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Research Article

When Conservation Becomes Dangerous: Human-Crocodile Conflict in Timor-Leste

SEBASTIAN BRACKHANE,[1] *Chair of Remote Sensing and Landscape Information Systems, Faculty of Environment and Natural Resources, University of Freiburg, Tennenbacherstr. 4, 79106 Freiburg, Germany*

GRAHAME WEBB, *Wildlife Management International, PO Box 530 Karama, NT, 0813 Australia; and Research Institute for the Environment and Livelihoods, Charles Darwin University, Darwin, NT 0909, Australia*

FLAMINIO M.E. XAVIER, *Ministry for Development of Housing, Planning and Environment, Biodiversity Directorate, Fomento Building, Rua Dom Aleixo Côrte-Real, Mandarin, Dili, Timor-Leste*

MARCAL GUSMAO, *Center for Climate Change and Biodiversity, National University of Timor-Leste, Avenida Cidade de Lisboa, Dili, Timor-Leste*

PETER PECHACEK, *Food and Agriculture Organization of the United Nations—Sub-regional Office for Central Asia (FAO-SEC), Ivedik Cad. 55, 06170 Ankara, Turkey*

ABSTRACT In northern Australia and nearby Timor-Leste, saltwater crocodile (*Crocodylus porosus*) populations were seriously depleted historically but recovered rapidly after protection: 1969–1974 in northern Australia, and 2000–2005 in Timor-Leste. In both places, recovery caused increased rates of human-crocodile conflict (HCC). Within northern Australia, the crocodile recovery and HCC have been documented over time. In contrast, this has not been the situation in Timor-Leste, where we investigated HCC based on 130 attack records (1996–2014; 52% fatal). In 1996–2006, 0.55 attacks/year were reported in Timor-Leste. By 2007–2014, 9 years later, a 23-fold increase had occurred (13 attacks/year). Traditional subsistence fishing (82.5% of all attack records) is the highest risk activity, followed by bathing (7.5%) and water collecting (4.2%). Although the human population was correlated with crocodile attacks in Timor-Leste, it likely does not explain the dramatic increase in crocodile attacks. Alternatively, crocodile numbers may have increased, either in the remnant resident crocodile population, or via migrants from elsewhere. Permanent crocodile habitat is limited, and limited breeding does not explain the high number of large crocodiles, and consequent increase in attacks in such a short time. A plausible explanation, consistent with traditional knowledge in Timor-Leste, is that the influx of large crocodiles attacking people are migrants from Australia. We examined this possibility from available sources. Within Australia crocodiles have recovered since protection and they regularly invade adjacent habitats, such as Darwin harbor, where they are removed to prevent attacks on people. Saltwater crocodiles have been sighted at oil rigs, in the open ocean, moving between northern Australia and the south coast of Timor-Leste. The likelihood of crocodiles migrating from Australia to Timor-Leste raises obvious conservation, moral, and ethical dilemmas when conserving a large dangerous predator in one country to increase abundance results in dispersal to another country, where the predator attacks and kills people.

KEY WORDS ancestor worship, biological dispersal, *Crocodylus porosus*, human-crocodile conflict, Timor-Leste.

The status of saltwater crocodiles (*Crocodylus porosus*) in different nations across the Indo-Pacific tropics, ranges from extinct to populations at carrying capacity (Webb et al. 2010). This is largely because the ecological and cultural values attributed to them are balanced in different ways. For example, their top-end predator status and traditional roles in culture need to be pitted against their predatory behavior (Kar and Bustard 1983, Webb and Manolis 1989, Caldicott et al. 2005, Manolis and Webb 2013, Fukuda et al. 2014).

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[1]*E-mail: sebastian.brackhane@felis.uni-freiburg.de*

Large saltwater crocodiles can exceed 6 m in length and weigh >907 kg (Britton et al. 2012).

Saltwater crocodiles mostly attack people as prey, and attacks are usually fatal if the crocodile is >4 m long (Manolis and Webb 2013, Fukuda et al. 2015). Attacks occur during the day and at night, in the open ocean, on mainland and island beaches, at near-shore reefs, and in diverse coastal wetlands, regardless of whether they are tidal or non-tidal, heavily or lightly vegetated, or contain saline, fresh, turbid, or clear water (Manolis and Webb 2013, Fukuda et al. 2015, CrocBITE 2017). The crocodiles responsible for attacks may be residents within a wetland (Ritchie and Jong 2002) or recent arrivals whose presence was unknown until an attack occurred. Movements around the coast between rivers and swamps are commonplace; hence, saltwater crocodiles removed from an area are soon replaced (Webb et al. 1978, Messel et al. 1981, Walsh and Whitehead 1993, Read et al. 2007, Fukuda et al. 2014). They also make long distance ocean voyages between countries (>1,000 km; Neill 1971, Allen 1974, Webb and Messel 1978, Read et al. 2007).

Historically, crocodiles were incorporated into the traditional cultures of people in various ways. The killing of saltwater crocodiles was often a cultural taboo in indigenous communities (Cox and Gombek 1985, Lanhupuy 1987, Kaiser et al. 2009, Barnes et al. 2017). But in colonial times, cultural sensitivities were ignored and saltwater crocodiles were hunted for sport, as pests, and later for their commercially valuable skins (Webb et al. 1984, Webb and Manolis 1989). This caused widespread population declines (Webb et al. 2010), leaving only 1% of the former biomass of saltwater crocodiles in the Northern Territory of Australia (NT; Fukuda et al. 2011).

Global concerns about extinction from the 1960s onward resulted in protective legislation to stop commercial hunting. When the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) came into force (1975), saltwater crocodiles were listed on Appendix II, then upgraded (1979) to Appendix I, except for Papua New Guinea (Hollands 1984, 1987). This helped focus attention on recovery, and the depletion of populations in most range countries stopped or was minimized.

The wild populations, all seriously depleted historically, recovered if their habitats were intact (Fukuda et al. 2011). This recovery has been documented in the NT and proved to be largely an intrinsic process; wary remnant adults would breed, producing annual cohorts of juveniles, which over time would grow and disperse (Webb and Messel 1978, Webb et al. 1978, Messel et al. 1981, Fukuda et al. 2011). Movement from one river system to another influenced the recovery in some rivers that were devoid of breeding habitats (e.g., Mary River NT: Fukuda et al. 2011). In the NT at the time of protection (1969–1974), neighboring countries also had depleted populations, so there were few if any immigrants. As crocodile numbers and sizes increased in the NT, which took time, crocodile attacks on people increased, particularly 23–27 years post-protection (Fukuda et al. 2014). In Timor-Leste, across the Timor Sea from NT, increasing rates of human-crocodile conflict (HCC) were reported (Käslin 2015, Sideleau et al. 2016), but the underlying causes for this remain unclear.

Our research quantified and partitioned HCC in Timor-Leste into likely causes: human and crocodile. We mapped the potential range of saltwater crocodiles in Timor-Leste and located the areas of reported crocodile attacks; quantified the relationship between human population growth and number of crocodile attacks; investigated the relationships between attack severity (fatal vs. non-fatal) and risks of attack (sex, activity, and age of victim); and compared HCC in Timor-Leste to incidences in neighboring countries (Australia and Indonesia), and to road fatalities and other biological agents (malaria and dengue) in Timor-Leste.

Our hypothesis was that if increases in HCC at the national, district, and community level were a function of the human population growth, the 2 variables would be highly correlated. If not, it would indicate that an increase in numbers of (large) crocodiles was the major factor causing the increasing rates of HCC in Timor-Leste. In this context, our initial assumption was that the Timor-Leste population of saltwater crocodiles would have recovered through intrinsic processes, as happened in Australia 30 years before (Fukuda et al. 2011, 2014; Manolis and Webb 2013). The recovery of crocodiles in Timor-Leste would have taken place when there was an abundant saltwater crocodile population 450 km away in the NT. We examined the hypothesis that dispersing saltwater crocodiles from the fully recovered NT population contributed to the reported increase in HCC in Timor-Leste.

STUDY AREA

The South-East Asian nation of Timor-Leste comprises 14.919 km^2, subdivided into northern and southern components by an east-west mountain range (Fig. 1). The climate is tropical, but the north has 1,000 mm of rainfall annually, in a 4–6-month wet season, and the south has 2,000 mm of rain in a 7–9-month wet season (Trainor et al. 2007). For administrative purposes, Timor-Leste is subdivided into 13 municipalities, formerly districts (Fig. 1), 2 of which are mountainous without any coastline or larger waterbodies, and 11 of which contain potential habitat for crocodiles. Wetlands with permanent water, preferred by crocodiles (Webb and Manolis 1989), are mainly in the south and south-east, particularly in Lautém, Viqueque, Manufahi, and Cova Lima Municipalities (Fig. 1; Kaiser et al. 2013, Seeds of Life 2013).

Timor-Leste has a human population of 1.2 million people, which has been increasing at 1.8%/year (2010–2015). In 2011, 37.4% of civilians lived below the international poverty line of $1.25/day ($U.S., purchasing power parity), and 40% were considered malnourished (United Nations Development Program 2012). Timorese livelihoods are predominantly rural, depending on agriculture (71%) and fisheries (Barbosa and Booth 2009, Mills et al. 2017). In 2015, 5% of Timorese households were engaged in small-scale fisheries, and today fish accounts for 31% of animal-source protein intake in the Timorese diet (World Fish 2017).

