Biological Conservation 280 (2023) 109965

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Integrating social and ecological information to identify high-risk areas of human-crocodile conflict in the Indonesian Archipelago

Ardiantiono [a,*], Sujan M. Henkanaththegedara [b], Brandon Sideleau [c], Sheherazade [d,e], Yogie Anwar [f], Iding A. Haidir [g,h], A.A. Thasun Amarasinghe [i,j,*]

[a] Durrell Institute of Conservation and Ecology, University of Kent, Canterbury CT2 7NZ, UK
[b] Department of Biological & Environmental Sciences, Longwood University, Farmville, VA 23909, USA
[c] Croc Attack: The Worldwide Crocodilian Attack Database, 2536 Avenida de Las Plantas, Thousand Oaks, CA 91360, USA
[d] PROGRES (Sulawesi Regional Ecological Conservation Initiative), Luwuk, Banggai 94711, Indonesia
[e] Department of Environmental Sciences, Policy, and Management, University of California Berkeley, California 94720, USA
[f] Wildlife Conservation Society-Indonesia Program, Bogor 16128, Indonesia
[g] Directorate General of Natural Resources and Ecosystem Conservation, Ministry of Environment and Forestry of the Republic of Indonesia, Jakarta 20270, Indonesia
[h] Wildlife Conservation Research Unit, Department of Biology, University of Oxford, The Recanati-Kaplan Centre, Abingdon OX13 5QL, UK
[i] Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Depok 16424, Indonesia
[j] Herpetology Lab, Research Center for Biosystematics and Evolution, The National Research and Innovation Agency (BRIN), Government of Indonesia, Cibinong 16911, Indonesia

ARTICLE INFO

Keywords:
Crocodylus porosus
Human-wildlife conflict
Media content analysis
Risk prioritization
Socio-ecological framework

ABSTRACT

Crocodile attacks on humans and subsequent retaliations are a pressing issue for saltwater crocodile conservation. As human-crocodile conflict is complex, integrating social and ecological information better explains the drivers and patterns of these interactions. Our study aims to incorporate ecological factors associated with the intensity of crocodile attacks together with social factors of mass media reports to identify high-risk areas of human-crocodile conflict in Indonesia. We compiled reports of crocodile attacks in the 2010–2019 period from media reports, field surveys, and local informants. The presence of attack was estimated by evaluating the influence of habitat, climate, human, and reporting effort. As tone of media coverage can reflect and shape reader's tolerance about a certain issue, we assessed the headline's tone from each media article that reported crocodile attacks from 2017 to 2019. A total of 665 crocodile attacks were recorded and mainly distributed in western and central Indonesia. The estimated number of crocodile attacks was higher in areas with lower forest biomass and human density, and wider cellular network coverage. Negative media coverages were frequently reported in western Indonesia. By combining social information of negative media reporting and the ecological information of crocodile attacks hotspots, we identified 170,500 km^2 priority risk areas in the western part of Indonesia, a notable 65.8 % reduction in area size compared to the attack hotspots. We highlight the application of socio-ecological information in risk prioritization to address the rising trends of negative human-wildlife interactions.

1. Introduction

Human-wildlife conflict has become a global conservation concern when wildlife presents actual or perceived threats to humans that negatively impacts people and/or wildlife (IUCN, 2020). As conflicts are complex interactions between human and wildlife, it is increasingly evident that integrating social and ecological information is critical to better explain the causes and dynamics of these interactions, and prioritize areas for intervention (Gálvez et al., 2018; Struebig et al., 2018). Yet, integration between these two disciplines is limited (Milner-Gulland, 2012).

Crocodilians are one of the major taxonomic groups that cause substantial threats to human livelihood (Fukuda et al., 2014; Webb et al., 2010). Although a major cause of human injuries or deaths (CrocBITE, 2020), human-crocodile conflict on a global scale has received relatively little attention (Torres et al., 2018). Out of 24 Crocodilian species, the saltwater crocodile (*Crocodylus porosus*) is responsible for the most reported attacks on humans, along with the Nile

* Corresponding authors.
E-mail addresses: ard24@kent.ac.uk (Ardiantiono), thasun.amarasinghe@ui.ac.id (A.A.T. Amarasinghe).

https://doi.org/10.1016/j.biocon.2023.109965
Received 21 May 2022; Received in revised form 5 February 2023; Accepted 13 February 2023

crocodile (*Crocodylus niloticus*) (CrocBITE, 2020; Sideleau and Britton, 2013). The saltwater crocodile is the largest living crocodilian, potentially reaching up to 6–7 m in length (Webb et al., 2010). Despite its name, saltwater crocodiles are distributed in a wide variety of saline and freshwater habitats that often overlap with areas of human activity (Brien et al., 2017; Webb et al., 2010).

Attacks on humans are a pressing issue for saltwater crocodile conservation (Amarasinghe et al., 2015; CrocBITE, 2020). The incidents foster increased fear and reduced tolerance towards crocodiles in communities living alongside them, often leading to retaliation and the removal of crocodiles which has led to the decline of crocodile populations in some areas (Amarasinghe et al., 2015; Das and Jana, 2018). This is a growing concern as there has been an increasing number of attacks in Southeast Asian countries with high human densities, specifically Indonesia and Malaysia (CrocBITE, 2020). Pressure on saltwater crocodiles (i.e. human population growth and habitat loss) is extensive in this region, as crocodiles are extinct throughout almost all of mainland Southeast Asia (Cambodia, Thailand, and Vietnam) (CrocBITE, 2020; Webb et al., 2010).

Understanding the patterns and drivers of saltwater crocodile attacks is important to develop effective mitigation strategies. However, incidents of human-crocodile conflict in the Indo-Malayan region are poorly studied with no peer-reviewed publications between 1990 and 2020, compared to Australia (11 publications) or South Asia (7) (Pooley, 2020). Crocodile attacks have been reported to be associated with habitat loss, human activities, and climatic factors, although the influence of these drivers may be location-specific (Webb et al., 2010; Amarasinghe et al., 2015). Habitat conversion (e.g. loss of riparian forest and mangrove covers) can reduce the prey availability and crocodile nest quality, thus pushing them to find alternative prey and explore new areas (Saragih et al., 2020; Amarasinghe et al., 2015). The loss of habitat often occurs in parallel with the establishment of human settlements, which intensify human activities in and around water bodies inhabited by crocodiles. Climatic factors such as daily temperature and precipitation may also influence attacks i.e. through the combination of the increased time spend by humans in the water during warmer weather and the effect of warmer temperature on crocodile physiology e.g. faster digestive rates (Powell et al., 2020).

Incorporating ecological information with the social dimension of human-wildlife conflict can be a powerful tool to identify priority areas of intervention (Gálvez et al., 2018; Struebig et al., 2018). Tolerance towards wildlife is a social concept that has been widely applied in studies of human-wildlife relations (Kansky et al., 2016). Tolerance is a passive acceptance of wildlife populations, while intolerance occurs when wildlife becomes unacceptable, leading to actions that harm or eliminate the target populations (Bruskotter and Wilson, 2014; Kansky et al., 2016). Tolerance concepts can be based on attitudinal aspects (e.g. negative attitudes) or behavioural aspects (e.g. retaliatory killing) (Bruskotter and Wilson, 2014). However, assessing tolerance across a large landscape is challenging. The examination of mass media reporting can address the issue as it plays key roles in both reflecting and shaping the views and attitudes of the readers (Boissonneault et al., 2005; Hughes et al., 2020; Sabatier and Huveneers, 2018).

