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TEMPORAL SEGREGATION OF SMALL FELINE PREDATORS AND CANIDS IN THE ESTUARINE MANGROVE DELTA OF KRISHNA WILDLIFE SANCTUARY, INDIA

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Abstract. A camera trap study was conducted in the mangrove of Krishna Wildlife Sanctuary, the eastern coast of India, to understand the assemblage, temporal segregation and dial activity pattern of small and medium-sized mammals. Forty-one pairs of passive infrared camera traps were deployed and monitored for 30 consecutive days, making a total of 1,230 trap days effort. The study reveals that the jackals accounted for 40.5%, while fishing cats and jungle cats accounted for 6.09% and 2.42% of all recorded animals, respectively. The analysis of the relative abundance index shows that the jackal is the most abundant mammal in the sanctuary (36.74). Free-ranging dogs, humans and cattle were recorded mostly during the daytime. The jackal showed a higher temporal overlap with the fishing cat (0.76, 95% CI (0.59–0.93)) and the jungle cat (0.72, 95% CI (0.62–0.82)). The jungle cat showed peak activity at dawn, while fishing cats showed peak activity at dusk. Both species temporally overlapped with the bimodal activity of the jackal. Moreover, the available prey may be shared between the three dominant predatory species by minimising the competition (effective resource partitioning). The anthropogenic threats can be a reason for a comparatively lower abundance of the fishing cat, and necessary steps are sought to protect this ecosystem.

INTRODUCTION

The concept of temporal partitioning describes the use of the same resource by different species at different times to reduce competition (Gao et al. 2020). The division of time between different species of carnivores for hunting or feeding activities is known as temporal partitioning in a carnivore guild. It appears to be an effective strategy to avoid competition for fishing cats and associated species, as determined by Shankar et al. (2020). Additionally, they showed spatial and temporal segregation towards human disturbances, which may have been helpful for protecting themselves. There is also effective temporal separation between large-ranging top predators such as tigers, leopards, and dholes, according to Shameer et al. (2021). Therefore, synchronized hunting and feeding between sympatric species in the carnivore guild is allowed through effective temporal partitioning. Generally, carnivores partition their time to minimize competition and maximize survival chances. It is possible for them to maintain a balanced ecosystem by using the same resources at different times.

The vast intertidal areas, mangroves and lagoons in the peninsular Indian coastline tract is home to several species of animals, including endemic as well as endangered species. Declining habitat quality and poaching can often lead to human–animal conflicts (Palei et al. 2018). The dependency of local human communities on these habitats for livelihood, such as fishing and aqua farming, intensifies wildlife threats. Nevertheless, these faunal assemblages are capable of coexisting with humans in these highly urbanized landscapes by spatio-temporal avoidance and provide necessary ecosystem services (e.g., predating on rodents). Hence, assessing the diversity and temporal segregation of such vulnerable mammals in response to various anthropogenic variables is essential, especially when conserving a vulnerable habitat like mangrove wetlands.

Camera traps are widely used to assess the diversity and efficiently estimate the absolute densities of mammals that have coat patterns. The time data extracted from these camera trap records are useful in assessing the activity pattern and understanding the interaction between these mammalian guilds (Santos et al. 2019; Durán-Antonio et al. 2020; Shankar et al. 2020; Shameer et al. 2021). This further helps us to understand the ecology of several elusive species and assist managers in maximizing conservation in biodiversity rich areas. Thus, camera trapping is now one of the most reliable techniques in monitoring wildlife globally and widely used for monitoring terrestrial vertebrates to understand their relationship towards various anthropogenic pressure (Palmer et al. 2018; Jhala et al. 2021; Chakraborty et al. 2021).

