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The evaluation of prospects for human and saltwater crocodile (*Crocodylus porosus*) conflict: the case of coastal Bhitarkanika National Park, India

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The preservation of biodiversity and managing human-wildlife conflicts are significant problems associated with conservation worldwide. The evaluation of the human-saltwater crocodile (*Crocodylus porosus*) conflict around the Bhitarkanika National Park revealed an overview of attacks on humans. In this study, it was found that between 2019 and 2025, a total of 28 fatal attacks were reported in the area adjacent to the National Park. It is also highlighted that the past 25 years of government investment policies in *C. porosus* conservation have led to a significant increase in the number of *C. porosus* individuals by approximately 36.4 individuals per year over this period of 25 years. The total population follows a moderately complex to highly nonlinear trend. The adult *C. porosus* follows a moderately nonlinear trend and the sub-adult follows a highly complex trend. The Combined population of both the adults and sub-adults increases by 12.6 individuals per year, revealing significant growth. A key aspect of this study is the difficulty of recovering and conserving large predator populations due to the inherent risk they pose to people and their livelihoods. The findings of the study will aid in creating strategies to reduce the risk of HWC.

KEYWORDS

crocodile, *Crocodylus porosus*, human-wildlife conflict, Bhitarkanika, reptile

1 Introduction

Conserving large predator populations is difficult due to the risk they pose to the health and safety of people and their livelihoods. Despite its challenges, it is important to get it right, as large predators often play a keystone role in ecosystems. Male saltwater crocodiles (SWC) (*Crocodylus porosus*) can reach lengths of 6-7 m and weigh up to 1,360 kg. Adult

males usually measure between 4.3 and 5.2 m and weigh between 400 and 1000 kilograms, while female SWC attain a smaller size than males, often reaching a maximum length of 2.5 to 3 m (Kar and Bustrad, 1989; Webb et al., 2010; Basu et al., 2023). In India, they are found on the eastern coast and the Andaman Islands (ICEM, 2023).

Overexploitation, poaching, and uncontrolled hunting caused a major decline in the SWC population until the 1970s. In the late 1960s, SWC went extinct in Kerala, Tamil Nadu, and Andhra Pradesh states, while it remained in smaller numbers in Bhitarkanika and the Sundarbans (Amarasinghe et al., 2015; Basu et al., 2023; Samuel et al., 2025). In 1974, the United Nations Development Programme (UNDP) and the Food and Agriculture Organization (FAO), in partnership with the Government of India, initiated a SWC conservation program named 'Baula' in Bhitarkanika National Park (BNP) to conserve the estuarine SWC by establishing a captive breeding program at Dangamal with 95 sighting including 34 adults in 1976 (relative density = 0.87/km) (Kumar et al., 2012; Nayak et al., 2018; Patro and Padhi, 2019). In 2009, 1596 sightings (1484 individuals in the park (relative density = 13.5/km), and an additional 112 in the adjacent regions), the *C. porosus* population in BNP has been growing since the restoration effort began (Kar, 2009; Kumar et al., 2012). This has resulted in a rise in human-crocodile conflicts, notably in areas such as the BNP in India (Pattnaik et al., 2024; Than et al., 2024). This park holds approximately 74% of the Indian SWC (Webb et al., 2010). The BNP comprises 153 villages of Bhadrak and Kendrapara districts of Odisha, which fall under the eco-sensitive zone of the sanctuary (MoEFCC, 2022).

Human-wildlife conflict (HWC) is a persistent issue arising from the conflict between the requirements of wildlife and human beings, adversely impacting both (Mekonen, 2020; Lu and Huntsinger, 2023). It has also been shown that the social and ecological conditions in which interactions between people and animals take place affect the conservation efforts (Baynham-Herd et al., 2018). Like other crocodilians, *C. porosus* is an opportunistic feeder, using aggressive hunting or 'sit and wait' tactics (Webb and Messel, 1978; Amarasinghe et al., 2015). Conflicts between humans and SWC arise when their behavior or needs negatively impact people or when human activities adversely affect the wildlife (Kumar et al., 2012; ICEM, 2023). This is particularly clear as the populations of humans and SWC are expected to increase, with human activity impacting wildlife habitats. In some cases, wildlife populations are now recovering and re-entering areas they formerly occupied that are now occupied by humans (Patro and Padhi, 2019). Therefore, this study aims to examine the frequency of human and SWC conflicts adjacent to the BNP from January 2019 to January 2025. We further assessed the population of SWC in the BNP that changed over time and its association with the frequency of HWC. Furthermore, a key aspect of this study is the difficulty of recovering and conserving large predator populations due to the inherent risk they pose to people and their livelihoods. Moreover, in doing so, we hope to notify wildlife managers to create strategies to mitigate HWC conflicts while guaranteeing the sustainable conservation of crocodiles.

