end of the century (Sodhi et al., 2004; Miettinen et al., 2011; Meyer et al., 2016), and in the Philippines deforestation rate has massively increased over the past decades causing more than 83% of native forest loss (Posa et al., 2008). This rate coupled with future climatic change is projected to increase extinction risk of a large proportion of bat fauna in the region, largely as a result of reduced suitable habitats (Lane et al., 2006; Hughes et al., 2012). Apart from the threats of environmental changes, negative perception and lack of knowledge of bat ecosystem services hinder effective conservation implementation and drive persecution of populations despite growing evidence on their importance (Hutson et al., 2001; Mickleburgh et al., 2009; Florens, 2015; Mildenstein et al., 2016).

To circumvent future habitat reduction and consequent species loss it is essential that conservation scientists understand how many species are at risk, the extent of threats in different scales and dimensions (e.g., species, genetics, landscape) and set achievable conservation targets, which address key gaps and drivers of species loss (Rudd et al., 2011; Brum et al., 2017; Conenna et al., 2017; Tanalgo and Hughes, 2018). Conservation threats and appropriate solutions vary in each country and initiatives to protect intact areas and species conservation prioritisation are typically refined and implemented according to geopolitical territories (Trimble and van Aarde, 2012; Tuttle, 2013; Ellison, 2014; Verde Arregoitia, 2016). Thus, the development of priorities and conservation management approaches should start in the local or national scales to compliment larger-scale targets e.g., regional or global

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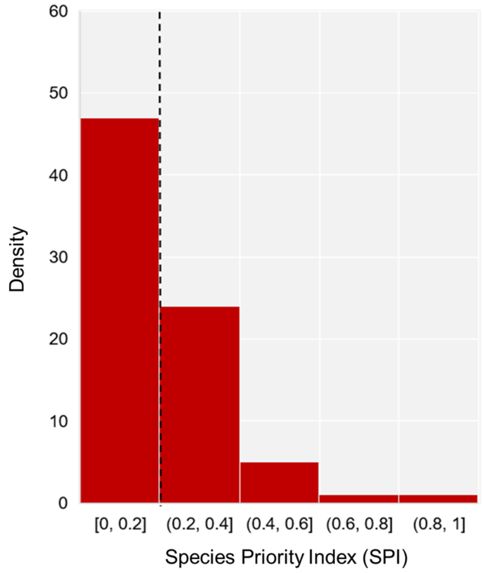

Figure 1 – Density and distribution of Species Priority Index (SPI) among Philippine bats. This analysis shows that thirty-nine percent (n=39 spp., 49%) of Philippine bats have above-average values (dashed line) vulnerability level based on combined threats, conservation status, and endemism under the scenario where direct threats are given higher proportion (T_{dir}=50%) vs. other threats (T_{ind}=40%, T_{nat}=10%).

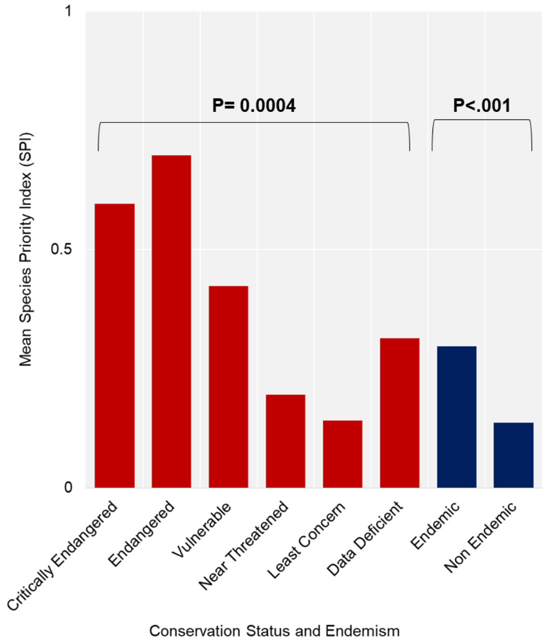

Figure 2 – The mean values of Species Priority Index (SPI) based on different Conservation Status (red bars) and Endemism (blue bars).

scale priorities (Gärdenfors, 2001; Kark et al., 2009; Rudd et al., 2011; Mazor et al., 2013; Beger et al., 2015). Moreover, developing and implementing national-level priorities makes it easier for policy-makers to address the most pressing concerns and allocate appropriate efforts (e.g., funding for research targets) targeting species that require immediate conservation intervention. In this paper, we originally aimed to (1) develop species conservation priorities based on endemism, conservation status and threats, (2) identify a key threatening process to Philippine bats, and (3) assess the links between threats and research efforts, which is a fundamental component to developing effective national to regional conservation prioritisation (Tanalgo and Hughes, 2018).

Materials and methods

We assayed the priorities of 79 species of Philippine bats based on a database of recent bat studies in the Philippines (Tanalgo and Hughes, 2018) based on the literature published between 2000–2017 obtained from Web of Science (Thompson Reuters), Google Scholar, self-archived ResearchGate and personal correspondence to bat scientists based in the Philippines. A total of 142 studies published online (full articles=93, conference proceedings=30, and technical reports=19) between January 25 and April 20, 2017, were reviewed. We supplemented our dataset using species accounts from the International Union for the Conservation of Nature (IUCN) Red List. We identified threats and classified them to 16 classes based on standard lexicon by Salafsky et al. (2008) and IUCN classification scheme representing direct, indirect, and natural. However, the comprehensive assessment of threats to multiple species is challenging as determining the severity and extent each threat poses to species quantitatively lacks detailed information available for each species. For example, many species lack the detailed range or population information, and the impact of various threats by reducing populations, reducing range-size, or reducing access to resources has been gauged for almost no species. In addition, the more potential threats posed to a species the more threatened it may be and the more challenging it would be to conserve given the different approaches required to effectively mitigate against each type of threat. Therefore we were largely limited to assaying what threats pose a risk to each species. In order to standardise our assessment, we used a scoring system, which when a threat is accounted for the species it is scored as a 1 and the summed value per species represents the absolute number of threats (T).

To assign priorities for species we ranked each species using the Species Priority Index ($SPI_{(s)}$). It is a simple index based on the species threats (T), conservation status, and endemism, which can be modelled into multiple scenarios based on the proportion of total threats or changes in conservation status. It can be calculated as the quotient of initial $SPI1_{(s)}$ and maximum SPI_{max}. This can be calculated using the mathematical formula:

$$SPI_{(s)} = \frac{SPI1_{(s)}}{SPI_{max}},$$

where $SPI1_{(s)}$ is the initial species (s) priority value from calculated sums of weighted means of species absolute number of threats ($T_{(s)}$, $T_{dir(s)}$=direct threats, $T_{ind(s)}$=indirect threats, $T_{nat(s)}$=natural threats) multiplied to species conservation status ($Con_{(s)}$) and endemism ($E_{(s)}$) values based from scoring assigned by Tanalgo and Hughes (2018) according to IUCN red list classification. This can be calculated using the mathematical formula:

$$SPI1_{(s)} = \sum[(\bar{x}T_{dir}w\%_{dir}), (\bar{x}T_{ind}w\%_{ind}), (\bar{x}T_{nat}w\%_{nat})] \times \sum\left(Con_{(S)}, E_{(s)}\right).$$

The final value of SPI ranges from 1 to 0; species with values near 1 indicates the species has a higher priority compared to species closer to 0. We simulated SPI in different scenarios by changing the weights of the threats (T_{dir}, T_{ind}, T_{nat}) with the assumption that conservation status and endemism remains the same, hence, the values remain the same. Although we found significant differences across scenarios (p<.05) we narrowed down our basis of present prioritisation according to the results using Scenario 1 (described in Tab. S1), where direct and indirect threats are higher than natural threats (see Tab. S2 for detailed scenario results and analysis).