The Krishna River basin is the third largest river basin in India after Ganga and Godavari. The twin delta system of Krishna and Godavari rivers, i.e. Krishna-Godavari delta, (K-G delta) drains into the Bay of Bengal in the east (Kallepalli et al. 2017; Kubo et al. 2018). Together, these adjacent deltas cover 12,700 km^2 with strand plains, lagoons, muddy regions, and mangrove forests (Selvam 2003). The Krishna delta region has an extensive mangrove vegetation on both sides of four distributing rivers (Jayakumar 2019). This delta region is a major habitat for the threatened mammals like the fishing cat (*Prionailurus viverrinus*) (Mukherjee et al. 2012; Palei et al. 2018), but these mammals' actual diversity and interaction assemblages remain understudied. Spatio-temporal studies on mammalian groups of Eastern Godavari wetlands showed negative interactions and conflicts in the ecosystem (Shankar et al. 2020), which are detrimental to the existing population of the fishing cat. Many mammals in this region are not limited to wetland habits but are attracted by the wetlands for essential resources. Much of these resources overlap with the people residing in the surrounding locality or vice versa. The human exploitation of mangroves limits the dependent mammalian supplies, leading to conflicts. The Krishna estuarine delta and the associated mangrove region are located in a human-dominated landscape, and they depend on these wetlands for livelihood, and aquaculture reclamation is a major threat (Chaudhury et al. 2015). For the conservation of these wetlands, it is of prime importance to understand the status, diversity, and activity pattern of mammals in such an ecosystem.

There hasn't yet been a thorough study of the animal assemblages in the Krishna wetlands. The information on the daily activity and abundance of different animal assemblages is urgently needed because it is a key fishing cat habitat. The goal of the current study is to keep track of the different mammalian species that live in these wetlands. The study also aims to comprehend the temporal relationships between the main animal fauna of the Krishna estuary delta and anthropogenic stress.

MATERIALS AND METHODS

Study area

The Krishna wildlife sanctuary (KWLS) is a wetland mangrove habitat located in the Krishna and Guntur districts in the Andhra Pradesh state, India. This vast mangrove stretch in the coastal plains covers the islands and mainland of the Krishna delta lying between 15°42′N and 15°55′N latitude and 80°42′E and 81°01′E longitude (Figure 1). The total area of the KWLS is 194.81 km^2, which encompasses nearly 50 km^2 of pristine mangrove regions. However, a recent study showed an increasing trend in the extent of mangrove forest in this region (Prasad et al. 2017). The KWLS includes seven reserve forest zones, among which three are in the Krishna district and four are in the Guntur district (Prasad et al. 2017). The KWLS is the home for many threatened species like fishing cat (*Prionailurus viverrinus*), smooth-coated otter (*Lutrogale perspicillata*), olive-ridley turtle (*Lepidochelys olivacea*), and various other mammals, birds, reptiles, fishes, and invertebrates. Mangrove flora like *Avicennia* and *Excoecaria* forms the dominant vegetation, followed by *Rhizophora* and *Bruguiera* (Ravishankar et al. 2004). The temperature ranges between 19°C–33°C, and the average annual precipitation is 1,100 mm (Nabi and Brahmaji 2012). Around 28 villages adjacent to the KWLS rely on mangroves for their livelihoods, such as timber logging, firewood collection, cattle grazing, and fishing. Pesticides from agricultural fields and industrial effluents harm this region's floral and faunal diversity (Van Roijen et al. 2009).

Data collection

We divided the entire 194.81 km^2 KWLS into 49 spatial grids of 4 km^2 (2 km × 2 km) in QGIS software version 3.16.0 (QGIS Development Team 2022) and deployed a camera trap from 1 April 2019 to 30 April 2019. Forty-nine transects of 1 km length were laid in all the grids and surveyed for the presence of indirect evidence like faecal matter, pugmarks, or any other signs left by the animals. The camera trap locations were identified based on the indirect evidence, and we ignored eight grids where data collection was not feasible and areas without any evidence showing the presence of animals. A pair of high-definition passive infrared trail cameras (model: Cuddeback C1) were installed in selected 41 grids at a minimum height of 30 cm from the ground

