*Phyllomedusa* 22(2):99–119, 2023

ISSN 1519-1397 (print) / ISSN 2316-9079 (online)
doi: http://dx.doi.org/10.11606/issn.2316-9079.v22i2p99-119

# An index to assess the level of vulnerability to crocodiles in coastal communities

**Alejandro Durán-Apuy,[1] José Manuel Mora,[2,3] Rosa Chavarría-Trejos,[1] and Andreina Madrigal-Vargas[1]**

[1] Universidad Nacional, Escuela de Ciencias Biológicas. Heredia, Costa Rica.

[2] Sede Central Universidad Técnica Nacional, Carrera de Gestión Ecoturística. Alajuela, Costa Rica. E-mail: josemora07@gmail.com.

[3] Portland State University, Department of Biology and Museum of Vertebrate Biology. Portland, Oregon, USA.

**Abstract**

**An index to assess the level of vulnerability to crocodiles in coastal communities.** Human-wildlife negative interactions are a recurring phenomenon worldwide, originating from the shared habitats and resources between both. In several coastal communities, negative interactions occur due to the presence of the American Crocodile (*Crocodylus acutus*). We have developed an index to assess the level of vulnerability of communities to this reptile. The construction of this index is based on the Approximate Sustainability Index developed by Gutiérrez-Espeleta in 1994. The Index of Vulnerability (IVU) is built upon several indicators across four parameters: social, biological-environmental, institutional, and spatial. These indicators are assessed using a performance scale and interpretation. The IVU assigns values to the vulnerability condition, which are presented in a color scale corresponding to defined intervals. For each indicator, reference categories and rating scales are represented with traffic light colors and numerical ratings. The IVU value obtained for a community can be visualized with a map and a corresponding figure, including a table of values for the assessed parameters.

**Keywords:** American Crocodile, Biological parameter, *Crocodylus acutus,* Institutional parameter, Social parameter, Spatial parameter, Wildlife.

**Resumen**

**Un índice para evaluar el nivel de vulnerabilidad a cocodrilos en comunidades costeras.** Las interacciones negativas entre seres humanos y animales silvestres es un fenómeno recurrente a nivel mundial y que se origina desde que ambos comparten los mismos hábitats y recursos. En varias comunidades costeras existen interacciones negativas dada la presencia del cocodrilo americano (*Crocodylus acutus*). Construimos un índice para evaluar el grado de vulnerabilidad de las comunidades ante este reptil. La construcción de este índice está basada en el Índice Aproximado de Sostenibilidad generado por Gutiérrez-Espeleta en 1994. El índice de vulnerabilidad (IVU) se basa

*Received 17 August 2023*
*Accepted 27 November 2023*
*Distributed December 2023*

en varios indicadores de cuatro parámetros: social, biológico-ambiental, institucional y espacial, con una escala de desempeño e interpretación de estos. El IVU genera valores de la condición de vulnerabilidad que se representan en una escala de colores según intervalos definidos. Para cada indicador se anotan las categorías de referencia y las escalas de calificación con colores tipo semáforo con una valoración numérica. El valor del IVU obtenido para una comunidad se puede representar de manera gráfica con un mapa en una figura que incluye un cuadro de los valores para los parámetros evaluados.

**Palabras clave:** Cocrodilo americano, *Crocodylus acutus,* Parámetro biológico, Parámetro espacial, Parámetro institucional, Parámetro social, Vida silvestre.

**Resumo**

**Um índice para avaliar o nível de vulnerabilidade a crocodilos em comunidades costeiras.** As interações negativas entre humanos e animais selvagens são um fenômeno recorrente em todo o mundo, originado dos habitats e recursos compartilhados entre ambos. Em várias comunidades costeiras, as interações negativas ocorrem devido à presença do crocodilo americano (*Crocodylus acutus*). Desenvolvemos um índice para avaliar o nível de vulnerabilidade das comunidades a esse réptil. A construção desse índice baseia-se no Índice de Sustentabilidade Aproximada desenvolvido por Gutiérrez-Espeleta em 1994. O Índice de Vulnerabilidade (IVU) é construído com base em vários indicadores em quatro parâmetros: social, biológico-ambiental, institucional e espacial. Esses indicadores são avaliados por meio de uma escala de desempenho e interpretação. O IVU atribui valores à condição de vulnerabilidade, que são apresentados em uma escala de cores correspondente a intervalos definidos. Para cada indicador, as categorias de referência e as escalas de classificação são representadas com cores de semáforo e classificações numéricas. O valor da IVU obtido para uma comunidade pode ser visualizado em um mapa e em uma figura correspondente, incluindo uma tabela de valores para os parâmetros avaliados.

**Palavras-chave:** Crocodilo americano, *Crocodylus acutus,* Parâmetro biológico, Parâmetro espacial, Parâmetro institucional, Parâmetro social, Vida silvestre.

## Introduction

Negative interactions between humans and wildlife are increasingly common, widespread, and significant among the challenges faced in conservation. These conflicts hinder coexistence and adversely affect both wildlife and human well-being (Solano-Gómez and Mora 2023). These conflicts create a barrier to achieving sustainable biodiversity conservation and community development (Solano-Gómez and Mora 2023).

In numerous areas where humans coexist with wild animals, both intentional and unintentional negative interactions between them are becoming increasingly problematic (Matanzima *et al*. 2022). The scope of this phenomenon is not limited to a specific geographic region or climatic condition; it occurs in all regions where human populations and wildlife share habitats and resources (Márquez and Goldstein 2014). This is a two-way problem: it arises when the needs and behaviors of wildlife negatively impact human life, and also when goals pursued by humans negatively impact wildlife needs (García-Grajales and Buenrostro-Silva 2015). Due to increasing human populations and the reduction of natural habitats, human-wildlife conflict has emerged as a "wicked problem": these conflicts are becoming more frequent, severe, and widespread, presenting extremely challenging obstacles to resolution (Sillero-Zubiri *et al*. 2023).

Negative interactions between humans and wildlife have consequences across various dimensions. Economically, they impact agriculture, livestock, and infrastructure. Socially, they result in threats, injuries, and even fatalities for humans and their domestic animals. Additionally, these interactions contribute to a negative perception of wildlife in society as a whole (García-Grajales and Buenrostro-Silva 2015). In response to these situations, the capture, aggression, and sacrifice of wild animals are becoming more frequent as emotional reactions from humans (Lamarque *et al*. 2009).

The escalation in the frequency and severity of negative interactions involving large predators is a direct outcome of human encroachment into wildlife habitats (Lamarque *et al*. 2009). Consequently, the management of wildlife populations entangled in conflicts poses multiple challenges related to conservation, perceptions of nature, animal welfare, and the economics of natural resources. Therefore, strategies aimed at addressing these conflicts need to take all these factors into consideration (Sillero-Zubiri *et al*. 2023).

Crocodilians are frequently involved in negative interactions with humans throughout their worldwide distribution (González-Desales *et al*. 2021). In the context of the American Crocodile, *Crocodylus acutus* (Cuvier, 1807), attacks on humans have been attributed to a combination of anthropic and biological factors. A crucial factor is the expansion of human settlements and activities, both productive and recreational, within crocodile habitats (Garel *et al*. 2005). On the contrary, it seems that at least some populations of the American Crocodile have experienced a recovery (Rainwater *et al*. 2022).

Wild populations of crocodilians were profoundly affected by hunting across their distribution areas (Casas-Andreu and Guzmán Arroyo 1970, Álvarez del Toro 1974). At the outset of the 1970s, the American Crocodile faced significant threats from hunting and habitat destruction (Thorbjarnarson 1989, Savage 2002). Nevertheless, due to conservation endeavors, including reproductive and reintroduction programs executed in various countries, population recovery has been achieved (Webb *et al*. 2001, Thorbjarnarson *et al*. 2006, Sánchez-Herrera *et al*. 2011). However, the American Crocodile confronts several threats, primarily habitat loss and degradation, alongside challenges posed by fishing nets, illegal hunting, and hybridization with sympatric species, mainly with Morelet´s Crocodile, *Crocodylus moreletii* (Duméril and Bibron, 1851) (Rainwater *et al*. 2022). The apparent success in recovery has led to an upsurge in crocodile populations and, consequently, interactions with humans, often evoking a negative response in society by associating them with dangerous species (Caldicott *et al*. 2005).

