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Conservation ecology of birds in Mt. Hilong-hilong, a Key Biodiversity Area on Mindanao Island, the Philippines

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Abstract: The identification of key areas for conservation and protection according to science-based evidence is an important component to circumvent the negative impacts of environmental changes within geopolitical territories and across the globe. Priority areas for biodiversity played an important role to ensure the protection of many species particularly those that are unique and threatened. There are more than 200 Key Biodiversity Areas (KBAs) in the Philippines, yet many important research and biodiversity data are either unpublished or unconsolidated. Birds are commonly studied indicators for KBA identification due to their high species richness, diversity, and sensitivity to forest ecosystems. By combining data from past and present surveys, we accounted for a total of 148 bird species of 51 families, with 20 new records from recent field surveys. Our analysis showed a high level of endemism within Mt. Hilong-hilong with 36% Philippine endemic, 14% restricted to Mindanao faunal region and 11% migrant. In terms of conservation, 8% of the species were considered in threatened categories. The species richness and endemism were higher in lowland to mid-elevation areas compared to higher elevation areas of the KBA. Endemism (i.e., Mindanao endemic) and increasing body mass were important determinants of binary extinction risk for bird species in Mt. Hilong-hilong. The high biodiversity in Mt. Hilong-hilong indicates an example of the vital role of KBAs in preserving nationally and globally important bird species. Lastly, we emphasise the importance of collaboration and integrating past and present information to synthesise relevant information to complement ongoing conservation efforts in Mt. Hilong-hilong and other key habitats in the Philippines.

Keywords: Anthropocene, collaboration, deforestation, ecological indicators, endemism.

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INTRODUCTION

The Philippines is the world's second-largest archipelago and its unique biogeographical features with more than 7,000 islands allowed the diversification of taxa, making it one of the megadiverse tropical country (Heaney & Regalado 1998). Birds are amongst the most diverse group in the Philippines, constituting more than 50% of the country's land vertebrates, and large proportions are considered distinct and globally threatened (Peterson et al. 2000), with 724 described species and at least 200 country endemics (Clements et al. 2019). These numbers will probably increase with proper taxonomic studies when integrative taxonomy approach is made (Sánchez-González & Moyle 2011; Gonzalez et al. 2013).

The diversity of birds in the Philippine contributes to the ecological balance and integrity of remnant native vegetation (Peterson et al. 2000). Birds have large range distribution, high mobility, and diverse traits that are sensitive to ecological changes (O'Connell et al. 2000; Trindade-Filho et al. 2012). Therefore high avian species richness can serve as an important ecological indicator in terrestrial ecosystems (Canterbury et al. 2000). The functional trait diversity across birds provides various key ecosystem services in different systems, from intact forests to more disturbed urbanised areas (Sekercioglu et al. 2016). Frugivorous and nectarivorous birds are vital for seed dispersal and pollination, respectively, therefore maintain gene flow and persistence of the population of many important tropical plant species (Ingle 2003; García & Martínez 2012). This group also serves as natural foresters in degraded areas through seed rain and dispersal (Gonzales et al. 2009; Mueller et al. 2014). Insectivorous birds can suppress insect pests and can reduce the use of environmentally harmful pesticides in agricultural landscapes (Koh 2008; Sekercioglu 2012). Carnivores are vital in the check and balance of prey populations, for example, rodent populations in urban or agricultural landscapes with high reproductive potential (Donázar et al. 2016).

The Philippine biodiversity, however, is threatened by various environmental and human pressures (Brooks et al. 1999) that may disrupt species diversity, their ecological function and services. Given the growing population in the Philippines, a large proportion of species and habitats are threatened by land-use changes to accommodate human needs (Brooks et al. 2002; Posa & Sodhi 2006; Posa et al. 2008). In the Philippines, over 67% of bird species are dependent on intact pristine forests (Dutson et al. 1993; Brooks et al. 1999; Gonzales et al. 2009). Deforestation poses a key threat to biodiversity loss in the country, driven by logging and shifting agriculture. For example, at least 74% of tree cover loss in 2001–2018 was caused by deforestation alone (Global Forest Watch 2020). In 2002–2019, an estimated 3.1% or 145,000ha of humid forest was lost in the Philippines, equivalent to a 12% tree cover loss (Global Forest Watch 2020).

The quality of the environment plays an important role in shaping the structure and function of biodiversity (Fried et al. 2019; Lelli et al. 2019), generally described using population density, species abundance, trait diversity, and distribution across different habitats (Davidar et al. 2005). To prevent eventual decline and species extinction, important areas for conservation such as Key Biodiversity Areas (KBAs) are identified by conservation biologists and respective governmental policymakers based on high biodiversity potential. KBA identification is not solely dependent on the species richness but in accordance to the presence of population or species that are (1) threatened globally, (2) distributed in a small restricted range (e.g., endemism), (3) restricted use during some stage of their life cycle, and lastly (4) restricted to a specific biome (Eken et al. 2004; Ambal et al. 2012). Birds are included as indicator groups for terrestrial KBAs identification due to their wide-breadth of diversity and sensitivity to ecosystem conditions (Canterbury et al. 2000; O'Connell et al. 2000; Eken et al. 2004). Currently, there are 228 KBAs in the Philippines, of which 101 are terrestrial (51,249 km^2) and 27 are fully protected, 25 partially protected, and 49 unprotected (Ambal et al. 2012). Although KBAs holds high biodiversity, not all are protected, and thus often challenged by several factors, particularly anthropogenic activities due to lack of well-defined statuary protection policy prohibiting encroachments and the persistence of threats (Butchart et al. 2015; Cai 2013; Knight et al. 2007). The effectiveness of conservation policies and initiatives often requires extensive and wide information on biodiversity, yet knowledge gaps continue to be a challenge, limiting effective and efficient decision making (Butchart et al. 2015; Nori et al. 2020).

