Diversity and spatial distribution of native bees in Mt. Banahaw de Lucban, Philippines

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Abstract

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Native bees are pollinators and bioindicators of ecosystem health but only little is known about its abundance, species distribution, and habitat range, especially in the Philippines. This study assessed the diversity and spatial distribution of native bees in Mt. Banahaw de Lucban (MBDL). Belt transect coupled with opportunistic sampling were used in the inventory of bees and their nests. Nests occurrence and 7 environmental predictor variables including; 1) annual mean temperature; 2) precipitation of warmest quarter; 3) elevation; 4) slope; 5) Normalized Difference Vegetation Index (NDVI); 6) distance to agricultural areas (m); and 7) distance to forested areas (m) were used for modeling species distribution by MaxEnt. A total of 16 species of native bees including representatives from genus *Apis, Tetragonula, Lasioglossum, Halictus, Hylaeus* and *Megachile* were identified. A total of 96 bee nests from 5 species were also recorded yielding a nests density of 234 nests per km^2. Results showed medium diversity of solitary native bees with *H'* of 2.488. Most bee nests were found in lower elevations while the distance from agricultural areas and the distance from forest areas had the highest contributions to the nesting of *Apis breviligula*, *A. cerana*, and *Tetragonula biroi*. The mean distance from forest areas of all bee nests was 649.930 m and the mean extent of suitable area for these species was 5.340 km^2. Hence, a landscape approach may be more appropriate to conserve native bees and sustain the ecosystem services they provide in MBDL.

Keywords

Apis breviligula, Apis cerana, bee forage, habitat suitability, Tetragonula biroi

Introduction

Bees are insects belonging to Order Hymenoptera. Bees live singly (solitary) or in groups or colony (eusocial). Native bees are indigenous in an area whose presence and distribution was influenced by natural ecological processes. These bees have adopted to changes in environment and have co-evolved mutually with associated organisms. In the Philippines, *Xylocopa* spp., *Apis breviligula*, *Apis cerana*, and *Tetragonula biroi* are some of the known native bees. These bees, especially the stingless bees, are common visitors of flowering plants in the tropics (Heard, 1999). They migrate seasonally depending on the availability of food sources and return to their nest site.

While bees are dominant pollen vectors (Liow et al., 2001) and pollination is one of their most significant functions (Kupsch et al., 2019), the presence of native bees population is also a good indicator of ecological con-

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ditions and health of the environment. Forests including mangrove ecosystems benefited from pollination by bees (Almazol and Cervancia, 2012). Likewise, agricultural crops such as coconut and vegetables have also shown to increase crop yield and improved seed quality with bee pollination. Bees are sensitive to environmental changes and their diversity may decline in simplified habitats distant from undisturbed areas (Cely-Santos and Philpott, 2019). They are also considered exceptional model organisms to assess the effect of climate variation on species richness along altitudinal gradients (Figueira Fernandes Elizalde, 2020). Aside from habitat degradation, climate change is currently threatening wild pollinators, compromising their ability to provide pollination services to wild and cultivated plants (Jaffé et al., 2019). For instance, plants may shift their phenology as a response to climate change which can disrupt plant–pollinator interactions (Razanajatovo et al., 2018).

Using bees as an indicator of ecosystem health can benefit the management of remaining forest ecosystems such as the protected areas in the Philippines. Mt. Banahaw-San Cristobal Protected Landscape (MBSCPL) is one of the remaining forested areas in the Philippines that serves as a life-support system for more than one million people in the provinces of Quezon and Laguna. Mt. Banahaw de Lucban (MBDL) is a portion of MBSCPL mountain complex. MBSCPL is known for its high floral and faunal diversity. However, like most of the protected areas in the country, its biodiversity is constantly threatened by unsustainable and irresponsible human activities such as indiscriminate logging, forestland conversion and over-harvesting of resources. Hence, assessing its health through native bees as bio-indicator is necessary.

Furthermore, determining the species diversity, distribution, and suitable habitat for native bees contributes to its protection and conservation, consequently sustaining its functional role in ecosystems. However, there are only a few researches that characterize their spatial distribution and none determines suitable habitat for native bees in most protected areas in the Philippines. Species distribution modeling (SDM) is a widely used method for determining species diversity and compositional patterns (Zhang et al., 2012) and has been recognized as a tool for conservation planning and policy development and implementation in tropical regions (Cayuela et al., 2009). Modeling quantifies the species distribution pattern by relying on species' occurrence or abundance and environmental or geographic predictors (Elith and Leathwick, 2007; Franklin, 2013). Modeling species distribution and suitable habitat for native bess in MDBL can contribute to the conservation of native bees and sustainability of remaining forest resources.

Beekeeping for honey production can also contribute in reducing pressures to utilize remaining forest