This study aims to incorporate ecological data associated with saltwater crocodile attacks together with the social aspect of media reporting to identify high-risk areas of human-crocodile conflict in Indonesia and propose subsequent mitigation methods. Firstly, we characterize the spatiotemporal patterns of crocodile attacks which consider the nature and distribution of attacks, as well as the temporal trends based on the extensive 10 years of crocodile attack data. Secondly, we evaluate the influences of habitat, climate, human density, and reporting effort as drivers of crocodile attacks to predict the attack hotspots. Third, we map negative media reporting towards crocodiles based on content analysis of media reporting of crocodile attacks. Finally, we combined crocodile attack hotspots with the negative reporting map to identify priority areas for future mitigation strategies. We anticipate that this study will provide a much-needed spatially explicit, landscape-scale, socio-ecological framework of human-crocodile interactions for future management.

2. Materials & methods

2.1. Study area

This study focused on the current distribution range of saltwater crocodiles across Indonesia, spanning an area of approximately 2.5 million km^2 (See Indonesia environmental profile in Supplementary Note 1). Saltwater crocodile distribution was determined using a combination of recent and historical attack records, itinerant/capture records, communication with local authorities, and the available literature (Supplementary Note 2). Currently, saltwater crocodiles are widely distributed throughout the islands of Sumatra, Kalimantan, Sulawesi, the eastern Lesser Sunda Islands, the Moluccas, and Papua with exemption in most of Java and western Lesser Sunda Islands (e.g. Bali and Nusa Tenggara Barat provinces) (Supplementary Fig. 1). The country's administration is divided into 34 provinces where crocodile attacks were reported in 29 provinces.

2.2. Data collection

2.2.1. Saltwater crocodile attacks

We compiled reports of saltwater crocodile attacks in Indonesia over the 10 years between January 2010 and December 2019 by compiling information from online mass media, crocodile specialists, regional wildlife authorities, and in-the-field data collection. Online mass media reports were used to collect the majority of attack information using keywords such as "*buaya, diterkam* (crocodile, attack)", "*buaya, warga* (crocodile, human)", "*buaya, digigit* (crocodile, bite)", and "*buaya, dimangsa* (crocodile, prey)". Sometimes these phrases were combined with location name abbreviations to narrow down the searches using keywords such as "*buaya, diterkam* (crocodile, attack)", "*Kalimantan Tengah* (name of province)". Regional wildlife authorities, primarily consisting of Balai Konservasi Sumber Daya Alam (BKSDA/Natural Resources Conservation Center), were contacted for information in various provinces, particularly in areas experiencing increased levels of conflict in the past five years (e.g. Nusa Tenggara Timur, Maluku, and Kalimantan Tengah). To complement and verify the abovementioned data, field data collection was conducted in Nusa Tenggara Timur province in the central part of Indonesia in 2015 and 2017 through village surveys (detail of methodology in Sideleau et al. (2021)).

We recorded encounters that resulted in non-fatal and fatal attacks (causing the death of people). We excluded reports of any encounters that did not result in human injury or death, attacks by captive crocodiles, and unconfirmed attacks such as victims went missing without witnesses or evidence. Then we verified each attack to ensure the species involved and to avoid multiple reporting of the same incident. In many cases, incidents were verified by contacting local authorities, although in some cases official confirmation was not possible and our best judgment was used. We determined the crocodile species responsible using a combination of traits including known distribution, behavior and when possible, confirmation via witness or captured/killed crocodiles (Supplementary Note 2).

Other details collected for each incident included the time (month, year), location (coordinates and provinces), outcome of attack (fatal or non-fatal), gender of the victim, and victim's activity during the attack. All reports were uploaded to CrocBITE Worldwide Crocodilian Attack Database (http://www.crocodile-attack.info/) and made available to the public. The CrocBITE database was established in 2013 and has since provided open access data of Crocodilian attacks that has been used for conservation management and studies of human-crocodile interactions across the globe (i.e. see González-Desales et al., 2021; Pooley et al., 2021; Sideleau et al., 2021).

2.2.2. Media reporting

To assess current media reporting, we compiled 225 online mass media reports of crocodile attacks covering 2017–2019 period using Google News search tool with specific keywords in Bahasa: "*buaya* (crocodile)", "*serangan* (attack)", "*manusia* (human)", and "*konflik* (conflict)". We focused on Bahasa Indonesia reporting only, the national language of the country, and limited the search period to a single year starting from 2017. We collected every article available about crocodile attacks, including multiple reporting of the same incidents. The data collection ended when there were no relevant articles after three pages of search results.

We assessed the tone of article headline as a proxy of media attitudes towards crocodile attacks, assuming it can reflect and shape readers attitudes (Dayer et al., 2017). We used the headline because it is the part of the article that people read first and shown in the article link. We categorized headline tone as negative, neutral, or positive based on criteria provided by Dayer et al. (2017). A negative tone was assigned when the headline blame crocodiles or use negative terms such as "conflict", "scary", "dangerous", or "attack" e.g. "WARNING! Crocodile terror is not finished" (read Wahid and Azhari (2016) for list of terms). A neutral tone was assigned when the headline does not indicate any evaluation of whether the events were either negative or positive terms e.g. "Crocodiles were seen in the river after the incidents". A positive tone was assigned when the headline promotes the conservation of crocodiles e.g. "The importance of living together with crocodiles".

2.2.3. Spatial covariate preparation

We generated 50 × 50 km sample grid (N = 993 cells) across the crocodile distribution range (Supplementary Fig. 1). The grid cell size was determined based on the average maximum distance from the centroid of 12 satellite-tracked saltwater crocodiles (Campbell et al., 2013).

To evaluate predictors of crocodile attack, we used eight spatial covariates that represent habitat: 1) water body (rivers, lake, and coastline) density (total length in km; BIG, 2019), 2) 2010 aboveground forest biomass, and 3) difference between 2010 and 2018 aboveground forest biomass (ton/ha; Santoro and Cartus, 2021); climate: 4) 2010 precipitations and 5) difference between 2010 and 2019 precipitation (mm^3/km^2; Funk et al., 2014); human activity: 6) 2010 human population density and 7) difference between 2010 and 2019 human population density (people/km2; Bright et al., 2011 and Rose et al., 2020); and crocodile attack reporting effort: 8) cellular network coverage (km^2, OpenCelliD, 2020). The preparation steps of the spatial covariates and collinearity test result can be seen in Supplementary Note 3 and Supplementary Fig. 2.

2.3. Statistical analysis

We performed statistical analysis using R statistical software version 4.0.2. (R Core Team, 2020). First, we summarized the number of attacks, attack outcome (fatal/non-fatal), and victim demographic profiles. We ran general linear models (*lm* function) to identify the temporal trends of crocodile attacks and any effects of human density at a nationwide scale. The average numbers of monthly attacks were analyzed using one-way ANOVA to evaluate the seasonality of attacks. The total number of attacks by victim's gender and activity were analyzed using Pearson's Chi-squared test (*chisq.test* function) with null hypothesis of there is no difference in crocodile attack frequency across victim's gender and activity.