The Island of Mindanao in the southern part of the Philippines holds many biodiversity-rich ecosystems with a high concentration of endemic species (Paz et al. 2013; Sanguila et al. 2016; Amoroso et al. 2019). The majority of the endemic and threatened species are concentrated in intact forests identified or protected by the government to conserve the species from total extinction (Sanguila et al. 2016; Amoroso et al. 2019).

Mt. Hilong-hilong (Fig. 1) is a KBA in Mindanao that lies on the boundaries of Agusan del Sur, Agusan del Norte, and Surigao del Sur Provinces in the northern portion of the Diwata Range of northeastern Mindanao or Caraga region. The whole KBA has an area of 2,432km^2 with the highest elevation at 2,012 metres above sea level (The Haribon Foundation 2018). Several taxonomic and biodiversity studies have been conducted in Mt. Hilong-hilong, focusing particularly on birds. Albeit information remains scattered or inaccessible. A major knowledge gap concerning Philippine birds in KBAs is the lack of clear understanding of the relationship of species diversity, the extent of the threatening process, and extinction risks. Understanding biotic potential and vulnerability are essential to developing effective conservation prioritisation in a certain habitat or ecosystems (Segan et al. 2016; Tanalgo & Hughes 2019). Here, we integrate field data collected in 2017 and the past survey to assess and analyse the overall biotic potential and diversity patterns for birds in Mt. Hilong-hilong in Mindanao Island, Philippines. Our study further aims to understand the conservation priorities of birds in this KBA based on their ecological status and potential threats. Our synthesis will serve as complementary science-based evidence to support ongoing conservation efforts in Mt. Hilong-hilong.

MATERIALS AND METHODS

Entry protocol and acquisition of permit

Prior to the field surveys, as a courtesy, we visited the major stakeholders from the local government and the local people in the area. This was followed by obtaining of the Wildlife Gratuitous Permit (GP # R13-2017-0036) following the procedure of the Department of Environment and Natural Resources (DENR) of the Republic of the Philippines.

Field survey

We conducted field surveys in Tandag Watershed in Mt. Hilong-hilong, Barangay Awasian, Tandag City, Surigao del Sur, situated between 9.075° N and 126.154° E. We primarily recorded birds using transects and point counts. We utilised established trails to establish 2-km transects in each elevation range. Birds were observed during peak activity, from 05.00h to 10.00h and from 14.00h to 18.00h, for four consecutive days per transect with five field researchers as observers. The samplings were performed in the first four days for transect 1 and the next four days for transect 2. The overall sampling effort was 180 observer-hours per transect. Point counts were carried out at every 250m of the transect making

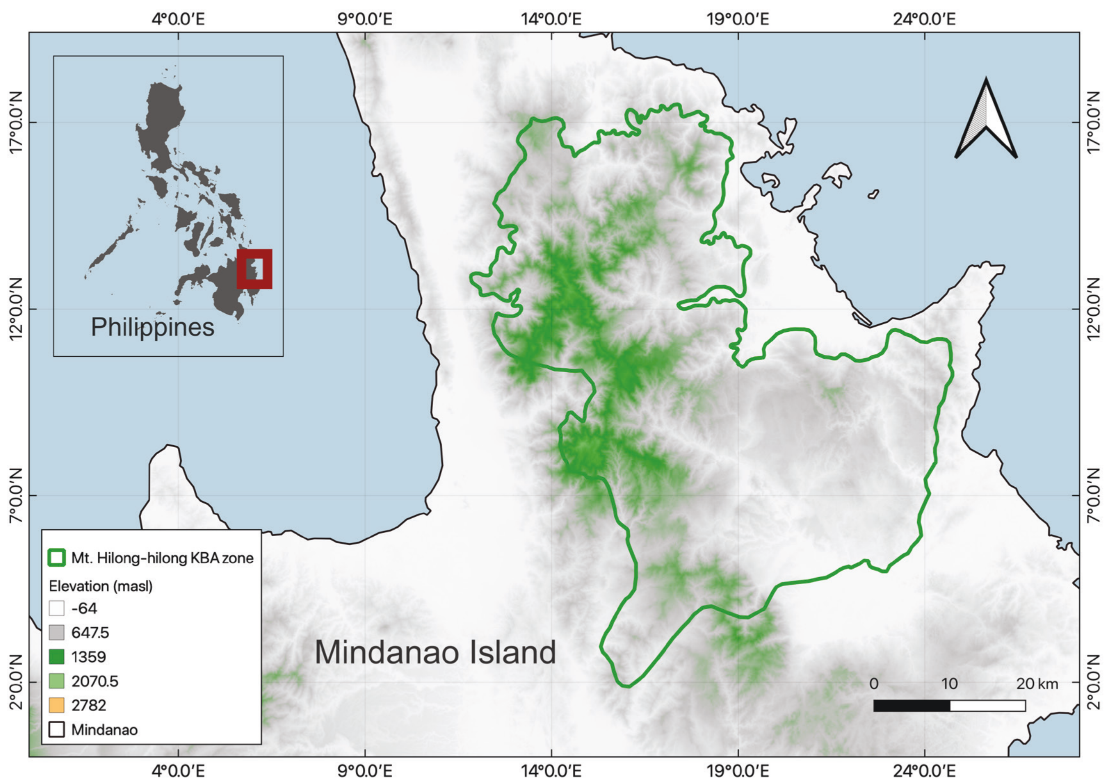

Figure 1. Elevational map of Mt. Hilong-hilong showing the boundaries of the Key Biodiversity Area. Map was generated using QGIS version 3.14.

a 9-point station on a 2-km transect line. We conducted surveys for 20 minutes at every point. All bird species observed and vocalisations during the transect walk and in the point-stations were counted.