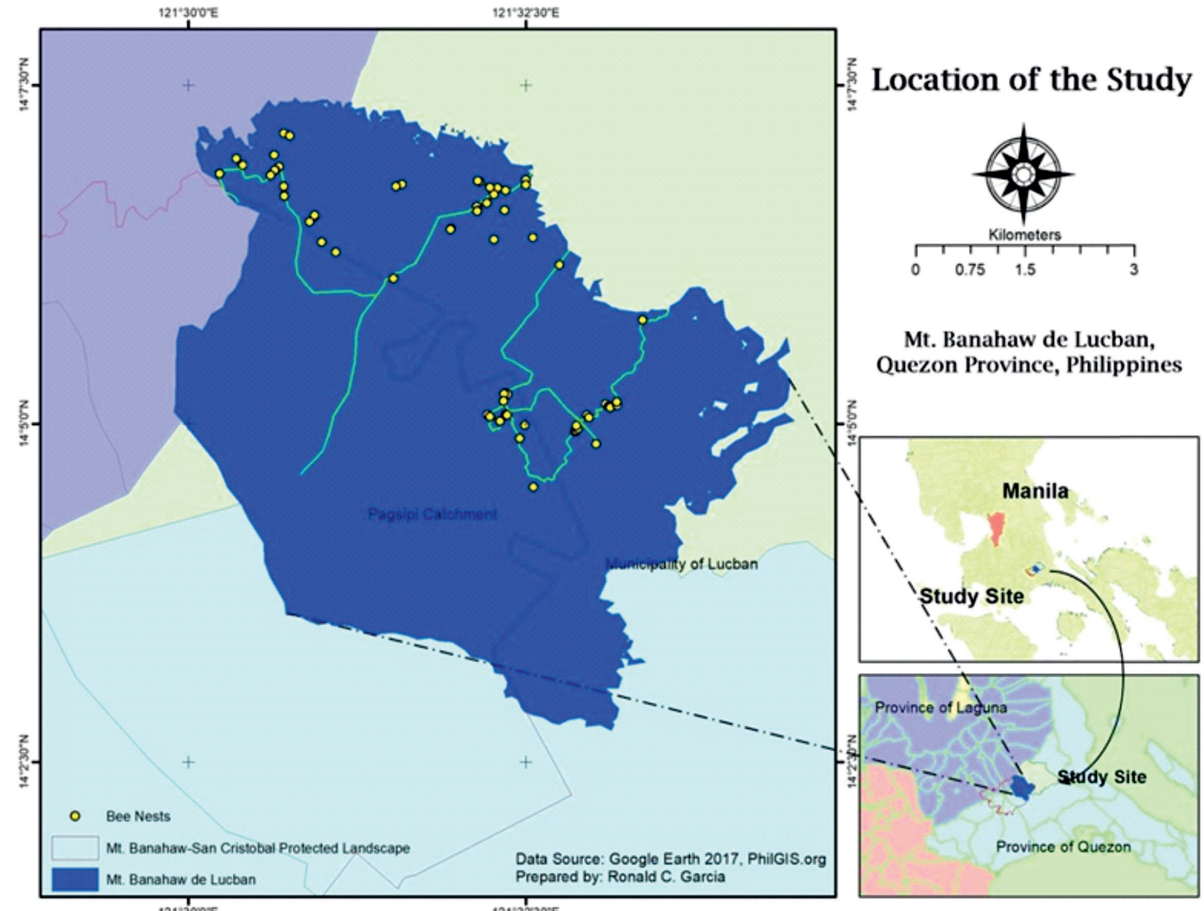

Fig. 1. The study was conducted in Mt. Banahaw de Lucban.

resources. Apiculture involves the maintenance of honeybees and hives for its honey and bee products. It can provide livelihood to people while also increasing agricultural productivity by pollination. However, the adoption of apiculture among farmers has been challenged by the choice of bee species, source of colonies and suitability of the areas for beekeeping as well as location of apiary (Kupsch et al., 2019) among others.

This study aimed to assess the diversity of native bees in MBDL and determine its spatial distribution using species distribution modeling. Likewise, the suitable habitat for native bees was determined by modeling. It was hypothesized that there will be high diversity of native bee species in the area since MBDL is known for high plant and habitat diversity. Also, it was hypothesized that the areas at low elevation (650–750 m asl) of MDBL will be suitable for bee nesting since it is close to agriculture and forest as food sources and less accessible for human disturbance.

Materials and methods

Study site

Mt. Banahaw De Lucban (MBDL) is among the mountain complexes of Mt. Banahaw San Cristobal Protected Landscape (MBSCPL). It is located in the north-eastern flank of MBSCPL and covers an area of 1,660 hectares (16.6 km^2) or about 15% of the total land area. Its elevation peaks at 1,875 meters above sea level (m asl). MBDL is geographically located at 121°29'53.5" to 121°33'02.8" East longitude to 14°02'50.96" to 14°06' 33.96' North latitude. This part of the mountain was leased to Southern Luzon State University. The climate of Lucban, Quezon falls on Type II characterized by the absence of dry season and with a very pronounced maximum rain period from December to February. Figure 1 shows the location of the study.

Inventory and mapping of bee nests

Systematic sampling via belt transect coupled with opportunistic sampling techniques was used in the study (see Figure 1). For belt transect, the existing road, forest trails and ranger patrol routes were traversed for sampling. Transect lines also traverse the different altitudinal gradient from about 500 to 1,875 meters above sea level (m asl) at the peak of MDBL. A total of 20.5 kilometers of transect line was traversed for this study. Bee nests identified within 10 meters from the left and right side of the transect line were sampled and recorded. Also, bee nests identified by local bee hunters were visited and inventoried. Sample specimens of each species were collected when encountered. Likewise, solitary bees encountered or captured via net sweeping were identified and surveyed. The geographic location of the bee nests, the plant species they are foraging and distribution throughout the study area were determined using the Global Positioning System (GPS) and mapped using ArcGIS 10.5 software.

Collected sample specimens were dried and/or preserved for identification and were stored at the Biodiversity Mini-museum at the College of Agriculture, Southern Luzon State University in Lucban, Quezon, Philippines. The preliminary insect identification was done at the National Museum in Manila, Philippines. Further verification was done at the Museum of Natural History at the University of the Philippines Los Baños, College, Laguna.