We then performed a negative binomial hurdle model (*pscl* package in R; Zeileis et al., 2008) to evaluate the significant predictors of crocodile attack occurrence (0–1) and intensity within sample grid cells. This class of model accommodates both binary and count data within a single framework that accounts for zero inflation and overdispersion (Zeileis et al., 2008). The zero hurdle part of the model analyzed the grid cells with no recorded crocodile attack (zero count data) to assess the influence of covariates on the probability of attack to occur in each cell. The count part of the model assessed grid cells with attack occurrence (above zero count data) to identify the influence of covariates on the number of attacks estimated to occur in each cell.

We built a global model that incorporates all eight covariates on count data (attack intensity) and five covariates (excluding differences of 2010 and 2019 biomass, human density, and precipitation covariates) on zero data (attack occurrence). We first removed each of the non-significant covariates in the zero hurdle model until the model performance did not improve (based on AIC value) and then applied the same approach to the count model. We then model-averaged top models with delta AIC <2. The prediction of the probability of crocodile attack (zero count data) and number of attack for the ten-year period (count data) in every sample grid cell was produced by back-transforming the regression coefficient output of the best model.

We created index of negative media reporting (0–1) using the assessment result of media headline tone. The index was produced by dividing the number of articles with negative headline tones in each province by the maximum number of negative articles across provinces. For example, if Kalimantan Tengah province had 24 negative articles and Riau province had the highest number of negative articles with 37, then the index of negative reporting for Kalimantan Tengah is 24/37 = 0.65. The index value of every province was transferred to each of the sample grid cell within the provincial boundary. We included only negative tones on crocodile attacks as they have stronger influence on reader attitude and tolerance (Jacobson et al., 2012; Kansky et al., 2016).

2.3.1. Human-crocodile interaction risk areas

We identified priority areas for human-crocodile conflict mitigation using a framework that combines the measure of crocodile attack hotspot (the number of attacks from Hurdle model) and the measure of media reporting (index of negative media reporting). The sample grid cells were partitioned into three priority scales: high (≥ 1 attack and above upper quartile (top 25 %) negative index), medium (≥ 1 attack and below upper quartile negative index; or otherwise), and low (< 1 attack and below upper quartile negative index).

3. Results

3.1. Patterns of crocodile attacks

Between 2010 and 2019 (10 years), we recorded 665 attacks on humans by saltwater crocodiles across the Indonesian archipelago, of which 47 % were fatal and 53 % were non-fatal. Crocodile attacks were mainly reported in the western and central parts of Indonesia. Three provinces with the highest attacks were Nusa Tenggara Timur (104 attacks), Kalimantan Timur (83), and Bangka-Belitung (67) (Supplementary Fig. 1; see Supplementary Table 1 for the full list of provinces).

We detected a significant positive trend ($F_{1,8} = 323.5$, $p < 0.001$) in the total number of attacks since 2010 with an average increase of seven attacks per year (Fig. 1A). Additionally, we also detected a significant positive correlation ($F_{1,8} = 71.83$, p < 0.001) between the number of attacks and human density showing a higher number of attacks in areas with increasing human densities. The total number of monthly attacks varied from as low as four incidents (May) to 116 incidents (March) (Fig. 1B). Similarly, the average number of attacks per month varied significantly among months ($F_{11,108} = 6.774$, $p < 0.0001$) with the most incidents occurred in March and the least incidents happened in May. Number of attacks in wet season (November–April; 408 attacks) were higher than in dry season (May–October; 239). A total of 18 attacks were reported without information on the month of incidents.

Higher number of incidents involved crocodile attacks on male victims (558 incidents, 84 %), compared to female (87, 13 %) ($\chi^2 = 775.6$, df = 2, $p < 0.0001$). Twenty attacks (3 %) did not report the victims' gender. Victim ages ranged from 4 to 90 years with an average of 37

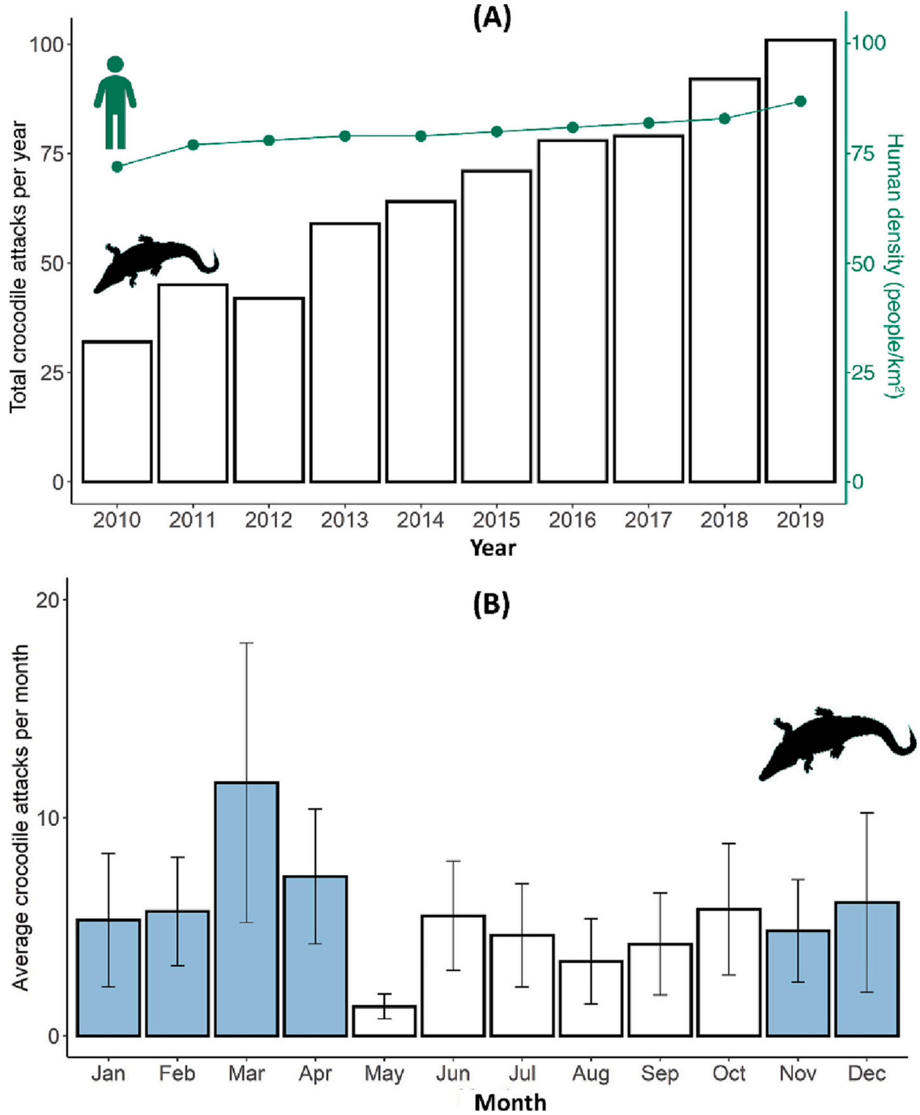

Fig. 1. (A) The total number of attacks by saltwater crocodile (*Crocodylus porosus*) in each year has been increasing significantly since 2010 ($F_{1,8} = 323.5$, $p < 0.001$). (B) The temporal distribution of the total of saltwater crocodile attacks on humans in each month across the 2010–2019 period (Blue-coloured bars indicate wet season). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

years. All the attacks occurred when victims were on the edge or in the water. We detected a significant difference between the total number of crocodile attacks for six categories of activities of victims during attack ($\chi^2 = 452.71$, df = 5, $p < 0.0001$). Three main human activities associated with crocodile attacks were fishing (292, 44 %), followed by self-cleaning (145, 22 %), and working (110, 17 %) (Supplementary Table 2).

