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Reassessment of Status and Spatial Analysis of the Distribution of *Crocodylus palustris* in Manjeera Wildlife Sanctuary, Telangana State, India

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***Abstract.*—We studied the population status of Marsh Crocodiles (*Crocodylus palustris*) in Manjeera Wildlife Sanctuary (MWS), Telangana State, India, and analyzed their size classes, distribution, and conservation status. We conducted 64 night-time spotlight surveys between 2011 and 2017 to estimate the *C. palustris* population in the sanctuary. The density of sighted crocodiles, excluding juveniles in the night-time spotlight survey, varied from 5.50/km² to 5.91/km². The population of *C. palustris* has grown from 0.41 to 5.4 individuals/km² in the sanctuary. Spatial analysis showed the statistically significant locations of high and low values and we discuss threats to the conservation of *C. palustris* to improve management practices in Manjeera Wildlife Sanctuary.**

Key Words.—Marsh Crocodile; Mugger Crocodile; reptiles; point density; hotspots; spotlight survey; threats

Introduction

The Marsh Crocodile (*Crocodylus palustris*; Fig. 1) is endemic to the Indian subcontinent and is the most widespread of the three species of crocodiles in India (Choudhury and de Silva 2013). This wide range is due to their high adaptability and ability to survive in an extensive range of habitats such as freshwater lakes, rivers, streams, marshes, irrigation canals, village tanks, reservoirs, and other man-made freshwater bodies (Whitaker and Whitaker 1989a; Choudhury and de Silva 2013). The population of this species in India declined greatly in the late 1960s as a result of poaching, interference due to fishing, and habitat destruction (Whitaker and Whitaker 1989b; Vijaya Kumar et al. 2007). The establishment of the Crocodile Breeding and Management Project of the United Nations Development Programme/Food and Agriculture Organization (UNDP/FAO) in 1975 helped re-establish and stabilize the non-hatchling population of the three species of crocodiles in India (de Vos 1984). The population of *C. palustris* was estimated to be around 2,000–3,000 individuals by 1989 (Whitaker and Whitaker 1989b). Globally, the current wild population of non-hatchling *C. palustris* has been estimated as 5,700–8,700 and the estimated wild population in India is 3,021–4,287 non-hatchlings (Whitaker and Andrews 2003). This species was assessed as Vulnerable by the International Union for Conservation of Nature (IUCN; Choudhury and de Silva 2013) and is protected under Schedule-I of the Indian Wildlife (Protection) Act, 1972. In late 1976, surveys for crocodiles began in the Krishna and Godavari river systems and their numerous tributaries in the erstwhile united Andhra Pradesh, and an estimated population of about 50 individuals was recorded in the six breeding locations of Manjeera, Pakhal, Sivaram, Kinnerasani, Ethipothala Falls, and Nagarjunasagar-Srisailam Tiger Reserve in the wild (Choudhury and Bustard 1982).

Between 1975 and 1982, 16 crocodile rehabilitation centers and 11 crocodile sanctuaries had been established throughout India (de Vos 1984). In 1978, the Manjeera Wildlife Sanctuary (MWS) was given permission by the Indian Government to breed and reintroduce crocodiles into the wild (Subba Rao 1993; Vijaya Kumar 1993). The wild population of *C. palustris* in Manjeera River was estimated as seven adults and five sub adults in 1978 (Choudhury and Bustard 1982; Choudhury and Chowdhury 1986).

Earlier studies reported the observed population density of *C. palustris* in MWS, using spotlight

Figure 1. Marsh Crocodile (*Crocodylus palustris*) seen during the spotlight survey in the Manjeera Wildlife Sanctuary, Telangana State, India. (Photographed by Krishna Prasad K.).

surveys, as 0.34, 0.31, 0.56, and 0.43 per km^2 in 1987, 1988, 1989, and 1990, respectively (Vijaya Kumar 1993; Vijaya Kumar et al. 2007). Since 1985, 212 *C. palustris* including 127 juveniles, 63 sub-adults, and 22 adults have been released into the MWS. Of these, 100 juveniles and 10 adults were released under the Crocodile Reintroduction Program (1985), which were reared in Nehru Zoological Park, Hyderabad (Vijaya Kumar et al. 2007). The remaining 27 juveniles, 63 sub-adults, and 12 adult *C. palustris*, which were reared in the Manjeera Crocodile Breeding Center, were also released into the sanctuary between 2005–2013 (Table 1). No significant research has been done in the last two decades on *C. palustris* in MWS. The aim of this study was to reassess of the status of *C. palustris*, including their size classes, spatial distribution, and threats to the conservation of this species.