2 Methods for assessment of conflicts

For this study, the primary data regarding the number of HWC from 2000 to 2025 was collected from the official records of the Mangrove Forest Division, Odisha, and from (Kar, and Nibas, 2024). Hatchlings (<0.6 m), yearlings (0.6-0.9 m), juveniles (0.9<1.8 m), adults, and subadults (>1.8 m) were categorized as per the data. Generalized Additive Models (GAMs) were constructed to account for the non-linear relationship between crocodile abundance and time. Only the total number of crocodiles, adult and sub-adult populations, were included in the analysis due to their involvement in attacks on humans. The model was demonstrated using the Mixed GAM Computation Vehicle with Automatic Smoothness Estimation (mgcv) package in R statistical software (Wood, 2017; R Core Team, 2021). Thin-plate regression splines smoothing was used by setting the default ($k = 10$) in mgcv. Generalized Cross-Validation (GCV) was used as a smoothing parameter selection method. The fit of GAMs was checked using gratia package in R (Simpson, 2024).

Previously, the attack of this species around the BNP has been documented up to 2018 (Patro and Padhi, 2019; Khan et al., 2020). Incidents of fatal attacks on humans around the BNP area during the seven years (January 2019 to January 31st, 2025) were collected from local and national news reports. The news search was conducted using the Google search engine and keywords such as "Crocodile attack in Kendrapara" or "Croc attack near Bhitarkanika" up to January 31st, 2025. The primary data, like attack location, size of the SWC that attacks, activity done by the victim prior to the attack, month and year of the attack, were collected by visiting individual location and through field observations from local citizens of Kendrapara district, adjacent to the BNP in Odisha, India, up to January 31st, 2025 by following (Khan et al., 2020). The obtained primary data was then verified by the forest official of the Mangrove Forest division, Odisha, to avoid duplication or any missing information during the study. The attacks were screened by following (Fukuda et al., 2014; Baker et al., 2024). The entire plot was generated using the ggplot2 package in the R programming language (Wickham et al., 2007).

3 Results

The data suggested that, according to the annual census conducted by the Odisha Wildlife Organization, the SWC population in Bhitarkanika increased to 1826 in 2025, surpassing the count of 914 in 2000 (Figure 1). The statistical analysis shows the total SWC population vs. year revealed a significant temporal trend (GAMs; EDF = 3.501, $F = 121.4$, $R^2 = 0.991$, GCV score: 1170.9), indicating that the number of SWC significantly increases ($P < 0.001$) over the years, approximately 36.4 individuals per year, which is a moderately complex to highly nonlinear trend. In adult (GAMs; EDF = 6.398, $F = 68.66$, $R^2 = 0.958$, GCV score: 179.94), a moderate nonlinear trend, and for sub-adult (GAMs; EDF = 6.909, $F = 19.47$, $R^2 = 0.869$, GCV score: 193.56), it is a highly complex, wiggly trend. Moreover, both populations revealed a significant