3.2. Spatial drivers of crocodile attacks

The presence of crocodile attacks was strongly explained by a combination of factors including habitat, climate, and reporting effort (Table 1; see Supplementary Table 3 for model performance evaluation). The probability of attack occurrence (0–1) was higher in areas with substantial water body (represented by water length) with less forest (represented by aboveground biomass) along the edge. Crocodile attacks were also more likely to occur in drier areas with lower rainfall. Areas that were well covered by cellular networks were more likely to report crocodile attacks.

The intensity of crocodile attacks was significantly influenced by habitat characteristics, human activities, and reporting efforts. The number of crocodile attacks was estimated to be higher in areas with lower forest biomass and human density near water bodies with wider cellular coverage. Crocodile attack hotspots were distributed in the western and central parts of Indonesia: the eastern part of Sumatra and Kalimantan, Sulawesi, and Nusa Tenggara Timur islands (Fig. 2A).

3.3. Negative media reporting towards crocodile attacks

We compiled 225 media reports of crocodile attacks across 21 provinces published between 2017 and 2019. A total of 164 article headlines had negative tones (73 %) and 61 used neutral tones (27 %). No positive headline tones were reported for this study. Intensive negative media coverages were identified in the western part of Indonesia, on the island of Sumatra and Kalimantan. Riau province had the highest index of negative media reporting (1; 37 negative headlines) followed by Kalimantan Timur (0.65; 24 headlines) and Bangka Belitung (0.57; 21 headlines) (Fig. 2B; see Supplementary Table 4 for the full list of provinces).

Table 1
Hurdle model describing the drivers of saltwater crocodile (*Crocodylus porosus*) attacks based on model averaging of top models with ΔAIC <2. The zero hurdle part represents a binary response (zero attack versus presence of attack per grid cell ≥ 1) and the count part represents number of crocodile attacks per grid cell (data above zero). Model-averaged coefficients (β) and standard error (SE) represent the strength and direction of influence. All statistically significant variables ($p < 0.05$) are highlighted in asterisk (*).

Zero hurdle model coefficients	β	SE	z value	p
Intercept*	−1.51	0.09	−16.28	<0.001
Water body length*	0.49	0.09	5.50	<0.001
Mean aboveground forest biomass 2010*	−0.32	0.09	−3.43	<0.001
Mean rainfall 2010*	−0.66	0.11	−6.03	<0.001
Proportion of area covered by cellular network*	0.38	0.08	4.61	<0.001
Count model coefficients				
Intercept	−0.58	0.69	−0.83	0.405
Mean aboveground forest biomass 2010*	−0.50	0.14	−3.57	<0.001
Mean human density 2010*	−0.36	0.18	−2.00	<0.045
Difference of mean human density 2010 and 2018	0.06	0.12	0.51	0.61
Proportion of area covered by cellular network*	0.40	0.13	3.00	0.003

3.4. Human-crocodile interaction risk areas

By combining crocodile attack hotspots with negative media reporting estimates, we identified 68 grids (6.8 %; 170,500 km^2) in Sumatra and Kalimantan islands in west Indonesia as high priority areas for future intervention (Fig. 2C and Fig. 3). Six provinces were within these high priority areas were Aceh, Riau, Jambi, Bangka-Belitung, Sumatera Selatan, and Kalimantan Timur. Medium priority grids (309 grids; 31.1 %; 772,500 km^2) were distributed mostly in the Sumatra, central and eastern Kalimantan, and in the central part of Indonesia including Sulawesi and Lesser Sunda Islands. About 62 % of our study area (1,540,000 km^2), mostly in the eastern part of Indonesia, was identified as a low priority due to the lack of attack and negative media coverage.

4. Discussion

Human-crocodile conflict is a pervasive threat to human livelihoods and saltwater crocodile conservation. This study demonstrates the importance of applying a socio-ecological model framework to identify human and saltwater crocodile high-risk interaction areas, where conservation efforts can be prioritized. We utilized the publicly available media reporting to document crocodile attacks and negative media reporting towards crocodiles, complemented by on-site information of the attacks. Through standard ecological information on crocodile attacks, we found attack hotspots were distributed in four regions in western and central Indonesia encompassing a vast area of 497,500 km^2. By incorporating the social information on media tolerance in our model, we identified priority risk areas in the eastern part of Sumatra and Kalimantan with an area of 170,500 km^2, a notable 65.7 % reduction in area size compared to the attack hotspots.

4.1. Drivers of crocodile attack

As an archipelagic country, there is a high dependence of local Indonesian communities on water bodies for economic activities such as fishing, and daily activities such as self-cleaning and cooking. We identified crocodile attacks were more likely to occur in drier regions of Indonesia, notably in Nusa Tenggara Timur province in the central part of Indonesia. This may be due to the higher dependence of the local communities on limited water sources within the habitat of the crocodiles. Nevertheless, we also noted the extensive reporting efforts may influence this pattern as we recorded most attacks distributed across wetter areas in western Indonesia. Moreover, we found a seasonality of attacks where more attacks were reported in the wet season during the breeding period, as adult crocodiles demonstrate long distant movement to major reproduction sites and female crocodiles start nesting and become more territorial (Fukuda et al., 2019, 2014).

Saltwater crocodile attacks were reported across Indonesia. Using the countrywide-scale analysis, we showed that the increase in attacks was associated with human population growth. However, spatial analysis on a finer scale (50 × 50 km grid) found that crocodile attacks were spatially more numerous in areas with lower human density. The latter characteristic was supported by studies that have reported a lower abundance of saltwater crocodiles in human habitations due to fewer viable habitats, hunting, and pressure to eliminate or translocate crocodiles seen near settlements (Fukuda et al., 2014; Pooley et al., 2021; Ramdani et al., 2021). We considered that crocodile attacks may not be influenced directly by the human density but because of the increased human activities. This assumption is in congruence with our findings as attacks were higher in localities with lower forest biomass indicating habitat loss or degradation which may reduce prey and nest availability for crocodiles (Saragih et al., 2020; Amarasinghe et al., 2015). This contrasting result highlights the importance of analysis of human-wildlife conflict at multiple spatial scales: local-scale with 50 × 50 km grid cells and national scale.

In this study, we included cellular network coverage to represent a reporting effort variable that is rarely considered in studies of human-crocodile conflict (Brien et al., 2017; González-Desales et al., 2021; Powell et al., 2020). It is relevant because most crocodile attack records were from secondary data such as media reporting and local correspondents which relies on cell phone communications for information exchange. As expected, crocodile attacks were found to be more frequent in areas with substantial network coverage. This finding may explain the interesting case of the eastern Indonesia region, especially in Papua island where few attacks were reported while it is believed to be a stronghold of saltwater crocodile populations (Webb et al., 2010). However, it must be noted that the lower human density combined with low forest conversion rates (Allan et al., 2019; Gaveau et al., 2022) may have contributed to these fewer attacks in Papua.