Materials and Methods

Study area.—Manjeera Wildlife Sanctuary is located in Sangareddy district, Telangana State, India (Fig. 2), and covers an area of 32 km^2 between Singoor and Manjeera Dams, following the course of the Manjeera River for about 26 km. It has nine islands with extensive marshy fringes, which are used as nesting sites by crocodiles and birds. The shorelines of the reservoir and river are fringed by various species of plants including *Prosopis* spp. (algaroba), *Ipomoea* sp. (pink morning glory), *Acacia* spp. (babool), *Butea* spp. (sacred tree), *Centella* spp. (Indian pennywort), *Santalum* spp. (sandalwood), etc., and agricultural lands. The reservoir also supports submerged and emergent vegetation including species of the genera *Nymphaea* (water lily), *Nelumbo* (lotus), *Polygonum* (dense flower knotweed), *Hydrilla* (waterthyme), *Pistia* (water cabbage; Prasad et al. 2013). The soil type is red loamy, sandy, and fertile black soil used in the fields for growing cotton, rice, jowar, maize, and sugarcane. The sanctuary experiences a tropical climate with temperatures ranging between a minimum of 15° C in the winter to a maximum of 42° C in summer, and the area receives about 1,000–1,100 mm of rainfall annually (Prasad et al. 2013).

Field methods.—We conducted surveys from January 2011 to June 2017 and collected data directly by day-time and night-time surveys on the river and reservoir. We also informally noted habitat, basking sites, and sizes and behavior of crocodiles. We explored habitats on foot along the coasts, near the villages on either side of the river, and on the islands, as well as by boat on the river and reservoir. We also collected data indirectly by interviewing residents, and by inspecting and recording different sign of crocodile presence (ventral scale tracks

Table 1. Identification number (ID) of released, rearing center, and date of release of released juvenile (< 0.7 m), sub adult (0.7–1.5 m), and adult (> 1.5 m) Marsh Crocodiles (*Crocodylus palustris*) into the Manjeera Wildlife Sanctuary, Telangana State, India.

ID	Rearing Center	Date	Juveniles	Sub Adults	Adults
1	Nehru Zoological Park, Hyderabad	January, 1985	10		
2	Nehru Zoological Park, Hyderabad	May, 1989			6
3	Nehru Zoological Park, Hyderabad	21 June 1994			4
4	Nehru Zoological Park, Hyderabad	29 September 1997	90		
5	Crocodile Breeding center, Manjeera Wildlife Sanctuary	16 September 2005			8
6	Crocodile Breeding center, Manjeera Wildlife Sanctuary	11 September 2006	10		
7	Crocodile Breeding center, Manjeera Wildlife Sanctuary	16 September 2007	6		
8	Crocodile Breeding center, Manjeera Wildlife Sanctuary	4 September 2008	11		
9	Crocodile Breeding center, Manjeera Wildlife Sanctuary	31 July 2012		10	
10	Crocodile Breeding center, Manjeera Wildlife Sanctuary	22 September 2012		10	
11	Crocodile Breeding center, Manjeera Wildlife Sanctuary	16 September 2013		43	4
Total			127	63	22