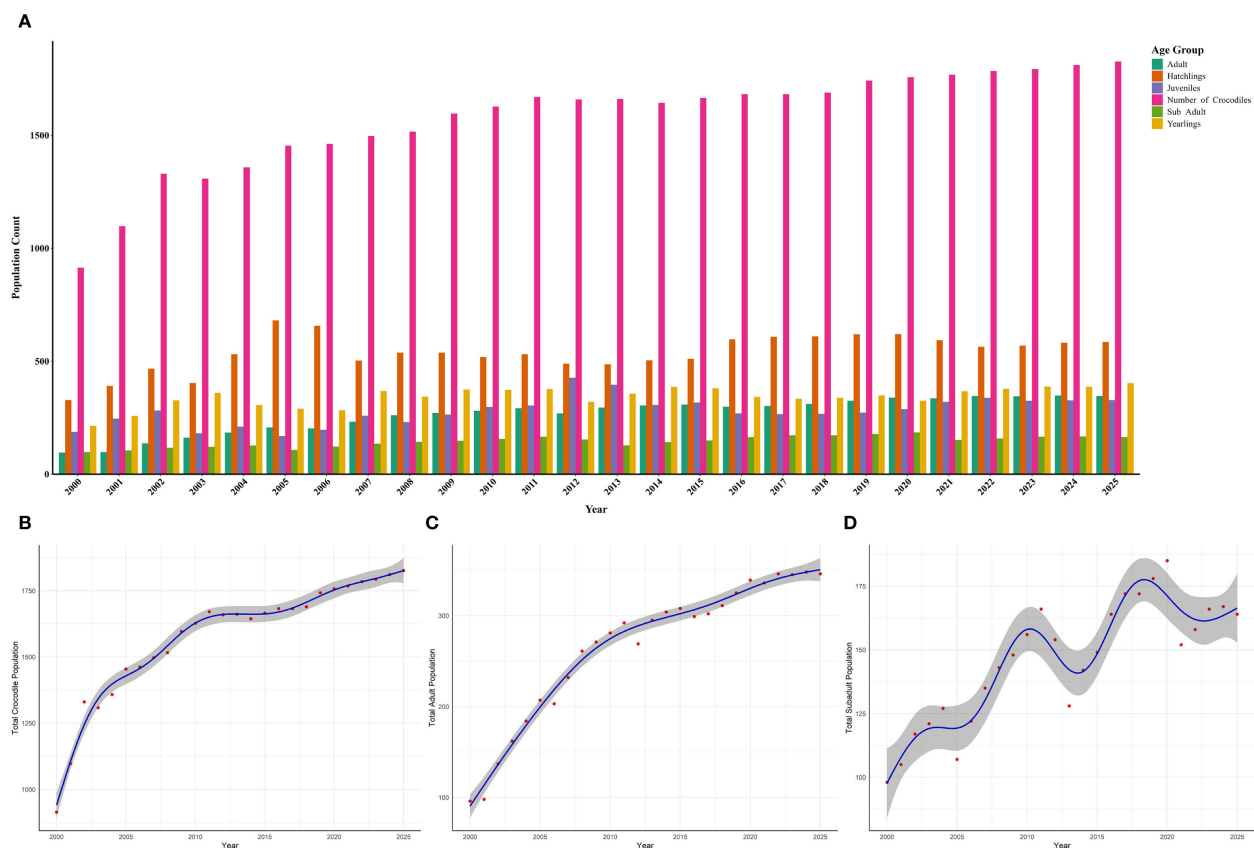


FIGURE 1

(A) The annual abundance estimates of the saltwater crocodile (*C. porosus*) population in Bhitarkanika National Park, India, between the year 2000 and 2025 (B) GAMs analysis plot of total number of population vs. years (C) GAMs analysis plot of total adult population vs. years (D) GAMs analysis plot of total number of sub-adult population vs. years.

increase ($P < 0.001$) over the years. The total summary of the GAMs is mentioned in (Supplementary Table S1). The adult and sub-adult populations combinedly increase by 12.6 individuals per year (Supplementary Figure S1).

During 2018-19 to 2024-25, a total of 14 geo-referenced sites were marked where attacks were recorded after verifying all occurrence sites (Figure 2A), and a total of 28 fatal attacks were recorded (Figure 2B). All the attacks occurred within 75 km upstream from the BNP, and victims were exposed to SWCs via activities such as bathing, washing, fishing, and grazing cattle, while the rest remained unclear (Figure 2C). The study also highlighted that all attacks were caused by the adult and sub-adult population of *C. porosus* of length (>1.8 m). The data also suggested that most attacks have been observed from June to October during the mating and nesting season of this species.

4 Discussion

4.1 Prey and habitat selection

Previous studies revealed that most conflicts occurred in the Brahmani, Kharasrota, and Baitarani Rivers, which are connected to

the BNP (Khan et al., 2020). There have been reports of some of them dispersing from the national park and moving upstream of the protected area, in search of prey, causing conflicts (Samuel et al., 2025). In this study, the conflict was observed more than 70 km upstream from the BNP marked on the map. Additionally, this study highlighted that most of the attacks were carried out by the adult and subadult population of SWC of size (>1.8 m). Adult or subadult SWC are the only ones that can kill people (Fukuda et al., 2014). A recommendation was made after the 2007 census, which revealed that there should be five to six SWCs per kilometer in the park area (Kar et al., 1989; Pandav and Gopi, 2009). Indeed, when these estimates are placed alongside the long-term monitoring data reported in (Patro and Padhi, 2019), it was evident that the SWC population in the national park plateaued and reached its carrying capacity in 2009-2010 of 1813 (Samuel et al., 2025). In the current situation, the SWC has reached the carrying capacity of populations in BNP, which might cause them to spread to nearby landscapes to reduce competition among themselves.