To assess and infer the extent of species' threats particularly deforestation, agriculture, and mining we extrapolated supplementary data from other sources. The rate of deforestation measured by tree cover loss by region was downloaded from Global Forest Watch (https://www.globalforestwatch.org/) and plotted against species density (based on survey records from 2000–2017, unpublished data) to identify areas that require needed attention (i.e., bat biodiversity assessments). The rate of agricultural expansion from major plantations and mineral mining were assessed using data from the Philippine Forest Management Bureau (http://forestry.denr.gov.ph/), Philippine roadmap for rubber

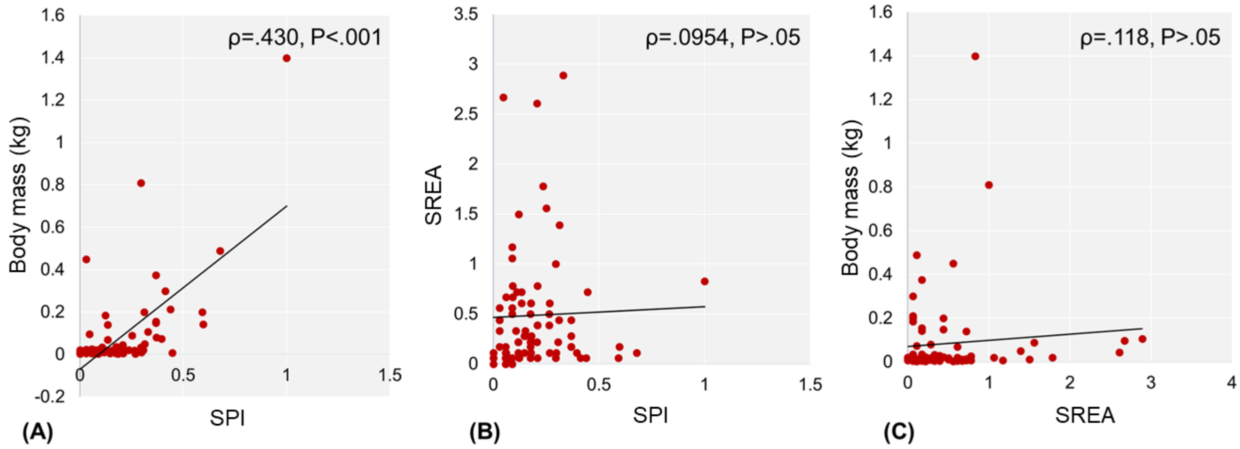

Figure 3 – The relationship between Species Priority Index (SPI), Species Research Effort Allocation (SREA), and bat body mass (kg). Spearman's rho and p values are shown.

and oil palm industries (Batugal, 2014; Yap, 2016), and Philippine Statistics Authority (https://psa.gov.ph).

We used the non-parametric Kruskal-Wallis Rank Test or Mann-Whitney U Test to test for the difference in Species Priority Index (*SPI*) across (i) conservation status and (ii) endemism. Spearman's Rank-Order Correlation was used to determine the relationship between Species Priority Index (*SPI*), body mass, and research effort as quantified by Species-Research Effort Allocation (*SREA*). *SREA* assesses the adequacy of research efforts provided to species in a certain period (see Tanalgo and Hughes, 2018 for the equation and Tab. 1 for *SREA* values). We used the JASP Statistical software v0.9.0.2 (JASP Team, 2018) for all statistical analyses and visualisations. Significance was set at p=0.05.

Results

Priorities for species conservation

A large percentage (35%, n=28 spp.) of Philippine bats are facing above the average number of threats ($\bar{x}$=3.15). The Absolute Number of Threats (T) does not differ significantly for conservation status (Kruskal-Wallis=6.659, d.f.=5, p=0.247) or endemism (Mann-Whitney U Test, p=0.573). Consequently, using Species Priority Index (SPI) as our proxy to gauge the conservation priority of each species showed that thirty-one (n=31 spp., 39%) species fall above the mean SPI value of overall species (0.201±0.169) (Fig. 1; Tab. S1) while there are nine species of Philippines considered as high priority (90th percentile). The top species with highest SPI values include globally threatened and rare species including eight fruit bat and a single insectivorous bat (Tab. 1). Whilst, SPI differed significantly across conservation status (IUCN standards; Kruskal-Wallis=22.811, d.f.=5, p=0.0004) and levels of threats are highest among Critically Endangered ($\bar{x}_{SPI}$=0.597) and Endangered species ($\bar{x}_{SPI}$=0.697) and Data deficient species have interestingly higher SPI values than least concern species ($\bar{x}_{SPI}$=0.314 and $\bar{x}_{SPI}$=0.142 respectively) (Fig. 2). Endemic species also experience significantly higher threats ($\bar{x}_{SPI}$=0.297, Mann-Whitney U Test, p<0.001) compared to non-endemic species ($\bar{x}_{SPI}$=0.137) (Fig. 2). When overall species are analysed, a positive significant correlation was found between SPI and bat body mass (kg) (overall species: Spearman's Test, ρ=0.430, p<0.001) (Fig. 3A). We found no congruence between species conservation priority (SPI) and research effort allocation (SREA) (Spearman's Test, ρ=0.0954, p=0.409) (Fig. 3B) and similarly no link between SREA and body mass (Spearman's Test, ρ=0.118, p>0.05) (Fig. 3C).

Key threats in the Philippine bats

Out of 79 species, 16 (20%) are considered "Threatened" based on IUCN standards (e.g., Vulnerable, Endangered, and Critically Endangered). The majority of studies from 2000 to 2017 focus on habitat destruction and direct human impacts as current threats to Philippine bats (Fig. 4). Around 80% of bats in the country occur and may depend on different forest types (Fig. 5) and deforestation by logging threatens the highest number of species at 71% (n=56 spp.) and agricultural conversion is the second most studied threat to 48% (n=38 spp.)