We also performed mist-netting to supplement the sampling. We set 22 standard-sized mist nets in every site at the heights: ground nets (0–5 m above the ground; N= 8), sub-canopy nets (at 5–10 m; N= 7), and canopy nets (10m above ground; N= 7), to capture ground-dwelling, sub-canopy, and canopy-dwelling species, respectively. A total of 168 net-days was carried out. We checked nets as regularly as possible to ensure no individuals are tangled for a long period. Captured individuals were placed in a cloth bag to avoid further stress, and were then identified using field guides by (Kennedy et al. 2000). All captured individuals were released in the same area where they are captured.

Synthesis of secondary data and analyses

We performed a simple meta-analysis to evaluate the diversity patterns of birds in Mt. Hilong-hilong by combining present survey data and previously published accounts. We only included those studies that contain a complete dataset that includes elevation of records, species name, conservation status, endemism, and feeding guilds. We curated and updated the species names and their species-specific information using the data from the International Union for the Conservation of Nature Red List (IUCN 2020). We exclude in the final analysis those species with dubious identification and ecological status. The elevation of species where the species was recorded was binned in intervals (e.g., 0–100, 101–500, 500–1,000, 1,000–2,000 m) as representative of lower to higher elevation gradients. We determined species feeding guilds based on published literature (e.g., Kennedy et al. 2000; Mohagan et al. 2015; Tanalgo et al. 2015, 2019) and grouped species into frugivores (feeding on fruits), nectarivores (feeding on nectars and floral parts), granivores (feeding on seeds), insectivores (feeding on insects and small arthropods), carnivores (feeding on large invertebrates and vertebrates), and omnivores (feeding on both plant and animal resources).

We performed all statistical tests and data visualisations using the open-source software Jamovi 1.2.6 (The Jamovi Project 2020). We omitted abundance-based data (e.g., species counts) to standardise the quantification and comparison. Species richness was based on absolute species count per elevation gradient interval. We compared richness and proportion of ecological status, e.g., conservation status, population trends, endemism, and feeding guilds across elevational gradient using descriptive statistics and Chi-square test of independence (χ^2). We performed simple generalised linear modelling (GLMs) using the gamlj module in Jamovi (v 1.2.6) (Gallucci 2019) to predict the binary extinction risk (global) of species recorded in Mt. Hilong-hilong, with adult body mass (kg), endemism, and feeding group as explanatory variables. We choose the best model based on the model with the lowest Akaike information criterion (AIC) values.

We categorised and quantified key threatening process for each species as direct human-use, land-use driven, and natural threats using the species threat index following Tanalgo & Hughes (2019) based on the IUCN Red List assessment (IUCN 2020) as rudimentary analysis to determine species risk from potential threats. We classified direct threats like those that potentially impact species biology and population immediately (e.g., hunting and harvesting), land-use driven are threats that affect species habitats (e.g., deforestation and agricultural conversion), and natural threats are threats that include the climate and geological driven threats (e.g., storm or extreme heat). We compared the number and means of key threatening process across endemism and conservation status using the non-parametric Kruskal-Wallis test.

RESULT

Bird records from the recent field survey

A total of 82 bird species with 20 new species records from 14 orders, 40 families, and 66 genera were documented in the present field survey in Mt. Hilong-hilong (Supplementary Data 1 https://doi.org/10.6084/m9.figshare.13168916.v1). The number of species in the recent survey was lower compared to the 120 reported by the Philippine Eagle Foundation (2007) from the four other sites of Mt Hilong-hilong located at Adlay, Sipang-pang, Pinasandi, and RTR. White-Collared Kingfisher *Todiramphus chloris,* Tricoloured Munia *Lonchura malacca*, and Yellow-vented Bulbul *Pycnonotus goiavier* were the most observed species in all stations, particularly in the less forested areas, such as grassland and cultivated-areas. Forest-dwelling species Mindanao Hornbill *Penelopides affinis,* White-eared Brown-dove *Phapitreron leucotis,* and Yellow-breasted Fruit-dove *Ramphiculus occipitalis* were only observed in the dense dipterocarp forests of the KBA. In the present survey, eight per cent (N= 7 spp.) of the species were categorised as threatened. Whereas there were 52% (N= 43 spp.) endemic species constituted by

35 (43%) species endemic in the Philippine, and eight (10%) are endemic to Mindanao Island.

