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No. 12, Thiruvannamalai Nagar, Saravanampatti - Kalapatti Road, Saravanampatti,
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Ph: +91 9385339863 | www.threatenedtaxa.org
Email: sanjay@threatenedtaxa.org

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Cover: Rufous-headed Hornbill *Rhabdotorrhinus waldeni* © Philip Godfrey C. Jakosalem.



Status and distribution of Mugger Crocodile *Crocodylus palustris* in the southern stretch of river Cauvery in Melagiris, India

Rahul Gour¹ , Nikhil Whitaker² & Ajay Kartik³

¹Kenneth Anderson Nature Society, No.9/2, HCF Post, Mathigiri, Hosur, Tamil Nadu 635110, India.

¹Department of Ecology & Environmental Sciences, School of Life Sciences, Pondicherry University, Puducherry 605014, India.

^{2,3}Madras Crocodile Bank Trust and Centre for Herpetology, 4, Mamallapuram, Tamil Nadu 603104, India.

¹rahulgour@gmail.com (corresponding author), ²nikhil@madrascrocodilebank.org, ³ajaykartik88@gmail.com

Abstract: A study was conducted to examine the population estimate and spatial distribution of Mugger Crocodile in the southern stretch of river Cauvery, Hosur Forest Division from February 2019 to May 2019. In total, 53 basking sites and 45 Muggers were encountered by direct sighting in the 24-km river stretch using daytime ground based survey approach. N-mixture models estimated an average Mugger density of 2.05 individuals per kilometre for daytime survey. A night spotlight survey across the seven segments of river stretch was also conducted which yielded direct sightings of 54 Muggers with an average encounter rate of 2.25 individuals per kilometre. Two crocodile nests with hatched egg shells were also observed on the sand banks of the river. We concluded that a potential healthy and breeding population of Mugger inhabits the studied stretch of the river. Multiple corresponding analysis was also performed, which demonstrated that Mugger responds to sandy banks alongside deep water pools for basking in contrast to river segments with shallow depth and dense riparian cover.

Keywords: Basking sites, conservation, Hosur Forest Division, nest, night spotlight survey, N-mixture models.

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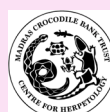
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Author details: RAHUL GOUR recently graduated from Pondicherry University with a master's degree in ecology and environmental sciences. He has associated with Kenneth Anderson Nature Society on various conservation projects in Melagiris. He is particularly interested in learning about the behavioural ecology of reptiles and megafauna. NIKHIL WHITAKER is a curator at the Madras Crocodile Bank Trust and Centre for Herpetology. He has studied environmental science and wildlife management at Charles Darwin University in Australia. An editor at journals including Taprobanica, Journal of Contemporary Herpetology, and Herpetological Review, and a member of the IUCN/SSC Crocodile Specialist group and Tortoise and Freshwater Turtle Specialist Group. AJAY KARTIK is a herpetologist with a keen interest in the behavioural ecology of reptiles. He has worked with diverse species across several landscapes of India and is an invited member of the IUCN/SSC Crocodile Specialist group and Tortoise and Freshwater Turtle Specialist Group.

Authors contribution: RG—contributed to the fieldwork and manuscript writing; NW—contributed to the work design, technical guidance and review of the manuscript; AJ—contributed to the field support and review of the manuscript.

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INTRODUCTION

The Marsh or Mugger Crocodile *Crocodylus palustris* (Lesson, 1831) (Image 1), is an apex predator and can be found in different forms of freshwater environment including rivers, ponds, reservoirs, marshes, and also inhabits estuarine habitats (Whitaker 1987; Whitaker & Whitaker 1989). Its range extends from southern Iran to the Indian subcontinent and is one of the most adaptable crocodilian species in India (Da Silva & Lenin 2010). The Mugger is legally protected in India under Schedule I of the Wildlife Protection Act, 1972, and categorized as 'Vulnerable' under the IUCN Red List of Threatened Species (Choudhury & De Silva 2013). Awareness about crocodile distribution and the ecosystem services provided by them is essential to better conserve the species and their habitats. An increasing number of studies have focused on the distribution of Mugger in various parts of India (Rao & Choudhury 1993; Singh 1999; Vyas 2012). Here we present the distribution and population status of Muggers in the small stretch of Cauvery river that runs through dense riparian forests of Tamil Nadu and Karnataka.