Conservation efforts are poised to fail if they do not address the fundamental causes of biodiversity loss, which often involves understanding human behaviors and the underlying attitudes driving them (Than *et al*. 2022). Human-crocodile interactions are recognized as a complex issue and quantifying them has proven highly challenging due to the absence of effective strategies to manage them (García-Grajales 2013). These interactions necessitate a comprehensive analysis of all the involved components, encompassing an evaluation of the vulnerability level of coastal communities to crocodile presence (García-Grajales 2013). To assist in achieving this objective, we have developed a vulnerability index that integrates the examination of indicators within the social, biological-environmental, institutional, and spatial dimensions.

The creation of a vulnerability index to address adverse human-crocodile interactions holds paramount importance, as it could not only save lives but also contribute to the promotion of crocodile conservation. This paper aims to introduce this technical tool that facilitates the determination of the extent of vulnerability within coastal communities in the presence of the American Crocodile.

The vulnerability index relies on four parameters: social, biological-environmental, institutional, and spatial. These parameters are assessed through indicators tailored to the requirements and anticipated outcomes of each category. In this paper, we present and examine the indicators for each of these four parameters, along with their corresponding scales and values, in order to establish the level of vulnerability of a specific community to crocodile interactions.

## Materials and Methods

To formulate our Index of Vulnerability (IVU), we drew upon the theoretical and practical underpinnings of the Approximate Sustainability Index (ASI; Gutiérrez-Espeleta 1994). The ASI introduces the assessment of four parameters aligning with the dimensions of sustainable development (social, environmental, economic, and institutional). In relation to each of the IVU parameters, we identified a set of indicators that we scrutinized utilizing a performance or interpretive scale that indicates the level of risk associated with crocodile encounters (Table 1). To calculate the ultimate value of each parameter, we employed the following equation:

Equation 1: $C_{kt} = \frac{1}{4\,x\,I_{kt}} \left\{ \sum_{i=1}^{I_{kt}} V_{ikt} \right\} + {}^{1}/_{2},$

where: $C_{kt}$ = Score of parameter k in year t, $I_{kt}$ = Number of indicators that estimate the parameter k in year t, $V_{ikt}$ = Value (-2, 2) of the i-th indicator that estimates k for year t.

Once the value of each of the parameters has been calculated, we estimate the IVU with the following equation:

Equation 2: IVU = $\frac{\sum_{k=1}^{4} C_{kt} I_{kt}}{\sum_{k=1}^{4} I_{kt}}$

The IVU value ranges from zero (0) to one (1), with 0 representing the lowest vulnerability and 1 indicating the highest. We defined five vulnerability levels, each aligned with a twentieth ($20^{th}$) percentile. In order to create a visual representation that conveys the degree of vulnerability, each of these levels is linked to a color scale resembling that of a traffic light (Table 2).

**Table 1.** Performance and interpretation scale of the indicators used to estimate an Index of Vulnerability (IVU). Source: Adapted from Gutiérrez-Espeleta (1994).

| Risk assessment | Value |
|---|---|
| Very low | -2 |
| Low | -1 |
| Medium | 0 |
| High | 1 |
| Very high | 2 |

**Table 2.** Vulnerability condition and respective color scale, according to each interval of the Vulnerability Index (IVU).

| Interval | Vulnerability condition |
|---|---|
| 0.00–0.20 | Little vulnerable |
| 0.21–0.40 | Something vulnerable |
| 0.41–0.60 | Moderately vulnerable |
| 0.61–0.80 | Vulnerable |
| 0.81–1.00 | Highly vulnerable |

## Results

### *Indicators of the Social Parameter*

1. *Percentage of water bodies visited.*—The frequency of visitation is determined by analyzing the number of people visiting each of the water bodies near the community. The suggested time for this parameter is one year, during which respondents enumerate how many bodies of water they visited in that time period. We consider that more than a year is not advisable, as it is more likely that people may confuse their activities from earlier dates. This indicator operates under the assumption that as the number of visited sites increases, the likelihood of encountering crocodiles also rises. The existing water bodies in the community area should be

counted, and it should be determined which ones are frequented by people. Risk levels are measured based on overall visitation percentages, and corresponding risk categories are assigned accordingly: 0–5% of water bodies visited indicate a very low risk, with 5.1–10% of water bodies visited, the risk is low. This increases to medium when 10.1–30% of water bodies are visited, and to high when 30.1–70% of water bodies are visited. If 70.1–100% of water bodies are visited, the risk is very high (Table 3), all referring to visitation within a year.

2. *Percentage of population engaged in activities within crocodile habitat.*—Risky activities encompass all actions carried out by both residents and visitors within the habitat of crocodiles that pose a significant potential for incidents. It is evident that an increased exposure to danger through such activities corresponds to a higher likelihood of incidents occurring. The identification of risky activities is based on the criteria established by Sandoval-Hernández *et al*. (2017). The risk assessment is categorized into three levels: high, medium, and low. The high level pertains to activities directly conducted in the water. The medium level applies to activities undertaken at the margins or shores of water bodies, or on the water using boats or machinery. The low level covers activities carried out at a safe distance from water bodies. Counts of the number of people involved in each identified risky activity during the last year must be conducted to estimate the percentage and assign the corresponding risk level (Table 3).

3. *Frequency of risky activities conducted within the crocodile habitat.*—The frequency of risky activities corresponds to the regularity with which high-risk actions are performed by people within the crocodile habitat (Table 3). We rely on the high-risk activities delineated in the Social Indicator #2 “Percentage of population engaged in activities within crocodile habitat” that encompass all activities related to resource utilization, recreation, and work. This indicator serves as a complementary element to Indicator #2, as an increased frequency of risky activities directly correlates with a higher likelihood of incidents. The risk assessment is categorized into three levels: high, medium, and low. Only one visit during the last year indicates a very low risk, a semiannual visit equals a low risk, a monthly visit signifies a medium risk, weekly visits carry a high risk, and daily visits mean a very high risk (Table 3), all during the last year.

4. *Perception of risk of suffering a crocodile attack.*—The perception of risk corresponds to the residents who recognize the potential for a crocodile attack while participating in activities within the species’ habitat. For example, if only 0–20% of the inhabitants perceive the risk, the vulnerability is considered very high (Table 3). This indicator complements with indicator #5 “Level of knowledge of the habitants about basic aspects of crocodile biology”, that is aim to gauge how well people are informed about those crocodile-related aspects that put them at risk of incidents and how to avert them. It is crucial for individuals to be able to identify a crocodile and grasp five fundamental aspects of crocodile biology. A very low level signifies knowledge in only one or none of these aspects, while a very high level corresponds to understanding all five aspects (Table 3). Interviews should be conducted within the local community, with a representative sample of the population, to assess the community’s risk perception in the study area.

5. *Level of knowledge of the habitants about basic aspects of crocodile biology.*—To assess the residents’ level of knowledge

**Table 3.** Selected indicators to evaluate the social parameter of the Vulnerability Index (IVU). For each indicator, the reference categories and the rating, coloring and numerical assessment scales are noted.

| **Social** | | | |
|---|---|---|---|
| **Indicators** | **Categories** | **Score** | **Value** |
| **(1) Percentage of water bodies visited** | 0–5% water bodies visited | Very low | -2 |
| | 5.1–10% water bodies visited | Low | -1 |
| | 10.1–30% water bodies visited | Medium | 0 |
| | 30.1–70% water bodies visited | High | 1 |
| | 70.1–100% water bodies visited | Very high | 2 |
| **(2) Percentage of population engaged in activities within crocodile habitat** | 0–5% of risky activities | Very low | -2 |
| | 5.1–10% of risky activities | Low | -1 |
| | 10.1–30% of risky activities | Medium | 0 |
| | 30.1–70% of risky activities | High | 1 |
| | 70.1–100% of risky activities | Very high | 2 |
| **(3) Frequency of risky activities conducted within the crocodile habitat** | Very low (annual) | Very low | -2 |
| | Low (semiannual) | Low | -1 |
| | Medium (monthly) | Medium | 0 |
| | High (weekly) | High | 1 |
| | Very high (daily) | Very high | 2 |
| **(4) Perception of risk of suffering a crocodile attack** | Very high (80.1–100%) | Very low | -2 |
| | High (60.1–80%) | Low | -1 |
| | Medium (40.1–60%) | Medium | 0 |
| | Low (20.1–40%) | High | 1 |
| | Very low (0–20%) | Very high | 2 |
| **(5) Level of knowledge of the habitants about basic aspects of crocodile biology** | Very high (80.1–100% correct answers) | Very low | -2 |
| | High (60.1–80% correct answers) | Low | -1 |
| | Medium (40.1–60% correct answers) | Medium | 0 |
| | Low (20.1–40% correct answers) | High | 1 |
| | Very low (0–20% correct answers) | Very high | 2 |
| **(6) Percent of residents taking measures to prevent incidents with crocodiles** | 80.1–100% residents take action | Very low | -2 |
| | 60.1–80% residents take action | Low | -1 |
| | 40.1–60% residents take action | Medium | 0 |
| | 20.1–40% residents take action | High | 1 |
| | 0–20% residents take action | Very high | 2 |
| **(7) Percent of residents consent to participate in environmental education processes** | Very high (80.1–100% of people agree) | Very low | -2 |
| | High (60.1–80% of people agree) | Low | -1 |
| | Medium (40.1–60% of people agree) | Medium | 0 |
| | Low (20.1–40% of people agree) | High | 1 |
| | Very low (0–20% of people agree) | Very high | 2 |

