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Revisiting environmental management zones toward conserving globally important species in western Philippines

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ABSTRACT

The establishment of environmental management zones is an important strategy for biodiversity conservation. However, identifying and assigning appropriate zones is a challenging task that is critical to the management's success. The Environmentally Critical Areas Network (ECAN) of the Palawan province is among the management strategies being implemented in the western Philippines. Under this strategy, natural resources needing the highest degree of protection are designated as core zones (CZ). Our study revisited this strategy to assess the current placement of the core zones with respect to species distributions and vegetation types. We conducted a series of field surveys in four municipalities of Palawan to assess the status of biodiversity. Gathered data was used to identify potential critical habitats by generating species distribution models and performing vegetation analysis using land satellite images. The placement of the CZ was evaluated using the identified critical habitats. Our assessments show that many Palawan endemic species persist despite increasing pressures from anthropogenic activities. We also found that a considerable extent of natural forest remains, generally confined in high elevations and steep terrains. The assessment of critical habitats and CZ revealed vital gaps in protection, suggesting that a revision is necessary to accommodate important habitats of threatened and endemic species. Overall, our study highlights the significance of integrating biodiversity data in improving conservation and management strategies, which has been overlooked in the current ECAN zones.

1. Introduction

The loss of natural habitats has negatively impacted the composition, population, and ecological function of many species, resulting in a global biodiversity collapse (Laurance et al., 2012; Ceballos et al., 2015; Ripple et al., 2017). Preventing biodiversity collapse while meeting human needs is among the utmost challenges of the present generation (Foley et al., 2011). In recent years, there have been reports of an increasing number and coverage of protected areas (PAs) globally to conserve biodiversity (Soutullo, 2010; Lewis et al., 2019). However, there is little information available about their success and how well they perform (Mallari et al., 2013). A recent analysis of PA conditions in the tropics revealed that many are still under threat of continued exploitation (Laurance et al., 2012). But despite the dwindling conditions of biodiversity in many PAs, the creation of PAs continues to be the most effective method for conserving biodiversity (Lewis et al., 2019).

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To strengthen the protection of biodiversity, studies suggest that key threats found within and outside of protected areas must be addressed directly (Laurance et al., 2012), reinforced by appropriate management programs such as the designation of critical habitats as the core of protection (Mallari et al., 2015).

Critical habitats (CHs) are defined as areas or habitats containing features significant to the conservation of endemic and threatened species (US Endangered Species Act of 1973; PCSD AO 12 series of 2011). Determining CHs for protection is an essential component of natural resource management. However, it is a challenging task that requires careful examination of species distribution, population size, habitat requirements, and threats. Identification of CHs globally is based mostly on species occurrences, with relatively few studies taking into account the data derived from species habitat suitability/requirement model, and population viability analysis (Camaclang et al., 2015). Therefore, having such information is vital to the success of identifying CHs, particularly in the tropics.

The tropical region has extremely rich biodiversity but also has the highest number of areas identified as hotspots for conservation (Mittermeier et al., 1998; Myers et al., 2000). The Philippines is among those with highly diverse and unique compositions of species but is under threat from anthropogenic activities (Posa et al., 2008; Brown & Diesmos, 2009). To inform and guide conservation efforts in the country, conservation priority sites were identified in the early 2000s (Mallari et al., 2001; PBCPP, 2002). However, after 20 years, 64% of the priority sites remain unprotected including a large portion of Palawan province in the western Philippines (Ambal et al., 2012; Mallari et al., 2015). The Palawan province is located between the West Philippine Sea and the Sulu Sea, with a total land area of ca. 14,600 km^2, and is considered an extension of Sunda Shelf landmasses due to the presence of several vertebrate species that Borneo and the Palawan Island Group share, and the notion that Palawan was previously linked to the Sunda Shelf (Dickerson et al., 1928; Inger, 1954; Heaney, 1991; Esselstyn et al., 2010). The province has retained approximately 48% of its original forest cover (PCSD, 2015), which is essential for its many forest-obligate endemic and threatened species. At present, more than 1700 plant species and 450 terrestrial vertebrates are known to occur in Palawan (Diesmos & Palomar, 2004; Madulid, 2002; PCSD, 2015), but given continuous biodiversity inventories and taxonomic revisions, this estimate is likely to change in the coming years (e.g., Brown & Guttman, 2002; Brown et al., 2016).

In 1993, the Philippine government through the Palawan Council for Sustainable Development (PCSD) began establishing the Environmentally Critical Areas Network (ECAN), a graded zoning scheme developed to protect and guide the management of Palawan's remaining natural resources (both terrestrial and marine; see Philippines Republic Act 7611). Under this strategy, natural resources needing the highest level of protection are classified as core zones, followed by less stringent zones (buffer and multiple-use zones). The first maps of ECAN zones were drafted in 1994 (PCSD Resolution No. 94-44; PCSD, 2015), but it was based solely on topographic and land classification data. Because of the limited data during its creation, the zones were updated and improved in 2001 by integrating vegetation data. In 2005, revisions were made again by considering the infrastructure development programs and other ongoing projects of municipalities. Since then, the zones are regularly updated by each municipality to integrate new data and adjust to current developments. However, with all these changes, none have considered integrating biodiversity data. Recent analyses of critical habitats of important species and the current ECAN zones revealed multiple mismatches where the core protection zones are not appropriately positioned to safeguard the endemic and threatened species of Palawan (CCI, 2018; Mallari et al., 2020; Supsup & Asis, 2018).