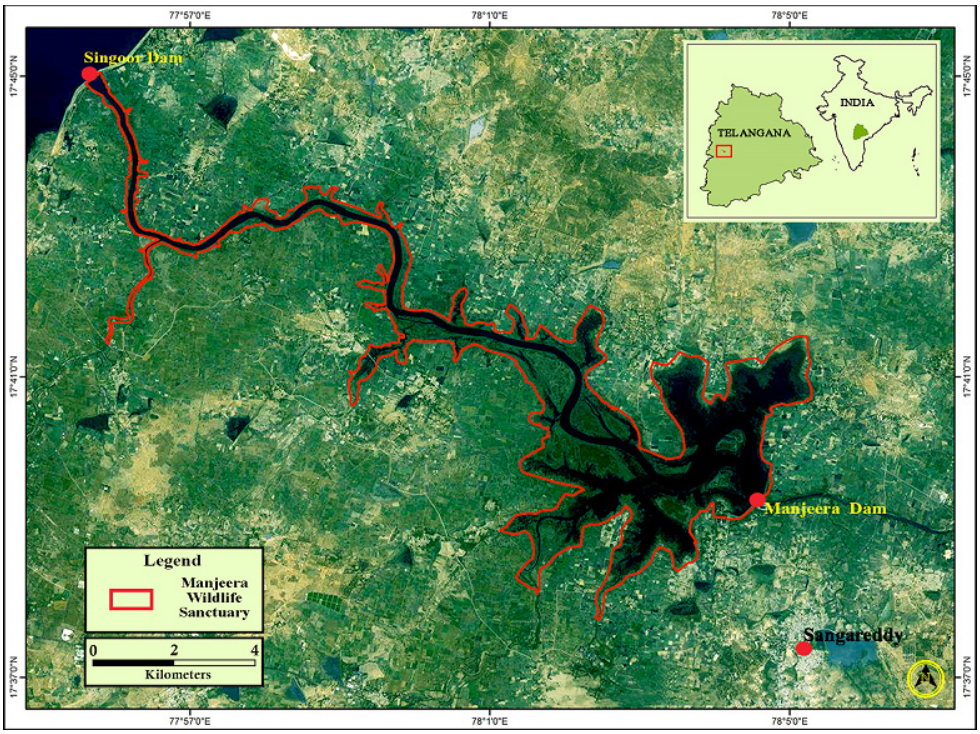

Figure 2. Map of the Manjeera Wildlife Sanctuary, Sangareddy District, Telangana State, India.

and footprints, fecal pellets, tunnels, eggshells, unused basking sites, nests).

To estimate the population status of *C. palustris* in the MWS, we used a boat to conduct night-time spotlight surveys in May 2011, 2014, 2015, and 2017, a time of the year that is known to be optimal for observing the species in the sanctuary (Bayliss 1987; Vijaya Kumar et al. 2007). We counted *C. palustris* at night (except on a full moon) from a boat, with the aid of powerful spotlights. We slowed down the boat when we detected the presence of *C. palustris* by the reflection of its eyes above the surface of the water, and we estimated sizes of all *C. palustris* for which we could estimate distances between eyes and snout (Bayliss 1987; Bayliss and Messel 1990). Size estimation was done by the Chabreck method, which describes the distance from the eye to the snout in inches, which is converted to body length in feet (Chabreck 1966). When we could not estimate the size of the crocodile, we recorded the sighting as Eyes Only. We divided the crocodiles for which we could estimate size into six size classes: < 0.7 m, 0.7–1.0 m, 1.1–2.0 m, 2.1–3.0 m, 3.1–4.0 m, and > 4.0 m. In general, we considered the animals < 0.7 m to be juveniles, between 0.7–1.5 m to be sub-adults, and > 1.5 m as adults (Whitaker and Whitaker 1984). We recorded coordinates of each crocodile sighting in the night surveys using a GPS (Model GPS 72H, Garmin, Olathe, Kansas, USA). Total night-time spotlight survey used as a relative index of the visible population of *C. palustris* excludes duplicate counts and juveniles (Bayliss 1987; Bayliss and Messel 1990). We mapped crocodiles sighted in the night-time spotlight survey by year, and we conducted spatial analysis using point density. Areas projected blue for low values to red for high values.

To identify the areas with high numbers of *C. palustris* in the MWS, we conducted day-time surveys in the sanctuary. We estimated these areas based on the number of *C. palustris* occurrences at basking sites in the sanctuary. We mapped the occurrences of crocodiles found during day-time surveys using hotspot analysis. Hotspot analysis identifies locations of statistically significant areas of high occurrence (hotspots) and areas of low occurrence (cold spots) of crocodiles. Areas projected blue for low occurrence zones to red for high occurrence zones. We classified High Occurrence Zones (HOZ) as areas with > 10 individuals/km^2, Moderate Occurrence Zones (MOZ) as areas with 5–9 individuals/km^2, and Low Occurrence Zones (LOZ) as areas with 0.1–4 individuals/km^2. We used ArcGIS v10.3 for spatial analysis and map production.