concerning fundamental aspects of crocodile natural history, biology, and habitat, the following elements should be evaluated: (1) ability to identify a crocodile, (2) familiarity with crocodile habitat locations, (3) awareness of crocodile dietary habits, (4) understanding of courtship and nesting sites and behaviors (crocodiles tend to be more aggressive during the reproductive season), and (5) Understanding of the causes of attacks on humans. Interviews should be conducted within the local community, involving a representative sample of the population, to assess the residents' understanding of basic aspects of crocodile biology. To evaluate residents' knowledge in each of these aspects, correct and incorrect responses are tallied in each case. The primary objective here is to determine how well individuals are informed about the specific aspects of crocodile behavior that put them at risk of incidents and how to prevent them. It is essential for people to be able to recognize a crocodile and comprehend these five fundamental aspects of crocodile biology. A very low level indicates knowledge in only one or none of these aspects, while a very high level corresponds to understanding all five aspects (Table 3).

6. *Percent of residents taking measures to prevent incidents with crocodiles.*—Preventive measures refer to actions taken by residents to reduce the risk of incidents with crocodiles while engaging in activities near or in the water bodies close to the community. In the Costa Rican context, the measures recommended by the National Crocodile Commission, a part of the National System of Conservation Areas (SINAC), serve as a reference. Interviews should be conducted within the local community, involving a representative sample of the population, to estimate the percentage of people taking preventive measures to avoid incidents with crocodiles (Table 3).

7. *Percent of residents consent to participate in environmental education processes.*—Consent to participate in environmental education processes indicates the interest or willingness expressed by residents to engage in educational and informational activities related to crocodiles. Interviews should be conducted within the local community, involving a representative sample of the population, to estimate the percentage of community members consenting to participate in environmental education processes (Table 3).

*Indicators of the Biological-Environmental Parameter*

1. *Presence of crocodiles in the habitat.*—To quantify the presence of crocodiles in waterbodies near the community, the percentage of water bodies occupied by crocodiles or another feasible method should be calculated during the implementation of the tool. A straightforward approach to establish the percentage is by determining the ratio of the number of waterbodies where crocodiles are observed to the total number of waterbodies sampled, and then multiplying by 100:

$$\text{Percentage of water bodies occupied by crocodiles} = \frac{\text{Number of water bodies where crocodiles were sighted}}{\text{Number of water bodies sampled}} \times 100$$

   The percentage of waterbodies occupied by crocodiles is categorized from very low (0–5% of waterbodies occupied), to very high (70.1–100% of waterbodies occupied) (Table 4).

2. *Index of crocodile number per kilometer.*—This is determined by the number of individuals recorded per linear kilometer along the waterbody's edge. One potential technique for measurement is using encounter rates (crocodiles/km of survey route), a method widely employed (e.g., Sasa and

**Table 4.** Selected indicators to evaluate the biological-environmental parameter of the Vulnerability Index (IVU). For each indicator, the reference categories and the rating, coloring and numerical assessment scales are noted.

| **Biological-Environmental** | | | |
|---|---|---|---|
| **Indicators** | **Categories** | **Score** | **Value** |
| **(1) Presence of crocodiles in the habitat** | Very low (0–5% waterbodies occupied) | Very low | -2 |
| | Low (5.1–10% waterbodies occupied) | Low | -1 |
| | Medium (10.1–30% waterbodies occupied) | Medium | 0 |
| | High (30.1–70% waterbodies occupied) | High | 1 |
| | Very high (70.1–100% waterbodies occupied) | Very high | 2 |
| **(2) Index of crocodile number per kilometer** | None (0 crocodiles/km) | Very low | -2 |
| | Low (1–10 crocodiles/km) | Low | -1 |
| | Medium (de 10–20 crocodiles/km) | Medium | 0 |
| | High (de 20–40 crocodiles/km) | High | 1 |
| | Very high (> 40 crocodiles/km) | Very high | 2 |
| **(3) Percentage of adult crocodiles present in waterbodies nearby the community** | 0–5% | Very low | -2 |
| | 5.1–10% | Low | -1 |
| | 10.1–15% | Medium | 0 |
| | 15.1–20% | High | 1 |
| | More than 20.1% | Very high | 2 |
| **(4) Distribution of crocodiles in the habitat** | Grouped-localized | Very low | -2 |
| | Singles-random | Low | -1 |
| | Grouped-random | Medium | 0 |
| | Singles-uniform | High | 1 |
| | Grouped-uniform | Very high | 2 |
| **(5) Reproductive season: copulation, nesting and hatchling** | No activity | Very low | -2 |
| | Post season | Low | -1 |
| | Beginning of season | Medium | 0 |
| | Peak of copulations | High | 1 |
| | Copulation and hatching | Very high | 2 |
| **(6) Percent of properties having domestic animals near crocodile habitat** | 0–5% | Very low | -2 |
| | 5.1–10% | Low | -1 |
| | 10.1–30% | Medium | 0 |
| | 30.1–70% | High | 1 |
| | 70.1–100% | Very high | 2 |

Chaves 1992, Sánchez *et al*. 1996, Charruau *et al*. 2005, Hernández-Hurtado *et al*. 2011). Chabreck (1966) and Charruau *et al*. (2005) utilized a nocturnal visual counting method, identifying the animals by their eye reflection using lamps. Crocodiles are counted along one edge, and then during a second sampling, they are counted along the opposite edge, preventing the duplication of individual counts. The level of risk associated with crocodiles recorded per linear kilometer is determined based on previously recorded values in several coastal communities of the country (e.g., Sasa and Chaves 1992, Sánchez *et al*. 1996) (Table 4).

3. *Percentage of adult crocodiles present in waterbodies nearby the community.*—The determination of crocodile sizes can be achieved through various methods. One commonly used approach involves estimating the distance from the tip of the snout at the level of the nostrils to the midpoint of the eyes (Cedeño-Vázquez *et al*. 2006). The obtained value can be multiplied by 7 to estimate the approximate total length (TL) of the crocodile (J. Bolaños, pers. comm.). However, the method for estimating TL varies among researchers. García-Grajales and Buenrostro-Silva (2021) noted, based on various sources, that in practice, a well-trained observer can estimate the length from the tip of the snout to the anterior corner of the eyes, and this is multiplied by 10 to obtain an approximation of the TL. The estimated TL forms the basis for establishing size and age categories, ranging from neonates (TL < 30 cm) to adults (TL > 180 cm) (Charruau *et al.* 2005, Platt and Thorbjarnarson 2000). The percentage of adult crocodiles (> 180 cm) is calculated by dividing the number of adults by the total number of individuals and multiplying by 100. The risk assessment is categorized into five levels or percentages of adult crocodiles present in waterbodies near the community. If only 0 to 5% of the individuals are adults, the risk is very low. However, if the percentage of adults is more than 20.1%, the risk is very high (Table 4).