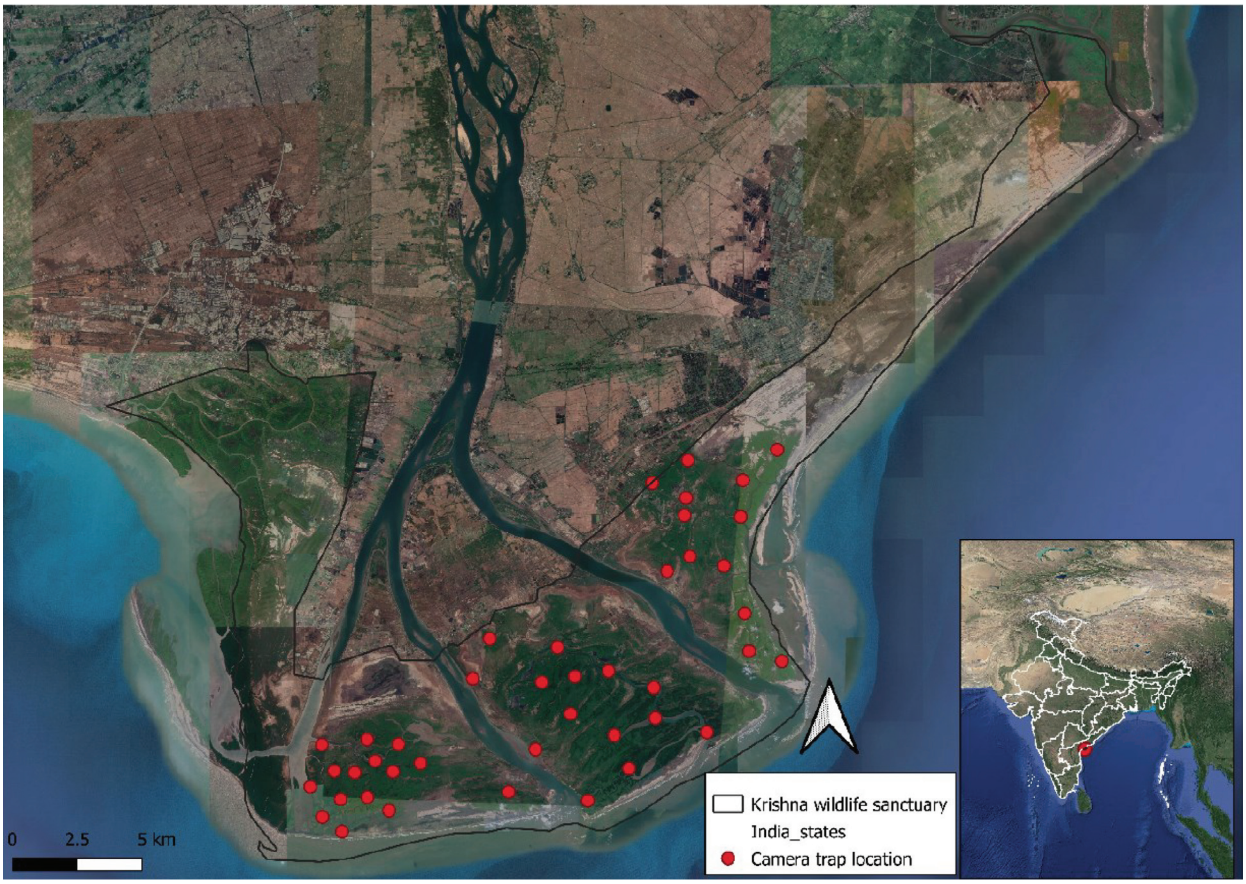

Figure 1. Map of the study area. Closed dots indicate camera-trap locations. Solid lines indicate the boundary of Krishna Wildlife Sanctuary.

level. Cameras were tied in trees or in poles, as most of the locations were banks of creeks and open spaces. Camera traps were monitored for consecutive 30 days totalling an effort of 1,230 trap days.

Data organization and relative abundance index

We ran 'camtrapR' version 2.0.3 (Niedballa et al. 2016) in R studio to organize and retrieve the camera trap data. We estimated the relative abundance index (RAI) following Kucera and Barrett (2011) and using the camera trap data. The index is the proportion of several single capture events (€) to the number of camera trap nights (c) scaled to hundred (RAI = (€/c) *100). We considered the multiple captures of the same species in an hour duration (≤ 1 hour) as a single capture event (Linkie and Ridout 2011; Shankar et al. 2020). Such independent events are recorded in a spreadsheet to estimate the abundance of data. The various species were identified following the descriptions given elsewhere (Prater 1971; Menon and Daniel 2003).

