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Habitat Mapping of the Saltwater Crocodile (*Crocodylus porosus*) in Timor-Leste

Human-Crocodile Conflict (HCC) is increasing worldwide (Fukuda et al. 2014; Amarasinghe et al. 2015; Pooley 2015; CrocBITE 2018), but limited financial and technical resources in many developing countries impede scientifically sound management to mitigate such conflicts. Analysis of crocodilian habitats is an important step for effective HCC management and crocodilian conservation (Thorbjanarson et al. 2006; Leach et al. 2009; Ihlow et al. 2015). Using Timor-Leste as a case study, here we demonstrate how potential habitats of Saltwater Crocodiles (*Crocodylus porosus)* can be mapped using cost-free tools and data from the World Wide Web, and local knowledge. One of the least developed countries in the World, Timor-Leste struggles to manage HCC with *C. porosus*, the largest and one of the most aggressive crocodilian species (Britton et al. 2012; Brien et al. 2013), the population of which has increased significantly in Timor-Leste since its independence from Indonesian occupation in 2002. Since 1996 at least 130 people have been attacked by crocodiles in Timor-Leste, yet the information available is insufficient to identify priority areas for a conservation scheme on a national scale (NBWG 2015; Sideleau et al. 2016; Brackhane et al. 2018). Thus, we suggest that crocodile habitat mapping is an important first step towards the development of the first crocodile management plan for the country.

We performed habitat analysis based on Geographic Information Systems (GIS) to identify: 1) core habitats (including perennial waterbodies such as lakes, swamps, billabongs and rivers providing possible breeding sites for *C. porosus*); 2) coastal marine habitats, *inter alia*, *C. porosus* perennial range for hunting; and, 3) seasonal range, namely potential habitat for *C. porosus* during the wet season.

Timor-Leste is dominated by a mountain ridge ranging from the westerly Mount Ramelau (2963 m elev.) to the Fuiloro Plateau in the east, which includes Timor-Leste's largest lake, Ira Lalaro (318 m elev.) (GERTIL 2002). These elevated areas divide the country into northern and southern parts with distinct seasonal variability affected by the West Pacific Monsoon (PCCSP 2011). Maximum precipitation is only reached in the high elevations of the central mountain ridge. The relatively dry northern coast is characterized by a rainy season from December to March with 50–350 mm precipitation/month, a transition period in November, April and May with 50–150 mm precipitation/month; and a distinctive dry season from June to October with little or no rainfall (0–50 mm precipitation/month) (Seeds of Life 2013). In contrast, the climate along the southern coast is characterized by a rainy season from December to June with 100–400 mm precipitation/month, a transition period in July and November with 50–150 mm precipitation/month; and a dry season from August to October (0–50 mm precipitation/month).

Almost all creeks and rivers originate in the central mountain ridge, with many of them running dry during the dry season. The number of perennial rivers, which potentially can be inhabited by crocodiles throughout the year, is limited to three rivers in the northern part (Northern Lacló, Seiçal, Loes) and eight in the southern part (Irabere, Bebui, Dilor, Tafara, Belulik, Caraulun, Southern Lacló, and Clerec). Potential habitat for *C. porosus* is limited to a narrow plain between the coast and the mountain ridges, and includes mangroves, mainly along the northern coast (Alonghi and Carvalho 2008), and various billabongs, lagoons, estuaries, floodplains, and swamps, especially in the southern part as a result of the higher precipitation patterns (Fox 2003).