MATERIALS AND METHODS

Study site

Cauvery (also known as Kaveri) is a perennial river that originates in the Brahmagiri range of the Western Ghats, Karnataka. The river enters Tamil Nadu through the Hosur Forest Division in Krishnagiri district leading to the flat plains where it meanders. A continuous river stretch of 24 km was chosen to conduct the survey starting from Dabaguli (12.205N, 77.545E) upstream to Moslaemaduvu (12.149N, 77.748E) downstream (Figure 1). The region comes under the Melagiri Hill ranges which is an important wildlife habitat between the Western and Eastern Ghats (Daniel & Ishwar 1994; Tiwari & Kaliamoorthy 2018). This region has a semi-arid climate. The average temperature during winter reaches a minimum of 16°C and a maximum of 40°C during summer. It receives rainfall mainly during the north-east monsoon (October–December) and low rainfall from south-west monsoon (June–September), which ranges 750–800 mm (Shenoy et al. 2006). The study section of the river flows through valleys and forests, with the Cauvery Wildlife Sanctuary, Karnataka in the south and the dense reserve forests under Hosur Forest Division, Tamil Nadu in the north. Vegetation along the river section mainly consists of dry deciduous forest and

southern tropical dry thorn riverine forests (Baskaran et al. 2011).

Method

The entire survey which included reconnaissance and preliminary surveys followed by replication surveys for daytime and night spotlight surveys, were conducted over the course of four months (February–May 2019) during the dry season.

Reconnaissance and preliminary survey: These surveys were carried out over the 24-km river stretch to explore site characteristics and to collect adequate data for planning and survey design.

Daytime survey: The 24-km stretch of the river was divided into seven segments (Table 1) that served as seven different sites for temporal replicated surveys. Out of the 24-km of total river section, a 4.2-km segment was not surveyed due to insufficient water level in the river to row the coracle (a small, rounded lightweight boat) and lack of accessibility for the survey team to walk due to dense thorn forest along the river. Hence, the survey was carried out at the remaining six replicated sites (six river segments). Each site was surveyed on five occasions. The daylight survey was taken place with a minimum of seven days and a maximum of 10 days' time space between each survey occasion. The surveys were carried out on foot along the river and by rowing coracle where riverbanks are inaccessible on foot. Teams of two to three observers recorded direct basking counts during maximum basking activity times, 0700–1000 h and 1500–1800 h (Venugopal & Prasad 2003). The survey team also searched for potential nests and nesting activities such as digging, presence of eggs or shells along the river banks. The locations of direct and indirect signs (scat,



Image 1. Mugger Crocodile *Crocodylus palustris*.