Here we revisited Palawan's environmental management strategy by examining the present placement of ECAN zones with respect to species distributions and vegetation types, which were not considered during the creation of the zones. Our study differs from previous assessments of CCI (2018) and Supsup and Asis (2018) as we used amalgamated field-based biodiversity data to generate an ensemble stacked species distribution model, mostly for Palawan endemic species, and used remotely sensed data to evaluate the vegetation status of four municipalities: Busuanga, El Nido, Roxas, Balabac. By using species distribution models and vegetation maps, we explicitly identify key habitats or areas of highest value. We then use this data to assess the placement of ECAN zones in the four municipalities, with a focus on the core protection zones.

2. Materials and methods

2.1. Study sites

Our study was conducted in the four municipalities of Palawan: the municipalities of Roxas and El Nido, found in the northern part of mainland Palawan; the municipality of Busuanga, situated on the western side of Busuanga Island (including Calauit Island) from the northernmost region of Palawan; and the island group municipality of Balabac, located at the southernmost tip of Palawan (Fig. 1). Mountain Ranges in these areas reach between 400 and 600 m asl. Natural vegetation is composed mostly of lowland dipterocarp forests, with beach and mangrove forests found along the coasts (Mallari et al., 2001). A few areas of El Nido and adjacent islands have forests over limestone rocks. The northern portion of Palawan (including the Busuanga and Calauit Islands) has two pronounced seasons: dry from November to April and wet during the rest of the year. This area has an annual mean temperature and precipitation of 27.10 °C and ca. 2350 mm, respectively. Whereas, southern Palawan (including the Balabac islands) does not have very pronounced seasons; many areas are relatively dry between November to April and wet throughout the year. The region has an annual mean temperature of 26 °C and receives annual mean precipitation of 1749 mm (DOST-PAGASA, 2022; Fick & Hijmans, 2017). We conducted our biodiversity and vegetation surveys in 2018 and 2019, at the onset of the wet season. Specific sites and dates are outlined in Table 1.

2.2. Biodiversity surveys

A 2-km transect line was used as the main method for the biodiversity survey. Sampling plots and shorter transect lines used for different taxonomic groups were positioned systematically along the transect. Transect lines were established to cover different habitat types (cultivation, secondary growth, old-growth forest) at approximately 250 m apart to avoid pseudo-replication or double counting of individuals, particularly for highly mobile species such as birds. A total of twenty-six 2-km transect lines were established in four municipalities. The following are the survey methods used for each taxonomic group: (1) Avifauna was sampled using the 2-km transect line, following Mallari et al. (2011). A combination of line and point count methods was employed while traversing the transect. Point count stations were positioned at every 250 m. Each transect was visited once, beginning at 06:00–1030 hr. Point count was done in each station for 8 min to avoid pseudo-replications, following Lee and Marsden (2008). Species encountered (audiovisual means) were recorded including the number of individuals. Activities upon first notice such as foraging and calling were also noted; (2) Herpetofauna was sampled using ca. 1 km of the main transect with nested strip transects of 10 × 100 m, following Supsup et al. (2016) and Supsup et al. (2020). Each transect was surveyed once by three persons at night between 1830 and 2200 hr with a few daytime visits from 0800 to 1100 hr. We searched all microhabitats such as rock crevices, tree buttresses, leaf litters, and deadwood. Species found within the transect were recorded, including the number of individuals and activity upon first notice; (3) Mammal surveys were conducted using a 12 m mist net for bats and camera traps for non-volant mammals. We followed the standard field techniques of Heaney (1999)

