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Determining Habitat Suitability for the Identification of Priority Conservation Sites for Indo-Pacific crocodile (*Crocodylus porosus* Schneider, 1801) in the Philippines

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This study examined the suitability of habitat occupied by the Indo-Pacific crocodile (*Crocodylus porosus*) in the Philippines using data on the presence of populations from 2011–2020, geospatial technologies, and species distribution models (SDM). Habitat suitability was mapped using an ensemble model based on Biomod2 package in R software. Results showed that slope, temperature, and precipitation were strong predictors of suitable habitat for Indo-Pacific crocodiles. Thirty-five percent (35%) of the total habitats (1,137,351 ha) that were considered suitable for *C. porosus* in the Philippines are currently protected under national legislation. The provinces of Palawan, Agusan Del Sur, Surigao, Ligawasan Marsh, and Sulu Archipelago contain the largest areas of suitable habitats and should be considered a priority for conservation and protection.

Keywords: crocodile, *Crocodylus porosus*, habitat suitability, Philippines, species distribution modeling

INTRODUCTION

Mapping crocodile habitat is crucial for conserving crocodile populations (Brackhane *et al.* 2018a; Than *et al.* 2020) and resolving human-crocodile conflicts (Brackhane *et al.* 2018b, 2019; van der Ploeg *et al.* 2019). The Philippines has developed a national crocodilian management plan and has been the basis for conservation priority actions of two species of crocodiles in the country – the Indo-Pacific crocodile (*Crocodylus porosus*) and the endemic Philippine crocodile (*C. mindorensis*). However, the management plan lacks an integrated SDM and information on the extent of the remaining habitat for both species. Since the 1980s, most *in situ* conservation efforts were focused on the endemic *C. mindorensis* (Manalo *et al.* 2018). However, in the last decade, *in situ* conservation of *C. porosus* has occurred in response to increasing human-crocodile attacks (Corvera *et al.* 2017) and the financial support of the crocodile farming industry to crocodile conservation programs in the Philippines.

C. porosus is a widespread species occurring in several countries throughout the Indo-Pacific region (Webb *et al.* 2010), inhabiting coastal areas, tidal and freshwater sections of rivers, marshes, and lakes. In the Philippines, the species was once widely distributed throughout coastal mangrove forests, lowland rivers, and inland freshwater marshes and lakes (Ross 2008), but hunting for trade, persecution by humans, and habitat destruction in the early 1980s (Manalo *et al.* 2016, 2018) has restricted their

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presence to several wetland habitats in northeast Luzon (Brown *et al.* 2013), Palawan, and Mindanao. The passing of the "National Integrated Protected Areas System Act of 1992," the "Wildlife Resources Conservation and Protection Act of 2001," and the Presidential Executive Order 578 in 2006, declaring all key biodiversity areas (KBAs) as "critical habitats" ensured the protection of habitats and wildlife species in the country. Whereas *C. porosus* is globally listed as Least Concerned under the IUCN Red List of Threatened Species with a stable global population, this species is locally listed as Critically Endangered under the updated National List of Threatened Terrestrial Fauna of the Philippines (Gonzalez *et al*. 2018). This national assessment, however, was mostly based on outdated population data from Palawan and does not include recently surveyed populations in southwest Mindanao. Moreover, insurgency issues render some areas in the southern Philippines – with reported presence of the species – inaccessible, thus hindering its validation.

Geospatial technologies, such as geographic information system (GIS) and remote sensing, have been implemented to understand the population dynamics of the crocodilian population worldwide. Coupled with statistical and environmental modeling techniques, these technologies have provided information to develop species conservation policies and programs. Several crocodilian studies have employed the use of GIS and remote sensing to map nesting habitats (Duffett *et al.* 2000; Harvey and Hill 2003), while drones and fuzzy logic models have been used in locating areas suitable as nesting habitats (Evans *et al.* 2016). LiDAR (light detection and ranging) data and GPS (global positioning system) telemetry have also been used to characterize riparian vegetation structure and crocodilian hunting behavior (Evans *et al.* 2017).