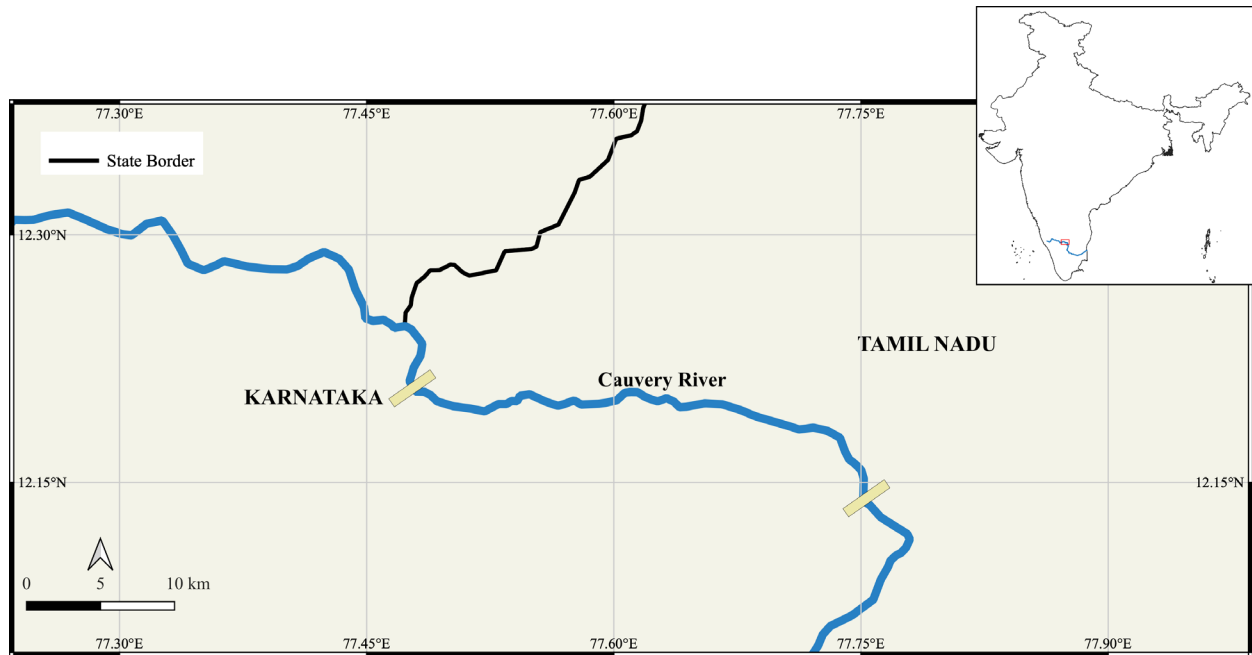


Figure 1. Cauvery river section (red box in inset map of India) where the study took place during February–May 2019.

spoor, basking and nest sites) of Muggers were recorded by using a GPS instrument (Garmin eTrex 20x). Animals were observed with Olympus binocular (10 x 50) and wherever possible images of Mugger and their habitat were recorded using a digital camera. The number of individuals detected in a given site were counted using standard monitoring techniques.

Spotlight survey: After completion of daytime replicated surveys, the same six sites (river segments) were used for conducting a night spotlight survey using coracles. All the six sites were surveyed at the same time by six different survey teams. Available spotlight survey procedure was carried out to perform night surveys (Messel et al. 1981; Bayliss 1987; Lentic & Connors 2006). At each segment of the river, all coracles were operated between 2000 h and 2300 h. Coracles were operated at about 2 m from and parallel to the shoreline, and one observer was stationed at the front in each coracle in addition to a fellow observer to record the data. A speed of 5–8 km/hr was maintained. A high-powered (1000+ lumen) searchlight was used by the observer during the survey, which produced a readily detectable eye shine up to a distance of approximately 100 m. When an eye shine was spotted, the Mugger was approached closer to obtain a size estimate. We assigned four size classes to the Muggers based on Andrews (1999): hatchlings (<0.5 m TL), small/juveniles (0.5–1.0 m TL), medium/subadults (1.0–1.5 m TL), and large/adults (>1.5 m TL). Unknown size classes when only eye shine was visible

were categorized as eyes only (EO).

Measure of abundance: Appropriate measure of abundance was chosen instead of a total population count as not all mugger crocodiles present in the area were observed for the each survey. For the daytime survey, N-mixture models were employed to estimate abundance based on repeated counts in a given site (Royle 2004; Dail & Madsen 2011). Since capture and manipulating of individuals are not required in N-mixture models and they also allow collecting abundance information over larger areas compared to traditional techniques (Kéry et al. 2009; Griffiths et al. 2015). The lengths of the river segments (sites) were considered as a site level covariate, and the sampling hours were considered as observational covariates which were recorded during each survey occasion for each site. We used R package ‘unmarked’ for N-mixture modelling to estimate abundance (Fiske & Chandler 2011). However, because the night spotlight survey was conducted only once at all sites, we considered the total spotted individuals as a relative index of abundance for night spotlight survey (Bayliss 1987; Cherkiss et al. 2006; Fukuda et al. 2012).

