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THE NUMBER OF FISHING CATS IN THE GODAVARI DELTA, INDIA, SUGGESTS THEY CAN COEXIST WITH HUMANS

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Abstract. Anthropogenic activities have significantly disrupted natural habitats, driving many species to the brink of extinction. While concerted conservation efforts and habitat restoration initiatives have successfully rescued several species from the brink, there remains a significant gap in our understanding of the population and distribution of numerous species. Among these are small carnivores, characterized by their elusive and nocturnal behaviour, complicating population monitoring efforts. One such species is the fishing cat (*Prionailurus viverrinus*), which is vulnerable per the International Union for Conservation of Nature Red List of Threatened Species (IUCN). The Godavari delta, a prominent mangrove ecosystem along the Andhra Pradesh coastline in India, is one of the prime habitats for this cat. Using camera traps, we monitored fishing cats in the Coringa Wildlife Sanctuary (CWS) and adjacent mangrove vegetation in the Godavari Delta. We placed 52 camera traps in 2×2 km^2 grids at 52 sites for 30 days and used spatially explicit capture-recapture (SECR) models to estimate population density based on individual identification. The analysis reveals that the population density in the CWS is 0.40 ± 0.06 individuals per km^2 and 0.37 ± 0.06 in the surrounding areas, with an estimated total population of 114.94 individuals (95% CI = 103.67–126.21). Our study identifies the Godavari Delta as a potential landscape for the long-term conservation of fishing cats. Continuous monitoring is essential to understand this species' population dynamics and discern the factors influencing its adaptation to human-dominated environments in the adjoining areas.

INTRODUCTION

Monitoring the population and dynamics of species in an ecosystem plays an integral part in conservation and helps managers refine and optimize conservation strategies. Globally, 80% of all wild mammals and half of plants by biomass have undergone extinction (Macdonald 2019), and several others are pushed towards high extinction risks due to stressors such as overexploitation, habitat loss, poaching, and various forms of environmental pollution (Briggs 2017). Proper surveillance of their population and range at various spatial and temporal scales is essential to effectively conserving such species from the brink of extinction. Mammalian carnivores face serious threats, population decline, and range contraction (Chatterjee et al. 2020). Large-scale conservation initiatives have brought back the population of charismatic carnivores (Qureshi et al. 2023; Jhala et al. 2020). However, small carnivores receive less attention. Due to their rarity and elusive behaviour, they are less studied and face serious conservation threats. Information regarding their distribution and population status is imperative, particularly given the endangered status of many. One such species is the fishing cat (*Prionailurus viverrinus*), which faces significant threats due to ecologically unbalanced land policies, direct persecution, and ritual hunts and trades (Mukherjee 2012; Thaung 2017).

The global distribution of fishing cats is primarily found in South and Southeast Asia's coastal areas, within inland wetlands and freshwater habitats (Cutter 2014) and some records of hilly regions of Sri Lanka (Thudugala 2016). The mangroves in the Sundarbans, Chilika and Andhra along the eastern coast account for the predominant distribution of fishing cats in India (Mukherjee et al. 2012, 2016; Shekhar Palei et al. 2018; Shankar et al. 2020). Fishing cats are also reported in the Keoladeo National Park and the Brahmaputra – Ganges basins in the Himalayan foothills (Mukherjee et al. 2012; Sadhu and Reddy 2013). The fishing cats were classified as endangered and are presently placed as Vulnerable on the International Union for the Conservation of Nature (IUCN) Red List (Mukherjee et al. 2016). The fishing cat is listed in Appendix II of Article IV of the Convention on International Trade in Endangered Species (CITES) and Schedule I of the Indian Wildlife (Protection) Act, 1972.

In the ecosystems of mangroves and marshes in human-dominated areas, fishing cats play a crucial ecological role as apex carnivores (Shankar et al. 2020). For such elusive species, which are difficult to monitor, it becomes increasingly important to provide baseline information on species distributions and population density (Phosri et al. 2021). Camera traps have proven to be an effective tool for assessing the density, distribution, threats, and spatiotemporal activity patterns over the last two decades. A significant benefit of camera trap-based density assessment is that it makes it possible to get baseline data for species conservation, planning, and population monitoring. The spatially explicit capture-recapture (SECR) model is often used for assessing population density because it estimates density clearly and excludes ad hoc calculations of the sampling area (Foster and Harmsen 2012; Efford and Fewster 2013). SECR assessment is a spatial method that assesses density as constant or variable via state space (Green et al. 2020).