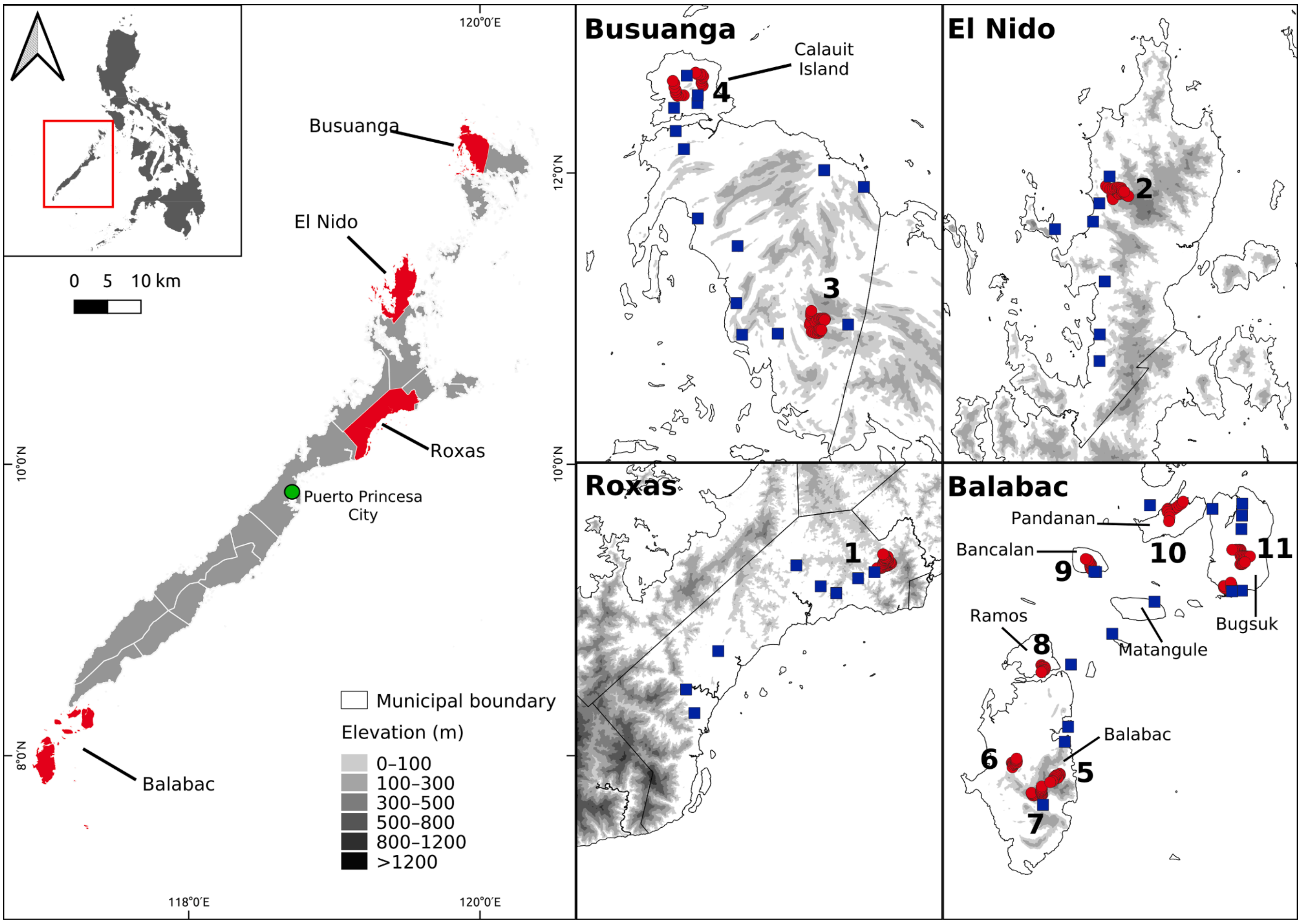

Fig. 1. Map of Palawan Province in the western Philippines (inset map), showing the location of the municipalities of Roxas, Balabac, El Nido, and Busuanga (left panel). The small panels on the right show the biodiversity survey locations (marked by numbers and red points) and vegetation assessments (blue squares). The incremental gray shading indicates the elevation contour. See Table 1 for a complete list of survey sites. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Location of survey sites in the municipalities of Roxas, El Nido, Busuanga and Balabac.

Site no.	General locality	Specific locality	Longitude	Latitude	Date of survey
1	Municipality of Roxas	Barangay Antonino	119.508772	10.439195	July 21–26, 2019
2	Municipality of El Nido	Barangay Pasadena	119.445055	11.25325796	July 28 –August 2, 2019
3	Municipality of Busuanga	Barangay Sagrada	120.006115	12.10185299	August 10–14, 2019
4	Municipality of Busuanga	Calauit Island	119.894191	12.29400996	August 14–17, 2019
5	Municipality of Balabac	Barangay Malaking Ilog	117.0612	7.9331	July 04–06, 2018
6	Municipality of Balabac	Barangay Catagupan	116.9963	7.9501	July 07–08, 2018
7	Municipality of Balabac	Barangay Indalawan	117.035129	7.911886	October 25–29, 2019
8	Municipality of Balabac	Ramos Island	117.0297	8.079	July 08–10, 2018
9	Municipality of Balabac	Barangay Bancalaan	117.10364	8.21907	October 30–November 1, 2019
10	Municipality of Balabac	Barangay Pandanan	117.208012	8.301865	November 01–03, 2019
11	Municipality of Balabac	Bugsuk Island	117.3153	8.238	July 12–15, 2018

and Heaney et al. (1998) for mist nets sampling. Ground and sky nets were established along the transect line. Nets were visited regularly during the day and at night. Nighttime watch for mist nets was conducted between 1800 and 2100 hr. Mist nets were left in the same location for 2–3 consecutive days and nights. Camera traps were set up mostly in potential pathways of animals (e.g., fallen logs and deadwood). Camera traps were also left on the same spot for 2–3 consecutive days and nights; and (4) Floristic surveys were done along the transect, using a 20 m circular plot with a 10 m nested plot. Plots were positioned at every 250 m along the transect. The circular plot method was employed over the typical quadrat technique to allow the assessment of vegetation types based on the relative successional stages initiated by Mallari (2009) and Mallari et al. (2011) for Palawan, which we used later in our vegetation analysis. A detailed vegetation assessment was conducted within the 10 m plot where the presence of understory and midstory plants (palms, pandan, rattan, herbs) and other environmental variables were recorded. The 20 m circular plot was used only to record tree species. Broad vegetation types (cultivation, early and advanced secondary growth forest, old-growth forest) were recorded at every 50 m. The description of each vegetation type is provided in Table 2.

Table 2
Description of vegetation types based on successional stages used in satellite imagery classifications.

Vegetation types	Description
Cultivation (CVT)	Areas with active or recently abandoned farmlands, grasslands, brushlands, and settlements.
Mangrove (MGR)	Mangrove vegetation found in coastal areas.
Early secondary growth forest (ESG)	Areas of newly regenerating forest (<20 years old), dominated by samplings and small to medium trees.
Advanced secondary growth forest (ASG)	Forest areas with less dense understory and dominated by medium to large trees (20–40 years old).
Old growth forest (OGF)	More than 40 years old forest, dominated by large trees and with less complex understory.