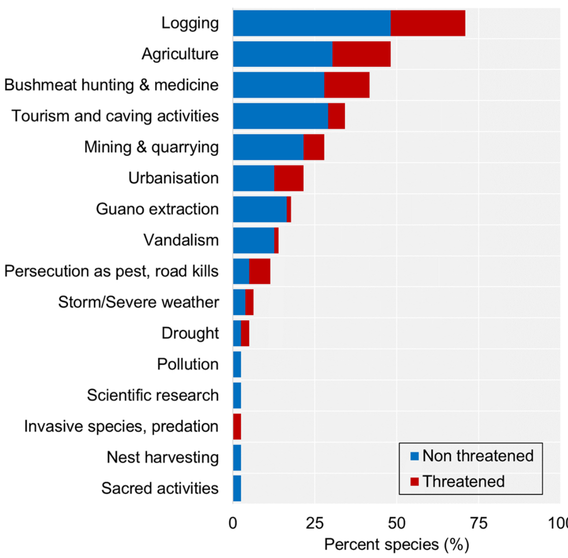

Figure 4 – Key threats to Philippine bats showing the proportions of threatened and non threatened species (according to the IUCN).

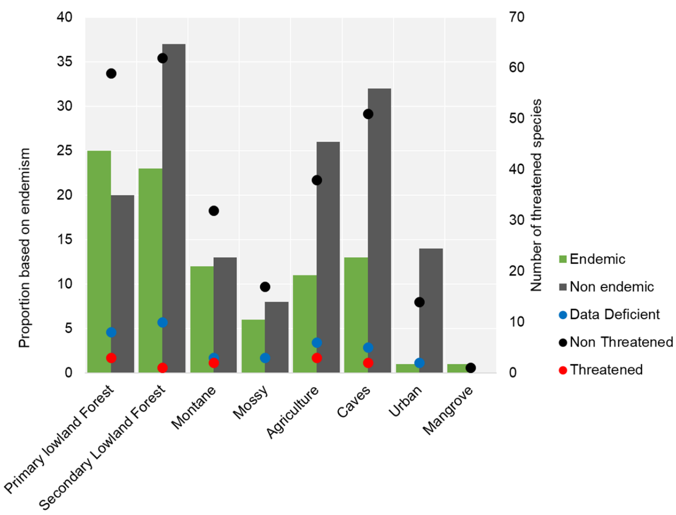

Figure 5 – Estimated distribution of Philippine bats across different major habitat types in the Philippines. Based on accounts of Heaney et al. (2010); Tanalgo and Hughes (2018).

Table 1 – Species Priority Index (SPI) and Species-Research Effort Allocation (SREA) of Philippine bats. Species ranked according to SPI values.

Family[a]	Species	SPI	SREA[b]
Pteropodidae	*Acerodon jubatus*	1.00	0.83
Pteropodidae	*Pteropus dasymallus*	0.68	0.11
Pteropodidae	*Dobsonia chapmani*	0.60	0.17
Pteropodidae	*Pteropus speciosus*	0.59	0.06
Hipposideridae	*Hipposideros antricola*[c]	0.45	0.72
Pteropodidae	*Stylonycteris mindorensis*	0.44	0.06
Pteropodidae	*Acerodon leucotis*	0.41	0.06
Pteropodidae	*Nyctimene rabori*	0.40	0.11
Pteropodidae	*Eonycteris robusta*	0.37	0.28
Pteropodidae	*Desmalopex leucopterus*	0.37	0.17
Pteropodidae	*Desmalopex microleucopterus*	0.37	0.17
Pteropodidae	*Dyacopterus rickarti*	0.37	0.44
Pteropodidae	*Rousettus amplexicaudatus*	0.33	2.89
Hipposideridae	*Hipposideros diadema*	0.31	1.39
Pteropodidae	*Pteropus pumilus*	0.31	0.44
Molossidae	*Chaerophon plicatus*	0.31	0.22
Hipposideridae	*Hipposideros coronatus*	0.30	0.11
Molossidae	*Mops sarasinorum*	0.30	0.06
Pteropodidae	*Pteropus vampyrus*	0.30	1.00
Vespertilionidae	*Pipistrellus javanicus*	0.27	0.61
Vespertilionidae	*Tylonycteris pachypus*	0.27	0.11
Pteropodidae	*Otopterus cartilagonodus*	0.26	0.39
Rhinolophidae	*Rhinolophus inops*	0.26	0.50
Pteropodidae	*Eonycteris spelaea*	0.25	1.56
Pteropodidae	*Macroglossus minimus*	0.24	1.78
Megadermatidae	*Megaderma spasma*	0.21	0.78
Vespertilionidae	*Myotis muricola*	0.21	0.39
Rhinolophidae	*Rhinolophus creaghi*	0.21	0.06
Emballonuridae	*Taphozous melanopogon*	0.21	0.39
Pteropodidae	*Cynopterus brachyotis*	0.21	2.61
Rhinolophidae	*Rhinolophus macrotis*	0.21	0.22
Hipposideridae	*Coelops hirsutus*	0.18	0.22
Hipposideridae	*Hipposideros bicolor*	0.18	0.28
Pteropodidae	*Megaerops wetmorei*	0.18	0.61
Vespertilionidae	*Myotis horsfieldii*	0.18	0.61
Vespertilionidae	*Tylonycteris robustula*	0.18	0.11
Pteropodidae	*Alionycteris paucidentata*	0.18	0.22
Vespertilionidae	*Murina cyclotis*	0.18	0.50
Vespertilionidae	*Murina suilla*	0.18	0.06
Emballonuridae	*Saccolaimus saccolaimus*	0.18	0.17
Vespertilionidae	*Myotis macrotarsus*	0.15	0.33
Rhinolophidae	*Rhinolophus subrufus*	0.15	0.28
Vespertilionidae	*Kerivoula pellucida*	0.15	0.11
Vespertilionidae	*Myotis rufopictus*	0.15	0.28
Pteropodidae	*Harpyionycteris whiteheadi*	0.13	0.72
Pteropodidae	*Ptenochirus minor*	0.13	0.61
Molossidae	*Cheiromeles torquatus*	0.12	0.06
Rhinolophidae	*Rhinolophus arcuatus*	0.12	1.50
Vespertilionidae	*Falsistrellus petersi*	0.12	0.11
Vespertilionidae	*Harpiocephalus harpia*	0.12	0.22
Vespertilionidae	*Philetor brachypterus*	0.12	0.22
Vespertilionidae	*Miniopterus schreibersii*	0.11	0.72
Rhinolophidae	*Rhinolophus rufus*	0.11	0.33
Emballonuridae	*Emballonura alecto*	0.09	0.78
Rhinolophidae	*Rhinolophus philippinensis*	0.09	0.67
Molossidae	*Cheiromeles parvidens*	0.09	0.00
Vespertilionidae	*Phoniscus jagorii*	0.09	0.06
Pteropodidae	*Haplonycteris fischeri*	0.09	1.06
Hipposideridae	*Hipposideros obscurus*	0.09	0.50
Hipposideridae	*Hipposideros pygmaeus*	0.09	0.56
Rhinolophidae	*Rhinolophus virgo*	0.09	1.17
Hipposideridae	*Hipposideros lekaguli*	0.08	0.06
Vespertilionidae	*Miniopterus australis*	0.06	0.67
Rhinolophidae	*Rhinolophus acuminatus*	0.06	0.11
Vespertilionidae	*Glischropus tylopus*	0.06	0.06
Vespertilionidae	*Kerivoula hardwickii*	0.06	0.17
Vespertilionidae	*Kerivoula papillosa*	0.06	0.11
Vespertilionidae	*Myotis ater*	0.06	0.00
Vespertilionidae	*Nyctalus plancyi*	0.06	0.06
Pteropodidae	*Ptenochirus jagori*	0.05	2.67
Hipposideridae	*Hipposideros cervinus*	0.03	0.17
Vespertilionidae	*Kerivoula whiteheadi*	0.03	0.33
Vespertilionidae	*Miniopterus tristis*	0.03	0.44
Pteropodidae	*Pteropus hypomelanus*	0.03	0.56
Vespertilionidae	*Scotophilus kuhlii*	0.03	0.44
Vespertilionidae	*Pipistrellus stenopterus*	0.00	0.00
Vespertilionidae	*Pipistrellus tenuis*	0.00	0.11
Rhinolophidae	*Rhinolophus borneensis*	0.00	0.06