It is generally appreciated that the IUCN's downlisting of fishing cats from the endangered to the vulnerable is primarily credited to ongoing conservation efforts. Fishing cat populations are also recorded in densely human-dominated landscapes in India and Sri Lanka, which have high extinction risks (Mukherjee et al. 2016; Kolipakka et al. 2019). The Coringa Wildlife Sanctuary (CWS) and adjacent mangroves lie in human-dominated landscapes with high anthropogenic pressure (Shankar et al. 2020; Shameer et al. 2022). There is a large population of fishing cats in the CWS and nearby areas, which have been the focus of research recently (Mukherjee et al. 2012; Sathiyaselvam et al. 2016; Shankar et al. 2020; Shameer et al. 2022, 2023). Shameer et al. (2022) identified blotched patterns among the CWS's fishing cats. The study hypothesised that there may be inbreeding or that the group evolved from an isolated bottlenecked population.

Only a proper assessment of population status can assess the stability of the population in an ecosystem. The present study aims to estimate the population density of fishing cats using SECR methods from the CWS and adjoining regions. This not only initiates the assessment of the actual density of fishing cat populations in the various areas but also helps to generate baseline data to develop a long-term conservation strategy.

MATERIALS AND METHODS

Study area

From Srikakulam to Nellore, the nine districts of Andhra Pradesh make up 973.7 kilometres (12 per cent of India's entire coastline). The estuaries of the rivers Godavari and Krishna cluster along the 582 km^2 of mangroves along this coast. The Godavari mangrove zone (321 km^2) is the second largest along the East Coast of India. The Coringa Wildlife Sanctuary (CWS) and the nearby mangroves (16°44' to 16°53'N and 82°14' to 82°22'E) are situated in the East Godavari District and represent one of the most extensive mangrove sections in the Godavari Delta (Figure 1). The CWS accounts for 75 km^2 of mangrove cover in the Godavari delta. In this region, there are sixteen distinct varieties of mangroves, predominantly belonging to the genera *Avicennia, Excoecaria, Rhizophora, Ceriops, Bruguera, Sonneratia, Aegiceras,* and *Lumnitzera*. In addition to the natural mangroves, numerous additional wetland plants are obligatory or optional in mangrove environments. The average annual rainfall is approximately 1000 mm, and seasonal temperatures range from about 17 °C to 40 °C. The CWLS is a home for invertebrates, fishes, amphibians, reptiles and birds (see Shankar et al. 2020 for more details).

Camera trapping

Using Qgis (3.0), the CWS and adjacent territories were stratified into 2 × 2 km^2 grids (sampling units), and camera traps were put in optimal locations based on the results of an indirect sign study (Figure 2). At least one kilometre of each grid was surveyed for signs, and 92 locations were identified. The camera locations included creek banks, animal tracks, and open areas within the grids. We mounted two passive, high-definition trail cameras (Cuddeback C1) in each location (to capture both flanks) at 30 cm above the ground, using poles to secure the cameras where necessary. In the first of two stages of camera trapping, 57 locations were camera-trapped for 30 days (1710 trap nights) from June to July 2018. In August 2018, cameras were installed in 35 locations as part of the second phase for 22 days (770 trap nights).

Population size and density estimation

The photographs of fishing cats obtained were organised by the left and right flanks for individual identification. Variations in the stripe pattern on fishing cats' necks, bodies, and legs were utilised for individual identifica-

Figure 1. Aerial perspective of the study area, highlighting its intricate mangrove habitats.