The Timor Sea (Fig. 1) separates the south coast of Timor-Leste from the much larger northern coast of Australia. There are oil reserves in the Timor Sea, some of which are subject to joint ownership by Timor-Leste and Australia. Northern Territory wetlands (Fukuda et al. 2007) contain 80,000 to 100,000 wild saltwater crocodiles spread among 8,272 km of coastline, 9,380 km of permanent river and creek, and 3,773 km^2 of swamp and billabongs (Webb et al. 1984). Timor-Leste has much less habitat, approximately 766 km of coastline (9.3%) and only 130 km^2 versus 4,120 km^2 (3.2%) of mangroves (*Avicennia marina*, *Sonneratia alba*, *Rhizophora stylosa*, *Ceriops tagal*, *Lumnitzera racemosa*; Lee 2003, Boggs and Edyvane 2009, Alongi 2014). The coastal and inland wetlands provide habitat for

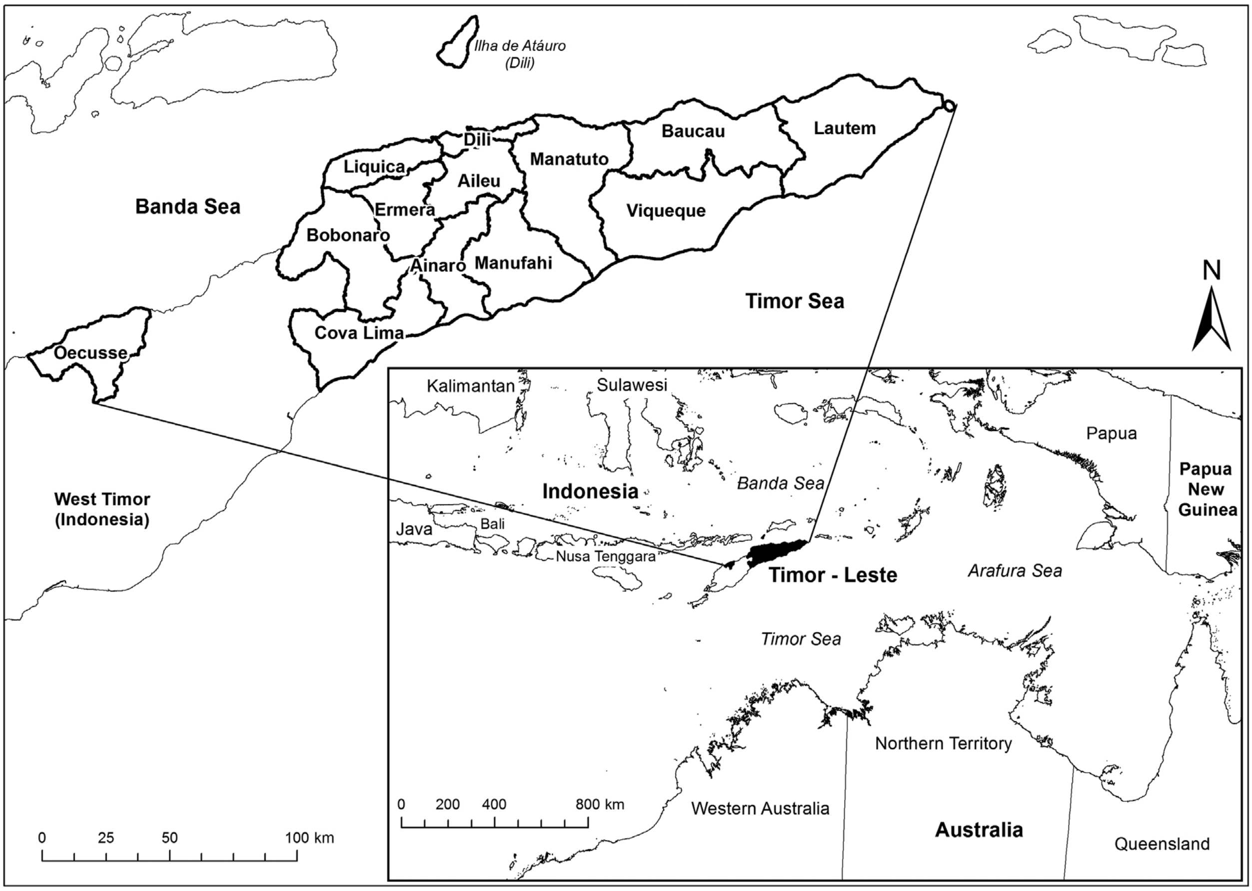

Figure 1. The location of Timor-Leste in Southeast Asia and of the 13 municipalities (formerly districts) in Timor-Leste in 2014.

typical crocodile prey such as fish (e.g., barramundi [*Lates calcarifer*], Sagor catfish [*Hexanematichthys sagor*], bluespot mullet [*Crenimugil seheli*]), mud crabs (e.g., giant mud crab [*Scylla serrata*]), waterbirds (e.g., wandering whistling duck [*Dendrocygna arcuata*]), snakes (e.g., Macklot's python [*Liasis mackloti mackloti*]) and freshwater turtles (e.g., Timor snake-necked turtle [*Chelodina mccordi timorensis*]; Trainor et al. 2007, Kaiser et al. 2011, O'Shea et al. 2012, FishBase 2017).

METHODS

Crocodile Population

Timor-Leste lacks formal survey data on the distribution and abundance of different sized saltwater crocodiles over time, so following Dunham et al. (2010), we used ArcGIS 10.2 (Environmental Systems Research Institute, Redlands, CA, USA) to develop maps on attack distribution and areas of potential crocodile presence, *inter alia* the areas constituting the potential range of saltwater crocodiles in Timor-Leste. We obtained shapefiles with administrative boundaries (Geographic Information Group in Timor-Leste 2018) and created shapefiles of the coastline, waterbodies, rivers, and riverbeds using heads up digitalization based on the World Imagery basemap (2.5-m SPOT Imagery; DigitalGlobe, Westminster, CO, USA). We included rice paddies and their irrigation channels because attacks occur there. We applied a 3-km buffer around wetland areas, after examining land cover, agricultural maps, and other literature (da Costa et al. 2013, National Biodiversity Working Group 2015, Pinto et al. 2017) to account for the seasonal expansion of wetlands. Like some wetland areas in Australia (Webb et al. 1991, Fukuda et al. 2007), most of those in Timor-Leste are reduced in dry seasons to refuges with permanent water, which expand in the wet season with perennial inundation.

We identified areas with >500 m elevation and >30 degree slope as not suitable for saltwater crocodiles (Letnic and Connors 2006, Fukuda et al. 2007), using a Shuttle Radar Topography Mission 3-arc second digital elevation model in ArcGIS 10.2. Because the coast, floodplains, billabongs and rivers of the flatlands are highly correlated with saltwater crocodile presence (Webb and Manolis 1989, Fukuda et al. 2004, Fukuda and Cuff 2013), we considered all waterbodies <500 m elevation in Timor-Leste, including the entire coastline, to be potential saltwater crocodile habitat (Kaiser et al. 2009, 2013; Käslin 2015; Sideleau et al. 2016). This included Atáuro Island, 25 km north of Dili, because despite no reported attacks, a saltwater crocodile could swim there in <1 day (Read et al. 2007, Campbell et al. 2010). To estimate the extent of waterbodies with perennial crocodile presence and potential breeding, we elaborated shapefiles based on experts from the Crocodile Task Force Timor-Leste (CTFT-L), field observations (2007–2017), and local information (Biodiversity Directorate, unpublished data).

Along with the location of reported attacks, we projected all shapefiles to the Universal Transverse Mercator coordinate system Zone 51 South (WGS 84), allowing us to calculate areas of potential (perennial) crocodile presence, using the ArcGIS calculate geometry tool, down to the village (Suku) level.

Human-Crocodile Conflict (HCC)

There are numerous records of crocodile attacks in Timor-Leste (United Nations Transitional Administration in East Timor [UNTAET]-Joint Mission Analysis Center [JMAC] 2008, Sideleau et al. 2016, National Directorate of Fisheries and Acquaculture [NDFA] 2017, CrocBITE 2017). The most comprehensive report lists 68 attacks between 1996 and 2014 (Käslin 2015). The probability of attacks being formally reported has been changing over time, so traditional knowledge, largely verbal, was an important source of information for our study. We followed Fukuda et al. (2014) in first defining the location of a fatal or non-fatal attack, and around that location, compiling information on the context (crocodile and human). The data we used came from assessing various databases and reports (UNTAET-JMAC 2008, Käslin 2015, Sideleau et al. 2016, CrocBITE 2017, NDFA 2017), conducting interviews with various Ministries and Institutions, and consulting the CTFT-L, who have been compiling information on crocodile attacks, including interviews with local authorities in affected communities and with victims of non-fatal attacks. We gained traditional knowledge, including information on local cultural attitudes towards crocodiles (Kaiser et al. 2009), from visiting and interviewing elected village headmen (the Xefe Suku), traditional elders (the Lia Na'in or Dato Lulik), and during a CTFT-L workshop on HCC (Dec 2014, Dili) attended by many holders of local (traditional) knowledge. We identified and visited major HCC hotspots to gather more detailed information on the incidents, including the locations of attacks, using techniques involving community-based monitoring, local ecological knowledge and citizen science (Brackhane 2015, Brackhane and Pechacek 2015, Brackhane et al. 2016, Sideleau et al. 2016).

Analysis

We examined Pearson's correlation coefficient between the number of attacks each year and the estimated annual human population over 2001 to 2014 by interpolating census data for 2001, 2004, 2010, and 2015 (General Directorate of Statistics 2018) at 3 levels of resolution: total attacks versus population size at the national level, attacks versus population size at the municipality level ($n = 10$ containing crocodiles [except Oecusse]), and attacks versus population size at hotspots ($n = 5$ with appropriate information on the year of the incident), defined as communities with ≥ 5 reported attacks since 1996.