Association and correlation: Multiple correspondence analysis (MCA) was carried out to measure the association among the habitat features and occurrence of Muggers. It is an adaptation of corresponding analysis to a data table containing more than two categorical variables (Greenacre & Blasius 2006). MCA can also

be seen as a generalisation of principal component analysis (PCA) when the variables to be analysed are categorical instead of quantitative (Abdi & Williams 2010). We specifically selected 10 categorical variables which were most dominant habitat features found in each river segment during the daytime surveys. We used R packages ‘FactoMineR’ for the MCA analysis and ‘factoextra’ for ggplot2-based visualization (Le et al. 2008; Wickham 2009; Kassambara & Mundt 2020).

All the map layouts were created using QGIS and Google Earth. Abundance and association measurements were carried out using open source software R v3.6.2 (R Core Team 2021).

RESULTS

We found 53 potential basking sites along the river section based on the frequent and numerous indirect signs, mainly spoors. During five repeated counts, we encountered a total of 45 Mugger Crocodiles by direct sighting which includes 12 adults (>1.5 m TL), nine sub-adults (1.0–1.5 m TL), 15 juveniles (0.5–1.0 m TL), and nine without any concrete size estimate. In N-mixture models, we selected the model with Poisson error, as it showed AIC values lower than the respective zero-inflated Poisson (ZIP) model (86.97 vs. 88.98). Assuming homogeneous density in the survey area, N-mixture models estimated an average mugger crocodile density of 2.05 individuals per kilometre. During daytime ground based surveys two nests were also observed very close to the riverbank on the sandy substrate (Image 2). At

Table 1. Type of association observed for Mugger Crocodiles with respect to the habitat.

River segment	Segment length (km)	Topography	Habitat type	Type of association*
Dabaguli–Dolamathi	3.6	Semi-boulders, mud and sparse riparian cover	Runs, pools and cascades	+
Dolamathi–Uganiyam	2.7	Boulders, semi boulders, sand, leaf litter, and riparian cover	Runs, pools and riffles	+
Uganiyam–Thumbaguli	3.7	Semi-boulders, Sand, and sparse riparian cover	Runs, pools and riffles	–
Thumbaguli–Upstream Raasimanal (Unsurveyed segment)	4.2	Boulders, bed rock, leaf litter, and dense riparian cover	Shallow river depth with cascades and rapids	NA
Upstream–Raasimanal	1.7	Semi-boulders, bed rock, mud, and riparian cover	Runs, pools and riffles	+
Raasimanal–Biligundlu	5.7	Semi-boulders, sand, mud, leaf litter, and dense riparian cover	Shallow river depth with runs and riffles	–
Biligundlu–Moslaemaduvu	2.4	Boulders, semi-boulders, mud, and less riparian cover	Runs, pools and cascades	+
Total	24			