Species richness and diversity

The species abundance of native bees in the study was largely dependent on the number of bee nests identified and sampled. The species richness (*R*) however was determined from the number of species sampled. The Shannon Index of diversity (*H'*), Simpson's Diversity Index (*D*), and Evenness Index (*E*) for solitary bees were determined using the following formula:

$$H' = -\sum_{i=1}^{R} p_i * \ln(p_i),$$

where *H'* is the Shannon diversity index and pi is the proportion of individuals of *i*-th species to the whole community.

$$D = \sum_{i=1}^{R} {p_i}^2,$$

where *D* is the Simpson's diversity index and pi is the proportion of individuals of *i*-th species to the whole community.

$$E = \frac{H'}{\ln(R)},$$

where *E* is the Evenness Index. *E* values can range from 0 to 1 wherein values near 1 indicate high evenness in the distribution of individuals among the species sampled.

Species distribution modeling

Rapid assessment of species distribution and habitat suitability of native bees in Mt. Banahaw de Lucban landscape was conducted by modeling using Maximum Entropy Species Distribution modeling (MaxEnt 3.4.4). MaxEnt models are a popular tool to predict species distributions with its capability to cope well with sparse, irregularly sampled data and minor location errors (Kramer-Schadt et al., 2013; Merow et al., 2013). It is a machine learning method considered to be robust for spatial autocorrelation between predictors at local scale (Støa et al., 2019; Cheng, 2008). Maxent is easy to use and typically outperforms other methods based on predictive accuracy (Merow et al., 2013).

Generally, the model requires species occurrence data and environmental predictor variables. The location of bee hives was used as species occurrence data in modeling. Only species of native bees with at least fifteen (15) occurrence data was used in modeling. This follows the suggested rule-of-thumb by Støa et al. (2019) of 10–15 species occurrence data to determine non-random models of a species. Maxent also performs well in estimating occupancy probabilities and even outperforms the other methods on small sample sizes (Guillera-Arroita et al., 2014). To minimize biases that may arise from sampling, the occurrence point was rarefied at 300 m distance.

Environmental predictor variables included rainfall, temperature, topography and vegetation cover. Climate parameters were adopted from Bioclimatic (Bioclim) data from the website of WorldClim (https://www.worldclim.org). There are 19 bioclimatic variables available in raster format at spatial resolution of 30 second (~1 km^2). Initial correlation analysis, however, showed that bioclimatic variable had high correlations – multicollinearity. Hence, for rapid assessment, only one of rainfall-related and temperature-related bioclimatic variables with least correlation between them but with high correlation with elevation were used in modeling. Since MBDL is only 1,660 hectares (or 16.6 km^2) and mountainous, the rainfall- and temperature-related variables were regressed with elevation in an attempt to increase the resolution from ~1 km to 30 m. The annual mean temperature (BIO1) and precipitation of warmest quarter (BIO18) were selected.

For topographic variables, Digital Elevation Model (DEM) in raster format with 30 m resolution were downloaded from the EarthExplorer website (https://earthexplorer.usgs.gov) of United States Geological Survey (USGS). Slope of the area, as environmental predictor variable, was formulated from DEM using ArcGIS 10.5.

Land use/land cover data was represented by the Normalize Difference Vegetation Index (NDVI) determined from satellite image. NDVI is considered the most commonly used vegetation index satisfactorily related to functional characteristics of vegetation particularly with the fraction of photosynthetically active radiation intercepted by vegetation (Baldi et al., 2018). Landsat 8 (Landsat Collection 2) Level 2 images dated 9 March 2019 and 1 July 2020 were downloaded from EarthExplorer. NDVI was determined using the reflectance at Near Infrared (Band 5 in Landsat 8) and Red band (Band 4 in Landsat 8) following the formula below:

$$NDVI = \frac{Near\ Infrared - Red}{Near\ Infrared + Red}.$$

NDVI was then clipped into the same spatial extent of MBDL and converted in asci format.

Additional vector data model of 2015 Land Use was also downloaded from the Geoportal Philippines (https://www.geoportal.gov.ph/) managed by the National Mapping and Resource Information Agency (NAMRIA). To determine if the forest and agriculture influence the presence of bee nests, the distance to these land use/ land cover was used as environmental predictor variable. The Euclidean distance from the forested area (included closed forest and open forest in the 2015 Land Use) was estimated using the Spatial Analyst extension in ArcGIS 10.5.1. Similarly, Euclidean distance from agricultural areas (included areas planted annual crop and perennial crops) was determined. The environmental predictor layers used in modeling species distribution are shown in Figure 2.

Species distribution models partitions data into training and testing samples. Models were created using training samples and validated using testing sample. Model training and testing were iterated 10 times for each of the bee species. Model performance was evaluated based on the area under the receiver operating characteristic curve (AUC) (Wisz et al., 2008) and models with