4.2. Media reporting to indicate tolerance

Crocodile attacks can result in retaliation against crocodiles especially when people have lower tolerance towards the animal. We extended the application of utilizing media reporting to estimate negative media coverage on a countrywide scale. We focused on attitudinal tolerance, assuming a negative headline tone can represent and shape a negative public attitude and thus a lower tolerance towards crocodile (Boissonneault et al., 2005; Jacobson et al., 2012; Kansky et al., 2016). While the abovementioned assumption need to be tested which is beyond our study scope, we used media reporting because of the challenges (e.g. limited resources and funding) in assessing tolerance across the country using a conventional method such as social surveys (Boissonneault et al., 2005; Jacobson et al., 2012). The use of media reporting in human-wildlife conflict studies has been justified as mass media has substantial role in reporting wildlife attacks (Athreya et al., 2015) and they can influence public tolerance and actions towards wildlife management and conservation (McCagh et al., 2015; Sabatier and Huveneers, 2018).

We showed that media reporting on crocodile attacks predominantly used negative headline tones, which may have been influenced by the species involved and the type of interactions. This is expected as news agencies often use sensational headlines, mostly depicting wildlife in a poor light to attract the attention of the readers. Attention to saltwater crocodile conservation, or crocodilians in general, is relatively lower than charismatic species like large mammals (Torres et al., 2018). Thus, awareness of saltwater crocodile ecology and conservation is limited and

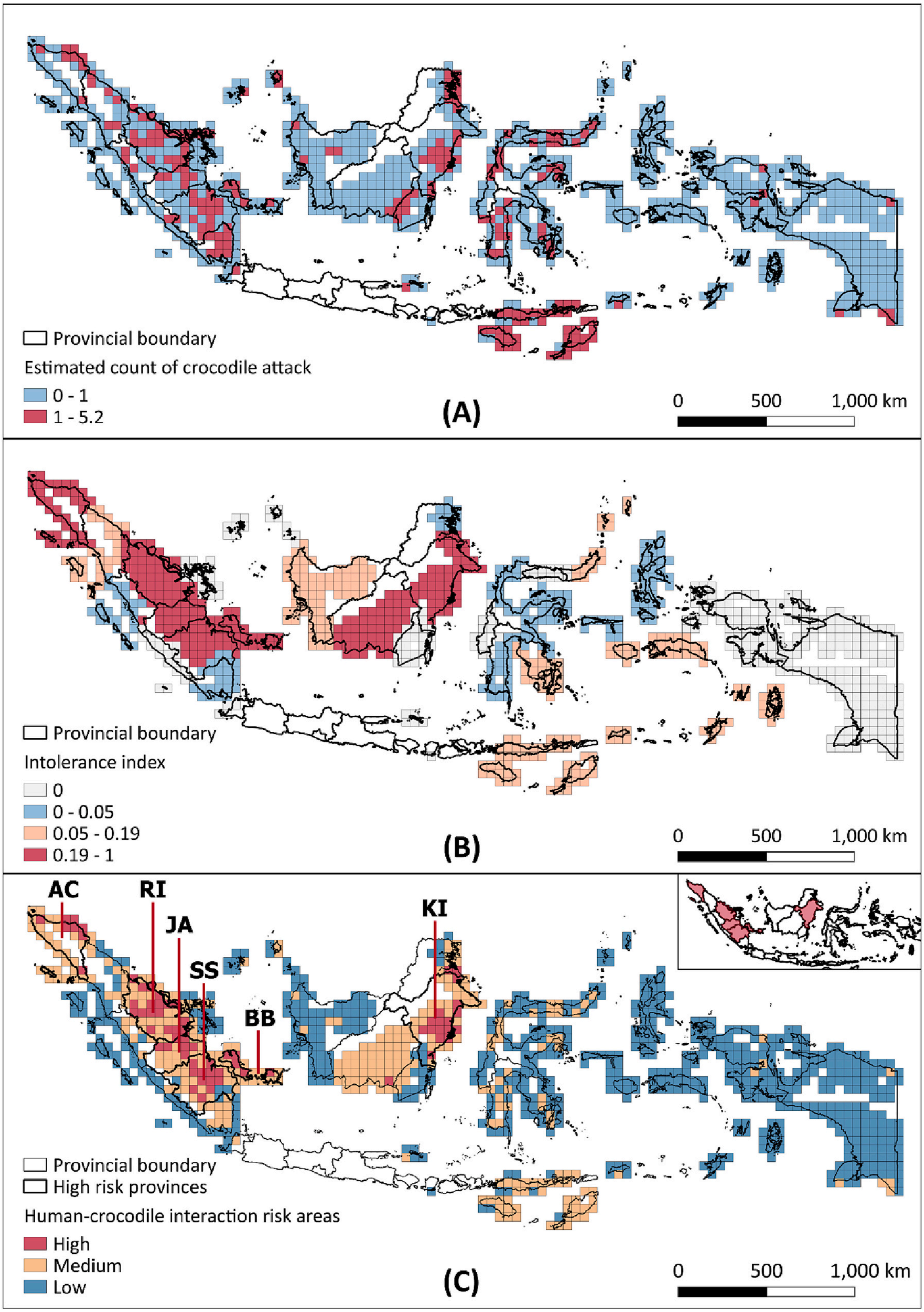

Fig. 2. (A) The estimated number of saltwater crocodile (*Crocodylus porosus*) attacks based on the output of the best hurdle model. Areas that were likely to experience repeated attacks (> 1) were represented in red grid cells. (B) The distribution of index of negative media reporting based on the number of negative headline tones. Provinces with higher negative coverages were indicated in red grid cells. (C) High-risk areas of negative human-saltwater crocodile interactions. Six priority provinces were highlighted: Aceh (AC), Riau (RI), Jambi (JA), Sumatera Selatan (SS), BB (Bangka Belitung), and Kalimantan Timur (KI). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

