A Preliminary Assessment of Bumble Bee (Hymenoptera: Apidae) Habitat Suitability Across Protected and Unprotected Areas in the Philippines

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Abstract

The Philippines is a biodiversity hotspot and is home to thousands of endemic species, including at least two understudied bumble bee species: Bombus flavescens Smith, 1952 and Bombus irisanensis Cockerell, 1910. Since the 1990s, there have been virtually no studies published on the biology, ecology, and taxonomy of Philippine bumble bees—evidence of the dearth of basic entomological investigations on these important insects. In this preliminary study, our objective is to briefly summarize the geographic distribution of bumble bee habitat suitability (HS) in the Philippines across protected and unprotected areas. Maximum entropy species distribution models (SDMs) of B. flavescens and B. irisanensis were constructed using 19 unique occurrence records and 11 bioclimatic variables to estimate HS in the Philippines. Our SDMs estimated that minimum HS for B. flavescens and B. irisanensis covers ~28,066 and ~24,603 km² of the 114 protected land parcels in the Philippines, respectively. Across unprotected areas, our SDMs estimated that minimum HS for B. flavescens and B. irisanensis covers ~146,063 and ~156,674 km², respectively. As predicted, high-elevation habitats have the highest HS relative to low-elevation habitats (r = 0.61, P = 0.003). While our SDMs predicts an extensive distribution of both species across both protected and unprotected areas, it is important to note that nearly 80% of the Philippines is deforested. Our study identifies high-elevation protected areas as places where bumble bees may still thrive, and survey effort should be prioritized to these places to determine the status of Philippine bumble bees.

Key words: Bombus flavescens, Bombus irisanensis, Philippines, southeast Asia, species distribution model

It is estimated that ~70% of the food humans consume is a product of animal pollination (Klein et al. 2007). Bumble bees (Bombus Latreille) are significant insect pollinators for numerous wild and agriculturally important flowering plants (Velthuis and Van Doorn 2006, Gallai et al. 2009, Potts et al. 2010). Their large body sizes, relatively long glossa (compared with Apis mellifera Linnaeus, 1758), abundance of plumose setae, and ability to sonicate poricidal anthers by rapidly contracting their thoracic flight muscles are traits that make them effective pollinators (King 1993, Velthuis and van Doorn 2006). In fact, 20 different bumble bee species (wild and managed populations) have been identified to be significant pollinators for a diversity of food crops across the globe (Kleijn et al. 2015). Like A. mellifera, several bumble bee species have been domesticated to deliver pollination services to food crops like tomatoes (Solanum lycopersicum), bell peppers (Capsicum annuum), and blueberries (Vaccinium ashei) (Velthuis and Van Doorn 2006, Strange 2015). Despite the value of bumble bees as pollinators, several species across the globe have declined in population size over the past several decades (Kosior et al. 2007, Cameron et al. 2011, Bommarco et al. 2012). The main anthropogenic activities that are suspected to be causing shifts in bumble bee community composition and population decline include 1) global climate change (Bartomeus et al. 2011, Miller-Struttmann et al. 2015, Biella et al. 2017), 2) the conversion from wild to agricultural or urban landscapes (McFrederick and LeBuhn 2006, Grixti et al. 2009), 3) pesticide misuse (Whitehorn et al. 2012), and 4) pathogen spread between commercially managed bee populations to wild populations (Cameron et al. 2011, Sachman-Ruiz et al. 2015, Dolezal et al. 2016).