4.2 Effect on population densities

The population viability analysis by (Samuel et al., 2025) on BNP, it was revealed that the current growth rate is 9.37%. Furthermore, the

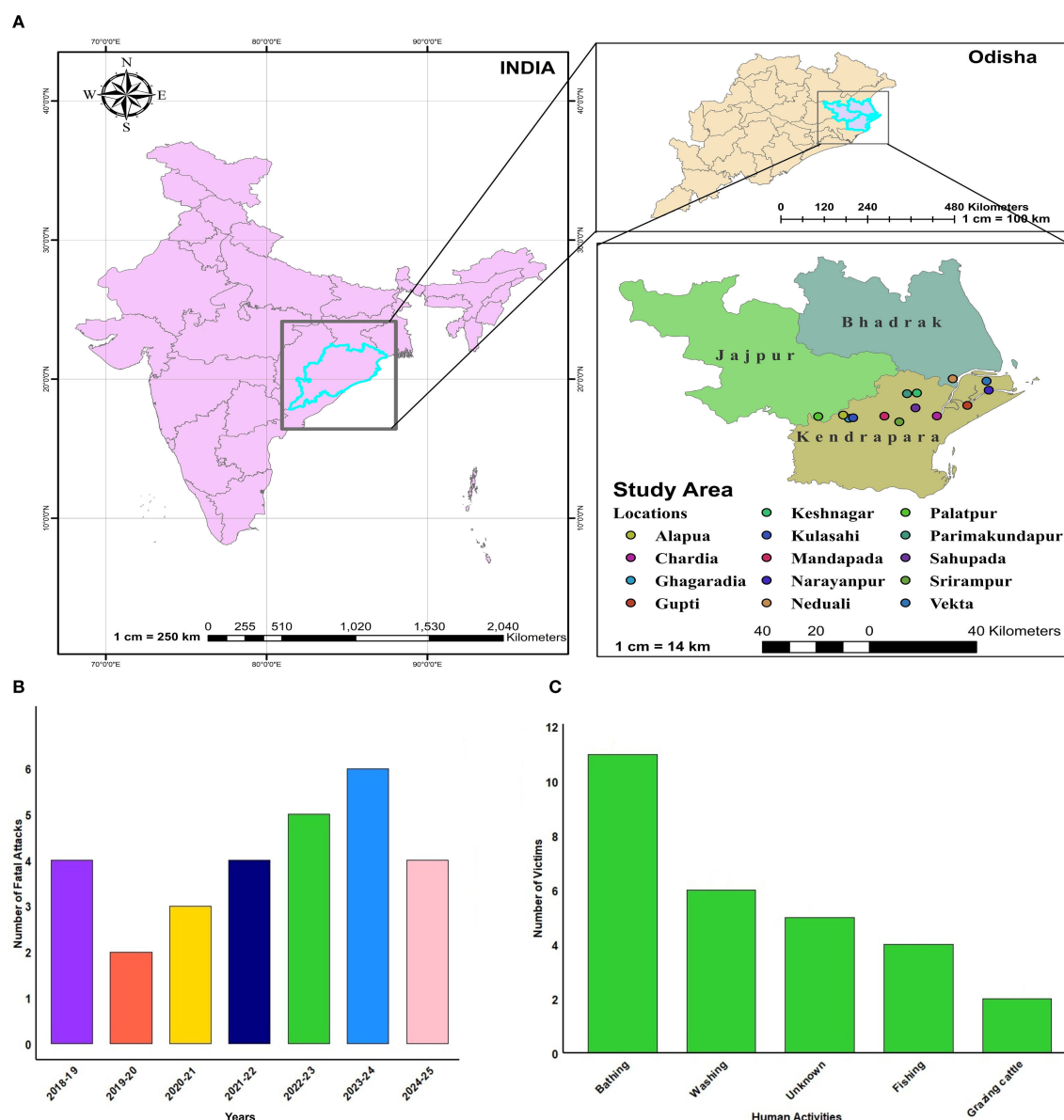


FIGURE 2

(A) The map showing the location of fatal attacks of SWC from the year 2019 to 2024, (B) Number of conflicts reported between 2019–25, (C) Activities done by the victims before being attacked by *C. porosus*.