4. *Distribution of crocodiles in the habitat.*—Crocodile distribution refers to the extent of clustering and dispersion of individuals within their habitat. Various categories can be defined in this context, ranging from grouped and localized to individual and random, where individuals do not form clusters and are distributed randomly. According to the methods for crocodile censuses described earlier, during searches, each crocodile is counted as being alone, in scattered groups, or in clusters. Fatal attacks have occurred both by solitary animals, mostly, and by animals close to each other, at least in the Tárcoles River in Costa Rica. However, we hypothesize that when crocodiles are clustered, the likelihood of one of them attacking a person is higher (Table 4). Two known facts by the authors, the first being the attack on a person in 2014 in the Tárcoles River, and the second a dead coati thrown into the Tárcoles River in 2017, attest to this behavior. In natural conditions, crocodiles position themselves in areas frequented by potential preys. Due to the reduction of water bodies caused by droughts, animals approaching to drink water have a higher probability of being attacked. We have learned of several cases reported by Tárcoles River residents of crocodiles attacking cows due to this behavior.

5. *Reproductive season: copulation, nesting and hatchling.*—This indicator highlights behaviors associated with crocodile reproduction. The reproductive season includes courtship, defense of high-quality sites, nesting, and parental care of the offspring. The presence of offspring (less than 50 cm in length) indicates the presence of reproductive females and males in the

area. The reproductive phases included in this indicator are: copulation, the union of a pair during mating, and dorsal rubbing; nesting, where the female constructs a nest or lays eggs; defense, where the animal protects the nest or young. It is crucial to determine when crocodiles engage in these behaviors in the study area, as they are much more aggressive during these phases (Cupul-Magaña *et al*. 2010). During this period, female Morelet's crocodile is very aggressive (González-Ramón and López-Luna 2018). Many females protect their nests and are potentially dangerous. When this is the case, the nest is very close or visible (González-Ramón and López-Luna 2018). The risk assessment is categorized into five categories from very low risk when there is not any activity of the reproduction parameters included (copulation, nesting and hatchling), low risk at post season, medium risk at the beginning of the season, high risk during the copulation peak and very high risk during the time of copulation and hatchling of young (Table 4).

6. *Percent of properties having domestic animals near crocodile habitat.*— The percentage of properties with domestic animals (i.e., pets, farm animals, and cultivated species) within 100 m of water bodies where crocodiles inhabit is considered. This information should be gathered through surveys of the population regarding the ownership of domestic animals. This indicator highlights the fact that crocodiles are opportunistic animals that feed on a wide variety of prey. Therefore, the presence of domestic animals and cultivated species (such as fish and shrimp) near their habitat can represent an easily accessible source of food. In this context, Bolaños (2012) documented the presence of crocodiles in tilapia farming ponds. Only free-ranging domestic animals or animals confined in tanks, in the case of cultivated animals, are included. If all properties (100%) have domestic animals, the risk of crocodile attraction is very high, corresponding to a high score (Table 4).

*Indicators Within the Institutional Parameter*

The institutional parameter includes policies, plans, programs, and protocols developed and implemented by the institutions in charge or competent in planning, development, and control of wildlife

1. *Crocodile management plan.*—A management plan is a tool containing a description of the species' biological aspects, spatial and ecological characterization of the habitat, analysis of population status, determination of population spatial distribution, and assessment of habitat utilization and health. All of this information is crucial for species management and conservation, as well as for developing strategies to foster harmonious coexistence with human populations. Collaboration among researchers and responsible authorities such as the local wildlife agency is needed to obtain information on the percentage of the management plan that has been implemented at the time of the IVU application. For example, if 41% to 60% of the management plan has been executed, the score to tally is medium with a value of 0 for the index (Table 5).

2. *Environmental education program.*—This indicator should encompass several essential elements to contribute to the harmonious coexistence between humans and wildlife (Marchini and Luciano 2009). Within the framework of this parameter, the presence and level of implementation of an environmental education program (EEP) in the study area should be assessed as execution categories (Table 5). To evaluate the efficacy of an EEP, an analysis of the intended goals and objectives is conducted. This assessment

**Table 5.** Selected indicators to evaluate the institutional parameter of the Vulnerability Index (IVU). For each indicator, the reference categories and the rating, coloring and numerical assessment scales are noted.

| Institutional | | | |
|---|---|---|---|
| **Indicators** | **Categories** | **Score** | **Value** |
| **(1) Crocodile Management Plan** | running between 81–100% | Very low | -2 |
| | running between 61–80% | Low | -1 |
| | running between 41–60% | Medium | 0 |
| | running between 21–40% | High | 1 |
| | running between 0–20% | Very high | 2 |
| **(2) Environmental Education Program** | running between 81–100% | Very low | -2 |
| | running between 61–80% | Low | -1 |
| | running between 41–60% | Medium | 0 |
| | running between 21–40% | High | 1 |
| | running between 0–20% | Very high | 2 |
| **(3) Training of officers in charge of handling dangerous situations** | 81–100% of staff trained | Very low | -2 |
| | 61–80% of staff trained | Low | -1 |
| | 41–60% of staff trained | Medium | 0 |
| | 21–40% of staff trained | High | 1 |
| | 0–20% of staff trained | Very high | 2 |
| **(4) Policies for the management of crocodile conflicts** | Applied in the last year | Very low | -2 |
| | Applied 1–2 years ago | Low | -1 |
| | Applied 3–4 years ago | Medium | 0 |
| | Applied 4–5 years ago | High | 1 |
| | Applied more than 6 years ago | Very high | 2 |
| **(5) Informative workshops for officials on crocodile issues** | Applied in the last year | Very low | -2 |
| | Applied 1–2 years ago | Low | -1 |
| | Applied 3–4 years ago | Medium | 0 |
| | Applied 4–5 years ago | High | 1 |
| | Applied more than 6 years ago | Very high | 2 |
| **(6) Information sources for prevention of crocodile incidents** | Abundant adequate and up-to-date sources | Very low | -2 |
| | Some adequate and up-to-date sources | Low | -1 |
| | Very few adequate and up-to-date sources | Medium | 0 |
| | Unsuitable or outdated sources | High | 1 |
| | There are no sources of information | Very high | 2 |
| **(7) Inventory of the crocodile population in the main waterbodies** | Less than 1 year of elaboration | Very low | -2 |
| | 1–2 years of elaboration | Low | -1 |
| | 3–4 years of elaboration | Medium | 0 |
| | 5–6 years of elaboration | High | 1 |
| | More than 6 years of elaboration | Very high | 2 |

includes an examination of the strategies and activities required to attain these goals and objectives, undertaken by the individuals responsible for their implementation, along with the budget and sources of funding. Additionally, the EEP should incorporate achievement indicators and mechanisms for assessing the program's impact. Collaboration among researchers and responsible authorities such as the local wildlife agency is needed to obtain information on the percentage of the EEP that has been implemented at the time of IVU application. For example, if there is no EEP or only 0% to 20% of it has been executed, the score is very high (Table 5).

3. *Training of officials in charge of handling dangerous situations.*—This indicator covers a crucial aspect to ascertain the existence and currency of a dedicated ongoing training program, aimed at keeping these officials well-versed in the latest wildlife capture and management techniques (Table 5). This training program should encompass information on the requisite procedures, techniques, and equipment essential for the adept and secure management of wildlife. To gauge the effectiveness of the program, metrics such as the count of trained personnel and the tally of addressed situations can be used. Collaboration among researchers and the personnel responsible for managing dangerous situations is needed to obtain information on how many of these officials have been trained in handling such situations. For example, if between 80% and 100% of the officials have been trained, the score is very low (Table 5).

4. *Policies for the management of crocodile conflicts.*—The generation and implementation of tangible measures by government agencies through responsible institutions are assessed, aiming to foster the conservation and management of both the species and its habitats (Table 5). Collaborative work among researchers and authorities responsible for managing conflicts with crocodiles is necessary to obtain information on when these policies were applied. If the policies were applied within the last year, the score is very low (Table 5). Conversely, if the policies were applied more than six years ago, the score is very high (Table 5).

5. *Informative workshops for officials on crocodile issues.*—This indicator involves the implementation of informative workshops for responsible officials, serving as a mechanism for gathering insights on the progression of human-crocodile interactions. Furthermore, its purpose is to foster the formulation of suggestions and initiatives that can be integrated into forthcoming policies and the crocodile management plan. Collaboration among researchers and personnel responsible, such as the local wildlife agency, is necessary to obtain information about informational workshops for officials regarding crocodile-related matters. If the workshops were conducted within the last year, the score is very low (Table 5). Conversely, if the workshops were conducted more than six years ago, the score is very high (Table 5).