Synthesis of bird diversity patterns in Mt. Hilong-hilong

We synthesised present and previous studies to estimate bird species biodiversity in Mt. Hilong-hilong. We tallied a total of 148 bird species belonging to 51 families (Supplementary Data 1 https://doi.org/10.6084/m9.figshare.13168916.v1). This number approximately represent 20% of the 724 Philippine bird species. The families Columbidae (N= 13 spp., 9%), Muscicapidae (N= 10 spp., 7%), Cuculidae (N= 9 spp., 6%), Nectaridae (N= 9 spp., 6%), and Dicaeidae (N= 8 spp., 5%) were the most represented families. Within feeding guilds, half of the overall species were insectivorous (N= 75 spp., 51%) followed by frugivorous (N= 28 spp., 19%), and carnivorous (N= 18 spp., 12%) (Table 1). Overall, without considering the elevational gradient distribution, we found significant relationships between species feeding guild and endemism (χ^2= 21.7, *df*= 10, *P*= 0.016), and across conservation status (χ^2= 50.9, *df*= 20, *P*< 0.001).

Thirty-six per cent (N= 53 spp., 36%) of the species were country endemic, 20 species (14%) restricted to Mindanao faunal region, and 16 (11%) species were migratory (Table 1). Large proportion of species (N= 135 spp., 91%) were considered in non-threatened category (Least Concern and Near Threatened), eight per cent (N= 12 spp., 8%) were threatened (Vulnerable and Endangered), and one per cent data deficient species. Although the majority of the species were non-threatened there was a significant number of endemic species within this category (χ^2= 57.9, *df*= 8, *P*<0.001) with 30% (N= 40 spp.) endemic in the Philippines and 10% (N= 14) endemic in Mindanao Islands. There were fewer number of threatened species but there was a significantly higher percentage of species in declining population trends (N= 78 spp., 53%) versus with stable (N= 59 spp., 40%) and increasing population trends (N= 5, 3%) (χ^2= 40.70, *df*= 12, *P*< 0.001). Moreover, the 66% (N= 48 spp.) of all endemic have significantly decreasing population trends compared to only 44% (N= 32 spp.) of the non-endemic species (χ^2= 29.00, *df*= 6, *P*< 0.001) (Table 1). Furthermore, using a simple logistic regression model, we demonstrated that adult body mass and endemism were significant determinants of binary extinction risk of birds in Mt. Hilong-hilong. Our best model (AIC= 136.133) indicated that larger species (β= 0.590, SE= 0.168, *P*< 0.001) and those Mindanao (β= 3.227, SE= 0.864, *P*< 0.001) and Philippine endemic (β= 2.557, SE= 0.802, *P*< 0.001) in contrast to non-endemic species were more likely at higher risk (Fig. 2; Supplementary Data 2 https://doi.org/10.6084/m9.figshare.13169396.v1).

Table 1. Diversity summary of birds in Mt. Hilong-hilong in terms species richness according to feeding guild, endemism, movement pattern, conservation status, and population status. See Supplementary Data 1 for full list of species listed and analysed in the study https://doi.org/10.6084/m9.figshare.13168916.v1

Diversity attributes	Number of species	%	Record from new field survey
Feeding guild			
Carnivores	18	12	10
Frugivores	28	19	18
Granivores	5	3	2
Insectivores	73	49	41
Nectarivores	15	10	9
Omnivores	9	6	2
Endemism			
Non endemic	75	51	39
Philippine Endemic	53	36	35
Mindanao Endemic	20	14	8
Migration Pattern			
Full Migrant	16	11	10
Non migrant	132	89	72
Conservation status			
Data Deficient	1	1	0
Least Concern	124	84	71
Near Threatened	11	7	4
Vulnerable	11	7	7
Endangered	1	1	0
Population status			
Decreasing	79	53	43
Increasing	5	3	4
Stable	60	41	33
Unknown	4	3	2

We found more species in the lower elevational gradient interval (N= 115 spp., 78%) albeit presence of particular families did not significantly differ across elevation gradient (χ^2= 110, *df*= 150, *P*< 0.994). Within the KBA, higher endemism proportion were recorded in the lower (49%) and mid-elevation (61%) (χ^2= 9.16, *df*= 9, *P*< 0.423) (Fig. 3), but only differed significantly within conservation status (χ^2= 21.60, *df*= 12, *P*< 0.04) (Fig. 3). We found no significant relationship amongst elevational gradient and feeding guild (χ^2= 9.92, *df*= 18, *P*< 0.934) (Fig. 3).

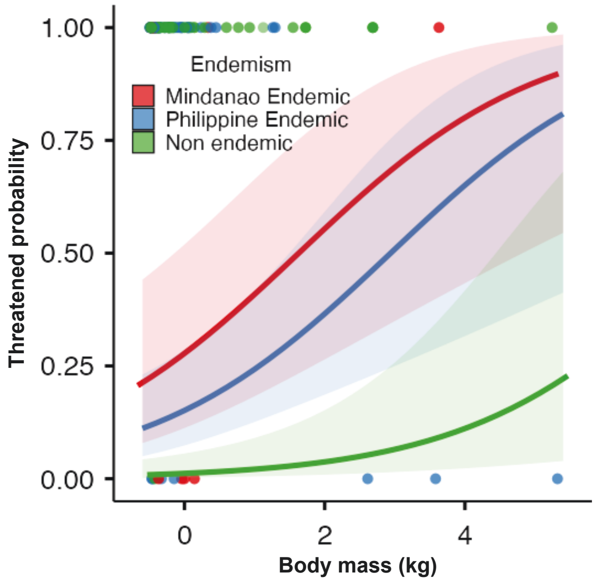

Figure 2. Simple logistic regression showing the link amongst species extinction probability, adult body mass (kg), and endemism of birds in Mt. Hilong-hilong.