Bumble bees are not a well-studied insect group in the Philippines. In fact, there have been at least four different papers published on Philippine bumble bee taxonomy and ecology (Cockerell 1920, Frison 1925, Starr 1989, Starr and Geronimo 1990). At present, there...
are two recognized bumble bee species in the Philippines, *Bombus* (*Pyrobombus*) *flavescens* Smith, 1952 and *Bombus* (*Megabombus*) *irisanensis* Cockerell, 1910 (Williams 2017). *Bombus irisanensis* is classified as 'Vulnerable' based on a preliminary investigation by the International Union for Conservation of Nature (IUCN) as no new specimens have been collected since the 1990s (Williams and Osborne 2009). Historically, both species were found to be distributed across high elevation mountain provinces in the Philippines (>1,500 m; Baltazar 1966, Starr 1989, Starr and Geronimo 1990). *Bombus flavescens* is not endemic to the Philippines, and likely belongs to a species complex that includes populations documented in the Himalaya, Myanmar, Thailand, Vietnam, Peninsular Malaysia, China, and Taiwan (Starr 1992; Williams et al. 2009, 2010; An et al. 2011). However, the phenotype exhibited by *B. flavescens* in the Philippines is different than the phenotypes found in other parts of Asia, and may prove to be a distinct species after careful systematic and taxonomic study (Duennes et al. 2017, Lecoq et al. 2016, Williams 2017). Finally, at the time of publication, the conservation status of *B. flavescens* has not been classified by the IUCN (http://www.iucnredlist.org/search).

Bumble bees are primarily identified by their color banding pattern of setal hairs on their body (Thorp et al. 1983). In fact, there have been 34 different names associated with *B. flavescens*, underscoring the effect of phenotype variability on the number of species descriptions proposed (Williams 2017). In the Philippines, the body color phenotype of *B. flavescens* (= *irisansensis* var. *baguioensis* Cockerell 1920) is described as having all parts of the head with black pubescence, dorsum of the metasoma and upper anterior corners of the pleura with black pubescence, and dorsum of the metasoma with yellow or fulvous-yellow pubescence on the first two terga, and the apical terga with red pubescence (Frison 1925; Fig. 1C). *Bombus irisanensis* appears to be endemic to the Philippines, and is primarily distributed in high-elevation habitats across all three major island regions (Cockerell 1920, Frison 1925). Unlike *B. flavescens*, there has been one name proposed for *B. irisanensis*, further evidence that this species is endemic to the Philippines, or that there is limited research on the taxa. Like *B. flavescens*, the head and dorsum of the mesosoma of *B. irisanensis* with black pubescence, pleura with yellow pubescence, the dorsum of the first two terga of the metasoma with yellow pubescence, and the remaining terga with black pubescence (Frison 1925; Fig. 1D).

The primary goals of this study are to 1) estimate *B. flavescens* and *B. irisanensis* habitat suitability (HS) in the Philippines with species distribution models (SDMs), and 2) identify the protected and unprotected areas in the Philippines that meet the minimum HS threshold estimated with the available specimen records. To meet our goals, we used maximum entropy to construct SDMs with specimen records and bioclimatic variables. Next, we applied geographic information systems techniques to quantify the distribution of bumble bee HS across protected and unprotected areas in the Philippines. Ultimately, the results of this investigation have the potential to guide future field surveys of bumble bees as SDMs can assist in the identification of areas with high HS, and therefore high probability of detecting the target species (Koch et al. 2016). Furthermore, the quantification of HS across protected areas provides a conservative estimate on the level of habitat protection that is available for bumble bees in the Philippines.

### Materials and Methods

We queried the Global Biodiversity Information Facility (GBIF) website (http://gbif.org) for bumble bee specimen records to be used in constructing SDMs. In addition to GBIF, we digitized label data associated with bumble bee specimens at the University of the Philippines Natural History Museum Entomological Collection (UPPC). If the locality information associated with the occurrence record was sufficient to be georeferenced, we used one of the following software tools to generate geographic coordinates: 1) GEOLocate web application (Rios and Bart 2010), 2) GeoHack (https://tools.wmflabs.org/geohack/), and 3) Google Earth Pro for Desktop (Google Inc. 2015). We did not include the specimen record in constructing SDMs if the locality description was too broad to be georeferenced (i.e., Island, Municipality).