tion. A few individually identified photographs of fishing cats are provided in Figure 3. We manually compared both flanks and used the flank with the most photos of fishing cats to estimate the population density. Each fishing cat was assigned a unique identity code after their fur patterns were examined as per earlier research on other carnivores (e.g., Schaller 1967; McDougal 1977; Karanth 1995). We created individual capture records in a standard X matrix format (Otis et al. 1978; Nichols 1992), trap operating matrix and habitat mask files based on the individually identified fishing cat. The population size and density were analysed using likelihood-based spatially explicit capture-recapture (SECR) algorithms that provide information on the spatial or "location" information of animal photo-captures and camera deployment (Borchers and Effords 2008; Efford and Fewster 2013). SECR methods have been widely used to estimate the density of species, which can be marked individually using photographs, providing more accurate and precise estimates than traditional methods do (O'Brien 2011; Thornton and Pekins 2015; Young et al. 2019). These methods have been successfully applied to various carnivore species, including large and small carnivores, and in various habitats (Harmsen et al. 2020; Rather et al. 2021; Bashir et al. 2013; Srivathsa et al. 2015; Thornton and Perkins 2015). Based on the vegetation classification, potential home range centre files were created (Borchers and Effords 2008) within a 5 km buffer of the research region (Bagaria et al. 2017). SECR assumes that the detection probability of animals decreases with increasing home range centre from the detector, similar to distance sampling (Buckland et al. 2001). The models fit g0 (detection probability) and σ (spatial scale) to produce D (density) and N (population size) as derived parameters. We used a half-normal detection function and binomial distribution to model the density and population using a null model, g0s0. The N was predicted to the 5 km buffer of the potential home range centre using the RN.method and its sampling variance (MSPE). The analysis used R Studio 1.1.456 and the secr package version 3.1.8. Trap nights were calculated by multiplying the number of sampling occasions by the number of camera trapping locations.

RESULTS

The sampling efforts of 1710 trap nights at 57 CWS trap locations provided 291 pictures of fishing cats' left and right flanks. We separated 150 photo captures as left and