2.3. Vegetation analysis

To generate the vegetation maps in the four municipalities, we collated and analyzed a set of 2019 Landsat 8 OLI and Sentinel-2 satellite images provided by the United States Geological Survey (https://earthexplorer.usgs.gov). We used Landsat 8 images for Busuanga and El Nido, acquired on 25 April and 05 February, respectively. Whereas, Sentinel-2 images were used for Roxas (acquired on 20 September) and Balabac. Two sets of images were used for Balabac: images acquired on 01 April for mainland Balabac, Ramos, and small adjacent islands, and images for islands of Bugsuk, Pandanan, Bancalan, and Matangule acquired on 02 December. We performed the vegetation types classification using a decision tree classification algorithm implemented in the *rpart* package of R v. 4.2.2 (R Core Team, 2022). This algorithm uses a tree structure to determine the best classification model that fits the data. The decision tree classification begins with the best predictor (in this case, satellite imagery band) and continually subset the data using if/else decisions (tree nodes). The outcomes of these decisions become the vegetation classes (tree leaves; Friedl & Brodley, 1997). To train the classification, we used geographic points of vegetation types assessed during surveys including areas that were visited outside the sampling sites (Fig. 1). Additional data points/regions of interest (ROI) were also created around our survey sites to increase the number of samples (a full list of training points is provided in Supplementary File 1). Vegetation types were classified based on relative successional stages (Table 2), following the classification of Mallari et al. (2011). Due to the difficulty in classifying advanced secondary-growth and old-growth forests because of overlapping wavelengths, these vegetation types were combined. Prior to any image classification, all satellite images were trimmed using the municipal boundary to remove areas outside the study region. Images were also calibrated using Quantum GIS (QGIS) v 3.16 to have a uniform extent, coordinate reference system (CRS; WGS84), and spatial resolution of 30 m for Landsat and 20 m for Sentinel-2. Then, cleaned images were imported to R for classification analysis. We evaluated the accuracy of classification using a confusion matrix where the predicted classes were compared to the observed classes. Vegetation types in all municipalities were classified well, with accuracy scores from 85 to 94% (Supplementary File 2, Table 1). Post-processing of classified vegetation types was performed on areas with no data due to cloud cover and misclassified small pixels were manually edited based on the assessments of the authors, aided by high-resolution satellite images available on Google Maps.

2.4. Species distribution modeling

We developed species distribution models (SDMs) for 49 species (seven plants, eight amphibians, nine reptiles, 15 birds, and 10 mammals) composed mostly of Palawan endemics. Highly celebrated Palawan endemic species included in our model were the Palawan Toadlet (*Peleophryne albotaeniata*), Philippine Flat-headed Frog (*Barbourula busuangensis*), Palawan Hornbill (*Anthracoceros marchei*), Palawan Peacock-Pheasant (*Polyplectron napoleonis*), Palawan Pangolin (*Manis culionensis*), Balabac Mouse Deer (*Tragulus nigricans*) and Palawan Medinilla (*Medinilla palawanensis*). Although some species were not detected during surveys, we included them in our model to account for species potentially present in our sampling sites, particularly species restricted to Palawan (a complete species list is provided in Supplementary File 1). The SDMs were generated using presence-only records with climatic and vegetation data as environmental predictors. Occurrence records were collected during surveys, supplemented by data from Global Biodiversity Information Facility (https://www.gbif.org/). To reduce the effects of spatial autocorrelation, species records were filtered by removing duplicate records within 1 km^2, followed by further removal of records that fall shorter than the minimum significant autocorrelated distance when the relatedness of predictors and occurrences is considered (see Boavida et al., 2016; Assis, 2020). We obtained 19 bioclimatic layers from World Climate Database v. 2.0 (Fick & Hijmans, 2017; https://www.worldclim.org/) and vegetation cover of 2019 from European Space Agency (https://www.esa-landcover-cci.org/). We selected the 2019 vegetation data to match the observation period of species records. Although vegetation analysis was performed for each municipality, we did not use the results because our model was projected throughout Palawan to take advantage of the records from other localities and to increase the predicting power of our model. We performed Pearson correlation analysis to remove highly correlated environmental predictors, retaining only 10 for the final model (Supplementary File 2, Table 2). These include 2019 vegetation types, annual mean temperature (BIO1), mean diurnal range (BIO2), isothermality (BIO3), temperature seasonality (BIO4), temperature annual range (BIO7), annual precipitation (BIO12), precipitation of driest (BIO17) and warmest (BIO18) quarters, and precipitation of coldest quarter (BIO19). All datasets were processed and calibrated using QGIS, having a uniform extent, CRS (WGS84), and spatial resolution of ca. 1 km^2.

Species distribution models were constructed using an ensemble approach or combining results from different modeling algorithms implemented in the *SSDM* package of R v. 4.2.2 (Schmitt et al., 2017; R Core Team, 2022). Algorithms used include Maximum Entropy (Maxent), Classification Tree Analysis, Generalized Linear Models, Support Vector Machines, and Random Forests. We chose these algorithms because they can perform well with few occurrence records and can handle both categorical and continuous data (Hernandez et al., 2006; Wisz et al., 2008). We treated vegetation as categorical and the rest as continuous data in our model. The ensemble model was evaluated using the Area under the Receiver Operating Characteristic Curve (AUC). A

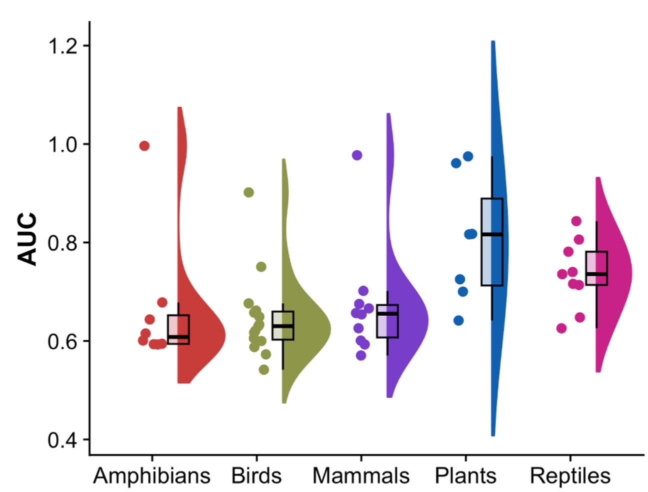

Fig. 2. AUC values of the fitted ensemble species distribution models denoting the accuracy of generated models for 49 species (seven plants, eight amphibians, nine reptiles, 15 birds, and 10 mammals). A model with an AUC value close to 1 is considered excellent.

model with an AUC value close to 1 was considered excellent. The results of ensemble models range from fairly good to excellent (Fig. 2). To generate a species richness map, all species distribution models were stacked by summing the probabilities of prediction. The stacked SDM (sSDM) was generated for the entire Palawan, then results for each municipality were extracted to represent the final model.