Several papers on the distribution of *C. porosus* in the Philippines, and the extent and quality of remaining habitat were published by Regoniel (1992). However, the amount of information on the potential crocodilian habitat in the Philippines, and the extent to which it falls within legally protected areas is still unknown, presenting an impediment to identifying priority conservation sites. The primary goal of this study was to identify the extent of potentially suitable habitat for *C. porosus* in the Philippines using updated presence data and associated habitat generally from Palawan and Mindanao, geospatial technologies, and habitat modeling techniques. Moreover, it aims to determine the extent of predicted suitable habitat that is under legal protection. The results will then be interpreted to initially identify priority sites for conservation and protection which could be discussed with the government and concerned stakeholders for its incorporation in the updating of the "Conservation and Management Plan for Crocodiles in the Philippines."

MATERIALS AND METHODS

Presence Data

Presence data were acquired through field surveys conducted from 2011–2020, primarily in the islands of Palawan and Mindanao. Data from published accounts, verified human-crocodile interactions, and grey literature from government agencies were included in the dataset (Table 1). A total of 108 presence data points were used in the model.

Table 1. Sources of presence data of Indo-Pacific Crocodiles (*Crocodylus porosus*) in the Philippines used in this study.

Island group	No. of points	Data source
Luzon	2	Brown *et al.* 2013
Palawan	56	Field surveys (2016–2020); Bucol *et al.* 2014; Manalo *et al.* 2016; Corvera *et al.* 2017; verified human-crocodile interactions; grey literature
Mindanao	50	Field surveys (2011–2020); Ross 2008; Tabora 2008; Pimentel *et al.* 2008; Pomares *et al.* 2008; Manalo *et al.* 2012; verified human-crocodile interactions; grey literature
Total	**108**	

Climatic and Environmental Variables

A total of 20 variables, 14 climatic and six environmental, were used to predict habitat suitability of *C. porosus* in the Philippines (Table 2). The variables were chosen based on literature and availability of spatial data.

Bioclimatic variables were derived from Worldclim dataset (www.worldclim.org) except for Bio 20 (number of consecutive dry days), which was derived from the International Center for Tropical Agriculture. High resolution (1 km^2 or 30 arc-seconds) global climate layers from 1970–2000 were used in generating SDMs. These described bioclimatic factors are relevant in understanding the species response to different climate factors (O'Donnell and Ignizio 2012). Moreover, the climatic and environmental variables used in the model have been selected on the basis of their influence on crocodilian population dynamics and with experts' opinions (Kamino *et al.* 2012). Temperature (Lang 1987; Taplin 1987; Miller 1994) and rainfall, particularly the cycle between dry and wet season (Fukuda and Saalfeld 2014; Brien *et al.* 2017), have been known to affect crocodilian behavior and the spatial and temporal aspects of crocodilian populations. The mean temperature in the coldest quarter of the year was dropped because of its high correlation with annual mean temperature and mean temperature of the wettest quarter.

Table 2. Derived environmental and bioclimatic variables based on presence data used in SDM.

Variables	Units	Mean	Min	Max	SD
Bio_01 (annual mean temperature)	Degree Celsius	26.9	26.5	27.5	1.74
Bio_02 (mean diurnal range)	Degree Celsius	8.8	7.1	9.9	0.66
Bio_04 (temperature seasonality)	STDEV * 100	613.11	256.00	1759.00	266.06
Bio_05 (maximum temperature of warmest month)	Degree Celsius	32.1	31.6	33.8	5.26
Bio_08 (mean temperature of wettest quarter)	Degree Celsius	26.5	25.5	27.4	4.65
Bio_09 (mean temperature of driest quarter)	Degree Celsius	26.9	26.0	27.8	3.19
Bio_10 (mean temperature of warmest quarter)	Degree Celsius	27.6	27.1	28.9	3.50
Bio_12 (annual precipitation)	mm/yr^{-1}	2147.28	1116.00	4386.00	764.68
Bio_13 (precipitation of wettest month)	mm	328.74	118.00	731.00	138.77
Bio_14 (precipitation of driest month)	mm	74.44	10.00	215.00	51.00
Bio_15 (precipitation seasonality)	Coef. of var.	44.67	16.00	80.00	13.26
Bio_16 (precipitation of wettest quarter)	mm	853.73	341.00	2014.00	363.27
Bio_18 (precipitation of warmest quarter)	mm	408.36	227.00	745.00	131.23
Bio_20 (number of consecutive dry months)	Count	2.38	0.00	5.00	1.56
EVI (enhanced vegetation index)	Unitless	4589.37	2840.40	5880.06	751.94
NWDI (normalized difference water index)	Unitless	–0.35	–0.68	0.18	0.16
Population density	Population/ha	2.65	0.44	42.37	4.84
Accessibility	Km	368.57	5.60	608.36	161.66
Slope (degrees)	Degrees	5.85	2.08	17.96	2.82
(TWI) topographic wetness index	Unitless	10.82	9.28	12.53	0.56