With regard to the severity of attacks, we formulated a binary response variable (fatal vs. non-fatal attacks) and used a generalized linear mixed effect model, with binomial error distribution, to test whether the year of the incident or the victim's activity, sex, or age explained variation in severity. We fit municipality as a random intercept to account for pseudoreplication of data (Pinheiro and Bates 2009). We included year as a variable affecting the severity of an attack, as in Fukuda et al. (2015). A potential bias, for which we have no real insights, could relate to the probability of an attack being fatal increasing during times of political unrest, ethically motivated violence, and the associated infrastructure destruction (1999–2002; 2006) in Timor-Leste, when the availability of medical treatment was compromised (Ofstad 2012). We performed all statistical analyses using R (R Development Core Team 2009) and the following packages within R: base, graphics, effects, Hmisc, lme4, MuMIn, plyr, and stats.

To put the risk of crocodile attacks into a broader context of other risk factors for people living in Timor-Leste, we compared risk factors from HCC with malaria and dengue fever (World Health Organization, Ministry of Health in Timor-Leste, unpublished data) and the frequency of traffic accidents (Timorese National Traffic Police, unpublished data). We also compared the rate of crocodile attacks in Timor-Leste with the neighboring West Timor (Indonesia) and NT, where the saltwater crocodile populations have reached carrying capacity in many places (Fukuda et al. 2011). Finally, to examine the hypothesis whether dispersing saltwater crocodiles from NT could contribute to the accelerating HCC in Timor-Leste, we conducted a literature review on the saltwater crocodile's biological ability to travel long distances (>450 km), and population dynamics of the saltwater crocodile population in NT with special regards to coastal movements. We searched for the terms saltwater crocodile (*C. porosus*), dispersal, movement(s), migration, biological capability, satellite tracking, and mark-recapture using Google scholar and the literature and expert knowledge available at Wildlife Management International (Karama, Australia). We identified key parameters that would allow us to discuss the potential for crocodile dispersal from the NT to Timor-Leste. We also interviewed staff working at and around the Bayu Undan oil rig platform, approximately 307 km north of Australia and approximately 220 km south of Timor-Leste, to compile information on saltwater crocodile sightings in the Timor Sea between Australia and Timor-Leste.

RESULTS

Our final data file contained 130 crocodile attack records (1996–2014) from 45 Sukus (i.e., local areas; Fig. 2), within 11 of the 13 Districts of Timor-Leste (Fig. 3). Of these, 123 (94.6%) included information on the severity (fatal or non-fatal), 120 (92.3%) included the victim's activity at time of the attack, 112 (86.2%) included the gender of the victims, 110 (84.6%) included reliable information on the year of attack, and 87 (66.9%) included the age of the victims. Where activity was reported, fishing (82.5%) accounted for most attacks followed by bathing (7.5%) and water collecting (4.2%). Most victims (83.0%) were men.

The potential range of saltwater crocodiles in Timor-Leste was 7,302 km^2 (Fig. 3). However, the risk of attack was likely minimal in much of this area and no crocodile attacks were reported from 283 out of the 328 Sukus intersecting with

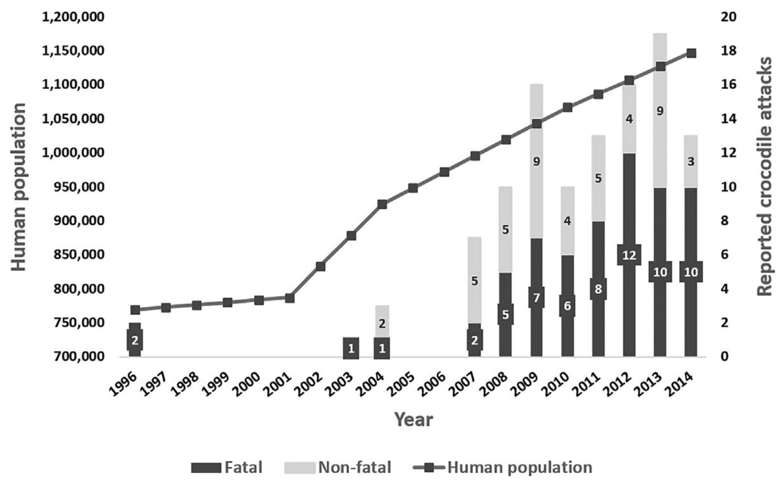

Figure 2. Frequency of reported crocodile attacks (fatal and non-fatal) relative to the increasing human population in Timor-Leste, 1996–2014.

potential crocodile range. Crocodile attacks were reported from 45 Sukus (13.7% of the Sukus intersecting with saltwater crocodile's potential range), which accounted for 2,255 km^2 (31%) of potential crocodile range in Timor-Leste. We identified 7 Sukus (each with $\geq$5 reported attacks), comprising 42% of all attacks in the database. Hence, the spatial analysis identified the communities (Sukus) constituting hotspots. They were all situated along the south coast and southeast part of Timor-Leste, especially in the municipalities Viqueque (south coast), Cova Lima (south coast), and Lautém (south-east coast; Fig. 3). Core habitat for saltwater crocodiles in Timor-Leste, where the native population can reside in permanent water and breed, is highly restricted: 23 sites encompassing 131.3 km^2 of waterbodies.

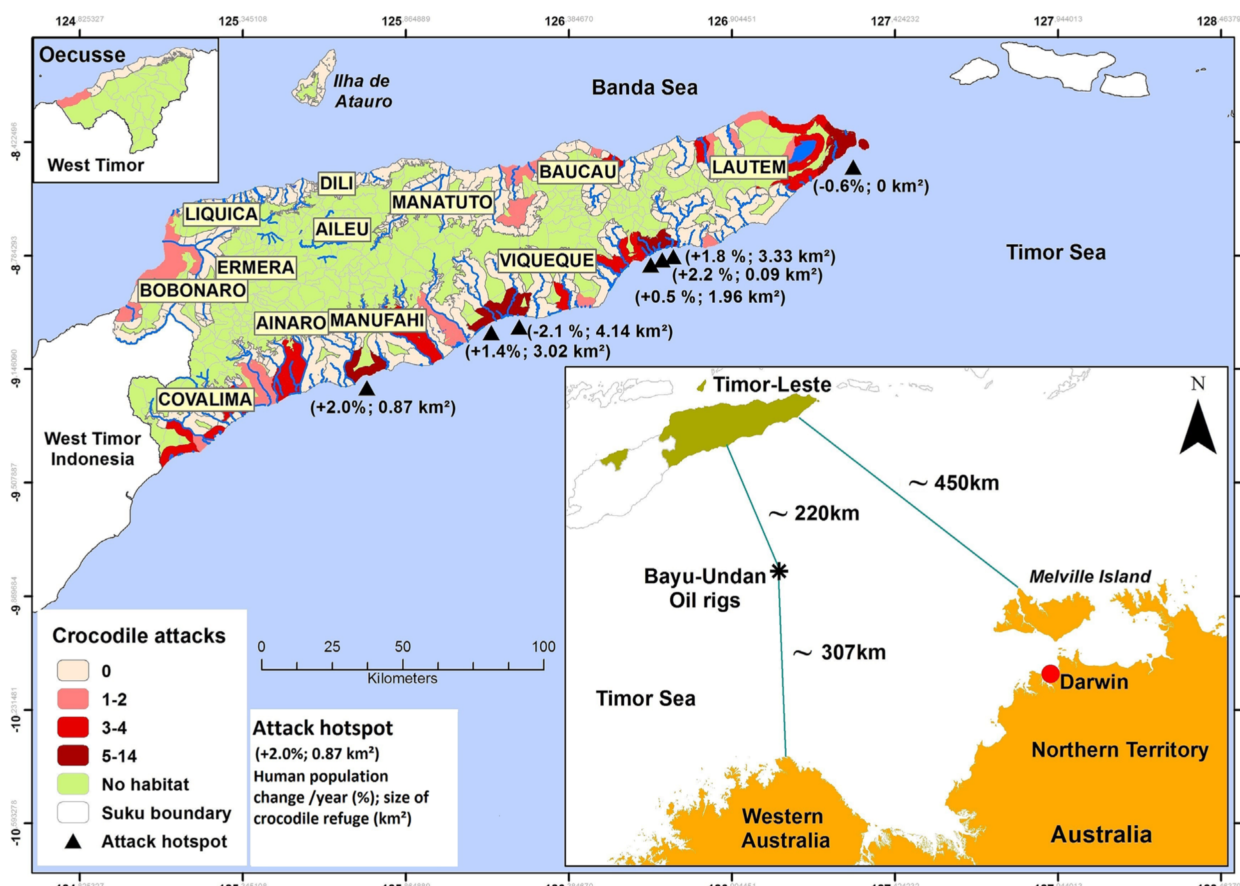

Figure 3. Potential for crocodile risk in Timor-Leste based on 130 reported attacks between 1996 and 2014, and human population change/year (%) and permanent crocodile habitat (km^2) in 7 crocodile attack hotspots. The inset presents distances of potential dispersal routes between Australia and Timor-Leste.

Trends in HCC

Timor-Leste's human population has more than doubled in the last 35 years (General Directorate of Statistics 2018). It has increased from 769,000 (1996) to 925,000 (2004), to 1,147,000 in 2014 (Fig. 2). The population rate of growth was 2.4% in 2004–2010 and 1.8% in 2010–2015 (Pereira 2015). Between 1996 and 2006, there were 6 crocodile attack reports in 11 years (0.55/yr), whereas between 2007 and 2014 there were 104 attacks reported in 8 years (13/yr), with a peak of 19 attacks in 2013. This represents a 23-fold increase in the 2 periods, separated by 9 years. In the NT, there were no attacks in the 8 years after protection (1971) but 62 attacks (1.63/yr) in the 38 years from 1979 to 2017.