To estimate HS, SDMs were constructed under the principle of maximum entropy with MaxEnt v3.3.1 implemented with the dismo package in R (Phillips et al. 2004). The algorithm in MaxEnt uses presence-only georeferenced spatial data and random background points sampled from the study extent to estimate the distribution of the species that is closest to uniform (=maximum entropy) under the suite of independent variables (i.e., bioclimatic variables) supplied to the model (Elith et al. 2011). HS is constrained between 0 and 1 where values closer to 0 represent low HS for the target bumble bee species, and values closer to 1 represent high HS for the target bumble bee species. Specifically, HS is a measure of how bioclimatically suitable an area unit is based on the known distribution (specimen occurrence record) of the target species.

SDMs are a useful tool for identifying locations with high HS but may be poorly surveyed to establish the presence of a target species (Koch et al. 2016). SDMs also have the potential to aid with species delimitation and the discovery of cryptic species complexes (Orr et al. 2014). Furthermore, SDM algorithms that only require presence data are known to successfully estimate HS, even with a limited amount of georeferenced occurrence data (Phillips et al. 2004, Wisz et al. 2008). Thus, even in poorly surveyed areas, a few specimen records that are broadly distributed can effectively estimate HS over the study landscape. Finally, applying SDMs of the target species with geographic information systems (GIS) data that spatially categorizes protected areas has the potential to inform effective management and conservation strategies (Kremen et al. 2008). Specifically, SDMs can provide a spatial framework that prioritizes areas with high HS for high habitat management priority and species monitoring, and areas of low HS for low habitat management priority and species monitoring.

We approximated HS for *B. flavescens* and *B. irisanensis* by aggregating occurrence records with a suite of 19 bioclimatic variables representing contemporary conditions (1950–2000) from the WorldClim v1.4 Bioclim database. The bioclimatic variables investigated included the following: BIO1 = Annual Mean Temperature, BIO2 = Mean Diurnal Range [Mean of monthly (max temp - min temp)], BIO3 = Isothermality (BIO2/ BIO7) (*100), BIO4 = Temperature Seasonality (standard deviation *100), BIO5 = Max Temperature of Warmest Month, BIO6 = Min Temperature of Coldest Month, BIO7 = Temperature Annual Range (BIO5-BIO6), BIO8 = Mean Temperature of Wettest Quarter, BIO9 = Mean Temperature of Driest Quarter, BIO10 = Mean Temperature of Warmest Quarter, BIO11 = Mean Temperature of Coldest Quarter, BIO12 = Annual Precipitation, BIO13 = Precipitation of Wettest Month, BIO14 = Precipitation of Driest Month, BIO15 = Precipitation Seasonality (Coefficient of Variation), BIO16 = Precipitation of Wettest Quarter, BIO17 = Precipitation of Driest Quarter, BIO18 = Precipitation of Warmest Quarter, and BIO19 = Precipitation of Coldest Quarter. Bioclimatic variables were downloaded at a spatial resolution of 2.5′ arc min and clipped to the spatial extent of the Philippine archipelago (Northernmost latitude: 20° Southernmost latitude: 5°, Easternmost...
Fig. 1. (A) Topographic map of the Philippines. Mountains, volcanoes, or mountain ranges* distributed throughout the three major island regions (Luzon, Visayas, and Mindanao) are labeled with lowercase Roman letters: a = Sierra Madre, b = Cordillera Central and Mount Pulag (2,922 m), c = Zambales Mountains, d = Mount Pinatubo, e = Mount Banahaw, f = Central Panay Range, g = Albinan Range, h = Kanlaon Volcano (2,465 m), i = Mount Talinis, j = Kitanglad Range and Mount Dulong-Dulong (2,941 m), k = Kalatungan Range, l = Mount Malindang, m = Mount Pipayungan (also known as Mount Ragang), n = Dugama Mountain Range, o = Kidapong Range, p = Mount Bunsu, q = Kisada Mountains, r = Mount Apo (2,954 m), s = Tandawan Mountains, t = Diuata Mountains (also known as Diwata Mountains), u = Mount Balatukan Range, v = Mount Mangabon, w = Mount Mayon, x = Mount Isarog, y = Mingan Mountains, z = Caraballo Mountains. Letters associated with a blue circle represent the highest peaks in the respective major island regions. The three major island regions are demarcated by dashed lines. (B) Distributed of protected areas in the Philippines, color-coded by the IUCN protected area management categories: IB = Wilderness Area, II = National Park, III = National Monument or Feature IV = Habitat/Species Management Area, V = Protected Landscape/Seascape, VI = Protected Area with Sustainable Use of Natural Resources. (C) Phenotype diagram and SDM of Bombus flavescens based on unique locality records (orange points). (D) Phenotype diagram of and SDM of Bombus irisanensis based on unique locality records (blue points). Phenotype diagrams illustrate the dorsum of the bumble bee body and general color patterns of specimens observed at the University of the Philippines-Los Banos Entomological Collection. In both (C) and (D) HS is constrained between 0 and 1 where values closer to 1 represent high HS and values closer to 0 represent low HS. *Not an exhaustive representation of all high-altitude landscapes.