Potential threats

Fundamental to developing effective conservation agenda is to identify potential threatening processes and their extent. We utilized the IUCN Red List data for each species recorded in Mt. Hilong-hilong as a rudimentary basis for determining the extent of potential threats faced by species; IUCN categories are globally standardised to provide a useful framework for our analysis. Overall, endemic and threatened species face a higher proportion of threats (Fig. 4A). Direct human use and land-use driven threats, such as land conversions are the key potential threat for the majority of the species (Fig. 4). Threatening processes significantly differed across conservation status and endemism. Overall threats (Kruskal-Wallis test: χ^2= 52.50, *df*= 4, *P*< 0.001; Land-use drive threats, χ^2= 111.29, *df*= 4, *P*< 0.001; Natural threats, χ^2= 27.81, *df*= 4, *P*= <0.001) significantly differed across conservation status except for direct human threats (Kruskal-Wallis test: χ^2= 6.62, *df*= 4, *P*= 0.157) (Fig. 4B,C). When conservation categories were compared, threatened species have higher mean threats (mean= 3.85 ± 0.99) compared to non-threatened species (mean= 1.165 ± 1.47) (Fig. 4A).

There was a significant difference in the number of species threatened by different threats categories within endemism categories (Fig. 4B,C). There were 48% and 47% of threatened by land-use driven threats in Mindanao and Philippine endemic species, respectively (Kruskal-Wallis test: χ^2= 18.02, *df*= 2, *P*< 0.001), while 84% of non-endemic species were threatened by direct-human threats (e.g., hunting) (Kruskal-Wallis test: χ^2= 19.03, *df*= 2, *P*< 0.001). Natural threats were higher among endemic species (Kruskal-Wallis test: χ^2= 10.15, *df*= 2, *P*= 0.01). In terms of average threats per species, Mindanao endemic has higher mean number of threats (mean= 2.00 ± 1.98) compared to non-endemic (mean= 1.41 ± 1.52) and Philippine endemic species (mean= 1.12 ± 1.53).

DISCUSSION

Biodiversity assessments and monitoring provide important information to understand species diversity and conservation (Tanalgo et al. 2015). Field data, particularly from rapid biodiversity surveys are often undervalued, but when carefully synthesised are useful to inform the local state of biodiversity, which aids or complement prioritise key areas, habitats, and species (Tanalgo et al. 2019). Mt. Hilong-hilong interests many natural history scientists and conservation biologist within and outside the region. Yet, most ornithological studies and surveys that occurred are rarely published. The Philippine Eagle Foundation pioneered the ornithological surveys on the western side of the mountain and reported 120 species with 51% Philippines endemics (The Philippine Eagle Foundation 2007). This was followed by an ecological study on the effects of vegetation on birds in Mt. Hilong-hilong by Paz et al. (2013). Forty-six species were observed in San Antonio located on the western side of the mountain (Hosner 2012). By combining past and current survey data from Mt. Hilong-hilong, we found an increase in recorded species and higher proportions of endemism, as other species were not previously recorded before were pooled together, supporting the importance of Mt. Hilong-hilong in conserving important populations of birds in the KBA zone. Key Biodiversity Areas are identified sites across large scale networks by identifying areas that contain unique, vulnerable, and irreplaceable population (Eken et al. 2004). KBA's primarily concerns to aid the conservation and protection of population viability of highly-threatened species or populations based on global-scale criteria (e.g., the IUCN Red List) (Margules & Pressey 2000). Although our analysis showed lower numbers of threatened species (N= 12 spp., 8%), we found a higher proportion of species with declining populations (N= 79 spp., 53%) in Mt. Hilong-hilong. Likewise, we found high proportions of species with restricted distributions (N= 73 spp., 50% endemism