Notwithstanding possible reporting biases, a >20 times increase in crocodile attacks (1996–2014) and a 1.49 times increase in the human population size (1996–2014) are correlated (Pearson's correlation coefficient = 0.88, $P < 0.001$) because both were increasing but are not necessarily linked by cause and effect. At the municipality level (Table 1), the separate correlation coefficients over 14 years ranged from 0.21 ($P = 0.46$) to 0.77 ($P < 0.01$). All were positive but there was no trend across all the data. The capital Dili had a high rate of population increase (>5.5%) and a high human density (762 persons/km^2) but a low rate of attacks (Table 1). In contrast, low population growth occurred in the rural municipalities of Lautém (>1.3%) and Viqueque (>1.5%), which had high rates of attack; together 62% of all reported attacks came from these 2 municipalities. They are also among the municipalities with the lowest human density in Timor-Leste: 41 persons/km^2 in Viqueque and 36 persons/km^2 in Lautém.

In the communities of Luca and Tutuala, among 2 of the 7 hotspots with ≥5 reported attacks (Table 1), human population decreased since 2001, whereas the number of reported crocodile attacks increased. Strong cultural attitudes towards crocodiles (ancestor worship), which may prevent crocodiles being killed, was present among many, but not all members of a rural community. For example, in Uani Uma (11 reported attacks), Luca (6 reported attacks), and Suai Loro (4 reported attacks), some family clans within the community hunt crocodiles for meat.

Risk Factors

Of the 123 reported attacks where severity was known, 52% were fatal. The severity was significantly less with fishing (50% survival rate) than other activities such as bathing and water collection combined (10% survival rate, $\beta = 2.169$, SE = 0.8641, Z = 2.510, $P = 0.012$; Fig. 4). The relationship between severity and age (fatal = 1 vs. non-fatal = 0) was parabolic (quadratic term: $\beta = 0.1238$, SE = 0.0656, $Z = 1.886$, $P = 0.059$), indicating attacks on people <15 years and >60 years of age had a >60% probability of being fatal, whereas attacks on people 30–40 years of age had a 45% probability of being fatal. That the severity of attacks has increased over time is probably meaningful, despite the trend not reaching statistical significance ($\beta = 0.154$, SE = 0.101, $Z = 1.511$, $P = 0.131$). The severity of attacks on males and females did not differ with sex (β male = 0.438, with the reference category female on severity of attack, SE = 0.692, $Z = 0.632$, $P = 0.527$).

In terms of comparative risk factors, by 2014 crocodile attacks constituted an 10 times greater fatal risk than malaria, and a 2.5 times greater fatal risk than dengue fever. Fatal crocodile attacks in Timor-Leste now equate to 14.3% of the people killed annually in road accidents (Fig. 5A). The number of crocodile attacks/100,000 people in 2014 was

Table 1. Number of reported crocodile attacks in Timor-Leste, 1996–2014, average human population change per year, 2001–2015, Pearson's correlation coefficient (PCC) for the relationship between crocodile attacks and population change, PCC *P*-value, human density, and estimated crocodile habitat in 11 municipalities and 7 communities with ≥5 reported attacks.

Site	Reported crocodile attacks	Population change/yr (%)	PCC	*P*	Human density 2015 (persons/km^2)	Crocodile refuge (km^2/coastline km)
Municipality						
Viqueque	54	1.5	0.31	0.24	41	9.14/77
Lautém	26	1.3	0.77	0.00	36	48.65/181
Cova Lima	14	2.0	0.41	0.15	55	31.74/69
Manufahí	9	2.8	0.77	0.00	40	3.05/46
Baucau	7	1.4	0.31	0.27	82	3.92/58
Manatuto	6	1.2	0.31	0.29	26	0.00/36
Ainaro	4	2.8	0.21	0.46	79	0.00/54
Bobonaro	4	2.5	0.34	0.24	71	3.25/21
Dili	4	5.5	0.39	0.16	762	23.07/104
Oecusse	1	3.1	NA[a]	NA	85	4.24/57
Liquica	1	3.4	0.38	0.18	129	4.21/63
Attack hotspots						
Irabin de Baixo	14	1.8	0.45	0.11	108	3.33/6
Uani Uma	11	2.2	NA	NA	57	0.09/3
Vessuro	9	0.5	NA	NA	40	1.96/2.5
Luca	6	−2.1	−0.24	0.40	20	4.14/11
Betano	5	2.0	0.60	0.02	52	0.87/13.5
Fatuwaque-Aubeon	5	1.4	0.41	0.15	55	3.02/8
Tutuala	5	−0.6	−0.42	0.14	14	0.00/13

[a] Not available.

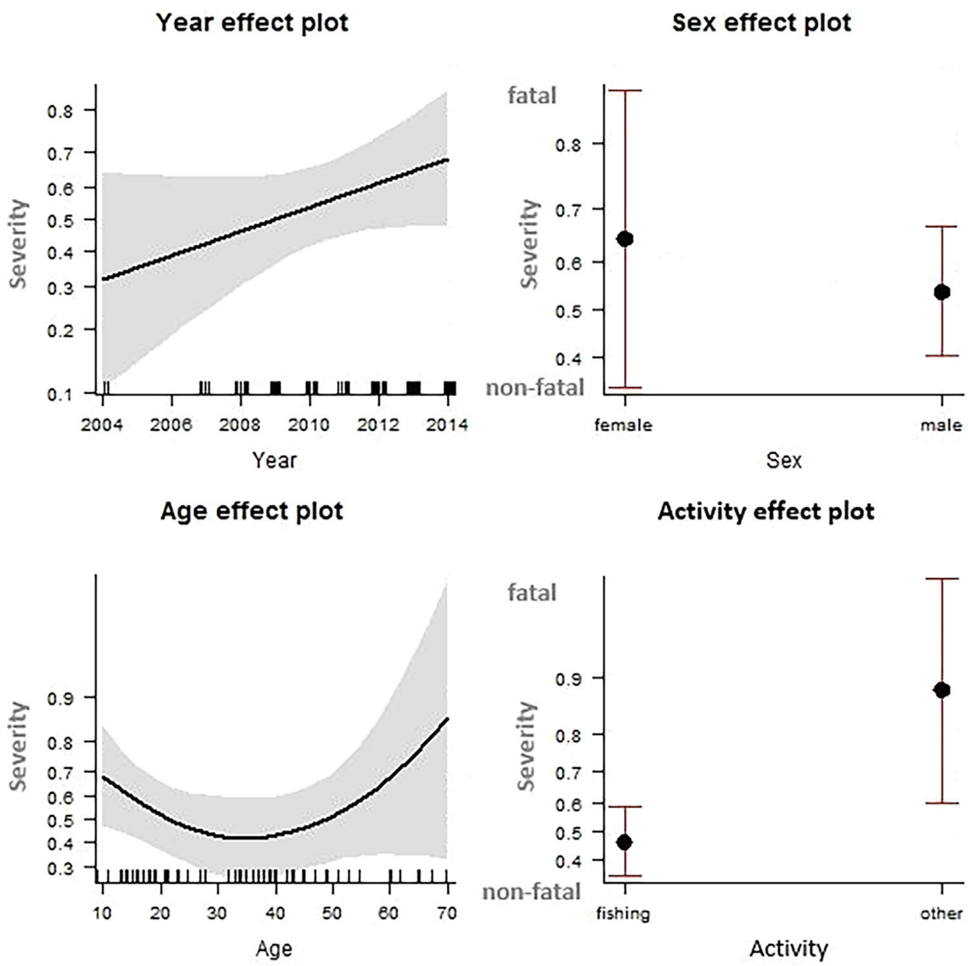

Figure 4. Relationship between risk activities and severity of crocodile attacks (1 = fatal, 0 = non-fatal) between 1996 and 2014 in Timor-Leste. Shaded areas and error bars represent 95% confidence intervals.

below the level in the sparsely populated NT of Australia but higher than in the adjoining state of West Timor Province of Indonesia (Fig. 5B). The fatality rate of saltwater crocodile attacks in Timor-Leste (52%) was similar to that calculated for Indonesia generally (55%) and West Timor specifically (57%; CrocBITE 2017). The rate calculated for Australia (30.4%; NT Government, unpublished data) was lower.

Migration from Australia?

Although we do not have definitive tracking or genetic data allowing us to assess the extent to which the recovery of saltwater crocodiles in Timor-Leste, and the increasing rate of HCC associated with it, may be due to immigration of large crocodiles, possibly from Australia, the following key parameters are germane to assessing the likelihood of this occurring.