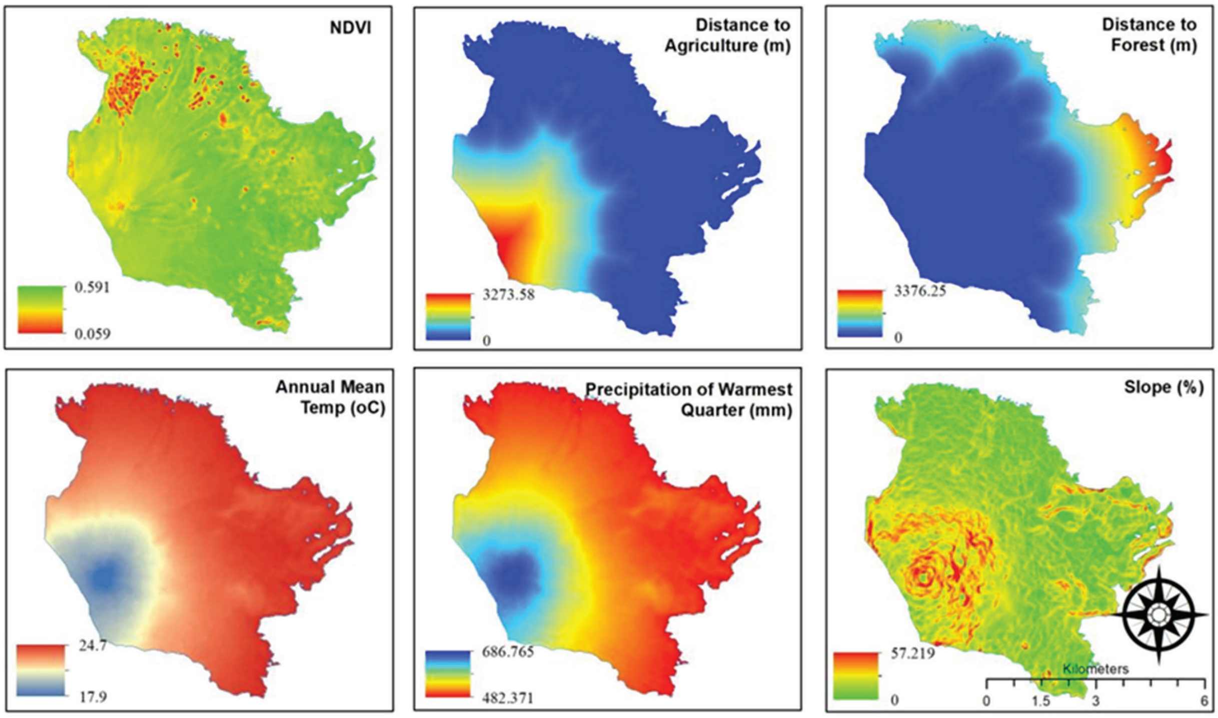

Fig. 2. Environmental predictor variables of bee nesting in Mt. Banahaw de Lucban.

AUC > 0.8 was considered acceptable. For models with AUC < 0.8 during the initial run, the least contributing environmental predictor variables based on Jacknife test were step-wise removed until AUC = 0.8 was reached.

Results and discussion

Species abundance, richness and diversity

A total of 16 species of native bees under four families and 11 genera were identified. The family Apidae were the most represented family with *Apis breviligula, Apis cerana* and *Tetragonula biroi*. Solitary bee species such as those belonging to Colletidae, Halictidae and Megachiladae families were also sighted and collected. A total of 96 bee nests were identified from transects. *Apis breviligula, Apis cerana* and *Tetragonula biroi* had 47, 21 and 23 bee nests respectively and were the most abundant. The species richness of native bees in MBDL is summarized in Table 1. Voucher samples are illustrated in Figure 3.

The 3 most common bee species recorded such as *A. breviligula*, *T. biroi*, and *A. cerana* differ in their habitat preference, although they seemed attracted to food sources at a landscape scale. Bees' nests were found on tree canopies, in the crevices such as stone, septic tanks, rubber/scrap materials such as sliced wheel, burrowing on the ground, and tree holes. For instance, most nests of *T. biroi* were found in the holes of tree trunks, attached to tree branches several meters high above the ground and in clusters of up to 10 nests. However, nests of solitary bees such as *Xylocopa* spp. and *Bombus* spp., *Megachile* spp., *Halictus* spp., *Hylaeus* sp., *Lasioglossum* sp., *Amegilla cingulata* and *Thyreus wallacei* were hardly located, although they were sited foraging on the flowers and were captured through net sweeping.

Nests of *A. breviligula* were found hanging on the tree bole or branches in or adjacent to agricultural land and residential areas. The hives found were at least 3 meters above ground up to more or less 20 meters hanging on tree branches. Nests were found in the cool and dry portions of the tree with a clear flyway for bees. Nests were found in tree branches of Narra *(Pterocarpus indicus)*, Malapapaya *(Polyscias nodosa)*, Marang *(Litsea cordata)*, Antipolo *(Artocarpus blancoi)*, Rimas *(Artocarpus altilis)*, Dapdap *(Erythrina variegate)*, Lipote *(Syzygium polycephaloides)*, Banilad *(Sterculia comosa)* and other species of Moraceae and Meliaceae. This shows that the vertical structure of the vegetation can be important local predictor to the response of individual bee groups such as *Apis* and *Trigona* (Cely-Santos et al., 2019).

Compared with *A. breviligula, A. cerana* can be found in natural cavities in tree trunk or the ground even in areas frequented by humans such as school buildings, plant nurseries, and in garden pots. The preference of *A. cerana* for nesting habitat can be influenced by its access and availability of water, flowering plants and temperature of the surroundings (Daud, 2021). All nests were found close to the ground with at most 1-meter height. This showed that residential areas and other human constructions may serve as refuges for several bee genera (Cely-Santos et al., 2019).