Topographic features were derived using a digital elevation model from the Shuttle radar topographic mission. The slope has been known to contribute to the accessibility of crocodiles to a certain area (Burbidge 1987; Webb 1991; Fukuda *et al.* 2008). Topographic wetness index (TWI), proposed by Beven and Kirkby (1979), has been used in many ecological studies (Radula *et al.* 2018) and is used as an indicator of control over some hydrologic processes, such as soil moisture. On the other hand, the slope is an indicator of landforms, soil properties, and accessibility.

Moderate resolution imaging spectroradiometer terra products were used to derive the enhanced vegetation index (EVI) and normalized difference water index (NDWI). These indicators can distinguish habitat in terms of the presence of vegetation and water, in which the latter indicator is preferred by *Crocodylus porosus*. Vegetation type affects crocodile population density (Webb *et al.* 1987) and availability of nesting habitats (Harvey and Hill 2003; Evans *et al.* 2016). A total of 23 datasets for each tile (H29-30 and V07-08) from MOD13Q1.v006 250-m resolution product was used to retrieve the EVI (based on Equation 1) and surface reflectance data from January–December 2019. NDWI was calculated using Equation 2. The averaged pixel values from the times series data were calculated to represent the most recent status of water and vegetation in the study site. One-year data was used to account for seasonal fluxes of vegetation and moisture conditions.

$$EVI = 2.5\ x \frac{NIR\ - Red}{NIR + 6\ x\ Red\ - 7.5\ x\ Blue + 1} \quad (1)$$

$$NDWI = \frac{NIR\ - SWIR_1}{NIR +\ SWIR_1} \quad (2)$$

Accessibility (Nelson *et al.* 2019) data contains information on the travel time from cities and ports for the year 2015. This describes how far each sighting is from urban centers and areas with high economic activity. An increase in distance to cities and ports means may indicate less disturbed habitats. Moreover, the population density [UN (United Nations)-adjusted] represents the human population with a resolution of 30 arc-second (~ 1 km) grid cells for the year 2015 collected from the Gridded Population of World Version 4 (CIESIN 2018). These population density grids contain estimates of the number of persons per 30 arc-second grid cell, consistent with national censuses and population registers with respect to relative spatial distribution but adjusted to match the 2015 Revision of the UN. Human population density has been considered as a factor affecting crocodilian distribution and abundance (Kofron and Smith 2001; Read *et al.* 2004).

All environmental variables were up-scaled to match the resolution of the bioclimatic variables. Pearson's correlation was used to pre-assess and identify environmental and bioclimatic variables that were highly correlated ($r \geq 0.8$) to reduce biases and over-fitting. Variables that have a 0.75 correlation coefficient were removed from the analysis.

Model Implementation and Validation

Habitat suitability of *Crocodylus porosus* was mapped using an ensemble model in Biomod2 package in R software. Ensemble models combine the strength of each model, which can perform better in cases where presence data is limited. The following six algorithms were used in mapping suitability: artificial neural network (ANN), flexible discriminant analysis (FDA), gradient boosting machine (GBM), generalized linear model (GLM), multivariate adaptive regression splines (MARS), and random forest (RF). Geographic records of presence data were filtered using pairwise distance calculation to ensure that pixels of 1 x 1 km resolution are only sampled once. Variable importance was used to evaluate the relative contribution of each variable to the model prediction based on RF. The importance score is returned is based on correlations (1-cor) of the standard (model) prediction and the new (shuffled) prediction (Thuiller *et al.* 2019, https://rdrr.io/rforge/biomod2/man/variables_importance.html). The model training phase was done for the whole Philippines to cover all geographic areas where the most recent presence data are available. However, the model projection – where predictions of suitability were done – was limited to the extent of the geographic area covering Palawan, a portion of the Visayas, and Mindanao where the majority of the presence data are located.