1. As discussed above, Timor-Leste has very limited core habitat for saltwater crocodiles with permanent water and suitable sites for nesting and the growth of successive cohorts of juveniles.
2. At its closest point, the NT and Timor-Leste are only 450 km apart. This is well within the range of saltwater crocodile ocean voyages, as demonstrated by small and large crocodiles arriving at islands well-distanced from known populations: Nauru (1,160 km), Eastern Caroline Islands (1,360 km), Woleai Atol Micronesia (1,050 km), Maldives (860 km), Iwo Jima (2,100 km), Eauripik Island Micronesia (2,000 km), Marshall Islands (2,300 km; Webb et al. 2010). Satellite tracking indicates the journey from the NT to Timor-Leste could be completed in 15 days (Read et al. 2007).
3. That saltwater crocodiles move at sea, between rivers and swamps, is evidenced by the continual replacement of the 200–250 saltwater crocodiles removed annually, for safety reasons, from Darwin Harbour, which has limited intrinsic breeding. The most commonly encountered size range (70%) are juveniles and subadults, 1.0–2.5 m long, which are moving around the coast. Animals >3 m long are dangerous to people and constitute about 15% of animals captured (Fukuda et al. 2014). Barnacles on some crocodiles indicate long periods at sea.
4. Crocodiles are indeed sighted in the open ocean between Timor-Leste and northern Australia, well-distanced from land. Roughly 150 km west of the Bayu-Undan platform (~220 km South of Timor-Leste and ~307 km Northwest of NT) a crocodile was sighted resting on a floating hose line, and at Bayu-Undan approximately

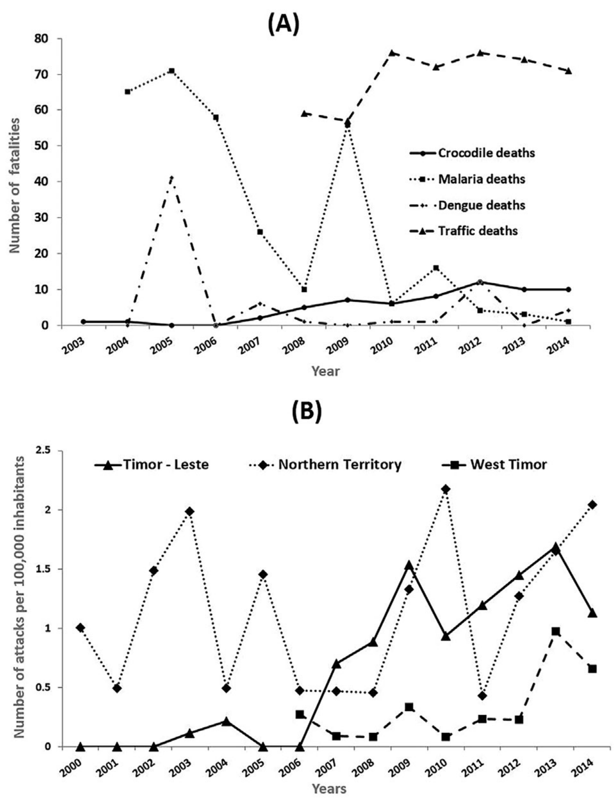

Figure 5. Crocodile risk in Timor-Leste in comparison to A) other biological agents and traffic accidents and B) neighboring countries.

4–5 crocodiles are sighted and opportunistically recorded each year. One oil worker described (to GW) a 4-m long crocodile resting on a moored barge but did not identify which platform.

5. Crocodiles in the Timor Sea could potentially come from Papua, roughly 1,300 km to the east, or from other parts of Indonesia or Papua New Guinea. Genetic research will be needed to resolve this. However, the current status of saltwater crocodiles in coastal rivers in these areas is thought to be very low relative to northern Australia, where the wild population is at carrying capacity (Fukuda et al. 2011).
6. Growth rates of saltwater crocodiles are relatively slow and highly variable between individuals, with males taking around 16 years to grow from hatching to maturity at about 3.1 m in length (Webb et al. 1978). It took 23–27 years after protection before large crocodiles, mostly hatched in northern Australia, increased greatly in abundance and caused HCC to increase sharply (Fukuda et al. 2014). For a similar sharp increase in large crocodiles and adults to occur within 9–10 years of protection (Fig. 3), could be achieved by dramatically faster growth rates, which seems unlikely, or by immigration of larger crocodiles.
7. Intensive monitoring of the recovery of the wild population of saltwater crocodiles immediately after protection in NT documented the build-up of successive cohorts of juveniles in rivers with intrinsic breeding (Messel et al. 1981, 1982, 1984). However, 80% of juveniles and subadults that reached >1–2 m long moved out to the coast, perhaps social excluded, and 60–70% of them disappeared. They were not recruited into other adjoining rivers and were thought to have moved away at sea or to have been predated at sea (Messel et al. 1981, 1982, 1984).
8. That larger crocodiles move around the coast and repopulate otherwise depleted populations is demonstrated by the monitoring results for the Mary River in NT (Fukuda et al. 2011). There was virtually no intrinsic breeding in this river at the time of protection, but 15 years afterwards, a very rapid increase of mostly 2–4-m long crocodiles took place. These were immigrants arriving via the coast from nearby rivers with populations building through intrinsic breeding. Within 10 years in the Mary River, the biomass of saltwater crocodiles/km was 5 times that of other rivers, with relatively few juveniles. The size of animals in what is now the highest density river for saltwater crocodiles in Australia suggests a male bias may exist.
9. At a national level, saltwater crocodiles, after the first 2 age cohorts, become highly mobile, and through immigration of large (>2.5 m) and small (<2.5 m) animals, can fill a recovery void where there is no capacity to rebuild the population through intrinsic breeding. It would be a reasonably small step to extend this from north Australia to Timor-Leste.
10. There is now evidence from satellite tracking (Read et al. 2007) and mark-recapture (Walsh and Whitehead 1993) that relocated adult crocodiles become highly mobile after release. They move long distances, back and forth around the coast, sometimes returning (homing) to their site of capture. The same high mobility could be expected from crocodiles arriving at a new area of coastline after a sea journey. Dispersing crocodiles would be searching for an area in which to reside, and possibly access to low salinity water. Such movements bring crocodiles into areas where there are few resident crocodiles, and where human behavior, for example fishing on the coast in Timor-Leste, had previously been conducted safely.
11. In captive saltwater crocodiles with limited movement, 50–70% of the food eaten goes to maintenance (Webb et al. 2013). Thus a highly mobile crocodile, unable to feed or replace water at sea, may well have a significant food deficit when it arrives and becomes highly mobile at a new location. Thus hunger may play a role in the higher rates of HCC if immigrant crocodiles are involved. Some fatal saltwater crocodile attacks in Australia are believed to have involved relocated large crocodiles.

DISCUSSION

Defining the social (Manfredo and Dayer 2004, Dickman 2010) and spatio-temporal patterns of HCC in Timor-Leste (Alessa et al. 2008, Miller 2015) is a fundamental first step towards developing an innovative management protocol. The saltwater crocodile population in Timor-Leste, which is only 450 km northwest of the NT population, was protected in 2000 (United Nations Transitional Administration in Timor-Leste 2000, Diploma Ministerial 2005) as part of sweeping changes introduced after an United Nations-led transition period (1999–2002) and independence (2002). Since then, the number of reported crocodile attacks on people have increased significantly (Käslin 2015, Sideleau et al. 2016), which is linked to the recovery of the wild population observed by local stakeholders and national experts (Brackhane 2015). Hence a nominal conservation success, the rebuilding of a depleted population, has come at the cost of many human lives. A management protocol tailored to the Timor-Leste context is urgently needed, but achieving this is complicated by Timor-Leste having a creation myth (i.e., Lafaek Diak, the good crocodile), which remains omnipresent in rural areas today (Kaiser et al. 2009, Barnes et al. 2017). Killing local crocodiles, which are part of the ancestor belief system, is not an acceptable management option for many Timorese people (Brackhane et al. 2017), even if it is deemed necessary to reduce the risk of attacks.

If crocodiles are arriving from Australia, effective management of saltwater crocodiles in Timor-Leste may need reciprocal management actions in Australia, which would also be unique among world crocodilians. Regional efforts to better define and understand the problem are needed, and in addition to cooperation between Australia and Timor-Leste, Indonesia needs to be involved. The rate of HCC in West Timor, Province of Indonesia is also on the increase (CrocBITE 2017), perhaps for the same reason.

Our reliance on traditional and local sources of information about HCC introduces potential biases, but we do not consider they would greatly affect the conclusions drawn. Underreporting of crocodile attacks cannot be excluded. Rough terrain and poor infrastructure in Timor-Leste impedes frequent and comprehensive monitoring within the available human and technical resources. Years of political instability in Timor-Leste (e.g., 1999–2006) may have compromised the assessment of crocodile attacks (Ofstad 2012), and the special cultural status of crocodiles in the country in some cases mitigates against reporting. Traditional elders in some communities perceive every crocodile attack as having been provoked because "Grandfather Crocodile" exclusively attacks humans as punishment for "acts against nature" (Thomas Suarez, village headman of Vessuro, personal communication). Some victims of non-fatal crocodile attacks are suspected to deliberately withhold reporting to avoid social discrimination within the community. Failing to report non-fatal attacks could be implicated in the comparatively high share of fatal attacks in Timor-Leste (52%) compared to Australia (30.4%).

The integration of local ecological (or indigenous) knowledge, increasingly acknowledged and valued by international organizations such as the International Union for Conservation of Nature (IUCN; Cross et al. 2017) and International Panel for Biodiversity and Ecosystem Services (Thaman et al. 2013), delivers baseline information for scientific analysis and helps to define the local context of human-wildlife interaction, which is critical to the development of appropriate integrative management and conservation regimes (Madden 2004, Treves et al. 2006) in cases like saltwater crocodile management. The heterogeneous data-gathering tools we used resulted in attack reports from all regions of Timor-Leste, and enabled identification of hotspots and meaningful quantification of victim demographics.