2.5. Critical habitat identification and ECAN core zone assessment

We identified critical habitats using the results of vegetation analysis and species distribution model. First, we determined the habitat importance by intersecting the generated sSDM (species richness) and vegetation map, allowing us to classify areas as: Not important (CVT with < 16 species), Very low importance (CVT with ≥ 16 species), Low importance (ESG with < 16 species), Moderate importance (ESG with ≥ 16 species), High importance (ASG/OGF and MGR with < 16 species) and Highest importance (ASG/OGF and MGR with ≥ 16 species). We used the threshold of 16 in our classification or the mean number of species predicted to be present in all municipalities. Second, we isolated areas with the high and highest importance to consider as critical habitats. Areas that were too small (<100 m^2) to be considered critical habitats were excluded. Lastly, to assess the placement of ECAN core zones, we intersected the zone with the extent of critical habitats. Areas with the overlapping extent of both critical habitats and core protection zones (CH & CZ) were appropriately positioned to protect ecologically important species. Whereas, critical habitats with no core zones (CH only) and core zones with no identified critical habitats (CZ only) were considered areas with a potential mismatch. All codes and documentations (R markdown HTML files) of the analyses performed above are available on GitHub (https://github.com/csupsup/CritHabPalawan).

3. Results

3.1. Species profile

We recorded a total of 312 species (137 flora, 107 birds, 14 frogs, 31 reptiles, and 23 mammals) with one new island record for reptiles (Perkin's Short-headed Snake *Oligodon perkinsi*; see Supsup & Carestia, 2020) on Busuanga and a country record for flora (*Scorodocarpus borneensis*; see Domingo et al., 2021). A relatively high level of endemicity was observed in birds, mammals, amphibians, and reptiles (Fig. 3). The conservation status of most species detected based on the International Union for Conservation of Nature (IUCN) is Least Concern, with one Critically Endangered (Philippine Cockatoo *Cacatua haematuropygia*) and five Endangered (Red-Headed Flameback *Chrysocolaptes erythrocephalus*, Apitong *Dipterocarpus grandiflorus*, Kamagong *Diospyros philippinensis*, Palawan Pangolin *Manis culionensis*, Philippine Mouse Deer *Tragulus nigricans*). Other threatened species observed include Nato *Palaquium luzoniense*, Great Slaty Woodpecker *Mulleripicus pulverulentus*, Palawan Hornbill *Anthracoceros marchei*, Palawan Peacock-Pheasant *Polyplectron emphanum*, Palawan Flat-headed Frog *Barbourula busuangensis*, Palawan Litter Frog *Leptobrachium tagbanorum*, Smooth-scaled Narrow-disked Gecko *Gekko athymus*, Schultze's Pit Viper *Boiga schultzei*, Palawan Rat Snake *Coelognathus philippinus*, and Palawan Fruit Bat *Acerodon leucotis* (for a complete species list, see Supplementary File 1). These observations only show that many endemic and threatened species are still occurring in the remaining suitable habitats of Palawan.

3.2. Vegetation status

Our analyses of 2019 land satellite images revealed that a significant extent of natural vegetation remains in four municipalities, confined mostly in high elevations and steep terrains (Fig. 4a, 5a). In Busuanga (land area: 45,251 ha; 126 ha - unclassified, no data), 30.4% is retained as ASG/OGF, found mostly in the interior. Approximately 65.8% is ESG and CVT (including built-up), abutting the edges of ASG/OGF and extending to coastal areas. The remaining 3.8% are patches of MGR distributed around Calauit Island to the western coast of the municipality. El Nido (land area: 56,590 ha; 2,010 ha - unclassified, no data) has 46.6% of ASG/OGF, found in the interior and on small islands over limestone rocks from the west of the municipality. Forty-nine percent is ESG and CVT, and 4.4% of MGR occurs along the eastern and western