Area under the ROC (receiver operating characteristic) curve (AUC) was used to validate the model's performance. AUC was generated using the presence-absence package in R software. In addition to the geographic points of *C. porosus* labeled as presence data, another set of points were generated using the pseudo absence generated by the model based on the surface range envelope (SRE) strategy and was labeled as absence data. SRE for pseudo absence was parameterized with a quantile value of 0.25 to force the pseudo absence to be selected outside of the broadly defined environmental range of *C. porosus*. The dataset was partitioned into 80% training and 20% testing with 20 evaluation runs for each model (a total of 120 model runs). Sensitivity and specificity were also calculated for all suitability values in the range [0,100]. The suitability threshold, the level at which the maximum value for sensitivity and specificity was recorded, was used as the optimal threshold to determine suitable habitats for *C. porosus*.

RESULTS

The model generated was based on presence data and associated habitats mostly from Mindanao and Palawan, the stronghold of the Philippine *C. porosus* population. Variable importance was evaluated for the 20 environmental and bioclimatic variables used to map habitat suitability based on six models with an overall accuracy of > 0.9 across all evaluation assessment using the testing data. The assessment of variable importance revealed that the indicator slope was consistently included in the upper quartile of all models (Table 3). This was followed by Bio_09 (mean temperature of the driest quarter) and Bio_01 (mean annual temperature), where four out of six models considered these variables as belonging to the upper quartile. Moreover, Bio_01 showed a strong variable contribution to GLM. In addition, MARS and GBM algorithms considered Bio_09 as the most important variable. A strong variable contribution was observed for Bio_16 (precipitation of wettest quarter) in ANN, while Bio_12 (annual precipitation) has the highest variable importance in FDA.

The model resulted in a total of 1,137,351 ha of remaining suitable habitats for *C. porosus* in the Philippines, encompassing 34 provinces excluding those with less than 1000 ha of suitable habitats (Table 4). Out of this, 14 provinces had confirmed the presence of *C. porosus* in the last decade. More than half (61.8%) of these remaining suitable habitats were distributed across six provinces, wherein Palawan recorded the highest (25%), followed by Agusan del Sur (12%), Bohol (8%), Surigao del Sur (6%), Cotabato (5%), and Tawi-Tawi (5%). Only Bohol had no currently known wild population of *C. porosus* out of these six provinces. Moreover, 56% of the suitable habitats were in the Mindanao region.

There were several legislated protected areas and identified KBAs throughout the country, which provided a layer of protection to natural habitats and their biodiversity. The incorporation of these in the analysis showed that 35% of the predicted *C. porosus* suitable habitat in the Philippines with protection. Moreover, 93% of the predicted suitable habitat in Palawan – which possessed the largest remaining suitable habitat for the species in the country – has legal protection.

Table 3. Variable importance of the six models used to map habitat suitability. Bold numbers indicate the values at 75th quartile.

Variables	MARS	GLM	GBM	RF	FDA	ANN
Bio_01[a]	**0.17655**	**0.7605**	**0.04515**	0.0052	**0.1331**	0.1117
Bio_02	0.11845	0.07355	0.02035	0.00155	0.0503	0.0856
Bio_04	0.221	0.1459	**0.0429**	0.0038	0.02945	0.27655
Bio_05	0.01885	0.11985	0.01205	**0.0102**	0.0963	0.09615
Bio_08	0.03165	0.0662	0.0009	0.0012	0.0839	0.133
Bio_09 [a]	**0.2945**	**0.3058**	**0.23735**	**0.01895**	0.0829	0.13395
Bio_10	**0.29125**	**0.4953**	0.0392	0.0016	0.10895	0.0891
Bio_12 [a]	0.0662	0.2036	0.0011	**0.00945**	**0.23745**	**0.3822**
Bio_13	0.04195	0.20395	0.00015	0.0016	**0.2171**	**0.4125**
Bio_14	0.0177	0.2354	0.0013	0.0035	0.01635	0.18605
Bio_15	0.00755	0.23795	0.00385	0.00355	0.03845	0.1257
Bio_16 [a]	0.04885	0.21395	0.00005	0.00195	**0.20635**	**0.6775**
Bio_18	0	0.0742	0.00225	0.00515	0.0003	**0.37785**
Bio_20	0.008	0.2351	0	0.00015	0.00455	0.02145
EVI	0.03705	0.0501	0.01175	0.00175	0.0117	0.1118
NDWI	0.01335	0.0305	0.0008	0.0008	0.0144	0.00005
Pop. density	0	0.00615	0.0001	0.0013	0.00045	0.03675
Accessibility	0.08975	0.1088	0.03675	**0.0199**	0.0564	0.24055
Slope [a]	**0.2756**	**0.26445**	**0.14325**	**0.0143**	**0.17085**	**0.41905**
TWI	0.0088	**0.27535**	**0.08335**	0.00925	0.0044	0.0083
75th quartile	0.132975	0.244575	0.040125	0.0093	0.1149875	0.301875