To reduce model complexity, we examined the relationship between the 19 continuous bioclimatic variables with a pairwise Pearson correlation coefficient (r) test. From each pairwise correlation coefficient estimate, we randomly retained only one variable for the final model if r ≥ 0.75. If more than two specimen records fell within a raster pixel of the bioclimatic data, only one specimen record was retained for the final SDM. With the dismo package, we constructed the SDMs using the default parameters of the maxent function to generate a logistic output (a measure of relative HS), averaged over 100 replicates with a subsampling scheme to evaluate model performance (75% train, 25% test). Models were evaluated with the area under the curve (AUC) statistic, where AUC values closer to 1 suggest good model fit, and values closer to 0 suggest poor model fit (Phillips et al. 2004).

We estimated the distribution of HS for both species across protected areas in the Philippines using ArcGIS v10.1 (ESRI 2011). With the Spatial Analyst Toolbox, we clipped the HS logistic raster outputs from the SDMs to the ‘Protected Areas on Land’ polygon data downloaded from the PhilGIS website (http://philgis.org/general-country-datasets/protected-areas). We then used the lowest HS value associated with a locality record as a threshold of HS to determine the geographic spread of HS based on the current SDMs. Finally, as B. flavescens and B. irisanensis have historically been detected in montane regions, we tested for a correlation between average altitude (m) and average HS across with a Spearman Rank-Order Correlation test (r). Except for raster processing and map visualization, all statistical analyses were conducted with R v3.142 (R Core Development Team 2014).

Results

We compiled a total of 147 specimen records between GBIF and UPPC, of which there are 69 B. flavescens records and 78 B. irisanensis records (Supp Table 1 [online only]). Of these specimen records, there were a total of 8 B. flavescens and 11 B. irisanensis unique locality records available to use in constructing SDMs. The B. flavescens records examined in this study were documented from Cordillera Central (b) and Mount Banahaw (z) in Luzon, Mount Canlaon (v) and Mount Talinis (w) in the Visayas, and Mount Malindang (l) in Mindanao (Fig. 1A and B). The B. irisanensis records in this study were documented from the Cordillera Central (b), Mount Banahaw (z), Mount Isarog (x), and Mount Mayon (y) in Luzon (Fig. 1A and C). After accounting for autocorrelation between predictor bioclimatic variables, we used the following seven bioclimatic