Bees were also found foraging on the flowers with yellow colors, violet, blue, white and with landing platforms of different plants such as vines, shrubs, herbs, and trees, including agricultural crops, weeds, and ornamentals. Bees do not always visit the forage species of plants as they flower indicating that the bees may be prioritizing the collection of food from other species and would look for other food sources only after they consumed the pollen/nectar of the species they currently forage on. In

Table 1. List of native bees found in Mt. Banahaw de Lucban

Family	Species	Common name
Apidae	*Amegilla cingulata* F.	Blue-banded bees
	Apis cerana F.	Asiatic honeybee/Eastern honeybee
	Apis breviligula	Philippine Giant honeybee
	Bumbos sp.	Bumble bee
	Tetragonula biroi (Friese,).	Stingless bee/Sugarbag bee
	Thyreus wallacei Cockerell	Humpbacked bee/nest parasite
	Xylocopa appendiculata circumvolans	Green carpenter bee/Japanese carpenter bee
	Xylocopa bombiformis	Carpenter bee
	Xylocopa sp.	Carpenter bee
Colletidae	*Hylaeus* sp.	Plasterer bees or polyester bees
Halictidae	*Halictus* sp. 1	Sweat or Halictid bee
	Halictus sp. 2	Sweat or Halictid bee
	Sphecodes sp.	Sweat or Halictid bee
	Lasioglossum sp.	Sweat or Halictid bee
Megachilidae	*Megachile* sp.	Megachile/Leaf cutter and mason bee/Fire-tailed Resin Bee
	Megachile (Callomegachile) mystaceana	Fire-tailed Resin Bee

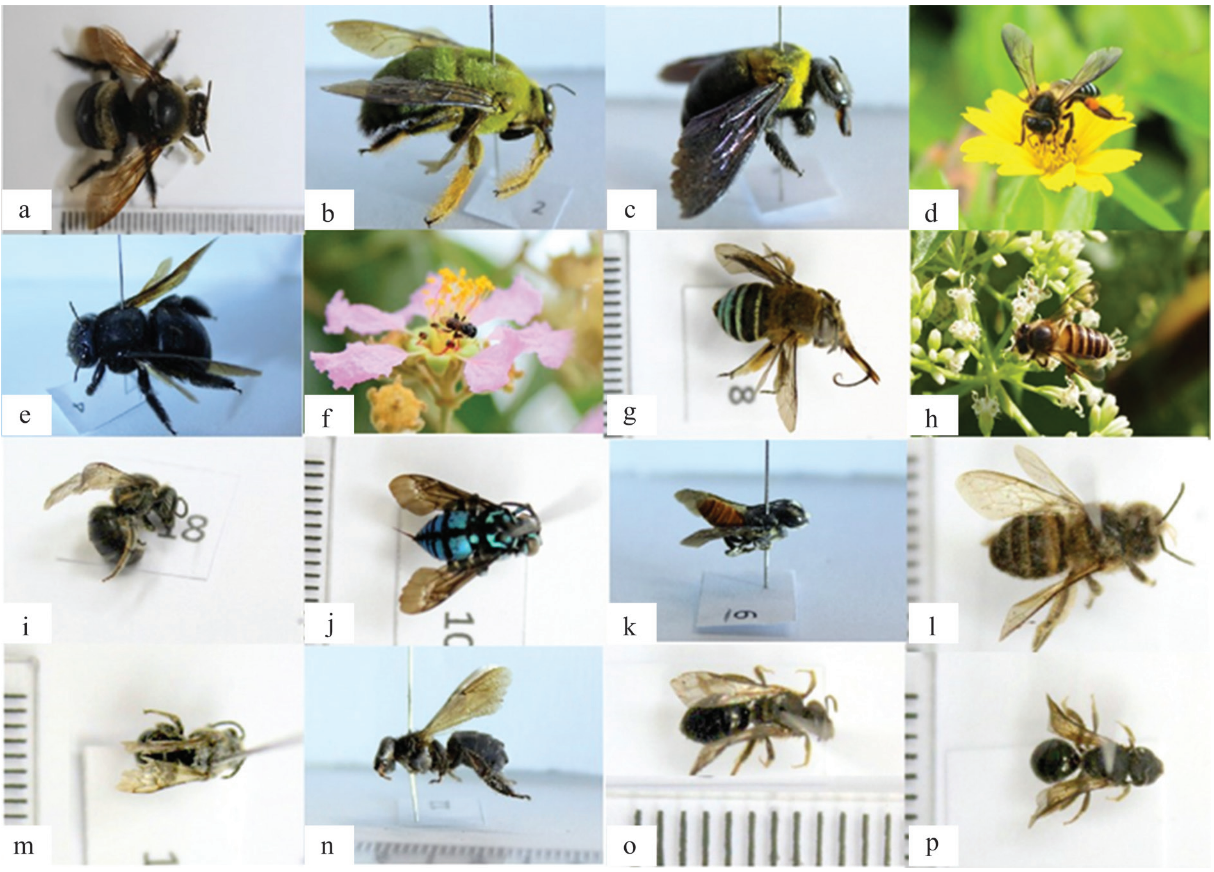

Fig. 3. Samples of native bees collected in Mt. Banahaw de Lucban: a) *Bombus* sp; b) *Xylocopa appendiculata circumvolans*; c) *Xylocopa* sp; d) *Apis breviligula*; e) *Xylocopa bombiformis*; f) *Tetragonula biroi*; g) *Amegilla cingulata*; h) *Apis cerana*; i) *Lasioglossum* sp.; j) *Thyreus wallacei*; k) *Megachile (Callomegachile)mystaceana*; l) *Halictus* sp. 1, m) *Halictus* sp. 2; n) *Megachile* sp.; o) *Hylaeus* sp.; and p) *Sphecodes* sp.

this study, native bees in MBDL were observed foraging on forest trees such as Lipote *(Syzygium polycephaloides)*, Makaasim *(Syzygium nitidum)*, Salinggogon *(Cratoxylum formosum)*, Kasau-kasau *(Gongrospermum philippinense)*, Alahan *(Guioa koelreuteria)* and Patalsik *(Decaspermum fruticosum)*. Biesmeijer and de Vries (2001) suggested that bee foragers may be involved in the exploration behavior of the colony, novice bees that become scouts, unemployed experienced bees that scout, and lost recruits, i.e. bees that discover a food source other than the one to which they were directed to by their nest mates.