Table 4. Predicted suitable habitat for *Crocodylus porosus* in the identified provinces in the Philippines and habitats with existing legal protection.

Province	Predicted suitable area (ha)	Suitable habitats with protection	
		Protected area coverage (ha)	KBA coverage (ha)
Palawan[a]	282,787	263,260	–
Agusan del Sur[a]	142,128	40,304	19,458
Bohol	89,196	857	293
Surigao del Sur[a]	72,753	152	4,339
Cotabato[a]	60,180	95	6,033
Tawi-Tawi[a]	56,131	–	16,830
Davao Oriental	41,563	1,311	59
Leyte	40,553	952	1,019
Zamboanga del Sur[a]	35,730	691	–
Maguindanao[a]	34,951	–	12,316
Zamboanga Sibugay[a]	32,167	935	–
Surigao del Norte[a]	28,828	20,740	–
Eastern Samar	28,241	2,031	187
Sulu[a]	26,809	–	356
Davao del Sur[a]	19,987	–	–
Northern Samar	19,215	988	–
Sarangani[a]	18,878	23	185

Province	Predicted suitable area (ha)	Suitable habitats with protection	
		Protected area coverage (ha)	KBA coverage (ha)
Negros Oriental	15,683	1	84
Lanao del Norte	10,099	19	–
Misamis Occidental	9,341	1.5	–
Siquijor	8,451	–	96
Basilan[a]	8,311	–	–
South Cotabato	7,957	12	–
Compostela Valley	6,501	17	12
Sultan Kudarat	5,921	–	–
Cebu	5,814	88	–
Zamboanga del Norte	5,626	–	–
Agusan del Norte	5,310	–	–
Samar	4,716	30	–
Southern Leyte	4,490	–	–
Isabela	3,218	5,278	26
Davao del Norte[a]	2,896	–	–
Davao Occidental	1,478	–	–
Cagayan	1,443	49	81
Total	**1,137,351**	**337,832**	**61,373**

DISCUSSION

Important Environmental and Bioclimatic Variables Affecting *Crocodylus porosus* Habitat Suitability in the Philippines

Five out of 20 variables highly contributed to the predicted suitable habitat of *C. porosus* based on six models, with the slope as the most important variable. The Indo-Pacific crocodile is rarely encountered in high elevation inland waters due to mobility constraints. They tend to avoid rapid and turbulent waters (Burbidge 1987; Webb 1991), which are a characteristic of the midstream sections of major river systems in the country. However, there have been instances where individuals were recorded in midstream sections of rivers and agricultural waterways but have no major obstacles along the way. The majority of the species' sightings were in lowland habitats – including coastal mangrove areas, tidal and freshwater sections of rivers, and inland marshes.

Mean temperature of the driest quarter and mean annual temperature were the next important contributing variables. As an ectotherm, the distribution of crocodiles is highly affected by environmental temperature (Carvajal *et al.* 2005; Espinosa *et al.* 2012). Lang (1987) discussed that tropical species of crocodilians are thermoconformers, *i.e.* they tend to avoid high ambient temperature. Precipitation of wettest quarter (mean 853.73 mm) and annual precipitation (mean = 2147.28 mm/yr^{-1}) were also major contributing variables in the results of the model. Previous studies have shown the impacts of rainfall on nesting success, hatchling density, population distribution (Fukuda and Saalfeld 2014), sighting probabilities, and even frequency of crocodile attacks (Brien *et al.* 2017). This was the time when adults became more mobile, males highly territorial, and females more aggressive defending their nests and young (Webb and Manolis 1989).