6. *Information sources for the prevention of crocodile incidents.*—This indicator pertains to the number, placement, and condition of information sources concerning preventive measures that residents need to adopt to avert encounters with crocodiles in their communities (Table 5). Information sources include posters, brochures, radio announcements, television segments, and informational workshops. The currency, quality, and accessibility of this information to all community members are evaluated. To assess this indicator, relevant information about the availability of crocodile incident prevention resources in the community needs to be gathered. If there are no information sources, the score is very high (Table 5).

7. *Inventory of the crocodile population in the main waterbodies.*—This information needs to be systematized within a database, accessible online and available free of charge, ensuring its accessibility for public institutions, non-governmental organizations, or any entity requiring it. Collaboration among researchers and responsible authorities, such as the local wildlife agency, is necessary to obtain information about the timing of crocodile population inventories in the community water bodies. If the last inventory was conducted within the last year, the score is very low (Table 5). Conversely, if the last inventory was conducted more than six years ago, the score is very high (Table 5).

*Indicators of the Spatial Parameter*

Apparently, the sites where crocodile attacks occur have very particular conditions (Guido-Patiño 2015). In this regard, variables such as altitude, distance from the community to water bodies, the presence of flood-prone areas, human population density, and the density of drainage networks have been used to determine areas at higher risk of crocodile attacks on humans in Mexico (Guido-Patiño 2015) as well as in Costa Rica (Sandoval *et al*. 2019). The spatial parameter involves evaluating the geographical and geomorphological characteristics that impact the existence of potential habitats and, consequently, the occurrence of crocodiles within a specific area or locality (Table 6).

1. *Proximity of the community to crocodile habitats.*—This indicator operates under the assumption that the nearer a community is to the crocodile habitat, the higher the likelihood that residents will engage in activities within it (Table 6). The proximity of the community is defined as the linear distance from the community boundary to the edge of the nearest natural water body where crocodile presence has been documented. If the distance to the water bodies is large, there is less likelihood that people will visit them, and therefore, there is a lower risk of accidents. Various software tools or other digital resources can be employed to calculate this distance. For example, some GPS devices with an uncertainty of less than 5 m are available. This measurement encompasses the banks of rivers, streams, other water bodies, and potential flood-prone areas influenced by heavy rains and tides. During such times, crocodiles tend to move into these areas, effectively extending their habitat. This indicator correlates with Spatial Indicator #3, "Presence of flooding areas," and establishes a link between social and spatial aspects. As an example, we constructed categories of proximities with their respective scores and values, with the highest score and value for a distance from 0 to 100 m between the community boundaries and the nearest water edge (Table 6).

2. *Altitude.*—The altitude must be assessed or measured for each specific situation. For instance, the crocodile habitat in the Costa Rican Central Pacific is associated with altitudes below 700 m above sea level (Sandoval *et al*. 2019). The closer the altitude is to this threshold, the lower the risk associated with crocodile interactions (Table 6). To determine the altitude, a Digital Elevation Model (DEM) can be created using contour lines from the country's official base map. In Costa Rica, for example, cartographic sheets (recommended scale of at least 1:50,000) from the National Geographic Institute (IGN) database can be utilized, along with the vector layer of contour lines. Subsequently, an interpolation process is executed, resulting in the DEM using the ArcGIS "interpolation/topo to raster" tool. This method, recommended by ESRI, is specialized for generating digital elevation models (Chavarría-Trejos 2019, Sandoval *et al*. 2019). In cases where greater precision in the value is needed, field verifications of

**Table 6.** Selected indicators to evaluate the spatial parameter of the Vulnerability Index (IVU). For each indicator, the reference categories and the rating, coloring and numerical assessment scales are noted.

| **Spatial** | | | |
|---|---|---|---|
| **Indicators** | **Categories** | **Score** | **Value** |
| **(1) Proximity of the community to crocodile habitats** | > 400 m | Very low | -2 |
| | 301–400 m | Low | -1 |
| | 201–300 m | Medium | 0 |
| | 101–200 m | High | 1 |
| | 0–100 m | Very high | 2 |
| **(2) Altitude** | > 300 m a.s.l. | Very low | -2 |
| | 151–300 m a.s.l. | Low | -1 |
| | 101–150 m a.s.l. | Medium | 0 |
| | 51–100 m a.s.l. | High | 1 |
| | 0–50 m a.s.l. | Very high | 2 |
| **(3) Density of the drainage network** | 0–0.64 | Very low | -2 |
| | 0.65–1.28 | Low | -1 |
| | 1.29–1.92 | Medium | 0 |
| | 1.93–2.56 | High | 1 |
| | 2.57–3.20 | Very high | 2 |
| **(4) Percentage of flooding areas** | 0–5% of flooding area | Very low | -2 |
| | 5.1–10% of flooding area | Low | -1 |
| | 10.1–30% of flooding area | Medium | 0 |
| | 30.1–70% of flooding area | High | 1 |
| | 70.1–100% of flooding area | Very high | 2 |
| **(5) Percentage of crocodile habitat reduction** | 0–1% habitat reduction | Very low | -2 |
| | 1–2% habitat reduction | Low | -1 |
| | 2–3% habitat reduction | Medium | 0 |
| | 3–5% habitat reduction | High | 1 |
| | > 5% habitat reduction | Very high | 2 |

altitude could be conducted using a GPS, and the obtained values could be interpolated in a GIS. The risk assessment is categorized into five altitude categories, with a very low risk at above 300 m a.s.l. because there are very few crocodiles at this altitude, and very high risk at 0–50 m a.s.l. given that most attacks occur here (Table 6).

3. *Density of the drainage network.*— Concerning the drainage network, areas with the highest concentrations of channels are

linked to optimal habitat conditions for the American crocodile (Sandoval *et al*. 2019). All potential water bodies, whether temporary or permanent, should be considered, and we recommend on-site verifications. Once the Digital Elevation Model (DEM) has been created, (see indicator #2 "Altitude"), the drainage network was derived by Sandoval *et al*. (2019) using the ArcGIS Hydrology tool, which is used in watershed delineation to ensure that river and stream channels match the DEM and prevent the displacement of existing river layers. With the generation of the hydrological network in the study area, Sandoval *et al*. (2019) applied the density/ Kernel Density tool to estimate the river density per square kilometer, facilitating the integration of variables later on. Sandoval *et al*. (2019) classified each variable into three categories (high, medium, and low) using equal interval classification. However, we used the reference values presented by Sandoval (2017) to establish the five categories included in table 6. With the drainage density variable classified and delimited per $km^2$, Sandoval (2017) reclassified it into three categories: low, medium, and high. We took the minimum and maximum values from that classification and divided that range into five categories, such that the category with the lowest value (0.64) is associated with a very low risk, and the highest (3.20) is associated with a very high risk (Table 6).

4. *Percentage of flooding areas.*—The indicator assesses the proportion of flooding areas within the study site (Table 6). Flooding areas arise from prolonged rainfall in flat terrains, facilitating the presence and movement of the American crocodile (Cupul-Magaña 2012). Regions highly susceptible to flooding pose a very high risk (Table 6). For instance, flooding areas within a specific region in Costa Rica can be extracted from the National Emergency Commission's (CNE) database. This indicator is interconnected with social indicator #1, "Percentage of population living near crocodile habitat," and is based on the information and methodologies outlined by Sandoval *et al*. (2019). Coastal areas, such as those on the Costa Rican Central Pacific region, are prone to flooding due to both rainfall and tidal effects, something we have experienced many times in the field. It usually happens that many water bodies become interconnected due to flooding, allowing crocodiles to move toward and into communities. Because of this, the risk categories for this indicator are not proportionally similar. Instead, an area with only 5% flooding area still presents a risk. As a result, for the purposes of the scores assigned, we assess 5% as a very low risk, between 5.1% and 10% as low risk, but we consider anything between 10.1% and 30% to be at least a medium risk (Table 6). Between 30.1% and 100% of flooding area, we divide into high and very high risk to complete the five proposed categories for all indicators (Table 6).