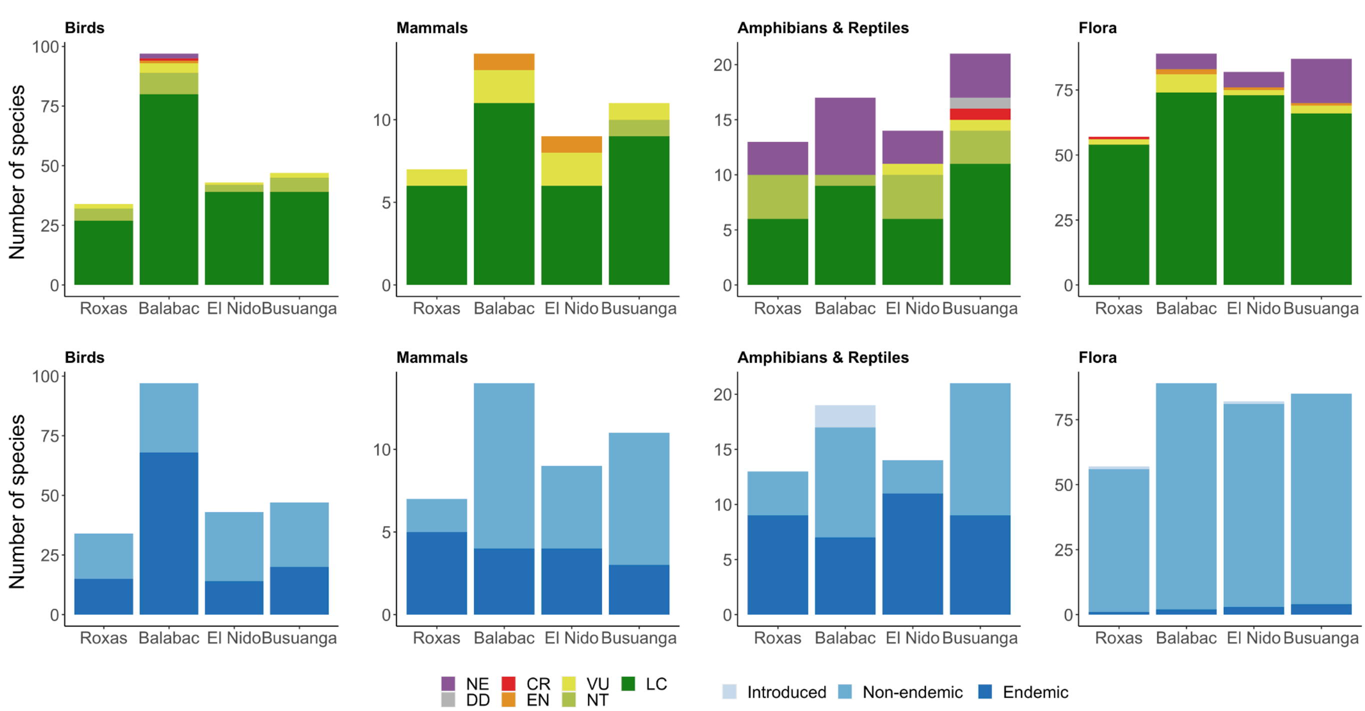

Fig. 3. Totals of species recorded in municipalities of Roxas, Balababac, El Nido, and Busuanga and the proportions of endemic and non-endemic species and their conservation status based on IUCN (2022). Categories were abbreviated as: CR- Critically Endangered, EN - Endangered, VU - Vulnerable, NT - Near Threatened, LC - Least Concern, DD - Data Deficient, NE - Not Evaluated.

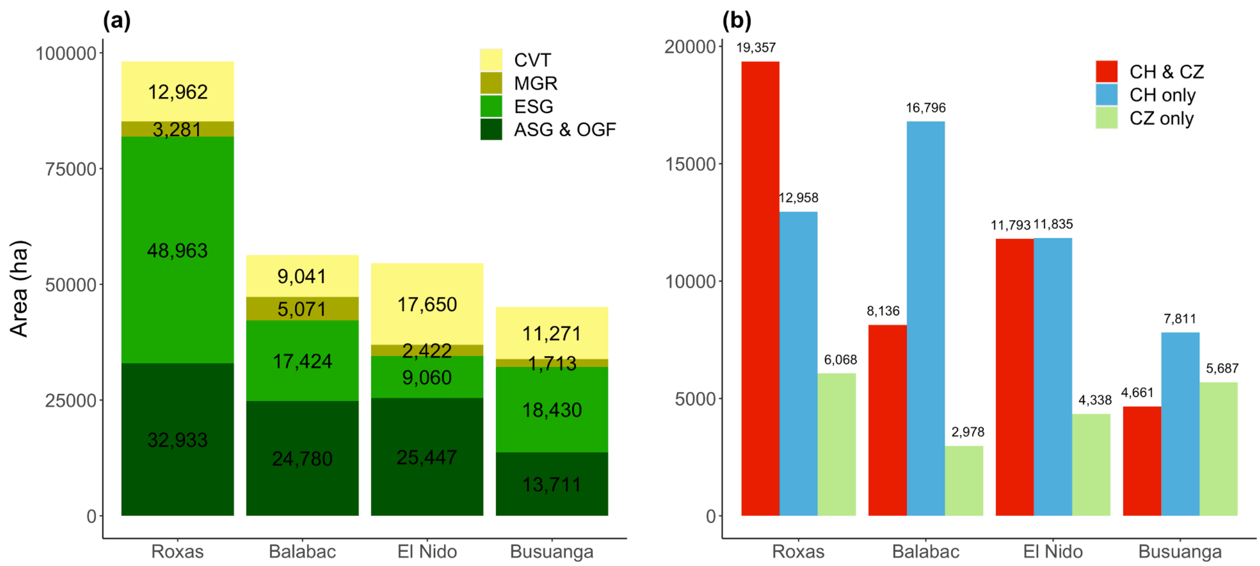

Fig. 4. The estimated extent of vegetation types (a) and total area of the identified critical habitats with core protection zone (CH & CZ), critical habitats with no protection (CH only), and core protection zone with no identified critical habitats (CZ only; b) in the municipalities of Roxas, Balabac, El Nido, and Busuanga. Maps showing the mismatch between the extent of identified critical habitat and core protection zone were provided in Fig. 5d. Vegetation types were coded as follows: CVT - Cultivation, MGR - Mangrove, ESG - Early Secondary Growth Forest, ASG - Advanced Secondary Growth Forest, and OGF – Old-growth Forest. Areas were calculated in hectares.

coasts. Roxas (land area: 98,138 ha) has 33.5% of ASG/OGF, found in high elevations of the southern and northern borders. The 63.0% is ESG and CVT, found in the lowland areas. Mangrove forests (3.3%) are found mostly along estuaries and coastal areas. Balabac (land area: 56,394 ha; 78 ha - unclassified, no data) has 44.0% of ASG/OGF, mainly found on mainland Balabac, Bugsuk, and Pandanan. The 46.9% is ESG and CVT, with large portions located on mainland Balabac and on smaller islands of Ramos, Bancalaan, and Matangule. The 9.0% MGR surrounds most of the islands, particularly on mainland Balabac.