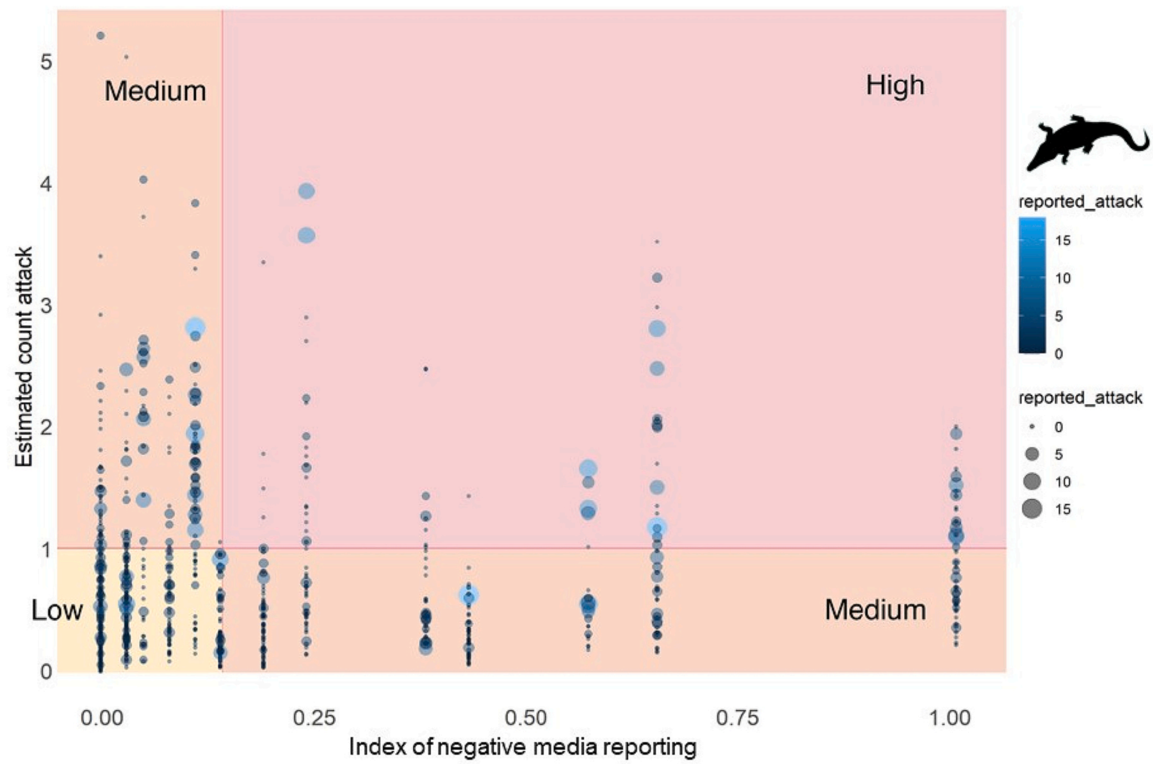

Fig. 3. Prioritization of sample grids based on attack counts and negative media reporting information partitioned into three priority scales: high ($\geq$ 1 estimated attack and above upper quartile negative media reporting index), medium ($\geq$ 1 attack and below upper quartile negative index; or otherwise), and low ($<$ 1 estimated attack and below upper quartile negative index).

people have a substantial fear of crocodiles as they associate crocodiles with predators of humans (Cavalier et al., 2022; Jacobs, 2009). This emotion is exacerbated by incidents of crocodile attacks on humans, which often receive a great deal of attention from the media. The frequent negative media reporting of crocodile attacks coupled with a lack of awareness and intense fear of crocodiles may have contributed to shaping the lower public tolerance towards crocodiles, as reported in other species (Bombieri et al., 2018; Hughes et al., 2020).

4.3. *Priority risk areas: the new capital city of Indonesia*

Human-crocodile conflict in high-risk areas encompassed five provinces in eastern Sumatra and one province in eastern Kalimantan. Among the six provinces identified as high-risk areas, five of them (excluding Jambi) were within the top ten provinces with the highest reported crocodile attacks. These areas are likely to experience both repeated crocodile attacks on humans and potential retaliation indicated by negative media reporting. The higher risk of conflict can be explained by the region's topography, human activities, and economic development. The remaining crocodile habitats in high-risk areas are dominated by lowland, wetland, and mangrove forests which have experienced substantial loss over time due to conversion into oil palm plantations and aquaculture farms (Gaveau et al., 2022). These identified risk areas are also among the most impacted regions by anthropogenic pressures as these regions experience rapid human population growth and economic development, mostly due to transmigration from Java Island over the last century (Allan et al., 2019; BPS, 2021).

It is worth noting while some areas in Central Indonesia (Sulawesi Island and Nusa Tenggara Timur Province) were categorized as crocodile attack hotspots, the negative media reportings were much lower. While the way local news companies operate (i.e. focus on other issues outside crocodile attacks) has influence, local beliefs may play a role. For example, in parts of Central Sulawesi (Personal observation) and East Nusa Tenggara Provinces (Paulus and Azmanajaya, 2020; Sideleau et al., 2021), there are local communities who believe crocodiles are their family relatives. These communities protect the crocodiles and would not blame the animals if there is an attack as they believe that incident happened because of mischief done by the victims or disturbance to crocodiles and their habitat. Similar beliefs are found towards other species e.g. Sumatran tiger (Struebig et al., 2018) and Komodo dragons (Sunkar et al., 2020) which shape local tolerance to these species.

We highlight Kalimantan Timur, the province that will host the new capital city, as our highest-ranking risk area. The capital zone, estimated at 2566.64 km^2 is within 27,500 km^2 of the high-risk area we identified in the province, having experienced 84 cases of saltwater crocodile attacks in the ten years. Upon the establishment of the new capital, it is expected to harbour 1.5 million people by 2024 and additional 0.46 million people by 2043 (Muhtar et al., 2021). The subsequent rapid infrastructure development and human settlement expansions will put pressure on the wildlife and remaining forest habitat (1083.64 km^2) in the capital zone (Mutaqin et al., 2021), potentially elevating the future risk of human-crocodile conflict. The strong association between the expansion of human settlements and the increase in crocodile attacks has been clearly shown in the past, followed by the extirpation of local crocodile populations (Amarasinghe et al., 2015; CrocBITE, 2020).

It is worth noting that the level of human-crocodile conflict in the new Indonesian capital will likely be determined by a combination of factors, including the level of poverty present, access to safe sources of freshwater/plumbing, the level of subsistence fishing activity, and the abundance of natural prey items. Considering the magnitude of human-crocodile conflict in the future capital of Indonesia that has been revealed by this study, mitigation measures and strategies should have been considered by the authorities. As the Government of the Republic of Indonesia aims to establish the most sustainable capital city in the world (i.e. >75 % area will be dedicated to green space; Mutaqin et al., 2021), we hope the implementation will minimize the risk of future conflict between humans and crocodiles.

4.4. Study limitations and way forward

We acknowledge a number of limitations of our study and the methodological framework that we used, and suggest that addressing these limitations would be relevant to broader human-wildlife conflict studies in the future. First is the issue of underreporting conflict incidents from remote areas and/or overreporting from areas with intensive surveys. While we used cellular network coverage as a covariate due to a potential reporting bias associated with remoteness of locations, an analytical approach like occupancy modeling that explicitly accounts for imperfect detection and the influence of data collection efforts, can serve to accommodate such reporting biases in human-wildlife conflict studies (Athreya et al., 2015; Goswami et al., 2015).

Second is the potential bias in the way media report conflicts to reflect underlying public attitudes. This bias can be addressed by an approach that accounts for false negative (not reporting positive attitudes when the public has a positive attitude) or false positive errors developed by Vasudev and Goswami (2020). Third, we did not directly evaluate the association between negative media reporting and public tolerance which need to be tested in future studies (Sabatier and Huveneers, 2018). Finally, although the large-scale quantitative analysis in this study captures the pattern of human-crocodile conflict and determines significant drivers of these interactions, a deeper qualitative research especially at smaller scales is needed to better understand underlying mechanisms and tailor mitigation strategy accordingly to the local context.

In broader context, our study findings can be extended to improve human-wildlife conflict management. We recommend focused mitigation intervention in the identified high-risk areas where frequent wildlife attack incidents and negative reportings overlap. In these areas, we suggest stakeholders to develop local and case specific strategies to reduce the number of attacks, for example through habitat enrichment and restoration, physical barrier or buffer zone establishment, signboards installation, and/or translocation of problematic animals following established guidelines (e.g. IUCN/SSC, 2013). We also strongly encourage collaboration with mass media to increase public tolerance by publishing objective and comprehensive reports on human-wildlife conflict (Ardiantiono et al., 2022). The reporting could explain the ecology and conservation of focus species, drivers and detailed chronology of attacks, and mitigation approaches to be taken.

The incorporation of social dimensions with ecological data in managing and mitigating human-wildlife conflicts will result in more effective and practical solutions to promote coexistence. Our study provides a socio-ecological framework that utilizes publicly available data to identify priority areas for future conservation interventions. We encourage conservation scientists and practitioners to adopt, verify, and expand our framework in studies of human-animal interaction to better understand the dynamics involved and effectively allocate resources to promote coexistence.