5. *Percentage of crocodile habitat reduction.*—This pertains to the reduction in the American Crocodile's habitat caused by human activities like the expansion of agricultural and livestock activities as well as increasing human settlements. We hypothesize that a greater rate of crocodile habitat loss corresponds to a higher risk of incidents. We propose to evaluate the alteration in crocodile habitat that has occurred over the last five years. All indicators should have a time scale as relevant as possible, although in some cases, there may need to be differences due to the nature of each indicator. For this particular indicator, we recommend evaluating changes over the last five years because it is not advisable to extend it much beyond the period of one or two years of other indicators. Additionally, it is important

to consider that land use changes in coastal areas have accelerated significantly in recent years, especially toward urbanization, putting more people at risk each year. An additional aspect to consider is the response time of the respective authorities regarding decision-making, such as adopting or implementing corrective measures for land use changes. Extended periods, for example, 10 years or more, would have a very negative impact, as corrective measures, for instance, wouldn't be taken with the required immediacy. As an example, 2 to 3 % of habitat reduction in the last five years would corresponds to a Medium score (Table 6).

*Degree of Vulnerability of the Communities*

The vulnerability level, and consequently the IVU value obtained for a specific community, can be visualized with a map in a figure including a table of values for the assessed parameters and indicators with the corresponding color scale. Figure 1 provides an illustration of such map and an IVU value generated to depict the vulnerability degree of a coastal community to the presence of crocodiles, modified from one presented by Chavarría-Trejos (2019).

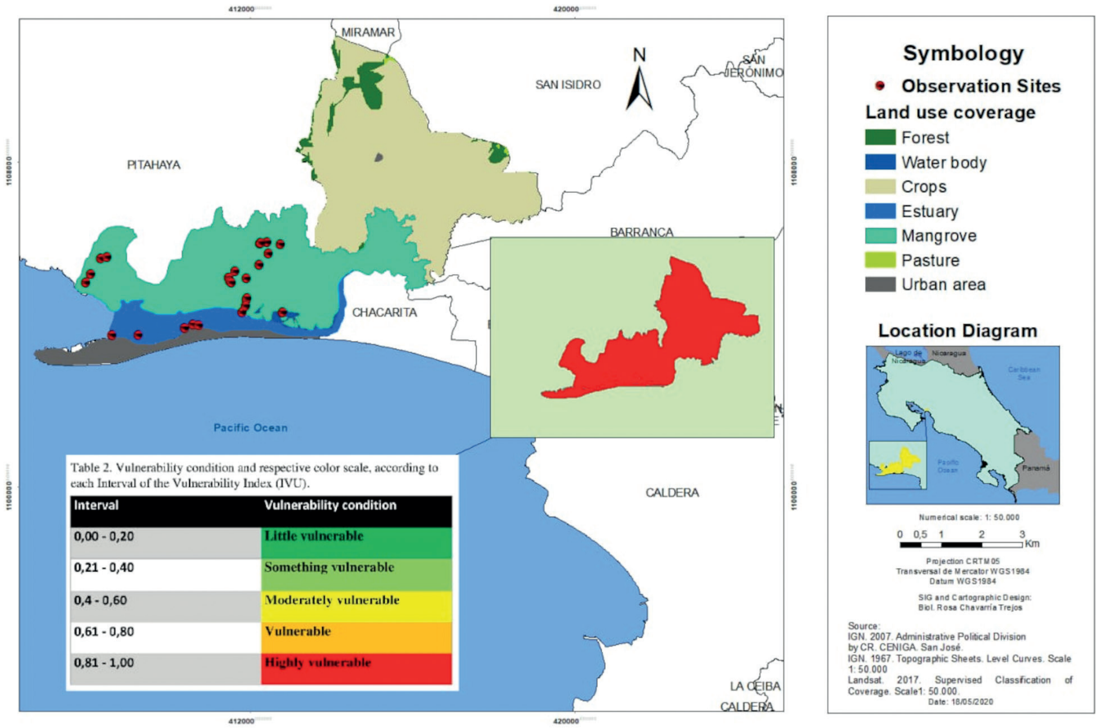
## Discussion

Our vulnerability index presented here should be modified in some aspects according to each specific case. Some of the weaknesses that we can currently point out mainly relate to the fact that certain indicators require specific technical knowledge for their estimation. The primary case is some of the indicators in the spatial parameter, as these involve having knowledge and skills in the use of Geographic Information Systems (GIS). However, even other aspects, including some very basic ones, require some degree or level of prior training. For example, a fundamental aspect is the estimation of the body size of crocodiles, which even involves training the personnel, including, for instance, practices with animals in captivity (J. Bolaños, pers. comm.). It is also essential to take the necessary sampling precautions to ensure the representativeness of different sectors of the community being worked with and include them in interviews, especially in large communities, so that their results are valid. Additionally, since the IVU provides a single overall result of the processing of information obtained from the four parameters, it must be ensured that the information is obtained within a reasonable time frame, so that the information is temporally comparable.

Despite these weaknesses, our vulnerability index can be employed to design targeted mitigation strategies aimed at reducing negative human-crocodile interactions. This vulnerability index relies on four parameters: social, biological-environmental, institutional, and spatial. Indicators are used to measure these parameters according to their respective needs and expected outcomes. We present and discuss the indicators for each parameter, along with their scales and values, to determine the level of vulnerability of a given community to crocodiles.

In broad terms, the tool we developed must effectively assess the contribution of each of the four parameters to the index's vulnerability evaluation. This ensures the indicators are consistent in their theoretical foundation, methodological design, and the sensitivity of their interpretation scales, offering comprehensive information to measure the risk of attacks. However, it is essential to adjust the indicators and even the parameters to fit the specific region, conditions, and needs of local communities. Primary aspects for adjustment include reevaluating the rating scale of indicators to suit each unique case, such as updating them in line with changes in community population and specific ecological conditions over time. Generally, indicators should be updated based on the ecological, social, and temporal dynamics of each case being analyzed.

As an example, we had included a seventh indicator for the biological-environmental




| Interval | Vulnerability condition |
|---|---|
| 0,00 - 0,20 | Little vulnerable |
| 0,21 - 0,40 | Something vulnerable |
| 0,4 - 0,60 | Moderately vulnerable |
| 0,61 - 0,80 | Vulnerable |
| 0,81 - 1,00 | Highly vulnerable |

**Figure 1.** An example of how the degree of vulnerability in a community to the presence of the American Crocodile (*Crocodylus acutus*) can be mapped. The box should contain the values of the Vulnerability Index (IVU) and the social, biological-environmental, institutional and spatial parameters. Modified from Chavarría-Trejos (2019).

parameter: Incidents with crocodiles (fatal and non-fatal) reported in the community. However, after several considerations, including the fact that the percentages of reports may not necessarily be similar in different communities, we decided to remove this indicator and instead we suggest to correlate this value with the index calculation at the community that has been evaluated as a way to test or calibrate the IVU.

In the social parameter, the analysis of social indicators enables an understanding of the role of individuals residing in the area in generating negative interactions between humans and crocodiles. This is accomplished by evaluating the quantity and frequency of hazardous activities conducted within the crocodile's habitat, along with the implementation of measures to prevent attacks, among other six indicators (Table 3).

The analysis of the biological parameter includes aspects related to the biology of the crocodile such as its presence, abundance, percentage of adults, distribution and behaviors on site (Table 4). On the other hand, policies, plans, programs, and protocols are evaluated by the institutional parameter and the actions of planning, development, and control of wildlife encompass environmental policies related to crocodile issues, management plans for the species, environmental education programs, training protocols for officials, and information campaigns to prevent crocodile attacks. However, institutional parameter includes indicators that may not be available at some communities or regions, or may be very different among communities.

One key indicator within the institutional parameter is a crocodile management plan, a tool that must have been developed with technical and scientific rigor, guided by current legislation, and possessing financial and operational viability (Castañeda *et al*. 2012). If a crocodile management plan is not available, references can be utilized to identify the essential components that such a plan should encompass. For instance, the standard management plan for the conservation and sustainable use of the Morelet´s Crocodile in Mexico (Balderas *et al*. 2014) can serve as a valuable example.

Similar to a management plan, an environmental education program (EEP) is useful because it must serve as an educational tool that fosters education for sustainable development and promotes the care of the natural environment and biodiversity (Avendaño 2012). An EEP should encompass objectives such as generating fundamental knowledge about the species' biology, behaviors, and habitat, as well as raising awareness about the causes and consequences of negative interactions between crocodiles and humans. It should involve planning actions that encourage sustainable coexistence between people and wildlife.