[a] We retain to use Vespertilionidae to classify species under *Miniopterus*.
[b] Based on (Tanalgo and Hughes, 2018).
[c] Formerly *H. ater*.

of Philippine bats (Fig. 4). Analysis of deforestation rate in the Philippines showed an increasing rate of 5.9% in tree cover in post-2000 (Fig. 6A; Tab. S3). Our analysis showed that tree cover loss is highest in areas where the extent cover is highest (Spearman's Test, ρ=0.8903, p<0.001, Fig. 6D; Tab. S3). Annually the Philippines is losing an average of 564.8 km^2 of tree cover (at >30 canopy cover) and the 39% of the average annual tree cover loss (2000–2015) is associated with commodity-driven deforestation, while 41% loss is caused by shifting agriculture (Fig. 6A and B; Tab. S3).

Hunting for recreation and bushmeat collection is the greatest direct threat (n=33 spp., 42%) threatening 80% of frugivorous species (Fig. 4). In caves and underground habitats, cave tourism and visitation threaten almost all known cave-dwelling bats identified in the country (n=26 spp., 33%). Apart from tourism and hunting, other threats e.g., guano extraction, vandalism, and bird's nest collection threaten 18% (n=14 spp.), 14% (n=11 spp.), and 3% (n=2 spp.) of cave-dwelling species in the Philippines respectively. Extractive industries chiefly mining and quarrying threaten at least 22 species (27%) of Philippine bats. There is an increasing number of operating metallic mines with 130 large-scale firms added between 2000 to present (see Fig. 8).

Discussion

Developing effective conservation management and priorities in megadiverse island country based on assessing only the taxonomic component is inadequate (Stem et al., 2005; Sibarani et al., 2019). It requires multiple approaches that identify species, population or regions facing the largest threats in the near future to effectively develop effective conservation interventions (e.g., Hughes et al., 2012; Struebig et al., 2015; Conenna et al., 2017). Here, our approach encompasses multiple facets of biodiversity conservation assessment, by combining species diversity, knowledge gaps, and threatening process to inform the identification of priority species that require immediate conservation attention. This present study showed that more than half of the Philippine bats are threatened by key threats including deforestation, agricultural conversions, and hunting. Threatened species with narrow geographical distributions (i.e., endemic and data deficient) face higher risks and thus attention is needed to prevent these species from becoming more vulnerable to extinction. Traits are also important determinants of species conservation, we found larger bats are under more intense pressure than smaller bats, for instance, large flying foxes are more prone to direct threats such as hunting in addition to its remaining habitats are threatened by deforestation and agricultural expansions. Nevertheless, there is an apparent bias on research effort allocated between smaller (insect bats) and larger bats (fruit bats) (Tanalgo and Hughes, 2018) as shown by no relationship between body size and research effort.

This is the first in-depth study to attempt to set national conservation priorities and summarise the key threats to Philippine bats, and further work is needed to better quantify the level of threat to each species. The incongruence between research effort allocation and species priority ranks is also notable and shows that intensive conservation effort and research is needed not only on formally designated as threatened by the IUCN but also for least concern species that may be that may encountering higher threats (i.e., Passenger pigeon fiasco effects) (Tanalgo and Hughes, 2018). To help achieve this goal, data standards for