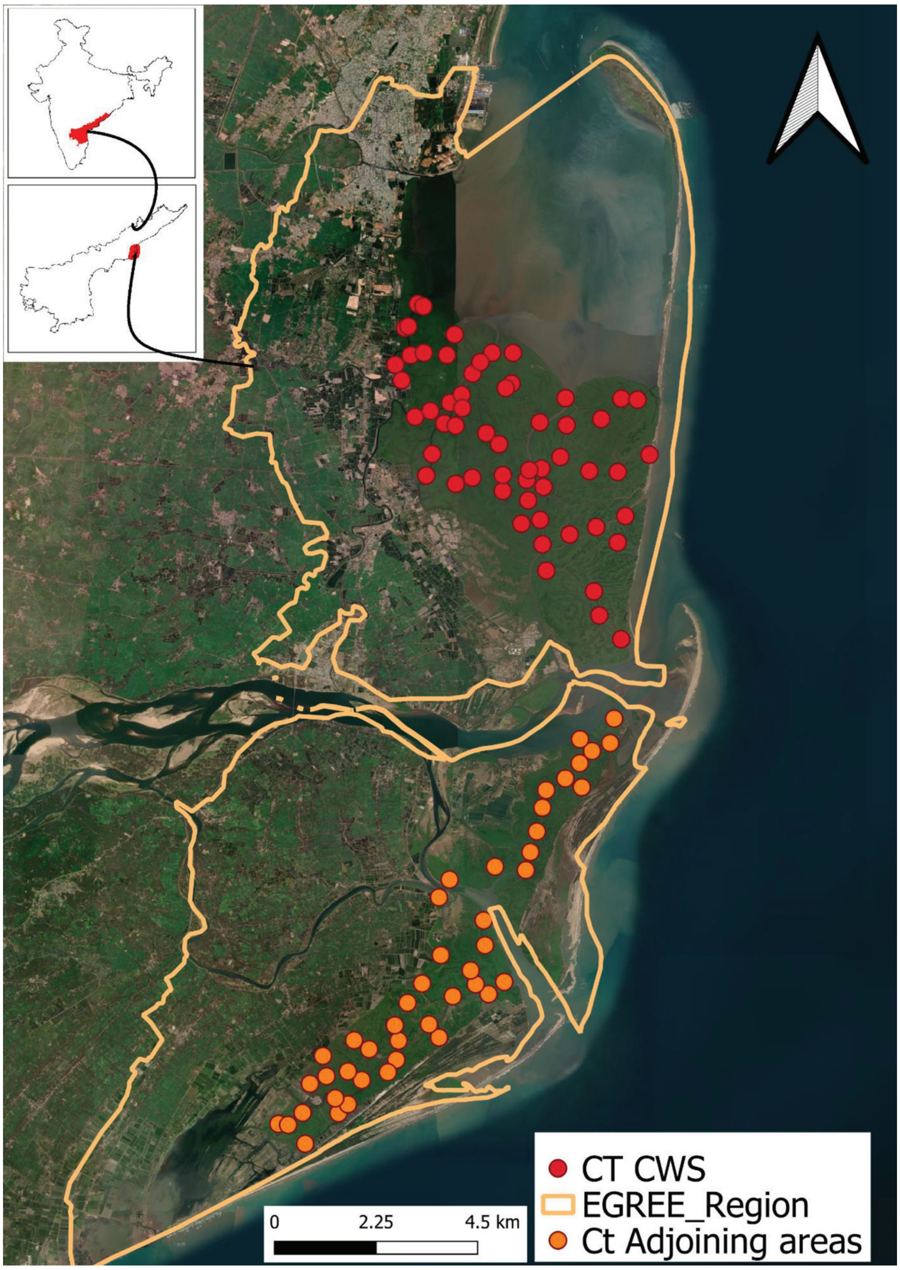

Figure 2. Map of the study area in which the red and orange dots indicate the locations of camera-trap sampling stations in the Godavari Delta.

141 as right flanks. From 150 photos of the left flank, the pelage pattern of 49 adults and two sub-adults were recognised. Twenty-three photos were either overexposed or lacked clarity, preventing their identification. A sampling effort of 770 trap nights from 35 locations in adjacent mangrove ecosystems in Godavari provided 213 photos of fishing cats. There were 121 photographs of the right flank and 92 of the left. Forty individuals were recognised from 121 pictures of the right flank, and twenty photographs were eliminated due to overexposure. Thus, 49 individuals were counted from the CWS and 40 from the adjoined mangrove region in the Godavari. Both regions' density and population estimates are provided in Tables 1 and 2.

DISCUSSION

Previous attempts from India to estimate the fishing cat population were made in Terai–Duar (Nair 2012), the CWS (Malla 2016; Sathiyaselvam et al. 2016), and the Lothian Wildlife Sanctuary in the Sundarbans (Das et al. 2017). The first three studies have methodological flaws, such as low precision, incomplete data reporting, or population overestimates (Phosri et al. 2021). The coefficient of variation (CV) estimate of the present study is comparable to that of Phosri et al. (2021) from Thailand and Das et al. (2017) from the Sundarbans. Malla (2016) estimated the density of fishing cats in the CWS to be 0.53 to 0.94 per km^2. Sathiyaselvam et

Figure 3. Left flanks of the various individual fishing cats' photos captured by the camera trap.

Table 1. Density estimates of fishing cats in the CWS and adjoined mangroves in the Godavari basin. D: density; SE: standard error; g0: probability of capture at the home range centre; σ: spatial parameter related to home range size (value is in km); CI: confidence interval; lower and upper confidence interval; N: number of individuals captured; CWS: Coringa Wildlife Sanctuary.

Location	Model	D ± SE (95% CI)	g0 ± SE (95% CI)	σ ± SE (95% CI)
CWS	g0s0	0.40 ± 0.06 (0.29–0.53)	1.73 ± 0.26 (1.28–2.34)	1.47 ± 0.11 (1.27–1.71)
Adjoined mangroves in Godavari basin	g0s0	0.37 ± 0.06 (0.26 - 0.51)	2.82 ± 0.51 (1.96– 4.03)	1.63 ± 0.15 (1.35–1.96)

Table 2. Population estimates of fishing cats in the CWS and adjoined mangroves. g0s0: model; M0Null: null model; n: number of individual photos identified; Pop: estimated population; SE: standard error; CI: confidence interval; P hat: sample proportion.