The Shannon Diversity index (*H'*), Simpson's Diversity index (*D*) and Evenness index (*E*) were 2.488, 0.093 and 0.897 respectively indicating medium diversity and even representation of species for solitary bees. These results are similar with the results of studies of Widhiono et al. (2017) and Liow et al. (2001). Accordingly, *H'* values were reported to change with elevation and cover types cum level of disturbance. Widhiono et al. (2017) reported increasing *H'* values from 1.4 to 2.04 with increasing elevation. Liow et al. (2001) also reported that H' ranges from 0.249 to 2.259 as cover type changes from primary forest to secondary forest to uniform oil palm stands while E ranges from 0.046 to 0.543 with highest value in oil palm plantation.

Although low in species diversity, the number of species and abundance of native bees appears to be sufficient to pollinate the plants in MBDL. From single plant to vegetation community, the number of important bee species may increased up to 7 times relative to the average number of plant species (Simpsons et al., 2022). This means that the forest community may require 7 times more bee pollinators than a single tree. This observed species richness in native bees indicates that MBDL is also abundant in flowering plants.

Ground-nesting bees constitute the majority of species found in many communities and only small numbers of eusocial bees (Winfree, 2010). In tropical bees, however, ground-nesting bees may be largely excluded because their nests would flood with rain and their larval food supplies would suffer fungal attack. This may explain the medium diversity and the few ground-nesting bees observed in MBDL. In this study, *Sphecodes* sp. was among the ground-nesting bees sampled.

Altitudinal distribution of bee nests

Table 2 shows the distribution of the bee nests along the altitudinal gradient found in MBDL. Bee nests were mostly found at 500–800 m asl. Specifically, 75% of the nests were identified at 500–600 m asl elevation range. *A. breviligula* constituted 48.96% of all nests identified. More than 90% of all hives identified were also found outside the protected area boundary. Although some bee species were observed visiting flowers in high elevation, no bee nests were recorded from these areas. This indicates the low suitability of the area for nesting causing altitudinal variation in the distribution of nests. Although high altitude can have diverse and rich bee species (Tenzin and Katel, 2019), abundance and species richness decline at increasing altitudes (Hoiss et al., 2012; Karunaratn and Edirisinghe, 2009). Interestingly, Figuera (2020) reported an increasing trend in bee diversity with increasing altitude but stressed the distinctive difference in community structure along the elevation gradient. These indicate variation among bee species not only on site preferences but also on adaptation to environmental gradients limiting their distribution. Apparently, suitable sites for bee nesting may differ from bee species and environmental factors that influence non-nesting in low and high elevations varies.

Distribution of native bees and nesting across altitudinal gradients may also be influenced by physiological limits within the species, interspecific competition and availability of forages. The ambient temperature and capacity of bees to regulate body temperature (Figuera, 2020), for instance, may favor larger bees that can tolerate and recovers better from more extreme temperatures thereby influencing the altitudinal distribution of native bees (Oyen et al., 2016). This implies that some bees are highly adapted and can be habitat-specific that they may not be reported from different environments (Raina et al., 2019).

The abundance of food and floral resources, floral habitat, and climate features relative to increasing altitude can also influence species richness of insects (Kumar et al., 2019), richness peaks at middle altitudinal zones. For instance, the low diversity of bumble bees was found in high altitude zones as explained by flower abundance and plant diversity and many bee-pollinated plants rely heavily on bumble species (Egawa and Itino, 2020). Likewise, there are bees completely dependent on pollen and nectar on the high altitude flora such that different bee species have different host plants (Raina et al., 2019).

Spatial distribution of native bees

From a total of 96 nests identified along 20.5 km transect, density was estimated to be 234 nests per km^2 in MBDL. Only *A. breviligula, A. cerana* and *T. biroi* with 47, 21, and 23 bee nests occurrences respectively were used in species distribution modeling in MaxEnt. Species distribution models for these 3 species are shown in Figure 4. Likewise, the performance of the species distribution model and the contributing environmental predictor variables were summarized in Table 3.

Table 2. Distribution of bee nests across elevation gradients in Mt. Banahaw de Lucban

Species	Elevation (m asl)			Total
	500–600	600–700	700–800	
A. cerana	18	2	1	21
A. breviligula	34	12	1	47
Sphecodes sp.	–	–	1	1
T. biroi	17	5	1	23
Xylocopa sp.	3	–	1	4
Total	72	19	5	96

The models generally show that there is a high probability of occurrence of bee nests in lower elevation in the northern to north-eastern portions of MBDL. *A. cerana* and *T. biroi* appears to have wider spatial distribution compared to *A. breviligula*. Overlay analysis, revealed that these areas were planted with annual and perennial crops. This result was parallel with the analysis variable contribution where the distance to agricultural areas showed the highest relative contribution to the occurrence of the three native bee species. The distance to forested areas, NDVI, and precipitation of the warmest quarter were also among the environmental predictor variables with high contribution to the occurrence of the three native species of bees. This shows that bee nesting of *A. cerana, A. breviligula* and *T. biroi* have an affinity to vegetation features in the landscape.