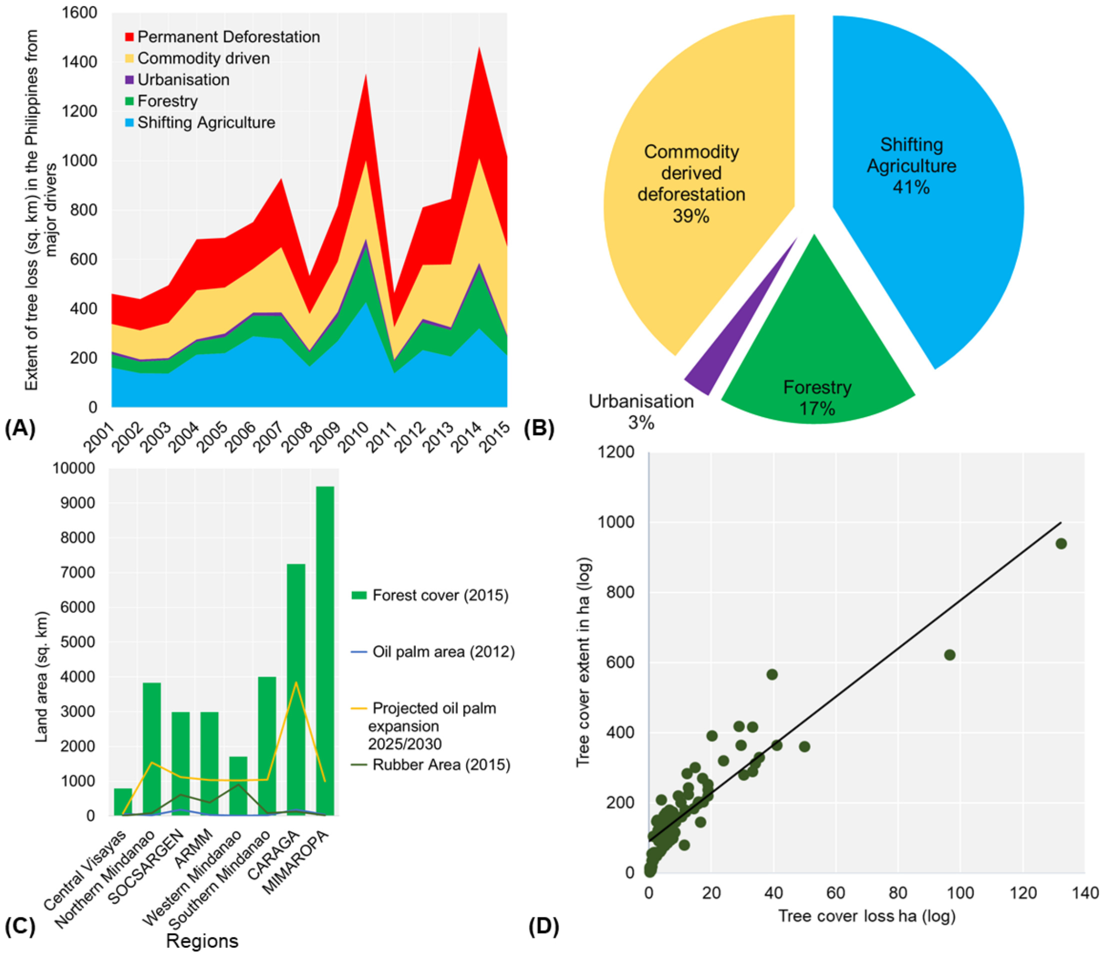

Figure 6 – (A) Trend of tree cover loss associated to major drivers of deforestation (2001–2015). (B) Percent contribution of major driver to average annual loss (2001–2015). (C) The extent of oil palm and rubber plantations and projected oil palm expansion in major producing provinces in the Philippines relative to the current forest loss (2001–2017) and forest cover (as of 2015). Rubber expansion is unknown but the Philippine rubber industry road targets 10000 ha per year increase in the country. (D) Relationship of (i) extent of tree cover and (ii) tree cover loss across Philippine provinces. (Actual values were provided in Supplementary Tables S3 and S4).

research and threat assessment are crucial elements to understand the extent of threats and vulnerabilities across species and habitats.

Key threats to Philippine bats

Logging

A large percentage of Philippine bats occur in forest ecosystems where 25% of the species are forest-dependent (primary to mossy montane forest: Heaney et al., 2010; this study, see Fig. 5). Our analyses showed that roughly, three-quarters of the Philippine bat species are threatened by logging. Consolidated results from major studies in different protected areas in the country (e.g., Ingle, 2003; Gomez et al., 2005; Heaney et al., 2005; Balete et al., 2013; Heaney et al., 2006; Rickart et al., 2013; Relox et al., 2017 suggest that intact forests and habitats are important for endemic bat species (see also Fig. 5). Additionally, bat species richness and foraging activities are higher in intact forests versus agropastoral sites (Sedlock et al., 2008). The extent of deforestation within Philippine terrestrial protected areas was up to 970 km^2 from 2000–2012 (=2.59% annual loss) and this is marginally lower by 0.1% versus the overall annual forest loss in the country of the same period (Apan et al., 2017). Over the 20th century, the extent of forest cover in the Philippines has dropped from 70% to 20%, with an estimated 9.8 million ha lost between 1935 and 1988 (Carandang, 2005; Suarez and Sajise, 2010; Forest Management Bureau, 2013; Apan et al., 2017). The country lost an estimated 10900 km^2 of tree-cover (5.9% reduction) from 2000 to present (Global Forest Watch, 2017, Fig. 6). Forest loss is primarily caused by illegal logging and *Kaingin* (slash and burn) for industrialisation and cultivation (Butler, 2014; Global Forest Watch, 2017) and may affect a large proportion of bat species especially forest-dependents roosting and foraging in intact and primary forests (Ingle, 2003; Jakosalem et al., 2005; Heaney et al., 2006; Nuneza et al., 2015). However, in areas where the rate of tree cover loss is higher fewer bat surveys have taken place (Fig. 7) and this has important implications to our understanding of the impacts of deforestation to bat biodiversity. In addition, the high endemism patterns of bats in forests and pristine ecosystems (Heaney et al., 2010; shown in this study) in the Philippines warrants more intensive protection of remaining forested areas in the country. Furthermore, only a small number of studies have explored how different threats interact (e.g., Sedlock et al., 2008; Phelps et al., 2016) and potentially exacerbate the impact on species survival and there is no comprehensive understanding of the impacts and dynamics of deforestation and land conversion to bat population and communities in the Philippines (Tanalgo and Hughes, 2018).

Plantations and shifting agriculture

The majority of land areas in the country (61.2% of land cover, 18.6 million ha) are allocated for agricultural use including plantations and shifting agriculture. Although agroecosystems could support 47% of bat species in the Philippines (Heaney et al., 1998, 2010; and shown here) (see Fig. 5), projected agricultural expansion in intact lowland forests particularly for Oil Palm and Rubber plantations (see Tab. S4) remains a threat to a large number of species particularly forest-specialists. Plantations (e.g. rubber and oil palm) can only support few generalist species (e.g., *Cynopterus brachyotis*) and species richness is lower compared to forested habitats (Bello et al., 2010; Achondo et al., 2014). The conversion of intact and secondary forests for agriculture (e.g., plantation) has intensified in the recent years across the globe particularly in Southeast Asia (Fitzherbert et al., 2008; Meyer et al., 2016; Hughes, 2017, 2018). The Philippines alone has 620000 ha converted to plantations in 2005 that is equivalent to 8.7% of forest

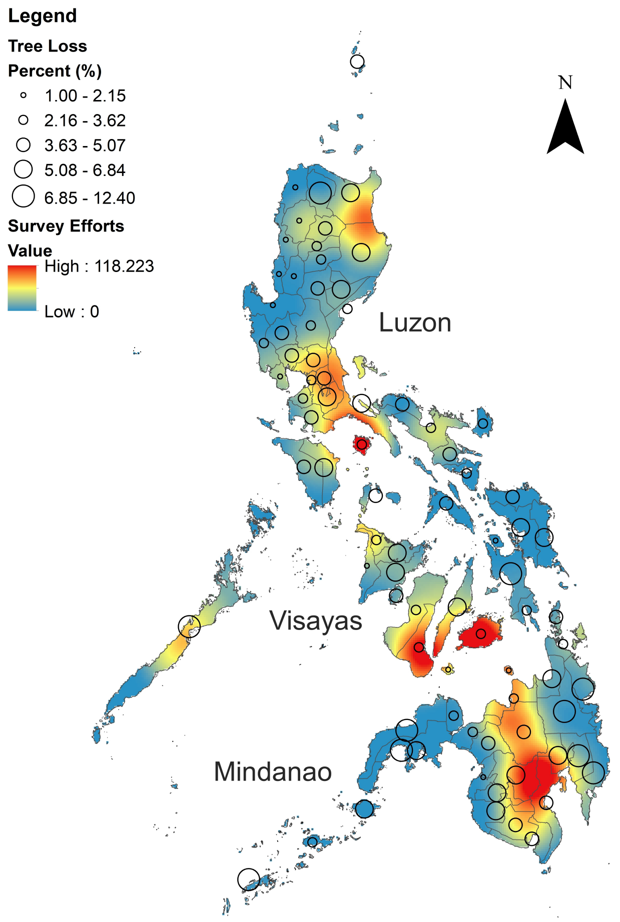

Figure 7 – Percent tree cover loss across provinces in the Philippines from 2001–2017 (Global Forest Watch data) plotted against survey density (species abundance) to infer areas that require priority for future surveys and inventories. It can be inferred that bat records or surveys are lower in areas where tree cover loss is higher.
The map was created using ArcGIS version 10.3.