Core crocodile habitats were identified based on knowledge of members of the Crocodile Task Force (CTF) who were familiar with the areas through regular sightings of crocodiles, and traditional ecological knowledge of local stakeholders from eight communities (Vessuro, Mehara, Uani Uma, Malahara, Com, Baucau, Hera, Irabin de Baixo) affected by HCC. Usually, local knowledge holders, Xefe Suku (Village headmen), Dato Lulik/ Lia Na`in (Traditional elders) or local fishermen were contacted during surveys (2007–2017) and asked to identify areas where saltwater crocodiles reside throughout the year. The identified areas were then inspected by the CTF to determine numbers of crocodiles and to measure GPS coordinates of control points of the relevant waterbodies using (Garmin) hand devices. The measured control points were transferred to a GIS where the extent of crocodile core habitat could be identified and measured based on Google satellite imagery (https://www.google.de/maps). As a sea-going species, with the potential for long-distance movement (Read et al. 2007; Campbell et al. 2010; Webb et al. 2010), *C. porosus* may be found along the entire coastline of Timor-Leste throughout the year. We applied a 1-km buffer to coastlines and core (buffer only inwards) habitats digitized by GIS to account for seasonal variations in the habitat extent as well as adjacent coastal habitats. These areas, accounting for 341.6 km² of core habitat (126.3 km² excluding the 1-km buffer) and approximately 766 km of coastline, represent the habitat where *C. porosus* can be found during the whole year.

We followed Brackhane et al. (2018) in defining the areas of potential crocodile range as temporary waterbodies with a 3-km buffer to include seasonally possible, but unusual habitat for saltwater crocodiles. These include rice paddies and the canals

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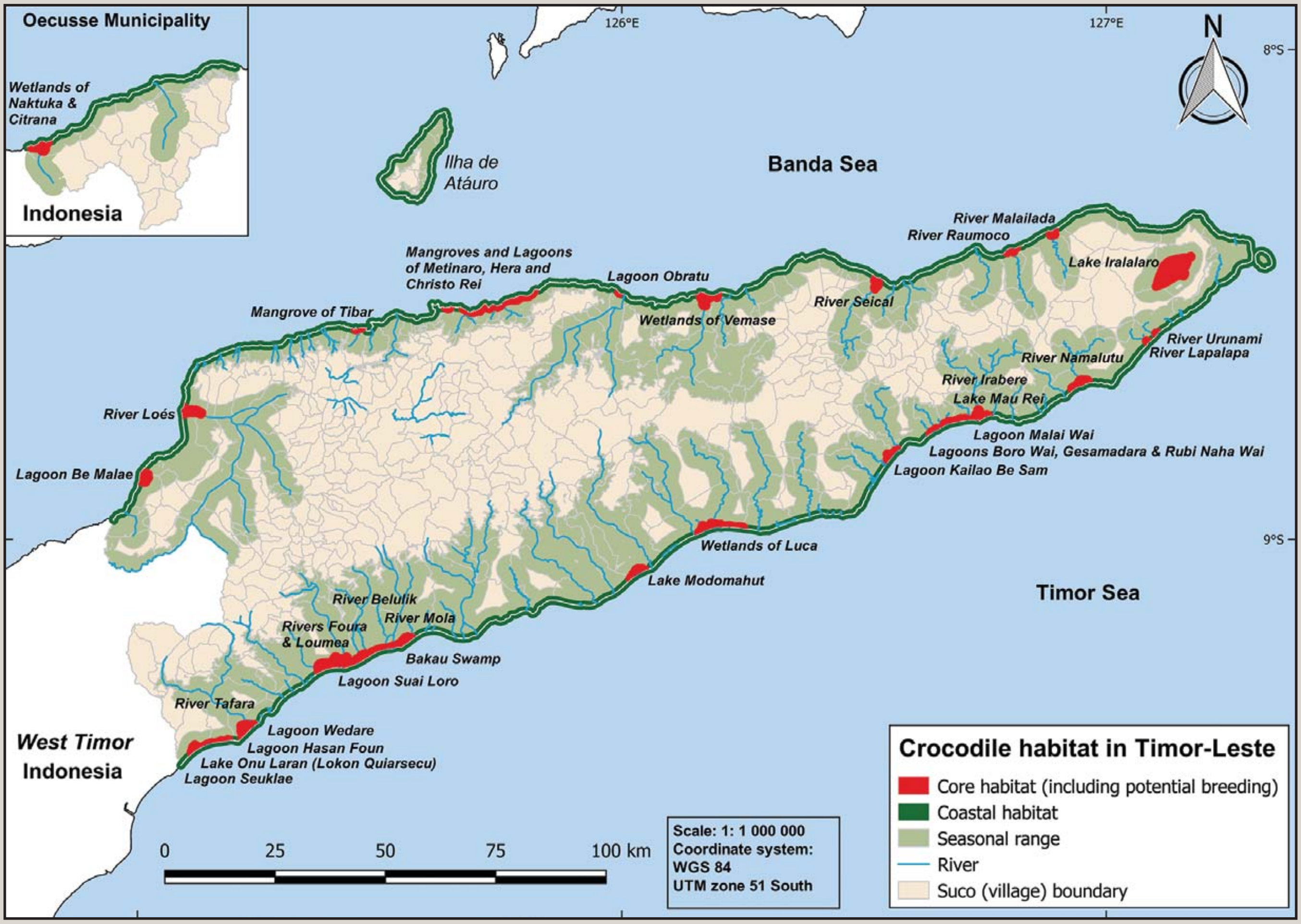