The affinity of bee nesting to vegetation features in the landscape can be due to the availability of food sources and suitability of the area for nesting. Majority of the hives identified were adjacent to agricultural areas at 500–600 m asl which can serve as food sources for bees. Food sources may influence the distribution and regulate bee population (Roulston and Goodell, 2011). The proximity of the food source to the bee nest can emphasize mutual relations between bees and flowering plants that can favor the rate of nectar flow and crop productivity. For some cavity-nesting wild bees, nesting resource density, food resource density in young forest stands and

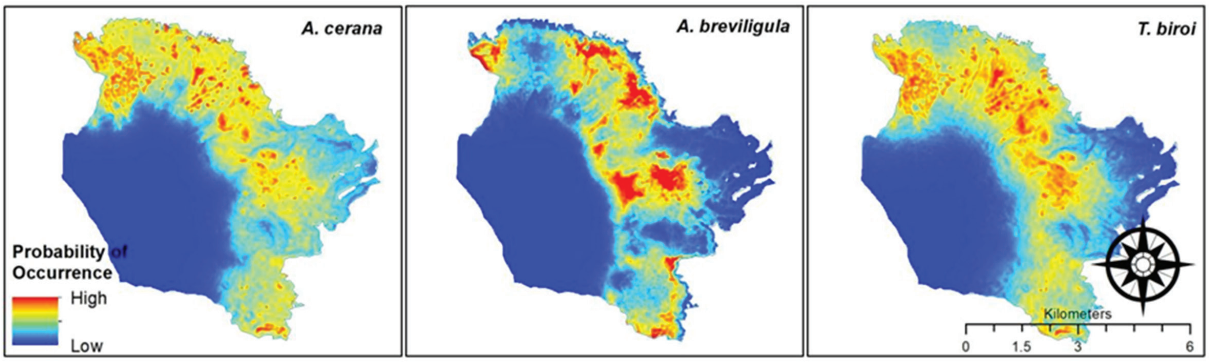

Fig. 4. The spatial distribution of *A. cerana*, *A. breviligula* and *T. biroi* in Mt. Banahaw de Lucban. Red color indicate high propability of occurrence.

Table 3. Performance of species distribution models for *A. cerana*, *A. breviligula* and *T. biroi*

Species	Environmental predictors	Mean AUC Training	Testing
A. cerana	Distance to agricultural areas (m)	0.817	0.817
	NDVI		
	Precipitation of warmest quarter (mm)		
	Slope (%)		
	Distance to forest area (m)		
A. breviligula	Distance to agricultural areas (m)	0.817	0.817
	Elevation (DEM)		
	Distance to forest area (m)		
	Precipitation of warmest quarter (mm)		
	NDVI		
	Slope (%)		
	Annual mean temperature (^{o}C)		
T. biroi	Distance to agricultural areas (m)	0.815	0.825
	Distance to forest area (m)		
	NDVI		
	Slope (%)		
	Elevation (DEM)		
	Precipitation of warmest quarter (mm)		
	Annual mean temperature (^{o}C)		

food resource density along sun-exposed roadsides explained 86% of the variation in abundance of bee nests (Westerfelt et al., 2018). In stingless bees, the location of food sources can be used in bee recruitment (Jarau et al., 2000) affecting their distribution.

The mean distance to agricultural areas of all bee nests was 27.95 m. *A. cerana* establishes its nest closest to agricultural areas at a mean distance of 10.43 m. This was significantly closer than *A. breviligula* (p = 0.035) with 38.64 m mean distance to agricultural areas but not to *T. biroi* with 14.65 m. Results imply that agricultural areas were preferred food sources of native bees than forested areas. Agricultural crops, especially in monoculture cropping, can exhibit mass-flowering when food becomes abundant and nesting near these sites can be favorable to bees. Mass-flowering at a specific time can considerably increase pollen and nectar sources compared to variable flowering periods in most tree species in natural forests. Mass-flowering in crops can have a long-term positive influence on the attractiveness of an area to bees and its density over the landscape (Riedinger et al., 2015). Although, there are native bee plants that can exhibit mass-flowering such as Lipote *(Syzygium polycephaloides)*, Makaasim *(Syzygium nitidum)*, Salinggogon *(Cratoxylum formosum)*, Kasau-kasau *(Gongrospermum philippinense)*, Malabuhan *(Aglaia lawii)*, etc. in MBDL, their wide distribution and low density may be reducing its attractiveness to bee nesting compared to mass-flowering in crops.

The mean distance from forested areas of all bee nests was 649.93 m. Bee nests of *T. biroi* were farthest from forested areas with 704.54 m but were not significantly different than *A. cerana* (657.35 m) and *A. breviligula* (635.26 m). Although, the forest areas were at a considerable distance from bee nests, they can still be important to bee nesting, especially as a food source during non-flowering and fallow periods in agricultural crops. Forest patches surrounding agricultural landscape was found to positively predict wild bee abundance even at distances greater than 1 km (Watson et al., 2011). Bees are also known to traverse distances greater than 1 km in search of their food although some bees prefer closer food sources and depend on a close connection between nesting and foraging habitat (Osborne et al., 2008; Walther-Hellwig and Frankl, 2000). Nest aggregations were more influenced by clumped resources and mutual defence benefits than short swarm dispersal distances (McNally and Schneider, 1996).

For solitary and other native bee species, visitation on flowering plants does not ensure bee nesting in proximity. Aside from *A. cerana*, *A. breviligula* and *T. biroi*, other native species were absent even though they were seen foraging the plants. In fact, nests of *Sphecodes* sp., a ground-nesting species of bees, nest was only found in the forests at 750 m asl. Brown et al. (2020) reported that soil-nesting bees were positively associated with pasture cover and above-ground nesting bees were positively associated with forest, but not with perennial woody crop cover despite frequently visiting flowers on these crops. Ground-nesting native bees may also nest in the fields and edges but nesting rates declined with distance into the field (Sardinas et al., 2016) and more apt to nest within bee forage plots than in fallow and in upland forests (Cope et al., 2019). The slope of the area and soil compaction were also found to be the most predictive nesting resources affecting nesting rates at the community level (Sardinas and Kremen, 2014). For some *Bombus* spp. with extreme foraging plasticity, floral diversity was found to drive foraging distance hence natural woodlands positively impacted their distribution (Jha and Kremen, 2013).