cover (annual change rate 2000–2005=-46400000 ha) (Butler, 2014). Oil Palm and Rubber are popular cash crops in the Philippines (Villanueva, 2011; **?**) covering 276681 ha of land areas in major producing regions (see Fig. 6C and Tab. S4). Although, the Philippines is not a major oil palm producer in the Southeast Asian region (Sheil et al., 2009) it has produced an average of 77 thousand metric tons of palm oil annually from 2000 to 2018 (Index Mundi, 2018)) and covers 54748 ha in 2012 (Batugal, 2014). With the largest expansion in Caraga (35%) and Soccsargen (30%), at present, the Philippines has roughly 90 thousand hectares of palm oil producing lands (Batugal, 2014; The Agriculture, 2018), with a projection of almost million hectares of land area for potential land production (Philippine Bureau of Agricultural Statistics, 2012, see Fig. 6). The highest projected expansion of Oil Palm is in Caraga region with 18102 ha (in 2012) to 384000 ha (in 2025–2030) (Batugal, 2014), but the projected potential impact of oil palm to forest cover is higher in Western Mindanao (60% of forest cover) compared to Caraga (54% forest cover) (Fig. 6C, Tab. S3). While rubber dominates larger areas than oil palm with 222601 ha (as of 2016) chiefly in Western Mindanao and Socsargen with 60966 ha and 89837 ha land area respectively (Fig. 6C, Tab. S4) (Philippine Statistics Authority, 2016; Yap, 2016). In the first quarter of 2018, rubber production increased by 4.4% (47.36 metric tons) compared to the same quarter in 2017 (45.37 metric tons) (Philippine Statistics Authority, 2018). Although, there are no definite projected expansion the Philippine rubber industry roadmap (2016–2022) targets to expand up to 10000 ha annually in the future (Yap, 2016). The land area covered with rubber is higher than oil palm but the negative impact of the former may be relatively lower because it is less intrusive and retains a large percentage of the native vegetation in addition to decreasing the erosion (e.g., Agduma et al., 2011). Plantations can support common species, but may not support rare species. For example, a study on insectivorous bats in forest fragments (primarily caused by Oil Palm plantation expansion) has resulted to declines in species richness that is congruent to population and genetic diversity loss, particularly in Kerivoulinae, which is more sensitive because of their limited capacity to disperse across open areas (Struebig et al., 2011). Considering the lack of empirical evidence on the effects of expanding plantation areas in the Philippines, it is imperative to systematically explore the effects of these threatening process to different bat diversity dimensions.

Hunting

Nearly 50% of species are threatened by hunting, a higher proportion than previously thought (e.g., Mildenstein et al., 2016). Poverty is an important driver of hunting, particularly in remote areas where agriculture and livelihood is poorly established, protein requirements partially rely on wild meat including large fruit bats and flying foxes (Scheffers et al., 2012; Raymundo and Caballes, 2016; Mildenstein et al., 2016; Tanalgo et al., 2016; Tanalgo, 2017). For example, in Mt. Apo National Park (Tanalgo, 2017) and Mountain ranges of Sierra Madre (Scheffers et al., 2012), large flying foxes (e.g., *Pteropus vampyrus* and *Acerodon jubatus*) are locally hunted for subsistence. Frugivorous bats are at higher risk of hunting and consumption because they are easy to hunt (i.e., these species are large, visibly roosting in trees), are available year-round and have high protein content (Mildenstein et al., 2016)). Cave-roosting bats are also highly vulnerable to hunting because they aggregate in large colonies inside caves making it easy for hunters to hunt large numbers simultaneously by netting major entrances (Tanalgo et al., 2016; Quibod et al., 2019). Hunted bats are mainly locally consumed and bushmeat trade also occurs (e.g., <1.00 USD per head in Pisan caves, >3.00 USD per head of *Pteropus vampyrus* in the Sierra Madre) but not highly reported or documented. Apart from hunting for food, urban residents in other parts of the country (e.g., in Subic Bay, Pampanga) hunt large fruit bats and flying foxes (e.g., *Acerodon jubatus* and *Pteropus vampyrus*) for sport and recreation (Mildenstein et al., 2016). The public misconception to bats is a major challenge for effective conservation and an important driver of persecution of large bat colonies. Bats are perceived as pests and this has become an important factor in the execution of bat colonies and this is mirrored to the low public awareness and knowledge of the ecosystem services of bats provide i.e., pollination in durian orchards (Tanalgo et al., 2016; Phelps et al., 2016). In villages, locals associate bats with the mythical creature the *Aswang* (Philippine version of vampires) and because of fear many large cave-dwelling and flying fox colonies are intentionally executed (Tanalgo et al., 2016; Phelps et al., 2016; Tanalgo, 2017). Mainstreaming of knowledge of bat ecosystem services provision through increasing outreach education programs may bolster efforts for bat conservation (Trewhella et al., 2005; Abdul Aziz et al., 2017a,b).

Cave disturbance and exploitation

Caves and underground habitats are important for almost half of global bat species (Furey and Racey, 2016) and around 40 bat species in the Philippines (Ingle et al., 2011; Sedlock et al., 2014; Phelps et al., 2016; Alviola et al., 2015; Tanalgo and Tabora, 2015; Quibod et al., 2019). There are over 2500 known caves in the Philippines yet only 18% have been classified for protection, tourism, and other uses, and of these, 37% are within Protected Areas (Biodiversity Management Bureau – Department of Environment and Natural Resources, 2017) and many remain understudied and may be facing diverse anthropogenic threats (Ingle et al., 2011; Sedlock et al., 2014; Alviola et al., 2015; Phelps et al., 2016; Tanalgo et al., 2016). We found evidence of drastic population declines from hunting (see "Hunting" section), unregulated tourism, and limestone mining (Mould et al., 2012; Sedlock et al., 2014; Tanalgo and Tabora, 2015; Phelps et al., 2016; Quibod et al., 2019). For instance, in 2001, an estimated 500000 bat individuals in Canlunsong cave drastically declined to only 200 bats in recent surveys (in Sedlock et al., 2014). Cave disturbance (e.g. guano mining and cave hunting) threatens species, especially more narrowly distributed species with extinction, for example, *Dobsonia chapmani* in Negros Island, a cave bat formerly common species from its range has severely declined (Pagun-