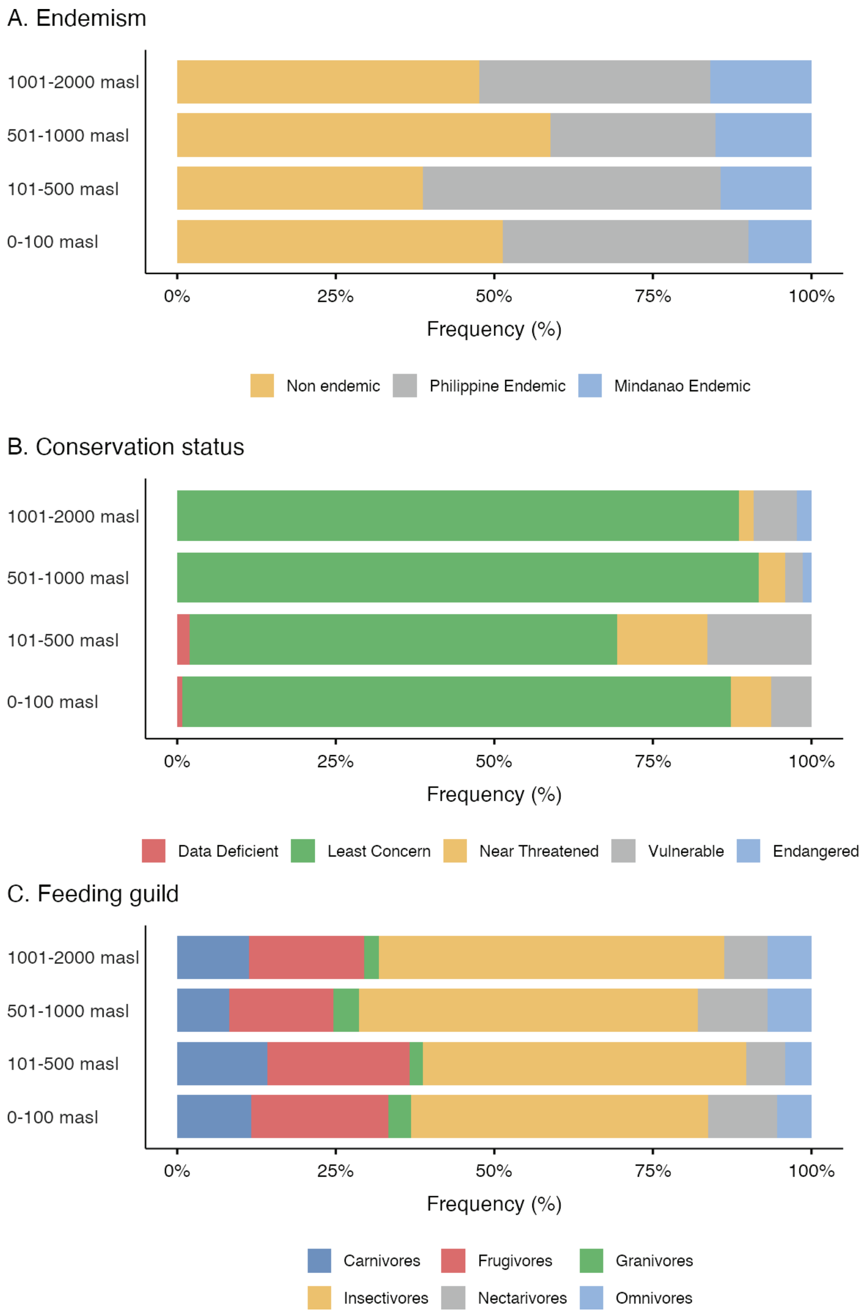

Figure 3. Distribution of birds in Mt. Hilong-hilong across elevational gradient interval based on: A—endemism, | B—conservation status | C—feeding guilds.

level) and this conforms to the other three criteria based on species irreplaceability (Margules & Pressey 2000).

Key Biodiversity Areas with relatively more intact vegetation represents an important site for conservation safeguarding populations of bird taxa from multiple threats (Plumptre et al. 2019). The risk of extinction for birds in Mt. Hilong-hilong is higher among Mindanao and Philippine endemic. Our study found high proportions of endemic species within Mt. Hilong-hilong, and this could be associated with relatively intact, denser and diverse vegetation of native plants within the KBA zone particularly in the lower to mid-elevation, thus more suitable to support wide-suit of bird species and their different life-histories. Tanalgo et al. (2019) compared different habitats in the lowlands of south-central Mindanao and found more endemic species in protected areas and at reforested sites with better vegetation structure compared to more homogenised plantations