Results

We conducted 64 night-time spotlight surveys on the river along the 32 km^2 area of the sanctuary. The density of sighted crocodiles, excluding juveniles in the night-time spotlight survey varied from 5.50/km^2

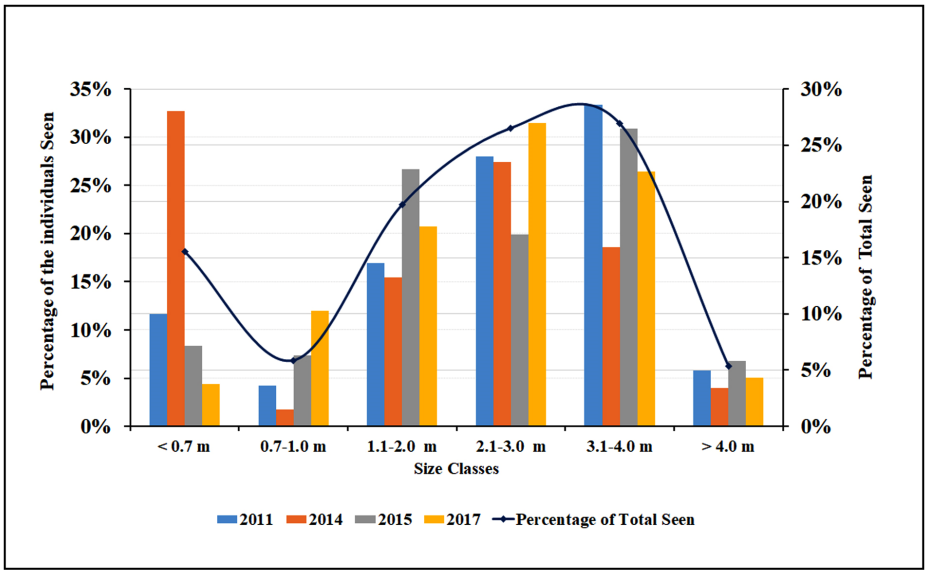

Figure 3. Size classes of Marsh Crocodiles (*Crocodylus palustris*) seen in the spotlight survey in the Manjeera Wildlife Sanctuary, Telangana State, India, between 2011 and 2017.

to 5.91/km^2 (Table 2). During night-time spotlight surveys, we sighted the size class 3.1–4.0 m most often (26.9%), followed by 2.1–3.0 m (26.5%), 1.1–2.0 m (19.7%), < 0.7 m (15.5%), 0.7–1.0 m (5.8%), and > 4.0 m (5.3%; Fig. 3). We sighted 81–85% of size class of < 0.7 m across the four years with their mothers in the submerged vegetation. We found 70.0–75.0% of sub-adult crocodiles sighted in the night-time spotlight survey in creeks and the remaining percentage of sub-adults were in the main river. We sighted 62.5–74.0% of adults (depending on the year) in creeks and the remainder in the main river.

We found 25 nests during the study period (Table 3). We saw that predation by Indian Wild Dogs (*Cuon alpinus*), nests drowned in flash floods, and hatchlings that could not emerge from nests without assistance of the mother crocodile in hard clay soil were the main reasons for hatchling deaths (Table 3). Overall, 12% of nests drowned in flash floods and 4% of nests faced predation by Indian Wild Dogs. Hatchlings in 16% of nests could not emerge without the assistance of mother crocodiles.

Spatial analysis.—The area of highest point density (individuals/km^2) was 37.38/km^2 in 2017 (Fig. 4D), followed by 2011 at 34.13/km^2 (Fig. 4A), 2014 at 29.25/km^2 (Fig. 4B), and 2015 at 27.62/km^2 (Fig. 4C). We identified four High Occurrence Zones and three Moderately Occurrence Zones in the sanctuary (Fig. 5). We identified crocodile habitat and basking sites in HOZ and MOZ in both the main river and creeks, but we only found nesting sites in HOZ.

Discussion

An average of past (Vijaya Kumar et al. 2007) and present observed population density of non-hatchling *C. palustris* in MWS, measured through spotlight surveys, has fluctuated since 1990, from 0.41 to 5.4 individuals/km^2. The observed population density of spotlight surveys in our study was highest in 2015 followed by 2011, 2014, and 2017. Since 1985, 212 crocodiles have been released by the reintroduction program into the sanctuary. This has resulted in the growth of the population of *C. palustris* after two decades, reaching

Table 2. Number of Marsh Crocodiles (*Crocodylus palustris*) sighted by size class (meters), eyes only (EO), total individuals (TI), total number of individuals excluding < 0.7 size class (TES), and density excluding of < 0.7 size classes per km^2 (DES) in night-time spotlight surveys in the Manjeera Wildlife Sanctuary, Telangana State, India, by year. In each year, we surveyed 32 km^2.