As the fourth indicator of the institutional parameter, collaboration between governmental entities plays a pivotal role in formulating and implementing public policies that encompass the comprehensive handling of crocodile-related matters. This effort should harmonize with and advance the social, economic, and cultural progress of coastal communities. Officials from public entities responsible for wildlife have the duty of addressing situations involving wild animals. To effectively discharge this role, a comprehensive management protocol should be in place, encompassing requisite methodologies, techniques, and equipment to promptly and securely handle any wildlife-related incidents. The percentage of personnel trained gives scores and values to the IVU following the determined categories (Table 5).

In addition, the indicator "Informative Workshops for Officials on Crocodile Issues" serves the purpose of fostering the formulation of suggestions and initiatives that can be integrated into forthcoming policies and the crocodile management plan. Accompanying this, the indicator regarding information sources for the prevention of crocodile incidents pertains to the number, placement, and condition of information sources concerning preventive measures that residents need to adopt to avoid encounters with crocodiles in their communities (Table 5).

Fauna population inventories are a widely employed tool for conducting temporal and spatial analyses of wildlife (Ministerio del Ambiente de Perú 2015). For crocodiles, these inventories should encompass current data concerning the population size, sex ratio, size distribution, and geographic distribution of the animals in the main waterbodies within the region (Bolaños *et al*. 1996, 2019, Sánchez *et al*. 1996, Sánchez 2001, Escobedo and González 2006). Consequently, the inventory's validity is crucial as an indicator for the IVU (Table 5).

Data for the spatial parameter are acquired through Geographic Information Systems (GIS) in conjunction with thorough on-site validation. All this information is key when evaluating the degree of risk of interactions between humans and crocodiles. For example, in coastal regions, the presence of rivers, streams, estuaries, and lagoons—both permanent and temporary—is crucial for the species' establishment (Ross 1998).

Initially, we included an indicator in the social parameter regarding the number of people living at a specific distance from the edge of the nearest waterbodies where the presence of crocodiles has been recorded. This was based on the fact that higher population density increases the likelihood of an incident involving a crocodile. However, this social indicator requires human demographic information that is not always available or easy to obtain. As a social indicator the information is based on human behavior, which is more difficult to predict or measure. Additionally, even if there are few people living nearby the crocodile's habitat, but incidents still occur, it means that the key point is that ultimately the threat comes from the crocodile, and the proximity of people to their habitat is crucial.

The Vulnerability Index can be a tool capable of quantifying the level of risk of suffering crocodile attacks to which the inhabitants of coastal communities are exposed. However, it is crucial to validate the IVU through the evaluation of at least four experts, with one representing each of the IVU components: biological-environmental, social, institutional, and spatial.

The indicators within each parameter have been proposed to provide enough information to satisfactorily establish the risk level of a community. However, adjustments can be made in the scales, especially in the social aspects that, by their nature, are more complex to rate. To strengthen the scope of the IVU, additional indicators can be incorporated to evaluate, for example, physical factors of the habitat besides changes in land use such as urban growth models, identification of vulnerable ecosystems, fragmentation indices, and loss of ecological continuity, among others. This would make it possible to better relate changes in the crocodile population parameters with modifications of its habitat.

Frequent interactions between humans and wild animals often lead to adverse consequences, and conflicting perspectives on managing these interactions can give rise to conflicts (Matanzima *et al*. 2022). The incidence of human-wildlife conflicts is projected to increase in the near future, demanding greater attention (Mora and Solano-Gómez 2022).

Although the American Crocodile is protected under Costa Rica's Biodiversity and Protected Area Laws (e.g., La Gaceta 2005), the government has not yet integrated local people's attitudes into conservation and management strategies. Studies have shown that people can possess high levels of knowledge about the local environment, crocodiles, and their habitats (Than *et al*. 2022). However, attitudes towards wildlife are spatially heterogeneous, influenced by cultural and demographic contexts (Than *et al*. 2022).

Nevertheless, sound management decisions based on science and public participation can lead to better conflict resolution. Several essential steps are required, including increasing environmental education, greater involvement of higher authorities and institutions, and the implementation of innovative tools, such as the vulnerability index proposed here.

## Acknowledgments

We greatly appreciate the positive comments and great input of two anonymous reviewers. We acknowledge Marvin Alfaro for his advice with the spatial parameter. José M. Mora acknowledges Emilce Rivera, GEC head department, Universidad Técnica Nacional for academic support.

## References

Álvarez del Toro, M. 1974. *Los Crocodylia de México (estudio comparativo)*. A. C. México. Instituto Mexicano de Recursos Naturales Renovables. 70 pp.

Avendaño, W. 2012. La educación ambiental (EA) como herramienta de la responsabilidad social (RS). *Luna Azul 35:* 94–115.

Balderas, S., I. García, and D. Barrón. 2014. *Plan de Manejo Tipo para la Conservación y Aprovechamiento Sustentable del Cocodrilo de Pantano (*Crocodylus moreletti*) en México*. México. Secretaría de Medio Ambiente y Recursos Naturales. 47 pp.

Bolaños, J. R. 2012. Manejo de cocodrilos (*Crocodylus acutus*) en estanques de cultivo de tilapia en Cañas, Guanacaste. *Revista de Ciencias Ambientales 43:* 63–72.

Bolaños, J. R., J. J. Sánchez, and L. Piedra C. 1996. Inventario y estructura poblacional de crocodílidos en tres zonas de Costa Rica. *Revista de Biología Tropical 44:* 283–287.

Bolaños, J. R., J. Sánchez R., L. Sigler, B. R. Barr, and I. Sandoval. 2019. Population status of the American crocodile, *Crocodylus acutus* (Reptilia: Crocodilidae), and the caiman, *Caiman crocodilus* (Reptilia: Alligatoridae), in the Central Caribbean of Costa Rica. *Revista de Biología Tropical 67:* 1180–1193.

Caldicott, D. G., D. Croser, C. Manolis, G. Webb, and A. Britton. 2005. Crocodile attack 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.

Casas-Andreu, G. and M. Guzmán Arroyo. 1970. *Estado Actual de las Investigaciones sobre Cocodrilos Mexicanos*. Serie Divulgación Nº 3. México. Instituto Nacional de Investigaciones Biológico Pesqueras. Secretaría de Industria y Comercio. 52 pp.

Castañeda, F., J. M. Mora, and N. Estrada. 2012. *Plan Nacional de Conservación del Jaguar (*Panthera onca*).* Honduras. Instituto de Conservación Forestal. 46 pp.

Cedeño-Vázquez, J. R., J. P. Ross, and S. Calmé. 2006. Population status and distribution of *Crocodylus acutus* and *C. moreletii* in southeastern Quintana Roo, Mexico. *Herpetological Natural History 10:* 53–66.

Chabreck, R. H. 1966. Methods of determining the size and composition of alligator populations in Louisiana. *Proceedings 20th Annual Conference Southeastern Association of Game and Fish Commissioners 20:* 105–112.

Charruau, P., J. R. Cedeño-Vázquez, and S. Calmé. 2005. Status and conservation of the American Crocodile (*Crocodylus acutus*) in Banco Chinchorro Biosphere Reserve, Quintana Roo, Mexico. *Herpetological Review 36:* 390–395.

Chavarría-Trejos, R. 2019. *Determinación del grado de vulnerabilidad de cinco comunidades a ataques del cocodrilo americano, en el Pacífico Central de Costa Rica*. Unpubl. Dissertation. Universidad Nacional de Costa Rica.

Cupul-Magaña, F. G. 2012. Registro de movimientos de dos ejemplares de cocodrilo americano *Crocodylus acutus*, en Puerto Vallarta, Jalisco, México. *Boletín de Investigaciones Marinas y Costeras 41:* 479–483.

Cupul-Magaña, F. G., A. Rubio-Delgado, C. Reyes-Núñez, E. Torres-Campos, and L. A. Solís-Pecero. 2010. Ataques de cocodrilo de río (*Crocodylus acutus*) en Puerto Vallarta, Jalisco, México: presentación de cinco casos. *Cuadernos de Medicina Forense 16:* 153–160.

Escobedo, A. and J. González. 2006. Estructura poblacional y proporción de sexos del caimán (*Caiman crocodilus*) en el río Sierpe, Costa Rica. *Acta Zoológica Mexicana 22:* 151–153.

García-Grajales, J. 2013. El conflicto hombre-cocodrilo en México: causas e implicaciones. *Interciencia 38:* 881–884.