Declaration of competing interest

The authors of this manuscript have no conflicts of interest to disclose.

Data availability

The data associated with the manuscript are available upon formal request to the first author.

Acknowledgements

We thank the Ministry of Environment and Forestry (KLHK) and Ir Wiratno, M.Sc, the Director-General of Conservation of Natural Resources and Ecosystems (KSDAE) of the Republic of Indonesia for their support. Associate editor Varun. R. Goswami for his support and invaluable suggestions to improve this manuscript. Three anonymous reviewers for their constructive feedback. Ricky K. Atmadja, Anastasia Wardhani, Yanuar Ishaq, Afrizal Alfarisi, Reza Septian, and Rhemawati for their assistance in the data collection. Additionally, we thank Nicolas J. Deere for his insightful statistical advice, Katie L. Spencer for her valuable review on the early manuscript, and Jatna Supriatna and the staff of the Research Center for Climate Change, University of Indonesia for their support to AATA. ARD was funded by the Leverhulme Trust's Tropical Defaunation Hub at University of Kent.

CRediT authorship contribution statement

AR, AATA, and SMH conceived the ideas and designed the study; AR and BS collected the data; AR, SMH, BS, and SH analyzed the data; AR, SMH, and AATA led the writing of manuscript. All authors contributed to the drafts and gave final approval for publication.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2023.109965.

References

Allan, J.R., Watson, J.E.M., Di Marco, M., O'Bryan, C.J., Possingham, H.P., Atkinson, S. C., Venter, O., 2019. Hotspots of human impact on threatened terrestrial vertebrates. PLoS Biol. 17, 1–18. https://doi.org/10.1371/journal.pbio.3000158.

Amarasinghe, A.A.T., Madawala, M.B., Suranjan Karunarathna, D.M.S., Manolis, S.C., De Silva, A., Sommerlad, R., 2015. Human-crocodile conflict and conservation implications of saltwater crocodiles Crocodylus porosus (Reptilia: Crocodylia: Crocodylidae) in Sri Lanka. J. Threat. Taxa 7, 7111–7130. https://doi.org/10.11609/JoTT.o4159.7111-30.

Ardiantiono, Alfarisi, A.M., Ishaq, Y., Wijaya, R., Septian, R., Hadi, A.N., Surya, R.A., Rahmi, T., 2022. Analisis konten pemberitaan interaksi manusia-satwa predator di Indonesia. J. Belantara 5, 153–168. https://doi.org/10.29303/jbl.v5i2.874.

Athreya, V., Srivathsa, A., Puri, M., Karanth, K.K., Kumar, N.S., Karanth, K.U., 2015. Spotted in the news: using media reports to examine leopard distribution, depredation, and management practices outside protected areas in southern India. PLoS One 10. https://doi.org/10.1371/journal.pone.0142647.

BIG, 2019. Peta rupabumi digital Indonesia [WWW Document]. Badan Inf. Geospasial Republik Indonesia. URL. http://tanahair.indonesia.go.id/portal-web/ (accessed 4.1.21).

Boissonneault, M.-F., Gladstone, W., Scott, P., Cushing, N., 2005. Grey nurse shark human interactions and portrayals: a study of newspaper portrayals of the grey nurse shark from 1969-2003. Electron. Green J. 1.

Bombieri, G., Nanni, V., Delgado, M.del M., Fedriani, J.M., López-Bao, J.V., Pedrini, P., Penteriani, V., 2018. Content analysis of media reports on predator attacks on humans: toward an understanding of human risk perception and predator acceptance. Bioscience 68, 1–8. https://doi.org/10.1093/biosci/biy072.

BPS, 2021. Berita resmi statistik hasil Sensus Penduduk 2020. Badan Pusat Statistik, Jakarta.

Brien, M.L., Gienger, C.M., Browne, C.A., Read, M.A., Joyce, M.J., Sullivan, S., 2017. Patterns of human-crocodile conflict in Queensland: a review of historical estuarine crocodile (Crocodylus porosus) management. Wildl. Res. 44, 281–290. https://doi.org/10.1071/WR17011.

Bright, E.A., Coleman, P.R., Rose, A.N., Urban, M.L., 2011. LandScan 2010. LandScan.

Bruskotter, J.T., Wilson, R.S., 2014. Determining where the wild things will be: using psychological theory to find tolerance for large carnivores. Conserv. Lett. 7, 158–165. https://doi.org/10.1111/conl.12072.

Campbell, H.A., Dwyer, R.G., Irwin, T.R., Franklin, C.E., 2013. Home range utilisation and long-range movement of estuarine crocodiles during the breeding and nesting season. PLoS One 8. https://doi.org/10.1371/journal.pone.0062127.

Cavalier, R., Pratt, E.N., Serenari, C., Rubino, E.C., 2022. Human dimensions of crocodilians: a review of the drivers of coexistence. Hum. Dimens. Wildl. 27, 380–396. https://doi.org/10.1080/10871209.2021.1953195.

CrocBITE, 2020. The worldwide crocodilian attack database [WWW Document]. Big Gecko. http://www.crocodile-attack.info.

Das, C.S., Jana, R., 2018. Human-crocodile conflict in the Indian Sundarban: an analysis of spatio-temporal incidences in relation to people's livelihood. Oryx 52, 661–668. https://doi.org/10.1017/S0030605316001502.

Dayer, A.A., Williams, A., Cosbar, E., Racey, M., 2017. Blaming threatened species: media portrayal of human–wildlife conflict. Oryx 1–8. https://doi.org/10.1017/S0030605317000783.

Fukuda, Y., Manolis, C., Appel, K., 2014. Management of human-crocodile conflict in the Northern Territory, Australia: review of crocodile attacks and removal of problem crocodiles. J. Wildl. Manag. 78, 1239–1249. https://doi.org/10.1002/jwmg.767.

Fukuda, Y., Webb, G., Manolis, C., Lindner, G., Banks, S., 2019. Translocation, genetic structure and homing ability confirm geographic barriers disrupt saltwater crocodile movement and dispersal. PLoS One 14, 1–20. https://doi.org/10.1371/journal.pone.0205862.

Funk, C.C., Peterson, P.J., Landsfeld, M.F., Pedreros, D.H., Verdin, J.P., Rowland, J.D., Romero, B.E., Husak, G.J., Michaelsen, J.C., Verdin, A.P., 2014. A quasi-global precipitation time series for drought monitoring. U.S. Geol. Surv. Data Ser. 832, 4.

Gálvez, N., Guillera-Arroita, G., St. John, F.A.V., Schüttler, E., Macdonald, D.W., Davies, Z.G., 2018. A spatially integrated framework for assessing socioecological drivers of carnivore decline. J. Appl. Ecol. 55, 1393–1405. https://doi.org/10.1111/1365-2664.13072.

Gaveau, D.L.A., Locatelli, B., Salim, M.A., Husnayaen, Manurung, T., Descals, A., Angelsen, A., Meijaard, E., Sheil, D., 2022. Slowing deforestation in Indonesia follows declining oil palm expansion and lower oil prices. PLoS One 17, e0266178. https://doi.org/10.1371/journal.pone.0266178.

González-Desales, G.A., Sigler, L., García-Grajales, J., Charruau, P., Zarco-González, M. M., Balbuena-Serrano, Á., Monroy-Vilchis, O., 2021. Factors influencing the occurrence of negative interactions between people and crocodilians in Mexico. Oryx 1–9. https://doi.org/10.1017/s0030605319000668.