Fig. 1. Potential core, coastal, and seasonal habitats of Saltwater Crocodiles in Timor-Leste.

of the associated irrigation systems. As there were no reported sightings of *C. porosus* at altitudes above 500 m, we excluded all areas above this altitude from the identified core habitats and seasonal range using 3-arc second Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM). The highest observed record of a Saltwater Crocodile in Timor-Leste is at 422 m elev., in Lete Foho, Manufahí district (9.14331°S, 125.58883°E; S. Brackhane, pers. obs.).

All spatial analysis was performed using the free QGIS 2.18 software including the relevant extensions such as OpenLayers Plugin for spatial analysis of Google satellite imagery and QuickMapServices 18.4 Plugin for basemaps (QGIS Development Team 2017). SRTM DEM was downloaded from SRTM 90m Digital Elevation Database v4.1 (http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1, accessed on 6 March 2017). Additional information such as administrative boundaries and waterbodies were downloaded at no cost from Geographic information Group (GIG) Timor-Leste (https://sites.google.com/site/gigtimorleste/data/administrative-boundaries, accessed on 6 March 2017) and Diva-GIS (www.diva-gis.orghttp://www.diva-gis.org/, accessed on 6 March 2017).

The map generated (Fig. 1) may be used by the CTF to identify priority areas for HCC management, i.e., to link management activities to areas where human and crocodile habitat frequently overlaps, especially by overlaying it with a current risk map showing hotspots of crocodile attacks or human density maps. Also, if made available through a website (e.g., www.common-environment.org or peskador.org), the map would help wildlife managers to raise public awareness and to inform local residents and tourists about areas of potential crocodile risk. The map will be improved as more crocodile-sighting and environmental data become available through field surveys or community-based monitoring approaches as described by Brackhane and Pechacek (2015). In particular, inclusion of crocodile sightings made by citizen scientists would be a cost-effective option to improve data availability (Brackhane et al. 2016). *Crocodylus porosus* habitat mapping will significantly improve when integrated with comprehensive vegetation data (Harvey and Hill 2003; Fukuda and Cuff 2013). In this context, the continuous assessment of available habitat suitable for nesting will be a crucial variable to estimate the capacity for a viable population of *C. porosus* in Timor-Leste (Magnusson 1980), and to inform wildlife managers on crocodile conservation needs.

Our case study here could hopefully serve as an example of the first step to habitat mapping for many developing countries, particularly those with limited resources, and facing HCC challenges like Timor-Leste. Whereas the methodology may be relatively easily applicable on islands with a rather simple habitat distribution such as Palau (Brazaitis et al. 2009), Vanuatu, Solomon Islands and several islands of volcanic origin in Papua New Guinea and Indonesia, its application to larger countries with extensive freshwater lakes and swamps, floodplains and large river systems may require more systematic assessment of habitat quality (e.g., Fukuda et al. 2007; Fukuda and Cuff 2013).

Particularly in these areas with high geographical complexity, the integration of local knowledge may constitute a valuable data source increasing the accuracy of habitat mapping. We caution that the presented methodology is designed for *C. porosus* and may be misleading for other crocodilian species.

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