Human-crocodile conflict is on the increase globally (Pooley 2016), and we suspect the approach we took has application to other developing countries, especially those in which saltwater crocodile recovery is causing increased HCC: Indonesia (CrocBITE 2017), Papua New Guinea (Solmu 2009), Solomon Islands, Vanuatu, Palau (Manolis and Webb 2014), India (Das and Jana 2017), and Sri Lanka (Amarasinghe et al. 2015). The significance of HCC fatalities when reported in isolation may be difficult to appreciate, but HCC fatalities in Timor-Leste equal 14.3% of road fatalities and exceed losses to both malaria and dengue fever; these are significant yardsticks for mortality risk in the tropics.

Our results confirm with even more data that crocodile attacks in Timor-Leste are a very significant public safety threat around the country's coastline (Kaiser et al. 2009, 2011, 2013; Käslin 2015; Sideleau et al. 2016). That our estimate of a fatality rate of 52% was lower than the 82% estimated by Sideleau et al. (2016) probably reflects proportionally more non-fatal attacks in our data base. Our study depended on data compiled from a range of different sources (Brackhane 2015, Brackhane and Pechacek 2015, Brackhane et al. 2016, Sideleau et al. 2016, CrocBITE 2017) because we focused on maximizing known attack records, rather than on standardized assessment, such as in the United States and Australia (U.S. Fish and Wildlife Service 1999, Saalfeld et al. 2016).

The status of saltwater crocodiles over time in Timor-Leste is not known precisely from scientific survey data but is known from local knowledge. National experts and local authorities reported independently that prior to independence (2002), crocodile abundance and HCC was less evident than it is today. This is claimed to be due to an earlier period, more than a century ago, of intense hunting over long periods by Portuguese and Indonesian colonialists (Brackhane 2015). More recently, local fishermen (Leopoldo Gueteres and Raimundo Suares, local fishermen from Uani Uma and Cova Lima, personal communications) and F. M. E. Xavier, (Biodiversity Directorate, Ministry for Development of Housing, Planning and Environment) reported that soldiers of the Thai Battalion, of the United Nations force, which ensured security in Baucau, Viqueque, and Lautém during the period of political instability (1999–2004; United Nations Transitional Administration of Timor-Leste Press Office 2002), actively looked for and shot every crocodile they could find. We have been unable to verify the magnitude of the harvest taken historically. For example, the Indonesian Crocodile Farmers Association, which has traded in skins since the early 1990s, was largely unaware of skins being accessed from Timor-Leste, suggesting the population was not known to be very high. Regardless, there is universal agreement among Timorese stakeholders, national and local, that the wild population of crocodiles has increased greatly since independence (Brackhane 2015), when protection for crocodiles became enshrined in law (UNTAET 2000, Diploma Ministerial 2005), adding to the protection afforded by those rural communities that worship the crocodile as an ancestor (Brackhane 2015).

The extent of permanent core habitat containing resident crocodiles in Timor-Leste is very limited relative to the NT of Australia. The volcanic origin of the country has resulted in 51% of land ≥500 m above sea level and river systems that are comparatively short with steep source-to-estuary distances. There are 11 permanent rivers and 1 larger lake system, and the ongoing depletion and fragmentation of coastal habitat in mangroves and lagoons (Alongi 2014), caused by resource extraction and farming (Bettencourt et al. 2015, Corey et al. 2017), is an added problem.

Crocodile attacks were reported from all coastal regions of Timor-Leste, but our spatial analysis revealed that a high percentage (42%) of all crocodile attacks were limited to 7 hotspots (≥5 attacks), all located along the southern and southeastern coast of the country. We were unable to identify any other significant patterns within the 7 attack hotspots nor among the 130 attacks in general, which would allow us to link the increasing HCC to changes in human-induced factors. Crocodile attacks occurred in terrestrial waterbodies and in the open sea, sometimes far from any terrestrial core habitat (Tutuala), in communities with reported ancestor worship (Tutuala, Vessuro), and within communities that hunt crocodiles for meat (Luca, Uani Uma, Suai Loro). In 5 attack hotspots, the human population was increasing since independence, whereas it was decreasing in 2 others. It suggests that the increase in numbers of (large) crocodiles is a primary factor driving the increased rate of crocodile attacks.

If it is assumed that the activities of people being attacked has changed little over time when crocodiles where depleted, then the frequency of crocodile attacks on people is a thumbnail index of the increasing abundance of larger crocodiles reported by everyone interviewed. A mean of 13 attacks/per year for 1,074,005 people (2007–2014), equates to an expected 10.2 attacks/year when the human population was only 838,787 (1996–2006); yet even with significant underreporting, a conservative estimate of 1.65 attacks/year in 1996–2006 (3 times the recorded 0.55) would mean the crocodile population, or at least the larger crocodiles within it, would have increased 7.9 times in abundance within 11 years.

In northern Australia, comprehensive data on the recovery rates of depleted populations of saltwater crocodiles are available (Messel et al. 1981, Fukuda et al. 2011). Where nesting habitat existed, recovery occurred largely through intrinsic breeding, adding an age class to the population each year (Webb and Messel 1978, Messel et al. 1981, Webb and Manolis 1992). But there was no breeding habitat on the coast and in rivers with limited freshwater input (Messel et al. 1981). In these rivers, recovery involved migrating animals arriving from other rivers in which recovery had occurred via intrinsic breeding. Fukuda et al. (2011) described the recovery rate in 11 NT rivers with intrinsic breeding, starting 4 years after protection, and the population increased by 0.7 times over the next 11 years. But in Mary River, repopulated by immigration, the population increased by 3.7 times in 11 years.

Given very limited core habitat for intrinsic breeding of saltwater crocodiles, the very rapid rate of crocodile population expansion that has taken place in Timor-Leste would be consistent with immigration rates being high. At a national stakeholder workshops held in Dili in 2014, and during field trips in 2014–2017, local authorities have increasingly suggested that crocodiles moving around the Timor-Leste coastline are coming from elsewhere, specifically from northern Australia.

The evidence we reviewed, far from allowing us to reject the possibility of immigration from Australia being implicated, provides compelling evidence for it. We derived a potential regime linking all these events together, for the purposes of identifying management research needs and generating testable hypotheses.

When saltwater crocodiles were protected in northern Australia, particularly in the NT (1971), wild populations of saltwater crocodiles were highly depleted everywhere. There was no nearby population where the species was abundant that could boost recovery rates by significant rates of immigration. In the case of Timor-Leste, where protection came 30 years later, there was a nearby population where the species was abundant that could boost recovery rates through significant rates of immigration.

In northern Australia the recovery occurred largely through intrinsic breeding, as described by Webb and Messel (1978) and Messel et al. (1982, 1984). It now seems likely that the disappearance of dispersing individuals may reflect sea journeys, as hypothesized. Today, juveniles, subadults, and adults in the NT are all highly mobile and move around the coast, and for example, they are continually repopulating Darwin Harbour. If crocodiles moving across the north coast of the NT, from east to west, did not turn 90 degrees south at Bathurst lsland but rather continued in the same direction they were moving, they would arrive at Timor-Leste, perhaps within 15 days. En route, in the open sea, some would pass platforms such as Bayu-Undan in the Timor Sea. On arrival in Timor-Leste, or other nearby countries, they could be expected to move around the coastline, presumably looking for food, water, or a refuge. They could be expected to have a food deficit due to their sea journey (no feeding) and contribute to the rates of HCC. Whether they move on to Indonesia, or eventually return to Australia, is unknown but possible. Research currently underway will determine whether significant numbers of crocodiles in Timor-Leste are indeed coming from northern Australia, and shed new light on the likely route.

MANAGEMENT IMPLICATIONS

The research undertaken here allowed us to identify hot spots of HCC in Timor-Leste and activities that more often lead to fatal attacks. Communities constituting hotspots can now be prioritized within a national management protocol that includes professional monitoring and the removal of problem crocodiles, as local authorities in Timor-Leste consider crocodiles from abroad are troublemakers, and view them in a culturally different light than those originating in Timor-Leste (Brackhane 2015, Käslin 2015). Professional monitoring and management must integrate the traditional ecological knowledge and expectations of local stakeholders and needs to be embedded in the traditional legal system *tara bandu* to ensure long-term applicability on the local scale (The Asia Foundation 2013). In the attack hotspot of Uani Uma (11 reported crocodile attacks since independence), for example, no crocodile attacks have been reported since traditional elders imposed a taboo on fishing in the local lagoon Malai Wai. Once sufficient information on the local and migratory crocodile population is available, and a technical infrastructure established, concepts of sustainable use, including ecotourism and crocodile egg harvest (Corey et al. 2017), can be developed in collaboration with local farmer and fishermen to provide an alternative source of income, while reducing the need for risk activities and creating incentives to retain rather than further deplete crocodile habitat in Timor-Leste.

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LITERATURE CITED

Alessa, L. N., A. A. Kliskey, and G. Brown. 2008. Social-ecological hotspots mapping: a spatial approach for identifying coupled social-ecological space. Landscape and Urban Planning 85:27–39.

Allen, G. R. 1974. The marine crocodile, *Cvocodylus porosus* from Ponape, Eastern Caroline Islands, with notes on food habits of crocodiles from the Palau Archipelago. Copeia 1974:553.

Alongi, D. M. 2014. Mangrove forests of Timor-Leste: ecology, degradation and vulnerability to climate change. Pages 199–212 *in* I. Faridah-Hanum, A. Latiff Khalid Rehman Hakeem, and M. Ozturk, editors. Mangrove ecosystems of Asia. Springer, New York, New York, USA.

Amarasinghe, A. T., M. B. Madawala, D. S. Karunarathna, S. C. Manolis, A. de Silva, and R. Sommerlad. 2015. Human-crocodile conflict and conservation implications of saltwater crocodiles *Crocodylus porosus* (*Reptilia: Crocodylia: Crocodylidae*) in Sri Lanka. Journal of Threatened Taxa 7:7111–7130.