Goswami, V.R., Medhi, K., Nichols, J.D., Oli, M.K., 2015. Mechanistic understanding of human-wildlife conflict through a novel application of dynamic occupancy models. Conserv. Biol. 29, 1100–1110. https://doi.org/10.1111/cobi.12475.

Hughes, C., Foote, L., Yarmey, N.T., Hwang, C., Thorlakson, J., Nielsen, S., 2020. From human invaders to problem bears: a media content analysis of grizzly bear conservation. Conserv. Sci. Pract. 2, 1–11. https://doi.org/10.1111/csp2.176.

IUCN, 2020. IUCN SSC Position Statement on the Management of Human-Wildlife Conflict.

IUCN/SSC, 2013. Guidelines for Reintroductions And Other Conservation Translocations, Version 1. IUCN Species Survival Commission, Gland, Switzerland.

Jacobs, M.H., 2009. Why do we like or dislike animals? Hum. Dimens. Wildl. 14, 1–11. https://doi.org/10.1080/10871200802545765.

Jacobson, S.K., Langin, C., Carlton, J.S., Kaid, L.L., 2012. Content analysis of newspaper coverage of the Florida panther. Conserv. Biol. 26, 171–179. https://doi.org/10.1111/j.1523-1739.2011.01750.x.

Kansky, R., Kidd, M., Knight, A.T., 2016. A wildlife tolerance model and case study for understanding human wildlife conflicts. Biol. Conserv. 201, 137–145.

McCagh, C., Sneddon, J., Blache, D., 2015. Killing sharks: the media's role in public and political response to fatal human-shark interactions. Mar. Policy 62, 271–278. https://doi.org/10.1016/j.marpol.2015.09.016.

Milner-Gulland, E.J., 2012. Interactions between human behaviour and ecological systems. Philos. Trans. R. Soc. B Biol. Sci. 367, 270–278. https://doi.org/10.1098/rstb.2011.0175.

Muhtar, R., Fitriadi, Y., Janna, J., Febriani, I., 2021. Tinjauan kewilayahan dan harmonisasi fungsi ruang kawasan calon ibu kota negara dengan Kabupaten Penajam Paser Utara sebagai wilayah pendukung. In: Seminar Nasional Geomatika, pp. 347–354.

Mutaqin, D.J., Muslim, M.B., Rahayu, N.H., 2021. Analisis konsep Forest City dalam rencana pembangunan ibu kota negara. In: Bappenas Work. Pap, 4, pp. 13–29. https://doi.org/10.47266/bwp.v4i1.87.

OpenCelliD, 2020. Global cell tower database [WWW Document]. URL. https://opencellid.org/ (accessed 5.6.21).

Pooley, S., 2020. Croc Digest: A Bibliography of Human-Crocodile Conflict Research And Reports, Third ed. Simon Pooley, London.

Pooley, S., Siroski, P.A., Fernandez, L., Sideleau, B., Ponce-Campos, P., 2021. Human–crocodilian interactions in Latin America and the Caribbean region. Conserv. Sci. Pract. 1–13. https://doi.org/10.1111/csp2.351.

Powell, G., Versluys, T.M.M., Williams, J.J., Tiedt, S., Pooley, S., 2020. Using environmental niche modelling to investigate abiotic predictors of crocodilian attacks on people. Oryx 54, 639–647. https://doi.org/10.1017/S0030605319000681.

R Core Team, 2020. R: A Language And Environment for Statistical Computing. https://doi.org/10.1038/sj.hdy.6800737.

Ramdani, Kusrini, M.D., Prasetyo, L.B., 2021. Mapping the distribution of saltwater crocodile (Crocodylus porosus) and risks of human-crocodile conflicts in settlements around Kutai National Park, East Kalimantan. Media Konserv. 26, 52–62. https://doi.org/10.29244/medkon.26.1.52-62.

Rose, A.N., McKee, J.J., Sims, K.M., Bright, E.A., Reith, A.E., Urban, M.L., 2020. LandScan 2019. LandScan.

Sabatier, E., Huveneers, C., 2018. Changes in media portrayal of human-wildlife conflict during successive fatal shark bites. Conserv. Soc. 16, 338–350. https://doi.org/10.4103/cs.cs-18-5.

Santoro, M., Cartus, O., 2021. ESA Biomass Climate Change Initiative (Biomass_cci): global datasets of forest above-ground biomass for the years 2010, 2017 and 2018, v2 [WWW Document]. Cent. Environ. Data Anal. https://doi.org/10.5285/84403d09cef3485883158f4df2989b0c.

Saragih, G.S., Kayat, Hidayatullah, M., Hadi, D.S., 2020. A preliminary study on the population and habitat of saltwater crocodile (Crocodylus porosus) in Timor Island, East Nusa Tenggara. IOP Conf. Ser. Earth Environ. Sci. 591 https://doi.org/10.1088/1755-1315/591/1/012044.

Sideleau, B.M., Britton, A.R.C., 2013. An analysis of crocodilian attacks worldwide for the period of 2008 - July 2013. In: Proceedings of the 22nd Working Meeting of the IUCN-SSC Crocodile Specialist Group, pp. 110–113.

Sideleau, B., Sitorus, T., Suryana, D., Britton, A., 2021. Saltwater crocodile (Crocodylus porosus) attacks in East Nusa Tenggara, Indonesia. Mar. Freshw. Res. https://doi.org/10.1071/MF20237.

Struebig, M.J., Linkie, M., Deere, N.J., Martyr, D.J., Millyanawati, B., Faulkner, S.C., Le Comber, S.C., Mangunjaya, F.M., Leader-Williams, N., McKay, J.E., St. John, F.A.V., 2018. Addressing human-tiger conflict using socio-ecological information on tolerance and risk. Nat. Commun. 9, 3455. https://doi.org/10.1038/s41467-018-05983-y.

Sunkar, A., Kusrini, M.D., Ramadhani, F.S., 2020. Role of culture in the emotional response towards komodo dragon in Komodo and Rinca Islands of Komodo National Park. BIO Web Conf. 19, 00021 https://doi.org/10.1051/bioconf/20201900021.

Torres, D.F., Oliveira, E.S., Alves, R.R.N., 2018. Conflicts between humans and terrestrial vertebrates: a global review. Trop. Conserv. Sci. 11, 1–15. https://doi.org/10.1177/1940082918794084.

Vasudev, D., Goswami, V.R., 2020. A Bayesian hierarchical approach to quantifying stakeholder attitudes toward conservation in the presence of reporting error. Conserv. Biol. 34, 515–526. https://doi.org/10.1111/cobi.13392.

Wahid, D.H., Azhari, S.N., 2016. Peringkasan sentimen ekstraktif di Twitter menggunakan Hybrid TF-IDF dan Cosine Similarity. Indones. J. Comput. Cybern. Syst. 10, 207–218.

Webb, G.J.W., Manolis, S.C., Brien, M.L., 2010. Saltwater Crocodile Crocodylus porosus. In: Manolis, S.C., Stevenson, C. (Eds.), Crocodiles. Status Survey And Conservation Action Plan. Crocodile Specialist Group, Darwin, pp. 99–113.

Zeileis, A., Kleiber, C., Jackman, S., 2008. Regression models for count data in R. J. Stat. Softw. 27, 1–25. https://doi.org/10.18637/jss.v027.i08.