population has a natural growth rate of 0.1756, which is sustained by maintaining conflict levels at their current state. In this study, the GAMs analysis revealed that the total population follows a moderately complex to highly nonlinear trend, the adults follow a moderately nonlinear trend, and the sub-adult follows a highly complex trend. The growth of adults and sub-adults is found to be statistically significant. The total population of *C. porosus* revealed an increase of approximately 36.4 individuals per year. Moreover, the total number of crocodiles across all size classes has seen a significant rise in population. Previous studies in large predators like SWC have identified that human population frequency is positively correlated to the frequency of attacks and HWC (Pandav and Gopi, 2009). For instance, it was revealed that the human and SWC conflict is rising

because of the increasing populations of both humans and SWC (Pandav and Gopi, 2009). Therefore, in the future, analyzing the human population density around the BNP as a variable might offer a better understanding of the conflict and guide effective mitigation strategies.

4.3 Local perception towards conflict

The tolerance would cost individuals in terms of energy, time, mental peace, and other intangible expenses. HWC often happens when animal populations move from protected areas into nearby human-altered landscapes, attracted by opportunities created by human

activities. The duration of HWC, from coexistence to conflict, depends on responsibility, justice, and inclusion (Thapa et al., 2024). In this study, the maximum attacks occurred when the victims were inside the water doing their usual activities. At the same time, a few instances were reported when the victims were on the bank of the river. Our findings are consistent with previous studies conducted within this region that found major attacks were seen while crossing the river, bathing, defecating, and fishing (Patro and Padhi, 2019; Khan et al., 2020).

Because humans and animals share the same landscapes, sustainable development objectives such as global food security and biodiversity protection may come into conflict. Therefore, cohabitation between humans and animals is more likely when adaptive mechanisms create and sustain mutual benefits (Killion et al., 2021). The state government has taken possible steps to minimize the conflict between humans and SWC. This includes placing barricades around the riverbanks where people typically congregate.

4.4 Involvement of stakeholders

The government is raising awareness among residents about the risks related to cohabitation with these reptiles. As a result, people and animals must coexist and inhabit nearby areas within these shared environments. Implementing suitable protective measures to achieve balance, especially by reducing harmful and tolerable levels. Promoting coexistence can help preserve biodiversity, protect ecosystem services, and ensure a sustainable future for humans and SWC. Some of the points that need to be considered for better management of conflicts include.

- Expanding SWC-friendly habitats and implementing conflict mitigation strategies could be a crucial step in addressing the carrying capacity of the BNP while maintaining the SWC population sanctuary
- The deployment of relevant officials to verify incident sites through photographic evidence and documentation, including geo-tagging to mark conflict areas, along with the installation of warning signs, an awareness campaign, and fencing in critical locations within SWC habitats near human communities
- Researchers, lawmakers, and environmentalists must collaborate across fields to understand the complex feedback loops and interactions between human communities and the SWC.

The past 25 years of government investment policies in SWC conservation have led to successful population recovery at BNP. Transdisciplinary planning and stakeholder-driven strategies will help reduce HWC. The study provides a clear picture of the SWC population and recent conflict around BNP. The findings of the study will aid in creating strategies to reduce the risk of HWC concerning human safety and livelihoods in the BNP.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was not required for the study involving animals in accordance with the local legislation and institutional requirements because no animal was used in this study.

Author contributions

SP: Conceptualization, Formal Analysis, Investigation, Resources, Writing – original draft. PT: Data curation, Formal Analysis, Resources, Software, Writing – review & editing. NK: Conceptualization, Data curation, Formal Analysis, Validation, Writing – review & editing. AR: Data curation, Formal Analysis, Software, Writing – review & editing. AP: Data curation, Resources, Visualization, Writing – review & editing. MD: Formal Analysis, Supervision, Writing – review & editing. PP: Formal Analysis, Resources, Validation, Writing – review & editing. BB: Conceptualization, Funding acquisition, Project administration, Supervision, Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/famrs.2025.1639071/full#supplementary-material>

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