Barbosa, M., and S. Booth. 2009. East Timor's fisheries catch reconstruction (1950–2009): fisheries under different regimes. Pages 39–51 *in* D. Zeller, and S. Harper, editors. Fisheries catch reconstructions: Islands, Part I. Fisheries Centre Research Reports 17, Fisheries Centre, University of British Columbia, Vancouver, Canada.

Barnes, S., H. Hägerdal, and L. Palmer. 2017. An East Timorese domain. Bijdragen tot de taal-, land-en volkenkunde/Journal of the Humanities and Social Sciences of Southeast Asia 173(2–3):325–355.

Bettencourt, E. M. V., M. Tilman, V. Narciso, M. L. D. S. Carvalho, and P. D. D. S. Henriques. 2015. The livestock roles in the wellbeing of rural communities of Timor-Leste. Revista de Economia e Sociologia Rural 53:63–80.

Boggs, G., and K. Edyvane. 2009. The Timor-Leste coastal/marine habitat mapping for tourism and fisheries development project. Charles Darwin University, Darwin, Australia.

Brackhane, S. 2015. Human-crocodile conflict in Timor-Leste—assessment and recommendations for management. Thesis, University of Freiburg, Baden-Württemberg, Germany.

Brackhane, S., X. Flaminio, O. Araujo, M. Mälicke, and G. Marcal. 2017. Community-based monitoring of saltwater crocodile (*Crocodylus porosus*) in Timor-Leste. Rufford Foundation, London, United Kingdom.

Brackhane, S., and P. Pechacek. 2015. Community-based monitoring (CBM) im Rahmen des Übereinkommens über die biologische Vielfalt: Das Leistenkrokodil (*Crocodylus porosus*) in Timor-Leste als Fallbeispiel. Pages 167–173 *in* H. Korn, and K. Bockmühl, editors. Treffpunkt Biologische Vielfalt XV. German Agency for Nature Conservation, Bonn-Vilm, Germany. [in German.]

Brackhane, S., R. D. R. Pires, F. M. E. Xavier, A. Pinto, M. Gusmao, and P. Pechacek. 2016. Cost effective options for crocodile monitoring in developing countries—a pilot study from Timor-Leste. Page 170 *in* Crocodiles. Proceeding of the 24th Working Meeting of the IUCN-SSC Crocodile Specialist Group, IUCN, Gland, Switzerland.

Britton, A. R., R. Whitaker, and N. Whitaker. 2012. Here be a dragon: exceptional size in a saltwater crocodile (*Crocodylus porosus*) from the Philippines. Herpetological Review 43:541–546.

Caldicott, D. G., D. Croser, C. Manolis, G. Webb, and A. Britton. 2005. Crocodile attacks in Australia: an analysis of its incidence and review of the pathology and management of crocodilian attacks in general. Wilderness & Environmental Medicine 16:143–159.

Campbell, H. A., M. E. Watts, S. Sullivan, M. A. Read, S. Choukroun, S. R. Irwin, and C. E. Franklin. 2010. Estuarine crocodiles ride surface currents to facilitate long-distance travel. Journal of Animal Ecology 79:955–964.

Corey, B., G. J. W. Webb, S. C. Manolis, A. Fordham, B. J. Austin, Y. Fukuda, D. Nicholls, and K. Saalfeld. 2017. Commercial harvests of saltwater crocodile *Crocodylus porosus* eggs by Indigenous people in northern Australia: lessons for long-term viability and management. Oryx 1–12.

Cox, J., and F. Gombek. 1985. A preliminary survey of the crocodile resource in Sarawak, East Malaysia. IUCN/WWF Project No. MAL 74/85. World Wildlife Fund, Kuala Lumpur, Malaysia.

CrocBITE. Worldwide Crocodilian Attack Database. http://www.crocodile-attack.info/. Accessed 20 Sep 2017.

Cross, R., S. Doornbos, R. Cooney, P. Wong, A. Mead, K. Lindeman, A. Kanagavel, S. Parvathy, S. Tomasini, B. Montanari, K. Gabrys, and T. K. Watson-Sproat. 2017. Guidance for integrating indigenous and local knowledge (ILK) in IUCN Red List assessments. International Union for Nature Conservation (IUCN), Gland, Switzerland.

da Costa, M. D. J., M. Lopes, A. Ximenes, A. do Rosario Ferreira, L. Spyckerelle, R. Williams, H. Nesbitt, and W. Erskine. 2013. Household food insecurity in Timor-Leste. Food Security 5(1):83–94.

Das, C. S., and R. Jana. 2017. Human–crocodile conflict in the Indian Sundarban: an analysis of spatio-temporal incidences in relation to people's livelihood. Oryx 1–8.

Dickman, A. J. 2010. Complexities of conflict: the importance of considering social factors for effectively resolving human-wildlife conflict. Animal Conservation 13:458–466.

Dunham, K. M., A. Ghiurghi, R. Cumbi, and F. Urbano. 2010. Human-wildlife conflict in Mozambique: a national perspective, with emphasis on wildlife attacks on humans. Oryx 44(2):185–193.

FishBase. All fishes reported from Timor-Leste. http://fishbase.org/country/CountryChecklist.php?what=list&trp*P*=50&c_code=626&c-sub_code=&cpresence=Reported&sortby=alpha2&ext_CL=on&ext_pi-c=on&vhabitat=all2. Accessed 10 May 2018.

Fukuda, Y., G. Boggs, and P. Whitehead. 2004. GIS-based habitat analysis of saltwater crocodile (*Crocodylus porosus*) in the Northern Territory. Pages 470–474 *in* Crocodiles. Proceedings of the 17th Working Meeting of IUCN-SSC Crocodile Specialist Group. IUCN, Gland, Switzerland.

Fukuda, Y., and N. Cuff. 2013. Vegetation communities as nesting habitat for the saltwater crocodiles in the Northern Territory of Australia. Herpetological Conservation and Biology 8(3):641–651.

Fukuda, Y., C. Manolis, and K. Appel. 2014. Management of human-crocodile conflict in the Northern Territory, Australia: review of crocodile attacks and removal of problem crocodiles. Journal of Wildlife Management 78:1239–1249.

Fukuda, Y., C. Manolis, K. Saalfeld, and A. Zuur. 2015. Dead or alive? Factors affecting the survival of victims during attacks by saltwater crocodiles (*Crocodylus porosus*) in Australia. PLoS ONE 10(5):e0126778.

Fukuda, Y., G. Webb, C. Manolis, R. Delaney, M. Letnic, G. Lindner, and P. Whitehead. 2011. Recovery of saltwater crocodiles following unregulated hunting in tidal rivers of the Northern Territory, Australia. Journal of Wildlife Management 75:1253–1266.

Fukuda, Y., P. Whitehead, and G. Boggs. 2007. Broad-scale environmental influences on the abundance of saltwater crocodiles (*Crocodylus porosus*) in Australia. Wildlife Research 34(3):167–176.

General Directorate of Statistics Timor-Leste. 2018. Key census results. http://www.statistics.gov.tl/census-2/. Accessed 15 Feb 2017.

Geographic Information Group in Timor-Leste. 2018. Data. https://sites.google.com/site/gigtimorleste/home. Accessed 15 Feb 2018.

Hollands, M. 1984. A preliminary examination of crocodile population trends in Papua New Guinea 1981–1984. Pages 219–238 *in* Proceedings of the 7th Working Meeting of the IUCN-SSC Crocodile Specialist Group, Caracas, Venezuela.

Hollands, M. 1987. Management of crocodiles in Papua New Guinea. Pages 73–89 *in* G. J. W. Webb, S. C. Manolis, and P. J. Whitehead, editors. Wildlife management: crocodiles and alligators. Surrey Beatty & Sons, Chipping Norton, Australia.

Kaiser, H., V. L. Carvalho, J. Ceballos, P. Freed, S. Heacox, B. Lester, S. J. Richards, C. R. Trainor, C. Sanchez, and M. O'Shea. 2011. The herpetofauna of Timor-Leste: a first report. ZooKeys 109:19.

Kaiser, H, V. L. Carvalho, P. Freed, and M. O'Shea. 2009. Status report on *Crocodylus porosus* and human-crocodile interactions in Timor-Leste. Crocodile Specialist Group Newsletter 28:12–14.

Kaiser, H., D. Taylor, S. Heacox, P. Landry, C. Sanchez, A. V. Ribeiro, L. L. De Araujo, A. Kathriner, and M. O'Shea. 2013. Conservation education in a post-conflict country: five herpetological case studies in Timor-Leste. Salamandra 49:74–86.

Kar, S. K., and H. R. Bustard. 1983. Saltwater crocodile attacks on man. Biological Conservation 25:377–382.

Käslin, E. 2015. Management of culturally significant wildlife—the saltwater crocodile. Pages 38-45 *in* Timor—Leste's Fifth National Report to the Convention on Biological Diversity. National Biodiversity Working Group, Dili, Timor-Leste.

Lanhupuy, W. 1987. Australian Aboriginal attitudes to crocodile management. Pages 145–147 *in* G. J. W. Webb, S. C. Manolis, and P. J. Whitehead, editors. Wildlife management: crocodiles and alligators. Surrey Beatty & Sons, Chipping Norton, Australia.

Lee, G. P. 2003. Mangroves in the Northern Territory. Department of Infrastructure, Planning and Environment, Darwin, Australia.

Letnic, M., and G. Connors. 2006. Changes in the distribution and abundance of saltwater crocodiles (*Crocodylus porosus*) in the upstream, freshwater reaches of rivers in the Northern Territory, Australia. Wildlife Research 33:529–538.