Activity pattern and overlap

We ran a nonparametric kernel density estimation model using the R package 'overlap 0.3.3' (Meredith and Ridout 2014) to visualize the active pattern. The overlap provides functions to estimate and compare activity parameters from sensor data to plot animal activity patterns. The model also approximates coefficients of overlap between two species activity and calculates bootstrap estimates of confidence intervals. The overlap coefficient is 'Δ', ranging from non-overlap (0) to complete overlap (1). We calculated the 95% confidence interval (CI) around the estimate of mean differences by bootstrapping 1,000 times. The percentile interval of the bootstrapped mean differences (> 25%, Δ_1 and < 75%, Δ_4) was taken as the 95% CI (Ridout and Linkie 2009; Linkie and Ridout 2011; Meredith and Ridout 2014). We prepared the species spatial distribution maps using the QGIS software.

RESULTS

Mammalian diversity

The initial indirect sign surveys indicated the presence of small to medium-sized carnivores like jackals, otters, and lesser felids. During camera trapping, we recorded a total of 1,116 individual captures belonging to the fishing cat (*Prionailurus viverrinus*), jungle cat (*Felis chaus*), golden jackal (*Canis aureus*), wild pig (*Sus scrofa*), rhesus macaque (*Macaca mulatta*), free-ranging dogs, birds, cattle, and humans. Of the total captures (Table 1), the golden jackal was recorded most often (452 times; 40.5%), followed by humans (268 times; 24.01%) and birds (231; 20.70%). The lesser felids like the jungle cat and fishing cat were recorded 27 (2.42%) and 68 (6.09%) times, respectively. We took the captures of humans, free-ranging dogs (22; 1.97%), and cattle (12; 1.08%) as the events of anthropogenic disturbances. The RAI of the golden jackal was 36.74, while that of the fishing cat (5.52) and the jungle cat (2.19) was comparatively lower. The other mammals like rodents (28), rhesus monkey (1), and the wild pig (7) were recorded at low frequency. The jungle cat (62.96%), fishing cat (80.88%) and jackal (78.54%) were observed to be predominantly nocturnal, while the other animals were diurnal.

Activity pattern and overlap

The fishing cat, jungle cat and jackal displayed a bimodal crepuscular activity pattern (Figure 2). The peak of human activity was observed towards the middle of the day. The free-ranging dogs showed a diurnal bimodal activity which may overlap with the lesser felids and jackals. The activity of birds and monkeys was apparent throughout the day with a peak around morning (9:00). The rodents seem to be mostly active towards early night hours with peak activity around 20:00. The activity peak of the fishing cat (19:00) differed from that of the jungle cat (6:00) but overlapped with the rodents. The second peak activity of the fishing cat ceased towards 6:00, where the jungle cat activity gained maximum momentum. The maximum activity of the jackal was in the morning hours, which corresponds to the jungle cat activity. Though a minor activity peak could be observed towards the dusk, it ceased before the activity peak of the fishing cat. The jackal activity pattern thus overlapped higher with that of the jungle cat (mean = 0.77, 95% CI (0.72–0.94)) than of the fishing cat (mean = 0.71, 95% CI (0.64–0.79)). The rodent activity also seems to overlap highly (mean = 0.77, 95% CI (0.62–0.92)) with the fishing cat activity. The fishing cat also showed temporal segregation with humans (mean = 0.31, 95% CI (0.22–0.41)) and free-ranging dogs (mean = 0.23, 95% CI (0.13–0.36)).

DISCUSSION

Human disturbances highly threaten wetlands, and their associated species face higher extinction risks, especially the faunal assemblages (Lomnicky et al. 2019). The KWLS is one of such habitats, and here we provide the first detailed outline of the diversity and activity of its faunal assemblage. The KWLS is reported as a pristine wetland habitat with a yearly increase of 3.5% of mangroves (Prasad et al. 2017). Our camera traps evidenced that human disturbance is high in this wetland. Recent studies in wetlands show that jackals exhibit bimodal activity with one of the two peaks in the afternoon (Shankar et al. 2020; Shameer et al. 2022). Jackals are highly adaptive mammals and are commonly recorded from wetlands (Khan et al. 2017). They exhibit phenotypic plasticity or altered coat patterns as an adaptation to human-dominated landscapes (Shameer et al. 2022). The RAI of the jackal is the highest in the KWLS, indicating that its population is larger than that of the other species in the reserve. Even if this is the case, jackals still face severe extinction threats, and their population is declining across the species distribution range (Negi 2014; Chawla et al. 2020).