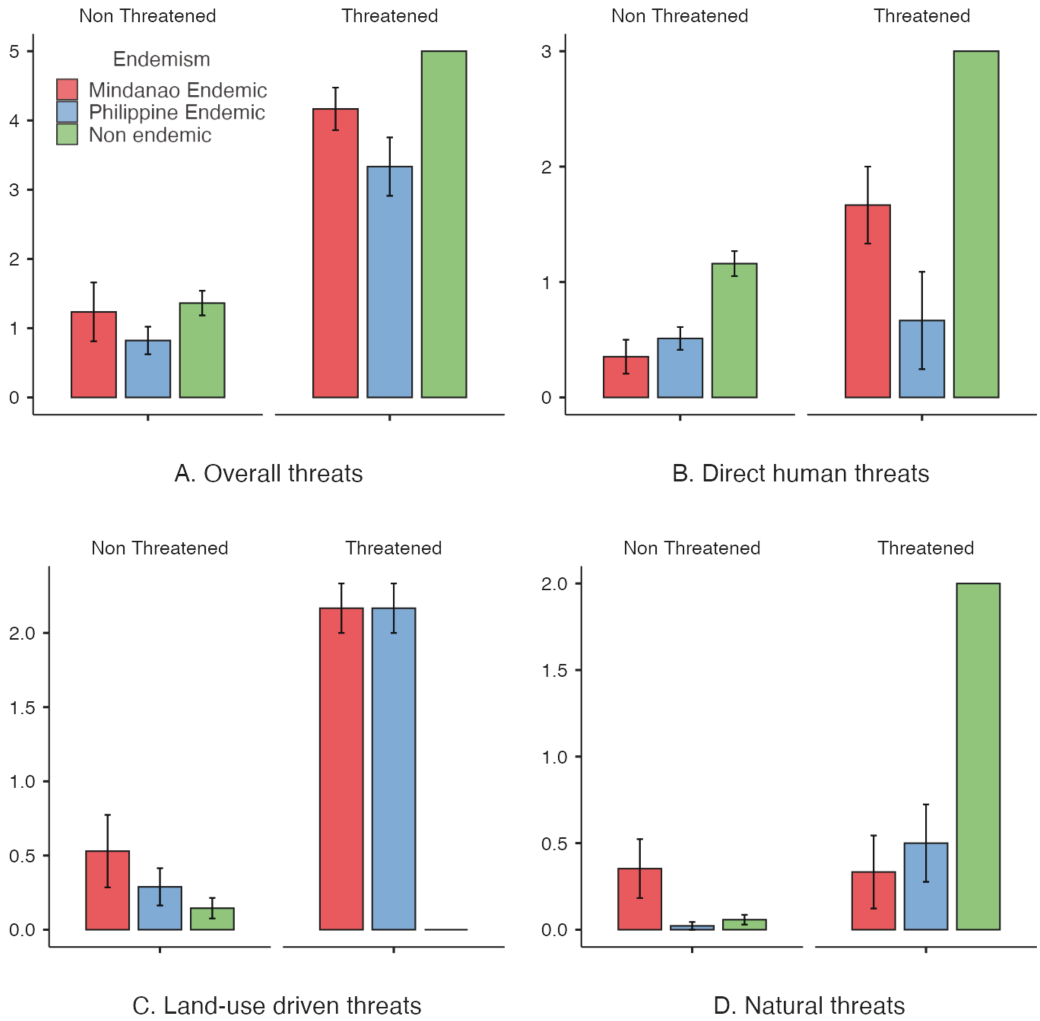

Figure 4. Species threat index of potential threatening processed based on: A—proportion of overall threats | B—direct human threats | C—land-use driven threats | D—natural threats, across endemism. Error bars represent the standard deviation.

and urbanised areas. Previous studies also showed that the density and richness of endemic bird species are strongly correlated with the vegetation intactness and structure (Mills et al. 1991; Daniels et al. 1992; Mejías & Nol 2020). Although the majority of avian species in Mt. Hilong-hilong are considered least threatened, yet large proportions are facing threats from direct-human threats such as hunting, albeit there is no clear evidence detailing the extent of this threat for birds and other wildlife in the KBA. Whereas land-use driven threats such as deforestation and agricultural expansion remain a key threat to 49% of species particularly those forest-dwelling species with narrow distributions. In contrast with other threats, deforestation and agricultural expansions led to habitat fragmentation that may immediately influence the alterations of diversity and composition of native species present in these systems (Bujoczek et al. 2020; Hatfield et al. 2020; Tchoumbou et al. 2020). Declining strict forest-dwelling species at a regional scale is widely associated with human disruption to habitats that reduce the space occupied by and affect the foraging grounds of a diverse set of species (Brooks et al. 1999; Renjifo 2001). Global meta-analyses showed that bird species richness and abundance were particularly susceptible to decline in areas with low structural heterogeneity such as plantations and farmland conversions (Bohada-Murillo et al. 2020). The continuous conversion within or near intact habitats for agricultural expansions during the last decades has driven high biodiversity loss in many hotspot regions including the Philippines (Brooks et al. 2002). Apart from the high diversity of forest-dwelling birds in Mt. Hilong-hilong, we recorded at least 16 migratory species. Intact areas (e.g., protected areas and key biodiversity areas) as interconnected networks of conserved and protected sites are crucial for migratory birds serving as routes supporting the full annual cycle of at least 9% of global migratory birds (N= 1,451 spp.) (Runge et al. 2015).

We found more endemic and threatened species in the lower elevation (0–100 m) and mid-elevations (100–500 m) of Mt. Hilong-hilong, but this should be taken with prudence as the sampling effort or the employed techniques per elevation may vary. This diversity pattern (i.e., species richness) may be explained by the vegetation structure in relationship to elevation in the KBA. In a previous study in Mt. Hilong-hilong, Paz et al. (2013) showed that vegetation and elevation were key drivers affecting endemic species distribution in the KBA. Vegetation is a key determinant of increased species richness and diversity (Canterbury et al. 2000; Tchoumbou et al. 2020) and the effect of elevation may negatively affect vegetation and consequently species diversity and richness across many animal taxa including birds (Kattan & Franco 2004; McCain 2009). In a study in the Rwandan mountains, elevation was found to have inverse effects and vegetation structure positively influenced bird diversity (Derhé et al. 2020). Similarly, this pattern was observed in the eastern Himalaya; Acharya et al. (2011) demonstrated that intermediate elevations had the highest bird species richness, where primary productivity was at the optimal peak.

In terms of feeding groups, the majority of the species recorded in Mt. Hilong-hilong are insectivorous, frugivorous, and carnivorous. Elevation has been shown to affect the distribution of functional groups, for example, elevation strongly influences insectivorous birds but not on frugivorous birds in tropical forest landscapes as influenced by their varying foraging strategies across different vegetation (i.e., more insect biomass) and climate strata (Jankowski et al. 2013; Santillán et al. 2020). Although there was no significant relationship found between feeding groups and elevation, species that were recorded strictly or specific in an elevation may represent an important indicator to future monitoring of bird response to habitat system within Mt. Hilong-hilong. Species feeding guild can indicate habitat structure or quality for species to persist. A study comparing a protected area with an agricultural area in Serengeti showed that at least 50% of insectivorous and granivorous birds found in forests were absent in agriculture, suggesting that more intact ecosystems can safeguard a large proportion of specialist species (O'Connell et al. 2000; Sinclair et al. 2002). In a similar study, bird functional diversity depended on the overall habitat types (Tanalgo et al. 2019), and the intactness of forest, in which species responded negatively to disturbance gradient, for example, omnivores, insectivores and frugivores were lowest in numbers in areas with selective logging and plantation conversions within a tropical rainforest (Tchoumbou et al. 2020). The intactness of KBAs strongly relies on the physical features (e.g., landscape structure), presence of threats, and changes in land-use (Rayner et al. 2014). To circumvent these threats, protected areas and other forms of designated sites serve as a chief tool optimising the conservation and protection of many species (Butchart et al. 2015). Conservation initiatives such as the establishments of KBAs allows the identification of important areas for protection (i.e., the establishment of protected areas) from human alteration. Yet, the identification of KBAs alone is not sufficient to ensure the protection of its ecosystems and important taxa; it requires effective monitoring of its biodiversity and the extent of the potential threatening process (Beresford et al. 2020). To optimise the role of KBA to safeguard critical habitats and their biodiversity it should be primarily protected first by the statutory policy.