Madden, F. 2004. Creating coexistence between humans and wildlife: global perspectives on local efforts to address human-wildlife conflict. Human Dimensions of Wildlife 9(4):247–257.

Manfredo, M. J., and A. A. Dayer. 2004. Concepts for exploring the social aspects of human-wildlife conflict in a global context. Human Dimensions of Wildlife 9(4):1–20.

Manolis, S. C. and G. J. W. Webb. 2013. Assessment of saltwater crocodile (*Crocodylus porosus*) attacks in Australia (1971–2013): implications for management. Pages 97–104 *in* Proceedings of the 22rd Working Group Meeting of the IUCN Crocodile Specialist Group. IUCN, Negombo, Sri Lanka.

Manolis, S. C., and G. J. W. Webb. 2014. Human-crocodile conflict in the Australia and Oceania region. Pages 200–208 *in* Proceedings of the 23rd Working Group Meeting of the IUCN Crocodile Specialist Group. IUCN, Gland, Switzerland.

Messel, H., W. J. Green, G. C. Vorlicek, and A. G. Wells. 1982. Surveys of tidal river systems in the Northern Territory of Australia. Work maps of tidal waterways in Northern Australia. Pergamon Press, Sydney, Australia.

Messel, H., G. C. Vorlicek, W. J. Green, and I. C. Onley. 1984. Surveys of tidal river systems in the Northern Territory of Australia. Population dynamics of *Crocodylus porosus* and status, management and recovery. Update 1979-1983. Pergamon Press, Sydney, Australia.

Messel, H., G. C. Vorlicek, G. A. Wells, and W. J. Green. 1981. Surveys of the tidal systems in the Northern Territory of Australia and their crocodile populations. The Blyth-Cadell River Systems study and the status of *Crocodylus porosus* populations in the tidal waterways of Northern Australia. Pergamon Press, Sydney, Australia.

Miller, J. R. 2015. Mapping attack hotspots to mitigate human-carnivore conflict: approaches and applications of spatial predation risk modeling. Biodiversity and Conservation 24:2887–2911.

Mills, D. J., A. Tilley, M. Pereira, D. Hellebrandt, A. P. Fernandes, and P. J. Cohen. 2017. Livelihood diversity and dynamism in Timor-Leste; insights for coastal resource governance and livelihood development. Marine Policy 82:206–215.

National Biodiversity Working Group. 2015. Timor—Lestés Fifth National Report to the Convention on Biological Diversity. National Biodiversity Working Group, Dili, Timor-Leste.

National Directorate of Fisheries and Aquaculture Timor-Leste [NDFA]. The National Fisheries Statistics System of Timor-Leste. www.peskador.org. Accessed 20 Jul 2017.

Neill, W. T. 1971. The last of the ruling reptiles: alligators, crocodiles and their kin. Columbia University Press, New York, New York, USA.

Ofstad, O. 2012. Reconciliation and conflict resolution in East Timor. Oxford Institute for Ethics, Law, and Armed Conflict Working Paper, Oxford, United Kingdom.

O'Shea, M., C. Sanchez, S. Heacox, A. Kathriner, V. L. Carvalho, A. Varela Ribeiro, Z. Afranio Soares, L. Lemos de Araujo, and H. Kaiser. 2012. First update to herpetofaunal records from Timor-Leste. Asian Herpetological Research 3(2):114–126.

Pereira, A. 2015. 2015 Census shows population growth moderating. Sixth Institutional Government of Timor-Leste, Dili, Timor-Leste.

Pinheiro, J. C., and D. M. Bates. 2009. Mixed-effects models in S and S-PLUS. Springer, New York, New York, USA.

Pinto, D., S. Shrestha, M. S. Babel, and S. Ninsawat. 2017. Delineation of groundwater potential zones in the Comoro watershed, Timor Leste using GIS, remote sensing and analytic hierarchy process (AHP) technique. Applied Water Science 7(1):503–519.

Pooley, S. 2016. Croc Digest: a bibliography of human-crocodile conflict research and reports. Simon Pooley, London, United Kingdom.

Read, M. A., G. C. Grigg, S. R. Irwin, D. Shanahan, and C. E. Franklin. 2007. Satellite tracking reveals long distance coastal travel and homing by translocated estuarine crocodiles, *Crocodylus porosus*. PLoS One 2(9): e949.

Ritchie, J., and J. Jong. 2002. Man-eating crocodiles of Borneo. Second edition. Natural History Publications (Borneo), Kota Kinabalu, Malaysia.

Saalfeld, K., Y. Fukuda, T. Duldig, and A. Fisher. 2016. Management program for the saltwater crocodile (*Crocodylus porosus*) in the Northern Territory of Australia, 2016–2020. Northern Territory Department of Environment and Natural Resources, Darwin, Australia.

Seeds of Life. 2013. Maps of Timor—Leste. http://seedsoflifetimor.org/climatechange/maps-of-timor-leste/. Accessed 20 Sep 2017.

Sideleau, B. M., K. S. Edyvane, and A. R. Britton. 2016. An analysis of recent saltwater crocodile (*Crocodylus porosus*) attacks in Timor-Leste and consequences for management and conservation. Marine and Freshwater Research 68:801–809.

Solmu, G. 2009. Increasing numbers of crocodile attacks with increasing crocodile population. Crocodile Specialist Group Newsletter 28(3):12.

Thaman, R., P. Lyver, R. Mpande, E. Perez, J. Cariño, and K. Takeuchi. 2013. The contribution of Indigenous and local knowledge systems to IPBES: building synergies with science. UNESCO, Paris, France.

The Asia Foundation. 2013. Tara Bandu: its role and use in community conflict prevention in Timor-Leste. The Asia Foundation, San Francisco, California, USA.

Trainor C. R., B. J. Coates, and D. K. Bishop. 2007. The Birds of Timor—Leste. BirdLife International & Dove Publications, Cambridge, United Kingdom.

Treves, A., R. B. Wallace, L. Naughton-Treves, and A. Morales. 2006. Co-managing human-wildlife conflicts: a review. Human Dimensions of Wildlife 11(6):383–396.

United Nations Integrated Mission in Timor-Leste—Joint Mission Analysis Center [UNTAET-JMAC 2008]. 2008. Crocodile assessment. 17 September 2008. United Nations, Dili, Timor-Leste.
United Nations Development Program. 2012. Timor Leste: Human Development Indicators. http://hdr.undp.org/en/countries/profiles/TLS. Accessed 20 Sep 2017.
United Nations Transitional Administration in East Timor [UNTAET]. 2000. Regulation N2000/19 on protected places. http://www.un.org/en/peacekeeping/missions/past/etimor/untaetR/Reg0019E.pdf. Accessed 24 Sep 2017.
United Nations Transitional Administration in East Timor [UNTAET] Press Office. 2002. Peacekeeping Force. Fact sheet 17. http://www.un.org/en/peacekeeping/missions/past/etimor/fact/fs17.pdf. Accessed 20 Sep 2017.
U.S. Fish and Wildlife Service. 1999. South Florida multi-species recovery plan. Ecological Services, Atlanta, Georgia, USA.
Walsh, B., and P. J. Whitehead. 1993. Problem crocodiles, *Crocodylus porosus*, at Nhulunbuy, Northern Territory: an assessment of relocation as a management strategy. Wildlife Research 20(1):127–135.
Webb, G. J. W., G. J. Hollis, and S. C. Manolis. 1991. Feeding, growth, and food conversion rates of wild juvenile saltwater crocodiles (*Crocodylus porosus*). Journal of Herpetology 25:462–473.
Webb, G. J. W., and S. C. Manolis. 1989. Crocodiles of Australia. Reed Books, Sydney, Australia.
Webb, G. J. W., S. C. Manolis, and M. L. Brien. 2010. Saltwater crocodile *Crocodylus porosus*. Pages 99–113 *in* S. C. Manolis and C. Stevenson, editors. Crocodiles. Status Survey and Conservation Action Plan. Third edition. IUCN Crocodile Specialist Group, Darwin, Australia.
Webb, G. J. W., and S. C. Manolis. 1992. Monitoring saltwater crocodiles (*Crocodylus porosus*) in the Northern Territory of Australia. Pages 404–418 *in* D. R. McCullough and R. H. Barrett, editors. Wildlife 2001: populations. Springer, Dordrecht, Netherlands.
Webb, G. J. W., S. C. Manolis, P. J. Whitehead, and G. A. Letts. 1984. A proposal for the transfer of the Australian population of *Crocodylus porosus* Schneider (1801), from *Appendix* I to *Appendix* II of C.I.T.E.S. Conservation Commission of the Northern Territory, Technical Report Number 21, Darwin, Australia.
Webb, G. J. W., S. Reynolds, M. L. Brien, C. Manolis, J. J. Brien, and K. Christian. 2013. Improving Australia's crocodile industry productivity. RIRDC Publication No. 12/139. Rural Industries Research and Development Corporation, Canberra, Australia.
Webb, G. J. W., and H. Messel. 1978. Movement and dispersal patterns of *Crocodylus porosus* in some rivers of Arnhem Land, Northern Australia. Wildlife Research 5(2):263–283.
Webb, G. J. W., H. Messel, J. Crawford, and M. Yerbury. 1978. Growth rates of *Crocodylus porosus* (Reptilia: *Crocodilia*) from Arnhem Land, northern Australia. Wildlife Research 5(3):385–399.
World Fish. 2017. Timor-Leste. https://www.worldfishcenter.org/country-pages/timor-leste. Accessed 24 Jan 2018.

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