Projected suitable habitat for bee nesting

Figure 5 shows the suitable habitat for the *A. cerana*, *A. breviligula* and *T. biroi* based on probability of bee nesting. Areas where bee nests would likely to occur ($p > 0.65$) included areas with "moderate suitability" and "high suitability" and considered suitable habitat for the three species mentioned.

The mean suitable area for the three native bee species was 5.340 km^2. The extent of suitable areas for *A. cerana*, *A. breviligula* and *T. biroi* were estimated to be 5.49 km^2, 3.48 km^2 and 7.05 km^2 respectively. A. breviligula had the least extent of suitable areas and appears to be more concentrated which can be due to its preference to forest patches for above-ground nesting forming honeycombs in tree trunks and branches. Structural features of trees such as diameter, bark characteristics, height, and spreading of branches as well as can influence the location of nests of *A. breviligula* (Thomas et al., 2009). These bee nesting requirements can be found in forest patches in the riparian buffers and live fences in agricultural areas in MBDL. *A. cerana* and *T. biroi* prefers cavity-nesting species.

The suitability of land for apiculture can be based on the capacity of the area to provide the biotic needs of the honey bees and other apiary management requirements (Maris et al., 2008) such as slope, elevation, aspect, distance to water resources, roads and settlements, precipitation, and flora criteria were included to determine suitability (Sari et al., 2020; Amiri et al., 2012). Temperature, crops, tourism and three restrictions namely: 1) soil use; 2) highways, and 3) wild areas are also important criteria for assessing apiculture suitability (Pantoja et al., 2017). Other spatial features can include land use and distance from settlements, distance from the market and altitude in suitability assessment (Ambarwulan et al., 2016).

This study stressed the importance of the actual occurrence/presence of nests of native bees and environmental predictor variables in assessing the suitability of the area. With the bee nest occurrence as the ultimate presumption of habitat suitability, areas that are more likely to be inhabited/nested by these native bees were considered suitable areas for the native bee species at least. As expected habitat suitability focuses heavily on the ecology of native bee species. Nonetheless, this study suggests that the integration of habitat suitability assessment may improve land uses suitability assessment for apiculture for native bees.

Furthermore, it is evident that native bees were not limited to foraging forest trees in high elevation areas of MBDL but visits agricultural crops, home garden and other vegetation patches in the lowland areas. Bee nests were also found within the tree trunks, cavities, boundaries of croplands, along roads, stream banks and even in some building and infrastructures. It is clear that although the study projected the species distribution and suitable habitat at least for *A. breviligula*, *A. cerana*, and *T. biroi*, the whole landscape plays significant role in the survival of native bees and should be the basis of management approach.

Conclusion

MBDL is rich in native species of bees. Solitary bee species representing families Colletidae, Halictidae, and Megachilidae were also recorded. Bee nests density was more than 230 nest per km^2 with nest of *A. breviligula*, *A. cerana*, and *T. biroi* being the most abundant. There is also high probability of finding these nests at lower elevation and the northern to north-eastern portions of MBDL. Bee nesting also showed affinity to vegetation features in the landscape such as distance from agricultural areas, distance from forest areas and NDVI were major contributor to nesting of these three native bees. Species distribution of native bees and its foraging were not limited to forest trees at higher elevation areas of MBDL. Native bees also build their nests and frequently visits agricultural crops and other vegetation at lowland areas. Therefore, it is only appropriate to adopt a landscape approach for the conservation of native bees in MBDL.

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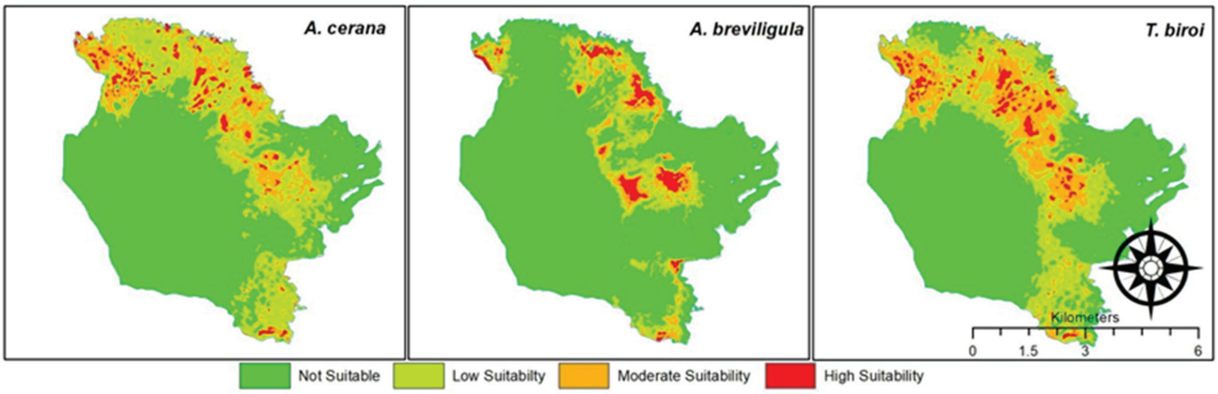

Fig. 5. Habitat suitability of *A. cerana, A. breviligula* and *T. biroi* in Mt. Banahaw de Lucban. Red color indicate high suitability for species.

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