In conclusion, our synthesis demonstrated the presence of high diversity of endemic and threatened bird species in Mt. Hilong-hilong harbour, and the vital role of the KBA as an important habitat for bird conservation and protection. Our study exhibited that local biodiversity could be effectively understood by integrating findings from multiple datasets, particularly those from rapid surveys and assessments (Fig. 5) (Tanalgo et al. 2019). Here, we acknowledge that our findings were based on the synthesis of the different dataset that employed varying sampling methods and approach (e.g., intensity and effort, taxonomic identification) that may have affect the robustness of data (Manu & Cresswell 2007) thus, careful interpretation is required. Yet these caveats warrant more intensive efforts and opportunities to produce robust data across elevational and vegetation gradient to fully elucidate their relationship to species diversity and other ecological indicator groups.

The rapidly changing environment and the growing development outside and the lowlands of KBA where habitat change is likely to occur and could pose important attention and concerns for conservation. For instance, from 2002–2019 at least 4.66Kha of humid primary forest was lost within the KBA zone, which most likely caused by deforestation and shifting agriculture (Global Forest Watch 2020). In addition to land-use changes, direct human impacts to birds such as hunting in the KBA may pose another threat to many populations. These threatening processes will likely

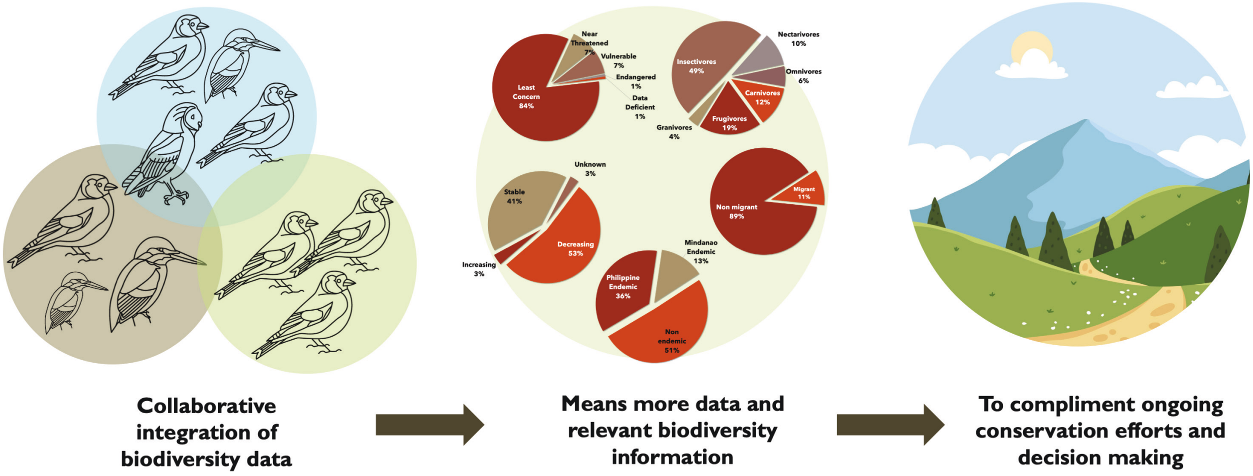

Figure 5. Schematic diagram showing the key importance of collaborative efforts for conservation such as the biodiversity data sharing and integration from different fieldwork and research to develop synthesis for clearer understanding of biodiversity patterns to inform better or complement existing conservation efforts. This figure was generated using the free version of clipart from https://logomakr.com/

affect many species particularly larger species (e.g., large-fruit doves) and those with narrow distributions (Tanalgo 2017). Thus future studies must aim to understand and explore the extent and impacts of these threats to species in Mt. Hilong-hilong. Future conservation priorities should advocate more protection of endemic species which more tends to be threatened in Mt. Hilong-hilong. Furthermore, we demonstrate here that collaborative efforts may promote effectual conservation by combining different data from different survey efforts that often remain in grey literature, enable biodiversity synthesis by increasing relevant information to better understand species diversity (Tanalgo et al. 2019). Bolstering efforts promoting transparent and collaborative science-based conservation intervention is central to better complement and sustain existing conservation management not only in Mt. Hilong-hilong (Mohagan et al. 2015; Amoroso et al. 2018) but across all other important biodiversity sites in the country (Fig. 5).

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Author contribution: AGG, ABM, FMA, and HPL conceptualised the project. AGG, JM, JB, WYJ, and RC carried out the fieldwork. AGG and KCT performed data curation and analyses. KCT performed the visualisation. KCT led the manuscript writing. All authors reviewed, edited, and approved the submission of the final version of the manuscript.

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