Most crocodilian attacks in the Philippines were recorded in the southern portion of the province of Palawan (Corvera *et al.* 2017) between September–November. Coincidentally, the study of Corporal-Lodangco and Leslie (2017) indicated that the wet season for central and southern Palawan started from July–October, with rainfall gradually decreasing by November. It was inferred that the breeding season of wild *C. porosus* in the southern Philippines started within the same months. This was also supported by nest encounters and egg hatching in September, October, and November in Palawan.

Crocodylus porosus Habitats in the Philippines

Most of the remaining suitable habitats for *C. porosus* were located in the southern Philippines (Figure 1). Despite some limitations on the presence data and the use of SDM, the habitat suitability map generated has identified five core habitats for *C. porosus* that were still

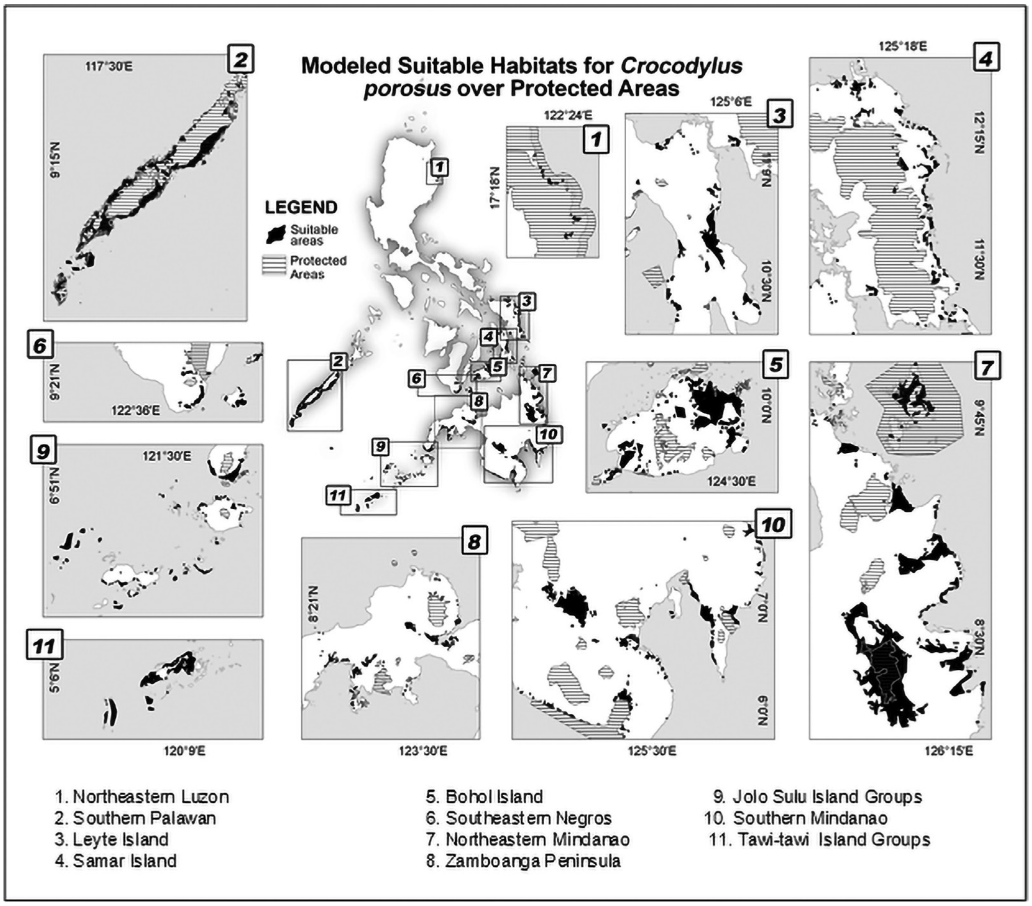

Figure 1. Suitable habitat for Indo-Pacific Crocodiles (*Crocodylus porosus*) based on the optimal threshold of 52% of suitability value, overlaid with protected areas in the Philippines.

intact and large enough to support the remaining viable populations. These were the mangrove forests and tidal rivers of Palawan, Bohol, Surigao del Sur, Tawi-Tawi, the inland wetland habitats of Agusan Marsh Wildlife Sanctuary (AMWS), and Ligawasan Marsh Game Refuge and Bird Sanctuary.