García-Grajales, J. and A. Buenrostro-Silva. 2015. Áreas de interacción entre humanos y cocodrilos (*Crocodylus acutus* Cuvier) en Chacahua, Oaxaca, México. *Revista Agroproductividad 8:* 25–33.

García-Grajales, J. and A. Buenrostro-Silva. 2021. Métodos prácticos para la estimación de las poblaciones de cocodrilos: una compilación actualizada. Pp. 83–104 *in* A. Villegas Castillo, C. González-Rebeles, and J. Aldeco-Ramírez (eds.), *Tópicos de Estudio y Conservación de los Cocodrilos en México.* México. Universidad Autónoma Metropolitana.

Garel, A., T. H. Rainwater, and S. G. Platt. 2005. Triathlon champion attacked by crocodile in Belize. *Crocodile Specialist Group Newsletter 24:* 8–10.

González-Desales, G. A., L. Sigler, J. García-Grajales, P. Charruau, M. M. Zarco-González, Á. Balbuena-Serrano, and O. Monroy-Vilchis. 2021. Factors influencing the occurrence of negative interactions between people and crocodilians in Mexico. *Oryx 55:* 791–799.

González-Ramón, M. del C. and M. A. López-Luna. 2018. Monitoreo de los nidos silvestres de *Crocodylus moreletii*. Pp. 40–47 *in* G. Barrios and J. C. Cremieux (comp.), *Protocolo de Rancheo para el Cocodrilo de Pantano (*Crocodylus moreletii*) en México*. México. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad.

Guido-Patiño, J. C. 2015. *Modelo espacial de ataques por cocodrilos en México.* Unpubl. Dissertation. Universidad Autónoma del Estado de México.

Gutiérrez-Espeleta, E. 1994. Indicadores de sostenibilidad: instrumentos para la evaluación de las políticas nacionales. *Revista Ciencias Económicas 14:* 37–50.

Hernández-Hurtado, H., J. D. J. Romero-Villaruel, and P. S. Hernández-Hurtado. 2011. Population ecology of *Crocodylus acutus* in the estuarine systems of San Blas, Nayarit, Mexico. *Revista Mexicana de Biodiversidad 82:* 887–895.

La Gaceta. 2005. Ley de Conservación de la Vida Silvestre No. 7317. La Uruca, San José, Costa Rica. Diario Oficial la Gaceta.

Lamarque, F., J. Anderson, R. Fergusson, M. Lagrange, Y. Osei-Owusu, and L. Bakker. 2009. *Human-Wildlife Conflict in Africa: Causes, Consequences and Management Strategies*. Rome. Food and Agriculture Organization of the United Nations. 112 pp.

Marchini, S. and R. Luciano. 2009. *Guía de Convivencia: Gente y Jaguares.* Fundación Ecológica

Cristalino, WildCru, Panthera. Brazil. Editora Amazonarium. 52 pp.

Márquez, R. and I. Goldstein. 2014. *Manual para el Reconocimiento y Evaluación de Eventos de Depredación de Ganado por Carnívoros Silvestres*. Version 1.0. Santiago de Cali. Wildlife Conservation Society Colombia. 35 pp.

Matanzima, J., I. Marowa, and T. Nhiwatiwa. 2022. Negative human-crocodile interactions in Kariba, Zimbabwe: Data to support potential mitigation strategies. *Oryx 57:* 452–456.

Ministerio del Ambiente de Perú. 2015. *Guía de Inventario de la Fauna Silvestre*. Lima, Perú. Dirección General de Evaluación, Valoración y Financiamiento del Patrimonio Natural. 83 pp.

Mora, J. M. and R. Solano-Gómez. 2022. Impacto económico de los conflictos humano-fauna silvestre en la zona de amortiguamiento de la Reserva Biológica Alberto Manuel Brenes, Costa Rica. *UNED Research Journal 14:* e4007.

Platt, S. G. and J. B. Thorbjarnarson. 2000. Status and conservation of the American crocodile, *Crocodylus acutus,* in Belize. *Biological Conservation 96:* 13–20.

Rainwater, T. R., S. G. Platt, P. Charruau, S. A. Balaguera-Reina, L. Sigler, J. R. Cedeño-Vázquez, and J. B. Thorbjarnarson. 2022. *Crocodylus acutus* (amended version of 2021 assessment). The IUCN Red List of Threatened Species 2022: e.T5659A212805700. Electronic Database accessible at https://dx.doi.org/10.2305/IUCN.UK.2022-1.RLTS.T5659A212805700.en. Captured on 26 October 2023.

Ross, J. P. 1998. *Crocodiles*. UICN/SSC Crocodile Specialist Group. UICN. 96 pp.

Sánchez, J. 2001. *Estado de la Población de Cocodrilos (*Crocodylus acutus*) en el Río Tempisque, Guanacaste, Costa Rica*. Costa Rica. Área de Conservación Tempisque. Instituto Nacional de Biodiversidad. 49 pp.

Sánchez, J., J. R. Bolaños, and L. Piedra C. 1996. Población de *Crocodylus acutus* (Crocodylia: Crocodilidae) en dos ríos de Costa Rica. *Revista de Biología Tropical 44:* 835–840.

Sánchez-Herrera, O., G. López Segura-Jáuregui, A. García Naranjo, and H. Benitez Díaz. 2011. *Programa de Monitoreo del Cocodrilo de Pantano (*Crocodylus moreletii*). México, Belice y Guatemala.* México. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. Secretaría de Medio Ambiente y Recursos Naturales. 269 pp.

Sandoval, L. 2017. *Zonificación de las áreas propensas a incidentes por ataques de* Crocodylus acutus *en el pacífico central de Costa Rica utilizando un sistema de información geográfico*. Unpubl. Dissertation. Universidad Nacional de Costa Rica.

Sandoval, L. F., C. Morera, and I. Sandoval. 2019. Zonificación de las áreas propensas a incidentes por ataques de *Crocodylus acutus* en el Pacífico Central de Costa Rica utilizando un Sistema de Información Geográfico. *Revista Cartográfica 98:* 259–279.

Sandoval-Hernández, I., A. Durán-Apuy, and J. Quirós-Valerio. 2017. Activities that may influence the risk of crocodile (*Crocodylus acutus:* Reptilia: Crocodilidae) attack to humans in the Tempisque River area, Guanacaste, Costa Rica. *Revista Uniciencia 31:* 13–22.

Sasa, M. and G. Chaves. 1992. Tamaño, estructura y distribución de una población de *Crocodylus acutus* (Crocodylia: Crocodilidae) en Costa Rica. *Revista de Biología Tropical 40:* 131–134.

Savage, J. 2002. *The Amphibians and Reptiles of Costa Rica*. Chicago. University of Chicago Press. 934 pp.

Sillero-Zubiri, C., F. Caruso, Y. Chen, D. Christidi, G. Eshete, N. Sanjeewani, L. Mathe Jr., and M. A. Pierre. 2023. From conflict to coexistence: the challenges of the expanding human-wildlife interface. *Oryx 57:* 409–410.

Solano-Gómez, R. and J. M. Mora. 2023. Conflictos entre humanos y fauna silvestre en una zona de amortiguamiento de San Ramón, Costa Rica. *UNED Research Journal 15:* e4462.

Than, K. Z., Z. Zaw, and A. C. Hughes. 2022. Integrating local perspectives into conservation could facilitate human-crocodile coexistence in the Ayeyarwady Delta, Myanmar. *Oryx 56:* 82–90.

Thorbjarnarson, J. B. 1989. Ecology of American crocodile, *Crocodylus acutus*. Pp. 228–259 *in* International Union for the Conservation of Nature (ed.), *Crocodiles: Their Ecology, Management and Conservation*. Gland. IUCN.

Thorbjarnarson, J., F. Mazzotti, E. Sanderson, F. Buitrago, M. Lazcano, K. Minkowski, M. Muñiz, P. Ponce, L. Sigler, R. Soberon, A. M. Trelancia, and A. Velasco. 2006. Regional habitat conservation priorities for the American Crocodile. *Biological Conservation 128:* 25–36.

Webb, G. J. W., A. Britton, C. Manolis, S. Ottley, and S. Stirrat. 2001. The recovery of *Crocodylus porosus* in Northern Territory of Australia: 1971–1998. Pp. 195–234 *in* Proceedings of the 14th Working Meeting of the Crocodile Specialist Group of the Species Survival Commission. Gland. IUCN.

*Editor: Jaime Bertoluci*