3.3. Critical habitats and gaps in protection

A total of 93,346 ha of critical habitat was identified based on areas with high and highest importance (Fig. 4b, 5a–d). Our results show that there are notable differences between the extent of the core zones and critical habitats. Only 47.0% of the critical habitats fell within the coverage of core zones. The remainder fell into less protected zones such as restricted and controlled-use zones (Supplementary File 2, Fig. 1). This is evident in four municipalities, particularly in Balabac where the islands of Bugsuk and Pandanan have virtually no core protection zones. In other municipalities, the core zones and critical habitats in high elevations seemingly are aligned, but a large belt of critical habitats in lowland areas of El Nido and Busuanga has no core zones. Our results also indicate that there were areas with core zones, but no identified critical habitats. These are found mostly along coastal areas, small islands, and forest edges. Hence, these results only suggest that a gap exists in the current ECAN zones.

4. Discussion

Our study demonstrates the importance of field-based assessment of biodiversity coupled with systematic analyses to improve the design of environmental management zones, which was overlooked during the creation and previous revisions of Palawan's Environmental Critical Areas Network (Supsup & Asis, 2018). Our results show that patterns of species compositions may vary in many areas, and that localized identification of critical habitats can provide invaluable information for biodiversity management and conservation.

A regular assessment and monitoring of biodiversity can provide up-to-date information on endemic and threatened species. Our recently completed surveys revealed that many Palawan endemics are still widespread and abundant in habitats where they are known to occur. For instance, populations of previously listed threatened species such as the Philippine Flat-headed Frog and Busuanga Wart Frog were believed to have been reduced significantly in the past years (IUCN, 2022). However, because of the sustained initiatives to survey and resurvey the many remote localities of Palawan, their population was documented to remain abundant, resulting in downlisting of their conservation status (Gonzalez, 2018). Some species are poorly known despite their conservation importance e.g., the Calamian Deer and Philippine Mouse Deer (Supsup & Asis, 2018; Supsup et al., 2021), which is probably due to limited efforts to study these species. Other species are suffering from continued loss of natural habitat and direct persecution (Quinnell & Balmford, 1988; Diesmos & Palomar, 2004; Supsup et al., 2021). For instance, the endangered Palawan Pangolin and critically endangered Philippine Cockatoo have suffered significant population decline in recent years (Schoppe, 2008). As a result, their populations became small and restricted to a few localities. During our surveys, locals reported that Palawan Pangolin is still present in El Nido, however, we failed to detect the species. Whereas, the Philippine Cockatoo had a fairly good population on Balabac, Bugsuk, and Pandanan Islands.

The results of land satellite image analyses revealed that a relatively good proportion of natural vegetation was left in four municipalities, suggesting that suitable habitats for many forest-obligate endemic and threatened species are still available. However, much of this is currently under threat of degradation. Between 1990 and 2010, Palawan's natural forest was reduced from 55 to 48 percent, with an annual forest loss of roughly 5500 ha/year (PCSD, 2015; Supsup et al., 2020). The primary causes of forest loss include forest conversion to agricultural plots, infrastructural development, quarrying, and large-scale mining (PCSD, 2015). The forest loss is particularly evident in four municipalities where most forests are becoming restricted to high elevations and steep terrains. With ongoing degradation, many remaining forests are on the brink of collapse. Despite having the ECAN zones as a protective measure, it is inadequate because of the frequent changes (mostly favoring urban development), some inappropriate classifications, and not well-monitored implementation (Supsup & Asis, 2018; Supsup et al., 2021).