*‘+’ shows positive and ‘–’ shows negative association

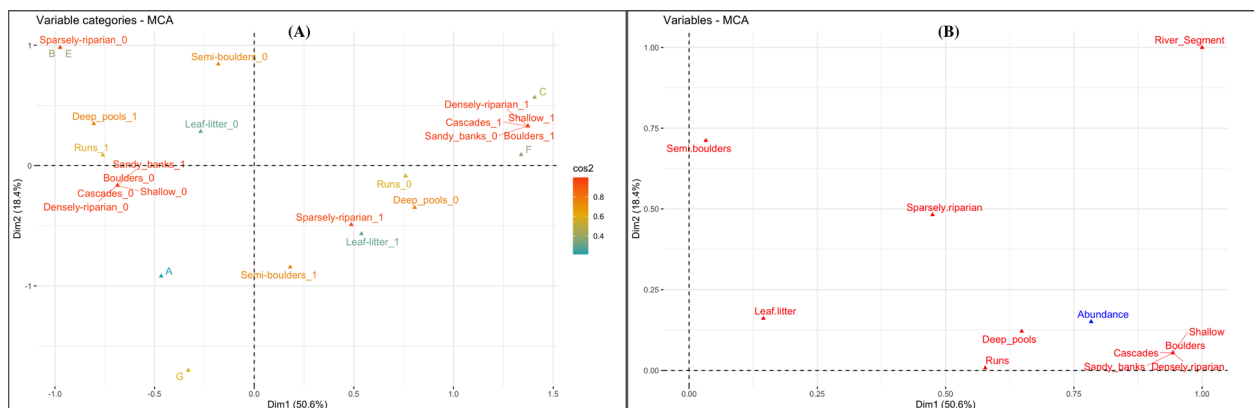


Figure 2. A—Quality of representation (squared cosine – \cos^2) showing the degree of association between variable categories | B—Correlation between variables and MCA principal dimensions.



Image 2. Spatial distribution of direct and indirect sightings of Mugger Crocodiles with the nesting sites recorded during day time survey.



Image 3. Spatial distribution of Mugger Crocodiles during night time spotlight survey.

the first nest, 13 empty eggshells, of which two had failed to hatch were observed. Near the first nest, three hatchlings (<0.5 m TL) were also observed in water and at the second nest, 11 freshly hatched eggs shells, and five hatchlings with an adult crocodile were spotted in the river. It should be borne in mind that all the available nests in the study site are not represented in

our nesting observations, as search effort for nests was not standardized among the river section and observers.

Night spotlight survey yielded direct sightings of 54 Muggers which includes 14 adults, seven sub-adults, five juveniles, and 28 with eyes only (EO) recorded in the targeted river section (Image 3). A relative abundance of 2.25 individuals per kilometre was obtained during

spotlight survey, comparatively higher than the daytime survey. We also observed the basking banks with deep-water river segments as the key determinant explaining the relatively high occurrences of mugger crocodiles. MCA biplots also displayed greater squared cosine values for deep pools, sandy banks and runs which shows the higher quality of representation (Figure 2A). And while comparing the river segments with shallow depth and dense riparian cover, the availability of sandy banks for basking alongside deep water pools revealed a substantially higher abundance as shown in Figure 2B, which also complemented with our field observations.

In addition to Muggers various other threatened species like Smooth-coated Otter *Lutrogale perspicillata*, Leith's Softshell Turtle *Nilssonina leithii*, Asian Elephant *Elephas maximus*, Sloth Bear *Melursus ursinus*, and Lesser Fish Eagle *Ichthyophaga humilis* were also observed a few occasions in the study area. Most of the river stretch was facing unrestricted fishing pressure. Human activities and livestock along the river stretch appeared to negatively influence the use of areas by Muggers. During the entire study period, no crocodile attacks were observed.

DISCUSSION

The present study with successful nesting and hatching records suggested the presence of a potential breeding population of Mugger along the targeted stretch of the river. It also demonstrated that Muggers preferred river sections with a wider width and greater depth while avoiding shallow regions with high rapids. Spotlight survey was found to be more effective out of the two survey strategies adopted in this study, yet the detection probability of hatchlings/ yearlings and animals resting in vegetation along the riverbank reduced significantly when compared with the daylight surveys (Woodward & Marion 1978; Bayliss 1987). However, the study shows that the spotlight survey can be an effective tool for monitoring crocodilian populations over the long term (Messel et al. 1981; Hutton & Woolhouse 1989; Webb et al. 2000; Fujisaki et al. 2011; Fukuda et al. 2012). It is expected that more systematic surveys will detect more populations across the Cauvery river ecosystem. An earlier study by Whitaker & Andrews (2003) also showed a stable population of Muggers in upper region (around 150 km upstream from the present study site) of river Cauvery in Ranganathittu Bird Sanctuary, Karnataka. A systematic multiscale study of Muggers, associated species, and their habitat in the entire stretch of river

will yield valuable information regarding the population dynamics and ecology of the species in the Cauvery river ecosystem. There is also a need to have local awareness campaigns focusing on the vulnerability and ecological values of crocodiles (Brito et al. 2011).

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ravi@threatenedtaxa.org

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