Palawan Province had the highest subtotal area of 282,787 ha and the largest interconnected habitat for the species in the country stretching along its southern coastlines. Palawan is the largest province (1,438,298 ha) in the country with a total mangrove area of 54,604.7 ha (Carandang *et al.* 2013). The Environmentally Critical Areas Network, a component of Republic Act 7611 (Strategic Environmental Plan for Palawan Act), established a graded system of protection of coastal and terrestrial habitat networks in Palawan. This has offered some layer of protection on the province's extensive mangrove forest cover. Encounters of *C. porosus* from surveys conducted in the southern portion of the province were mostly within tidal rivers surrounded by old-growth and/or secondary-growth mangrove forests and inland marshes. Manalo *et al.* (2016) conducted population surveys in southern Palawan between 2014–2016, which resulted in a corrected population density estimate of 0.23 individuals/km for six mainland rivers in three municipalities and 2.15 individuals/km in small island rivers in the Municipality of Balabac. Moreover, the highest population density of the species for one river in the country has been recorded in Bugsuk River in the island of Bugsuk, Municipality of Balabac with 10.92 individuals/km. The private management of Bugsuk Island seemed to have contributed to the preservation of its intact habitat. No households were found near crocodilian habitats and minimal disturbance was observed. Furthermore, there has never been any record of human-crocodile attacks on the island despite the dense crocodile population.

Agusan del Sur, where the AMWS is located, had the second-highest suitable habitat area for *C. porosus*. The largest Indo-Pacific crocodile "Lolong" was caught in AMWS in September 2011. However, Manalo *et al.* (2012) observed that the marsh supports a small crocodile population with an increase in non-traditional fishing practices and human pressure on the habitat that displaced crocodiles in the marsh.

Despite Bohol being the third province with the highest area of suitable habitat, the only record of the species for the province was a single captive male breeder acquired by the Philippine government (Ortega and Regoniel 1994). Other than that, no confirmed presence or reports of *C. porosus* originated from the area in the past three decades. The provincial government unit and the local Department of Environment and Natural Resources (DENR), with their mangrove conservation banner program, largely contributed to the preservation of its 15,320-ha mangrove forests (Camacho *et al.* 2011).

The coast of Surigao del Sur had the fourth largest predicted suitable habitat for *C. porosus*. Historically, there were known records of *C. porosus* in the area. However, no encounters have been reported since the acquisition of the Philippine government in the 1980s. It was only in 2018 that an estimated 10-ft adult was encountered along the coast of Bislig City in the province (Mascariñas 2018). With this, surveys have been conducted in the tidal rivers of Bislig and showed areas with intact habitats for *C. porosus*. A year later, a *C. porosus* was encountered within the same river surveyed, suspected to be the same individual encountered in 2018. The nearest known *C. porosus* population in the area was in the mangrove forests in the Municipality of Hinatuan, Surigao del Sur, which was approximately 20 km from Bislig City. This suggested that, if suitable crocodilian habitats were still present despite being devoid of crocodiles, re-colonization could happen.

Ligawasan Marsh Game Refuge and Bird Sanctuary encompassed three provinces – namely, Cotabato, Maguindanao, and Sultan Kudarat – all of which possessed suitable habitats for *C. porosus* with the highest area in Cotabato. Combined, it was the third-largest intact habitat for the species in the country with a total area of 101,830 ha. The marsh is known to have confirmed the presence of both *C. porosus* and *C. mindorensis* (Ross 2008; Pimentel *et al.* 2008; Pomares *et al.* 2008) and is inferred to have a viable population for both species. However, insurgency issues in the area rendered the conduct of field surveys logistically impossible, halting the generation of population data. On the other hand, the presence of armed groups has been perceived by some to have contributed to the protection of the marsh from destructive habitat encroachment and development.