The number of fishing cat photo captures was comparatively lower in the KWLS than in the nearby EGREE wetlands (Shankar et al. 2020). The activity pattern of the fishing cat also indicates an altered behaviour to avoid competition. The RAI of the jungle cat indicates that the jungle cat is the next abundant species in the

Table 1. Proportion of capture and the relative abundance index of species recorded in the study (*VU* = Vulnerable; *LC* = Least Concern; RAI = relative abundance index; *The proportion of day/night capture).

Species & Status	Total capture No (%)	Diurnal (%)*	Nocturnal (%)*	RAI
Fishing cat (*Prionailurus viverrinus*) *VU*	68 (6.09)	19.12	80.88	5.52
Jungle cat (*Felis chaus*) *LC*	27 (2.42)	37.04	62.96	2.19
Golden jackal (*Canis aureus*) *LC*	452 (40.50)	21.46	78.54	36.74
Humans (*Homo sapiens*)	268 (24.01)	100.00	0	21.78
Free-ranging dogs	22 (1.97)	100.00	0	1.78
Rhesus macaque (*Macaca mulatta*) *LC*	1 (0.09)	100.00	0	0.08
Wild pig (*Sus scrofa*) *LC*	7 (0.63)	100.00	0	0.56
Cattle	12 (1.08)	100.00	0	0.97
Rodents	28 (2.51)	0	100.00	2.27
Birds	231(20.70)	100.00	0	18.78