![Fig. 2. Average habitat suitability across altitude (m) for B. flavescens and B. irisanensis in the Philippines.](https://academic.oup.com/aesa/article-abstract/112/1/47/5214003)
variables to construct SDMs to predict HS: BIO1 = Annual Mean Temperature, BIO2 = Mean Diurnal Range (Mean of monthly (max temp – min temp)), BIO3 = Isothermality (BIO2/BIO7) (+ 100), BIO7 = Temperature Annual Range (BIO5-BIO6), BIO16 = Precipitation of Wettest Quarter, BIO18 = Precipitation of Warmest Quarter, BIO19 = Precipitation of Coldest Quarter. Average AUC for the *B. flavescens* SDM was 0.89 (SD = 0.07) and average AUC for the *B. irisanensis* SDM was 0.88 (SD = 0.06). The lowest HS value associated with *B. flavescens* and *B. irisanensis* locality records are HS = 0.11 and HS = 0.14, respectively. As expected (based on natural history records and published literature), both SDMs predict that *B. flavescens* and *B. irisanensis* HS is greatest in montane regions of the Philippines, particularly the Cordillera Central (b) in Luzon and the Central Panay Range (f) in the Visayas; and the Kitanglad Range and Mount Dulang-Dulang (j), Kalatungan Range (k), Mount Busa (p), Mount Apo (r), Tandawen Mountains (s), Mount Balatukan Range (u), and Mount Mangabon (v) in Mindanao (Fig. 1A, C, and D).

Based on the PhilGIS protected areas on land (PAL) polygon data, there are a total of 114 PAL parcels in the Philippines classified by the IUCN. The IUCN classifies the PAL parcels into six categories: IB = Wilderness Area, II = National Park, III = National Monument or Feature, IV = Habitat/Species Management Area, V = Protected Landscape/Seascape, and VI = Protected Area with Sustainable Use of Natural Resources (Fig. 1B). In total, the 114 PAL parcels investigated in this study cover ~19% (57,457 km²) of the total land area in the Philippines (~301,780 km²). On a minimum threshold of 11% HS, the estimated total area associated with *B. flavescens* HS in protected areas is ~28,066 km² (~48.8%). Next, based on a minimum threshold of 13% HS, the estimated total area associated with *B. irisanensis* in protected areas is ~24,603 km² (~42.8%). In unprotected areas, our SDMs found *B. flavescens* and *B. irisanensis* HS to be distributed across ~146,063 km² (~48.8%). The IUCN classifies the PAL parcels into six categories: IB = Wilderness Area, II = National Park, III = National Monument or Feature, IV = Habitat/Species Management Area, V = Protected Landscape/Seascape, and VI = Protected Area with Sustainable Use of Natural Resources (Fig. 1B).

**Discussion**

In this study, we constructed preliminary SDMs with limited *B. flavescens* and *B. irisanensis* specimen occurrence records and bioclimatic variable dataset. *Bombus flavescens* and *B. irisanensis* SDMs predict a broad latitudinal distribution of HS in the Philippines (Fig. 1C and D), restricted primarily to montane environments (Fig. 2). Based on the minimum HS threshold associated with available specimen occurrence records, PALs are estimated to be very suitable for both *B. flavescens* (~48.8% total area with >0.11 HS) and *B. irisanensis* (~42.8% total area with >0.13 HS) (Fig. 1). However, as habitat degradation is the primary threat to biodiversity in the Philippines (Bankoff 2007, Suarez and Sajise 2010), we strongly encourage an assessment of Philippine bumble bees to assess their contemporary status in PALs.

Compared with investigations being pursued in North and South America, Europe, East Asia, and New Zealand, bumble bee research is lacking in the Philippines. It has been nearly 30 years since a study on Philippine bumble bee species has been conducted. Our estimation of HS for *B. flavescens* and *B. irisanensis* is a significant step in evaluating the potential distribution of these species in the Philippines. Based on historic investigations and available data compiled in this study, regions in the Philippines that should have high priority for future bumble bee investigations include Baguio (16.4167° N, 120.6000° E), Mt. Irig (13.6592° N, 123.3733° E), and Mt. Apo (6.9875° N, 125.2708° E). Furthermore, a concerted effort to digitize bumble bee specimens across natural history collections in the Philippines, as well as from collections in Asia, Europe, and the Americas will improve the resolution of *B. flavescens* and *B. irisanensis* SDMs. Finally, there is a strong need to conduct taxonomic revisions and a systematic investigation of Philippine bumble bees using molecular and ecological data.

**Supplementary Data**

Supplementary data are available at *Annals of the Entomological Society of America* online.

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