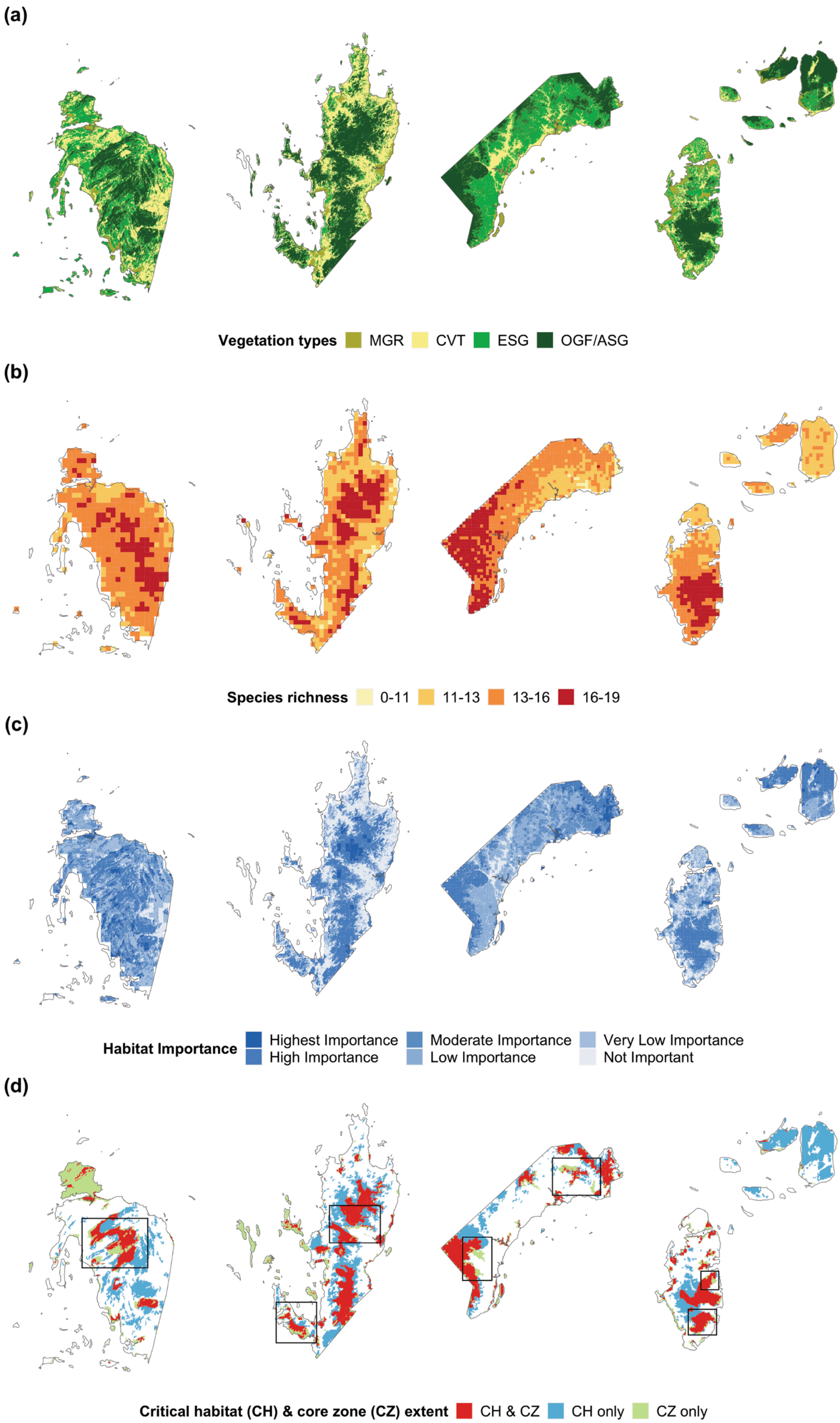

Fig. 5. Maps of vegetation types (a) in the municipalities of Busuanga, El Nido, Roxas, and Balabac (left to right) derived from 2019 land satellite images, the stacked species distribution models of 49 endemic species (b), the classified importance of habitats based on the intersection of vegetation types and stacked species distribution models (c; see methods for classification details), and (d) the identified critical habitats with core protection zone (CH & CZ), critical habitats with no protection (CH only), and core protection zone with no identified critical habitats (CZ only; small boxes denote areas of no critical habitat along forest margins). Vegetation types were coded as follows: CVT – Cultivation, MGR – Mangrove, ESG – Early Secondary Growth Forest, ASG – Advanced Secondary Growth Forest, and OGF – Old-growth Forest.

The identified critical habitats were mostly advanced secondary and old-growth forests. This result is expected as many Palawan endemics are forest-obligate (Diesmos & Palomar, 2004). As discussed above, some critical habitats were not designated as core zones such as those in Balabac and the lowland areas of Busanga and El Nido. These critical habitats were possibly overlooked during the creation of ECAN zones due to a lack of biodiversity data. It is also interesting to note that our assessments revealed some extent of core zones with apparently no identified critical habitats, particularly habitats along the coasts and on small islands. We believe that pockets of secondary growth and mangrove forests present in these areas must have been classified as critical habitats. However, satellite images were not available for small islands and the resolution of environmental predictors used in SDM was too coarse to provide sufficient data along the coasts. Intriguingly, the case of core zones with no identified critical habitats along the edges of interior forests (see Fig. 5d) suggests that vegetation might have changed in previous years, which resulted in not being identified as critical habitats. We suspect that these portions of the core zones previously contained natural vegetation that was converted to other land use (an example of forest cover change on Busuanga is available in Supplementary File 2, Fig. 2). The Calauit is an exception because it was declared a wildlife sanctuary in 1976 to secure African animals that were translocated there (Agaloos & Nepomuceno, 1977), allowing the entire island to be designated as a core zone regardless of vegetation types. Alternatively, these were classified as core zones due to other important factors such as land classes and topographic features. But to us, the former is the more compelling cause for the absence of critical habitats. Nonetheless, we highly recommend validating these findings with local authorities and researchers, particularly in areas that were not visited during surveys.

The identified gaps between the core zones and critical habitats only suggest that reevaluation and reclassification of the ECAN zones are necessary for the effective management of biodiversity. Among areas that require adjustments are the islands of Bugsuk and Pandanan in the municipality of Balabac. These islands are home to the remaining populations of Philippine Mouse Deer and Philippine Cockatoo (Mallari et al., 2001; Supsup et al., 2021). Designating core zones on these islands or establishing wildlife sanctuaries would benefit the many endemic species found here. The core zones in Busuanga, El Nido, and Roxas were apparently aligned with the critical habitat, but a needed adjustment must be made to include lowland secondary forests as part of the core zones because higher diversity has consistently been observed in this habitat type (Mallari et al., 2011; Supsup et al., 2020, 2022).

5. Conclusion

The results of our study only provide a fraction of information on the biodiversity found in four municipalities and should not be viewed as complete. Follow-up surveys or monitoring must be conducted regularly as this is among the best practices in conservation management that can provide reliable and up-to-date information on species' geographic distribution, population status, and threats. Additionally, the integration of data such as local community resource use can also contribute to improving Palawan's environmental management strategy and elsewhere. Soliciting information on the type, propensity, and location of resource use can help us understand how the practices of communities can impact critical habitats. Maps showing changes in natural vegetation could be ideal complementary data to resource use since these would enable us to identify areas undergoing degradation. Such data can guide the identification of critical habitats that need to be prioritized for conservation. The framework we provided for classifying vegetation can be used to perform vegetation change analysis by comparing the results of classification from different time periods. However, conducting such tasks may require staff with technical knowledge of geographic information systems (GIS) and remote sensing, which are not often available in many protected areas or local government agencies in the tropics (Mallari et al., 2015, Mallari et al., 2020). Therefore, we highly encourage local authorities to address the gaps in human resources in parallel to the reassessment of management zones in order to sustain its improvement and to keep the strategy afloat with the rapidly changing landscape.

Author contributions

All authors participated in the design and conduct of the study. CES performed the analyses, prepared all figures and tables, and wrote the first draft. All authors reviewed and commented on early drafts and approved the final version of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

I have shared the data at the attach file step.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jnc.2023.126415.

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