Year	Size classes									
	< 0.7	0.7–1.0	1.0–2.0	2.1–3.0	3.1–4.0	> 4.0	EO	TI	TES	DES
2011	22	8	32	53	63	11	9	198	176	5.50
2014	74	4	35	62	42	9	16	242	168	5.25
2015	16	14	51	38	59	13	14	205	189	5.90
2017	7	19	33	50	42	8	12	171	164	5.12

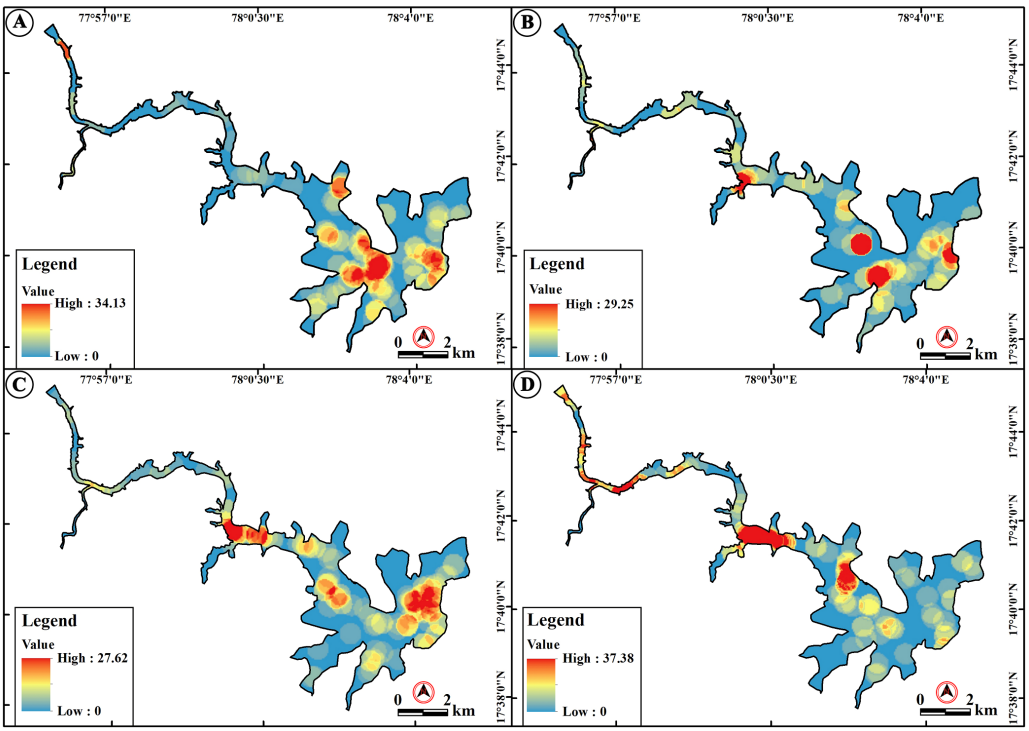

Figure 4. Point density areas of high and low values (individuals/km^2) of Marsh Crocodiles (*Crocodylus palustris*) seen in the night-time spotlight surveys in the Manjeera Wildlife Sanctuary, Telangana State, India, for (A) 2011, (B) 2014, (C) 2015, and (D) 2017.

5.5 crocodiles/km^2 in 2011. Because of low water levels in the creeks due to drought conditions in 2014, we could not conduct spotlight survey in all creeks and this resulted in the lowest observed population density recorded in that year. However, better water conditions in 2015 provided the chance to conduct the spotlight survey in all parts of the sanctuary and resulted in the highest density recorded. Among all surveys, the lowest density recorded in 2017 may have been due to floods (which occurred October and November of 2016), which may have forced adult crocodiles to move downstream and we noticed that crocodiles disappeared easily among the extensive growth of weeds like *Polygonum* spp. throughout the river.