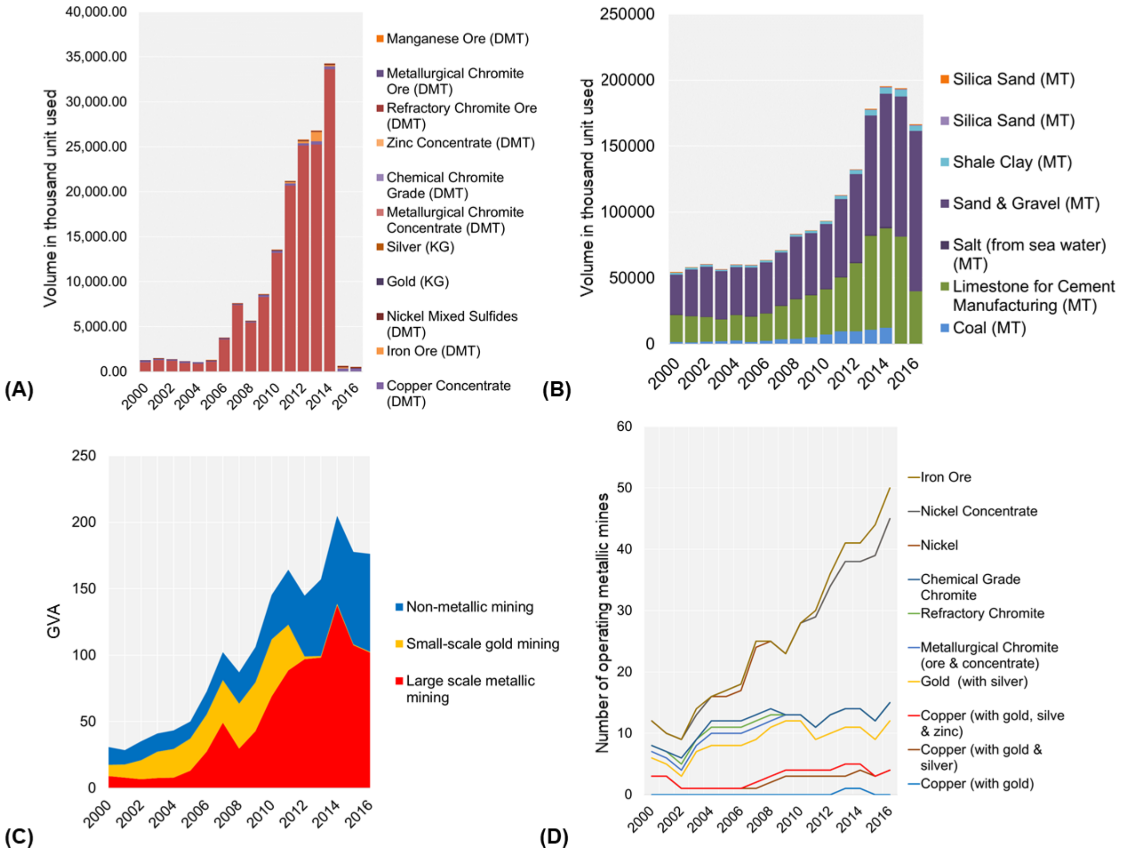

Figure 8 – Mining and quarrying statistics in the Philippines. Volume of production from 2000–2016. (A) metallic resources; (B) non-metallic resources; (C) gross production value of metallic mining, non-metallic mining, and small scale mining; (D) number of operating metallic mines from 2000–2016. Data source: Compendium of ENR Statistics (2016), The Department of Environment and Natural Resources..

talan et al., 2004; Raymundo and Caballes, 2016). The extent and impacts of different threats in cave bats vary across species and their capacity to withstand a certain degree of threats and disturbance (Phelps et al., 2016). However, the continuous destruction of limestone caves within karst systems threatens sensitive species. There are an estimated 3876 metric tonnes of limestone deposits in the Philippines. The cement production from karst areas has an annual 3.62 metric tonnes production from 2000–2016 (Fig. 8B) (Compendium of ENR Statistics, 2016; Fong-Sam, 2017). Regardless of the importance of caves for a large proportion of Philippine bats, most of the country's cave ecosystems lack scientific studies (Ingle et al., 2011; Alviola et al., 2015) and lack specific statutory protection. The existing policy, National Cave and Cave Resources Management and Protection Act (Republic Act 9072), aims to identify and protect cave biodiversity and geological importance, although important it often focuses on tourism potential and economic values which undermines the protection of cave-dwelling bats and cave biodiversity as a whole (Protected Areas and Wildlife Bureau, Department of Environment and Natural Resources, 2008). Thus, strategies to effectively conserve and monitor caves in the Philippines using holistic and consistent procedures is an important step forward to better understand the vulnerability of cave-dwelling bats (Tanalgo et al., 2018).

Extractive industries

Mining activities and the establishment of mining roads are prominent in a few protected areas with high bat biodiversity (e.g., documented in Mt. Hamiguitan, Relox et al., 2009). Whilst information on the effects of mining and associated activities remains poorly understood, preliminary bat surveys on small-scale mining sites in Mindanao Island showed low species richness and only generalist species persist during the entire sampling period (Tanalgo et al., 2017). This is probably due to extensive removal of foraging grounds for bats (e.g., the density of fruit trees) to establish roads, extract minerals, and loud noise from mine blasting i.e., dynamite explosions to excavate mining grounds. The development of roads can destroy both foraging and roosting areas for bats (Palmer et al., 2010; Berthinussen and Altringham, 2012). There have been few studies on the impacts of mining areas in the Philippines and this warrants a more comprehensive investigation considering the increasing rate of this industry. As of August 2018, 703846.67 hectares (2.35% of Philippine land area) has been covered by mining tenements with a further 9 million hectares for potential mineral mining (Mines and Geosciences Bureau, 2018). There are 48 metal mines and 61 stone mines (e.g., limestone/shale quarries) and 3389 small quarries are currently operational (Mines and Geosciences Bureau, 2018). Among mining types in the Philippines, large-scale metallic mining has the highest annual gross production value 53.02 GVA (2000–2016) followed by non-metallic mining (32.58 GVA) and small-scale mining (18.37 GVA) (Fig. 8 C). In terms of geographic distribution, mining operations are higher in Caraga (n=18) and Central Visayas (n=17) region, which may threaten a large proportion of forested areas (Mines and Geosciences Bureau, 2018). The Department of Environment and Natural Resources legislated the Philippine Extractive Industries Transparencies Initiative (PH-EITI) to improve the accountability and transparency in the Philippine mining sector (Agub, 2013; Jamasmie, 2014). The government's new strict environmental policy considers biodiversity conservation prior to mining project implementation and mandating mining companies to restore former mining areas (Villanueva, 2017) but should also prevent destruction to diversity hotspots.

Scientific (over) collections for disease research and public perception: an emerging concern for Philippine bats?