Tawi-Tawi Province in the Sulu Archipelago held the sixth-largest suitable habitat for *C. porosus* in the country. The first known records of *C. porosus* in the province were that of the wild acquisitions by the Philippine government for its captive breeding program in the late 1980s and 1990s. Then, in 2017, a 16.11-ft *C. porosus* was captured by a fisherman in Simunul Island, southwest of mainland Tawi-Tawi. It was only in 2019 when the first-ever standard crocodile surveys started due to security-related problems. The main island of Tawi-Tawi possessed multiple rivers lined with healthy old-growth mangrove forests and coastal and inland marshlands, inhabited by a viable population of *Crocodylus porosus*. Current population estimates based on surveys conducted in three municipalities resulted in a corrected population density of 1.31 individuals/km. In addition, the presence of the species has been confirmed in several surrounding islands despite the absence of freshwater habitats.

Habitats with Protection and Identified Priority Conservation Sites for the Species

More than a third (35%) of the predicted *C. porosus* suitable habitats were under some degree of protection. Habitats that were within the boundaries of legislated protected areas accounted for 29.7% of the total predicted suitable habitats, while 5.3% were within KBAs. The overlap of the identified core habitats for the species and the total protected area varied between the six provinces. Almost all (93%) predicted suitable habitats in Palawan were under legislated protected areas with well-established management plans. Palawan currently has the highest known population for the species in the country. This provided an assurance that large protected intact habitats with viable crocodile populations could be maintained. Agusan del Sur covered both legislated (28%) and national declaration (14%) of the predicted suitable habitat for the species in the province. It was plausible that when non-traditional fishing practices were regulated and anthropogenic disturbances limited, a gradual increase in crocodilian population in the marsh could be observed.

Ligawasan Marsh was the third largest intact habitat for the species but only 0.16% of it is under a legislated protected area. On the other hand, almost half (45%) of the suitable habitats in the marsh were under a KBA designation. Though no surveys have been conducted within the marsh due to insurgencies problems, multiple reports and capture of the species in the area indicated an extant viable population. Also, the presence of the Critically Endangered *C. mindorensis* in the marsh (Ross 2008; Tabora 2008; Pimentel *et al.* 2008; Pomares *et al.* 2008) provided an additional conservation value to the site.

Bohol had the fourth largest predicted suitable habitat for the species, but only 0.96% of it was under a legislated protected area and 0.33% under a KBA designation. Though the province has no extant population of the species, its importance in assuring a network of viable intact habitats should not be disregarded considering its proximity to Mindanao with known *C. porosus* populations. Surigao del Sur had the fifth-largest predicted suitable habitat but with only 0.21% under a legislated protected area and 6% under KBA. The recent encounter of one adult individual in the province indicated that re-colonization of empty suitable habitats should be considered in future conservation management plans. The island province of Tawi-Tawi had the sixth-largest predicted suitable habitats, where 30% are under KBAs. Currently, the province's mangrove forests and tidal rivers have the second largest population of the species known in the country. However, this population data has been based on surveys that only started in 2019 and were limited to two municipalities. It was highly likely that it will increase as other areas of the province are surveyed.

CONCLUSION

The predicted remaining suitable habitats for *C. porosus* were mainly located in the southern Philippines. Although there were some limitations on the use of SDM, this conservation tool has reflected that 35% of suitable habitats were under some degree of protection. Thus, in order to ensure a large network of intact habitats that could support a large viable population of the species in the future, we identified the following areas as priority conservation sites where conservation efforts and funds could be focused in the next decade:

a.) the mangrove forests and tidal rivers of southern Palawan and the Sulu Archipelago, which are both home to the largest viable population of the species;
b.) the mangrove forests and tidal rivers of northeast Mindanao, which includes the provinces of Surigao del Norte and Surigao del Sur;
c.) Ligawasan Marsh encompassing the provinces of Cotabato, Maguindanao, and Sultan Kudarat; and
d.) AMWS in the province of Agusan del Sur.

The identified suitable habitats that are outside the protected area can also be declared as critical habitats under the Philippine Wildlife Resources Conservation and Protection Act of 2001 for translocation and future release program.

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