The size classes give an idea of population trends of the crocodiles. The most stable population of released crocodiles in the sanctuary are the size classes > 2.1–3.0 m and > 3.1–4.0 m. Unless survivorship drops, crocodiles in the size class > 4.0 m will increase in the future as crocodiles grow. The least sighted size class of > 0.7–1.0 m in overall night-time spotlight surveys may indicate that hatchlings are facing more threats to their survival in the sanctuary than larger size classes. However, we cannot discount that this smaller size class simply do not venture as far into open water and therefore are less conspicuous during spotlight surveys. We found most hatchlings in the last week of May 2014 during the study period. This period is considered the best period for hatchlings to emerge from the nests in the sanctuary. In 2014, drought conditions in the sanctuary may have facilitated the favorable conditions to the nests, which were close to the river bank and this could be a reason for more hatchlings recorded in 2014.

Hotspot analysis indicates the presence of *C. palustris* individuals at long-lasting basking sites, as well as in their general habitat. No changes were seen in the distribution of hotspot areas during the study period, while the point density of *C. palustris* sighted during the night-time spotlight surveys changed yearly due to the movement of active *C. palustris* when hunting. Point density denotes the yearly change of prey availability to the crocodiles in the sanctuary and indicates new habitats and basking sites made by active crocodiles in

Table 3. Fate of eggs/hatchlings Marsh Crocodiles (*Crocodylus palustris*) in nests (sample size) in the Manjeera Wildlife Sanctuary, Telangana State, India, by year. Fate of all individuals in nests (number of nests) included predation by wild dogs (PWD), drowned in flash floods (DFF), and hatchlings not emerging from nests (HNE).

Year	Nests	PWD	DFF	HNE
2011	6	1	2	2
2014	9	0	0	1
2015	5	0	1	0
2017	5	0	0	1
Total	25	1	3	4

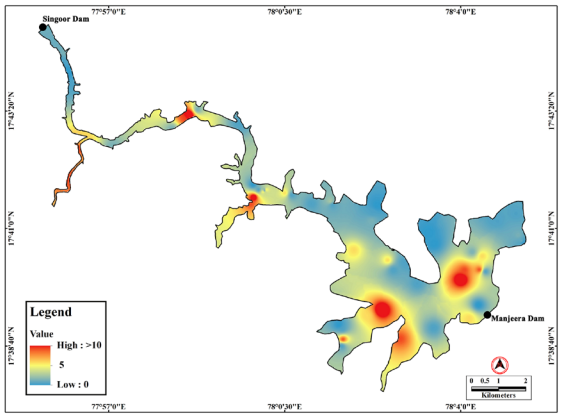

Figure 5. Hotspot areas of high occurrence (hot spot) and low occurrence (cold spot) zones (individuals/km^2) of Marsh Crocodiles (*Crocodylus palustris*) seen in the day-time surveys in the Manjeera Wildlife Sanctuary, Telangana State, India.

the sanctuary. We include both HOZ and MOZ areas as hotspots, and in these areas, there is a need to protect general habitats, basking sites, and nest sites, and to decrease the human activities on the riverbed in the sanctuary.

There are several threats to crocodiles in the sanctuary. We observed habitat destruction and loss caused by anthropogenic impact on the sanctuary due to loss of wetland area by the alteration of riverbanks, construction of canals, expansion of fields, and because people fear crocodiles and want to reduce areas for the crocodiles to live. People damage burrows of crocodiles by setting the entrance on fire or by throwing rocks and big stones. Human activities on the river bank also force crocodiles to leave their nest sites.

There are also direct threats to hatchlings in nests. Humans destroy eggs when they find nests. Sometimes hatchlings drown in fishing nets (Subba Rao 1993; Vijaya Kumar 1993), although we rarely saw this in the sanctuary. We also have seen hatchlings that have died, and nests inundated (killing hatchlings) because of flash floods due to water released from Singoor Dam. Besides nest drowning, Indian Wild Dogs can dig up and eat hatchling crocodiles. Nests of *C. palustris* require special attention in the sanctuary to protect the population into the future.

The population of *C. palustris* has grown in the sanctuary. However, with population increases of crocodiles, we expect more human-crocodile and livestock-crocodile conflicts, which could jeopardize continued protection of *C. palustris* in the sanctuary. Hence, there needs to be a program to create awareness among the people inhabiting the area surrounding the Manjeera River of the sanctuary and also the fisherman in the area to reduce their impact to crocodiles.

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