Scientific collection and disease research is not currently known to be problematic in Philippine bats but may emerge as a threat in the future due to an increasing trend of bat-associated diseases studies (exploring the role of bats as vectors) in the Philippines over the past 2 decades (Tanalgo and Hughes, 2018). We found at least thirty-five species (n=35 spp., 44%; n=7 spp. endemic) used for disease research for the

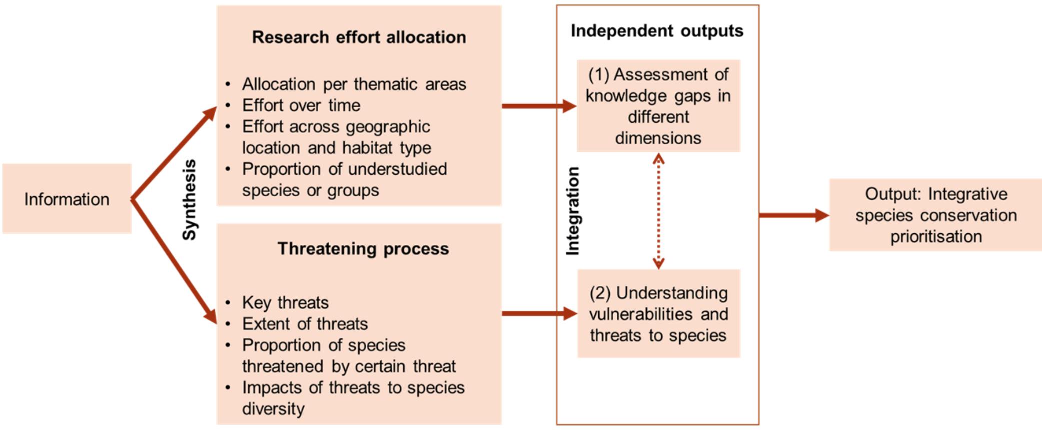

Figure 9 – The proposed integrative framework to support developing effective species conservation priorities and management relevant for the Southeast Asian bats, which encompass information knowledge gaps and species threats..

last 17 years. Most of these studies have euthanised numerous individuals, for example, at least 1047 individuals (the brain of 821 individuals were collected) from 14 bat species were used to explore associated viruses, and other studies may have collected 21 species (see Tanalgo and Hughes, 2018 for the list of studies). Most species collected (and killed) for disease research in the Philippines are not classified threatened based on the global list but many species have declining local populations due to multiple threats. Despite the high volume of research no clear evidence on the incident of bat mortality, transmission to human or livestock that associated bat-microbes (e.g., virus, bacteria, and fungi) (Tanalgo and Hughes, 2018). Globally, around 13% of 222 recent studies collected bats for disease surveillance and largely came from the tropics (Russo et al., 2017), even before accounting for studies published in local languages but often mentioned by individual researchers (e.g. in Thailand). Although only a small number of species are currently at risk of the scientific collection in the Philippines, the number of species and individuals collected for disease research if not regulated may pose a significant threat. Bat disease studies and surveillance are equally important to understand bat biology yet the over-collection of bats is posing threats and should be minimised using non-invasive alternative (e.g., mentioned and detailed in Russo et al., 2017) and disease-related studies have significantly contributed to the negative image of bats and undermine lifelong efforts to conserve and protect many bat populations (Tuttle, 2017; López-Baucells et al., 2018; Racey et al., 2018). Thus, studies that require or involve bat collection (e.g., disease studies) should consider the conservation implications of their collections and should follow strict ethical procedures to minimise impacts on the population. Furthermore, many studies could limit themselves to buccal or anal swabs, or urine and faeces analysis without the need for specimen collection (Russo et al., 2017).

Changing climate: an unknown threat to the Philippine bats

Changing climate will impact a large number of bat species in the future (Sherwin et al., 2013; O'Shea et al., 2016). In mainland Southeast Asia, Hughes et al. (2012) has projected the effects of future climate scenarios on bat diversity and predicted changes in range size for 171 bat species throughout the region. In 2050 and 2080, the scenarios set by the IPCC together with the climate change predicts 3–9% of the species would lose their niche and 2–6% of species may have no suitable niche space. In the Philippine Islands, however, the knowledge on the projected impacts of a global changing climate to bats is lacking (Tanalgo and Hughes, 2018). In Islands like the Philippines, the effects of climate change on species distribution and persistence may differ from those from the mainland. Island bat species may face severe effects and are more vulnerable to sea rise limiting the roost sites in coastal caves, changed frequency and intensified typhoons will affect tree-roosting bats, and altered phenology of food source i.e., flowering and fruiting of plants, insect abundance (Sherwin et al., 2013; Jones et al., 2009b).

To circumvent expected biodiversity loss it is a priority to progress on solid research design to understand climate-driven impacts to establish effective conservation measures particularly vulnerable bat groups (e.g., tree-roosting species, or coastal caves) and create reliable habitat suitability models to identify areas where highest conservation protection is required to avoid future species loss.

Priorities for conservation

Here we present evidence-based conservation priorities for Philippine bats through quantifying and synthesising the best available information, developing and applying a holistic yet practical measurement approach, and providing directions based on strengths and needs for Philippine bat research and conservation. Our analysis suggests that endemic and threatened species are the top priority for bat conservation in the Philippines. Integrative biodiversity conservation should encompass not only species distribution and endemism but also the threats to species to guarantee the holistic setting of conservation and research priorities based on broad and multiple-dimensions of diversity. For Philippine bats, prioritisation should balance effort allocation (e.g., funding for research or protection) towards understudied threatened or endemic species and protection of key habitats which are important for large numbers of species. Future priorities should advance our present understanding on the extent of threats and its impacts to species, their distribution and persistence to their critical habitats. The approach and framework (Fig. 9) we developed and employed in this study is not only holistic and applicable for Philippine-setting but is relevant in other tropical regions chiefly in Southeast Asia, where species diversity, natural history, and types of threats experienced are likely similar (Hughes et al., 2012).

Epilogue — a dedication to our fallen heroes of the night

The 7107 islands of the Philippines are one of Asia's bat biodiversity hotspots, home to more than 70 species, which many still to be discovered and described. The discovery and our present understanding of these diverse fauna are due to the work of many dedicated researchers. We, the current generation of scientists, owe the current knowledge that we relish and the passion that drives us to protect biodiversity, from the collective effort made by our past and present colleagues in the field. It is through the dedication and passion of everyone who cares for the future of our biodiversity and security of human welfare. It is through their hardships and never-ending effort that we achieved this present understanding of our own biodiversity. Yet this work is not without risk, and many scientists have suffered in order for us to reach our present state. Recently, two of Filipino colleagues, Danny Balete and James Alvarez both lost their lives, both young, respected, and full of potential, and among the pillars of Philippine wildlife and conservation. Both have significantly changed our understanding of different aspects of Philippine wildlife biodiversity, especially bats and their ecology, and advocated for its protection and conservation. The Asian community of bat researchers and Philippine biodiversity all mourn their tragic losses, but we hope their work, passion and energy will live on through the efforts of those who were privileged to work with and learn from them. We may continue the journey without them, but their contributions and memories will always be with us on this journey. Their work and effort will always be cherished and remembered by families, friends, colleagues, and future generations of scientists. We dedicate this work to our heroes; this work may have remained incomplete even longer without their contribution to the field of Philippine bat ecology and conservation. May their work and effort live on through us, and may we honour their memories by continuing to better understand and protect the systems and species they loved.

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Supplemental information

Additional Supplemental Information may be found in the online version of this article:

Table S1 Different scenarios for species priorities using different weights of Species Priority Index (SPI) components (T_{dir}, T_{ind}, and T_{nat}).

Table S2 Values of Species Priority Index (SPI) under different scenarios.

Table S3 The rate of tree cover loss (>30% canopy cover) from major drivers in the Philippines from 2001-2015 (based on Global Forest Watch data).

Table S4 Land area, forest cover, and tree cover loss in Oil palm and Rubber plantations dominated regions in the Philippines including the projected oil palm expansion for 2025-2030.