Location	Model	Pop ± SE (95% CI)
CWS (n = 49)	g0s0	50.91 ± 2.71 (49.23–64.50)
Adjoined mangroves in Godavari basin (n = 40)	g0s0	64.03 ± 7.67 (53.04–84.27)

al. (2016) calculated 0.7 individuals per km2 from the CWS in the same year. Our research revealed a population density of 0.40 ± 0.06 per km^2, which is lower than prior estimates. Sathiyaselvam et al. (2016) did not employ the SECR model to calculate population density in their analysis. The closed capture-recapture approaches required individual-specific capture histories across a well-defined research area (White et al. 1982) and implicitly measured density (Royle et al. 2014). According to studies, closed capture-recapture systems consistently overestimate population density (Obbard et al. 2010; Pesenti and Zimmermann 2013; Green et al. 2020). Malla's high dispersion estimates render the study untrustworthy (Phosri et al. 2021). The Sundarbans fishing cat population density estimate by Das et al. (2017) (0.44 ± 0.13 per km^2) is comparable to our findings. SECR population estimating models have recertified the inaccuracies generated by non-spatial estimators when individuals differ in their exposure to traps or when the target population is poorly defined (Efford and Fewster 2013). We employed a systematic sampling design and rigorous population estimation techniques, and the results can serve as the first valid baseline population estimate for the CWLS and adjacent mangrove habitats. Thus, our results are deemed more accurate than the estimates in previous studies.

Combining the findings of the CWS and adjacent mangrove habitats, we can conclude that the Godavari delta region contains at least 115 fishing cats. The CWS has a diverse population of mammals, and the fishing cat is the primary predator, coexisting alongside jackals and jungle cats (Shankar et al. 2020). We demonstrate that fishing cats are evenly distributed outside the CWS reserve. In this region, anthropogenic pressure is high, and the local community threatens the fishing cat population (Shankar et al. 2020). Fishing cats are found to inhabit human-dominated areas despite the frequency of human–fishing cat conflicts involving retaliatory killing. No research has yet demonstrated the poaching of fishing cats for their body parts. As fishing cats are tolerant of perturbations, the altering land patterns, human settlements, and other anthropogenic causes (other than massive habitat degradation) have little effect on their population density (Phosri et al. 2021).

While the majority of members of the Felidae family are small cats, their ecological and socioeconomic significance is unknown due to the limitation of ecological data. These species, primarily preying on terrestrial rodents, play vital roles in their ecosystems (Srivathsa et al. 2015). However, their elusive behaviour poses challenges for population monitoring, leaving their status largely unknown. Our study underscores the efficacy of camera trapping and SECR techniques in accurately estimating the population of fishing cats. Similarly, this approach has been used to estimate the densities of various small carnivores (Petersen et al. 2019; Thornton and Perkins 2015; Anile et al. 2012). This methodological approach holds promise for assessing populations of various small mammals with natural markings that allow individual identification. By employing this method, biologists gain valuable insights into the population densities of elusive species, facilitating informed strategies for long-term conservation.

India's Godavari Delta region harbours a stable fishing cat population that extends beyond protected areas and is distributed in human-dominated areas. A comprehensive conservation strategy for the fishing cat population in the Godavari delta includes several key initiatives. Firstly, regular camera trapping exercises should be conducted to assess population dynamics. Monitoring efforts should extend beyond protected areas to understand the presence and behaviour of fishing cats in human-dominated landscapes. Documenting conflicts and poaching incidents in fringe areas is crucial for understanding threats. Outreach activities aimed at public education on the importance of mangrove and fishing cat conservation should be conducted periodically. Promoting sustainable aquaculture farming in mangrove fringes can help reduce habitat destruction. Collaboration with various stakeholders is essential for developing effective conservation models. Monitoring the diet of fishing cats and analysing water quality in their habitat is vital for assessing ecosystem health. Periodic analyses should be conducted to determine the impact of solid waste and chemical contamination on fishing cat populations. Monitoring cropping patterns, pesticide use, harvest practices, and wetland quality is essential for understanding human-wildlife interactions and attitudes toward conservation efforts. Recognizing the interconnectedness of various subpopulations along the eastern coast of the Indian subcontinent could prove crucial in sustaining the fishing cat population.

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Competing Interests

The authors state that they have no known competing financial interests or personal ties that could be perceived as having influenced the work described in this study.

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