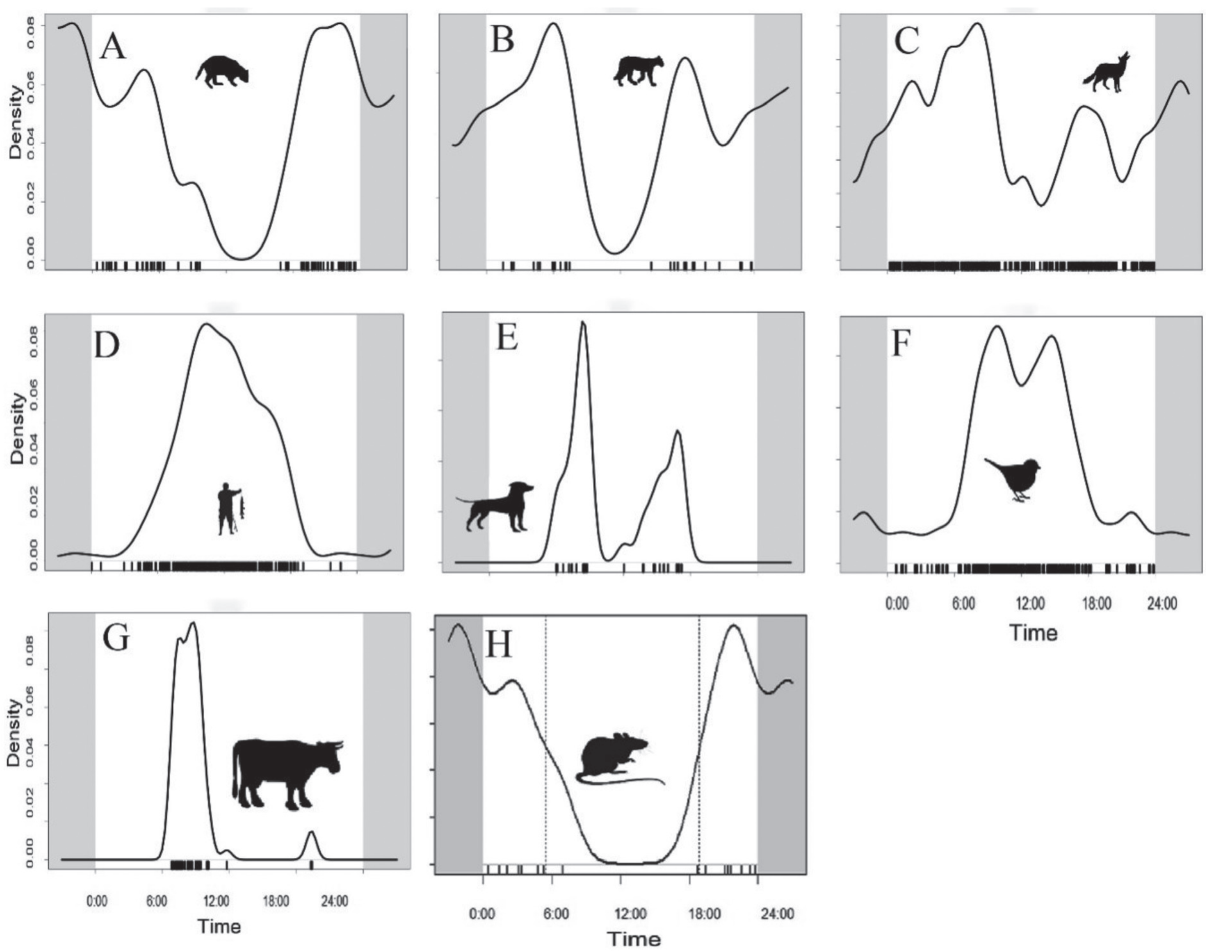

Figure 2. Temporal activity pattern of (A) fishing cat, (B) jungle cat, (C) jackal, (D) humans, (E) free-ranging dogs, (F) birds, (G) cattle, and (H) rodents from top left at Krishna Wildlife Sanctuary. The vertical dotted lines indicate the approximate sunrise and sunset time of the study location, and the grey extend areas indicate 3 hrs before and after the main 24-hr period.

KWLS following the fishing cat. The two species seem to adjust competition by altering their peak activity patterns. The jungle cat restricts its activity more in the dawn, while the peak acvtivity of the fishing cat is predominantly at early night hours. The dominant prey species of the smaller felids are mainly rodents (Mukherjee et al. 2004; Kamler et al. 2020). The capture results indicate the rodents (especially rats) are more active throughout the night. The nocturnal activity of rodents corresponds to that of predators, the jungle cat, and the fishing cat. It appears that the lesser felids share the resources by altering the peak activity to reduce competition. In a competitive environment, the dominant predator pushes the co-predator to adjust the activity pattern. Studies by Shameer et al. (2021) from the Periyar Tiger Reserve show that the jungle cat has a predominant activity pattern in the early night hours. Studies from EGREE showed that the fishing cat is crepuscular (Shankar et al. 2020).

The pattern of activity of the smaller cats depends on many factors like prey availability, predation, competition, threats, and environmental factors (Holt and Lawton 1994; Brook et al. 2012). The fishing cats face severe threats in human-dominated habitats and are exterminated by villagers for poultry picking (Chowdhury et al. 2015; Chakraborty et al. 2020). A significant overlap of activity of jackals with that of the fishing cat and the jungle cat suggests the absence of competition or resource partitioning due to increased niche breadth. Jackals seem to be a dominant species in the KWLS, and competition is a reason for a comparatively lower density of the fishing cat.

The KWLS witnessed a heavy loss of mangrove cover, i.e. approximately 13.24 km^2 of mangrove cover from 1970 to 1990 (Kubo et al. 2018). The subsequent efforts in understanding the importance of the crucial habitat loss led to the restoration of approximately 74.4 km^2 by mangrove planting (Prasad et al. 2017). This mangrove cover loss and other anthropogenic disturbances during the last decades might have played a role in shrinking the fishing cat population. We can postulate that the pristine mangrove habitat with minimum anthropogenic stress positively affects the fishing cat population. The study demonstrates a high level of human and free-ranging dog presence during the daytime. This can threaten small wild mammals and jackals, adapting them to be predominantly nocturnal. A negative temporal segregation (antagonistic interactions) was observed in the fishing cat with humans and free-ranging dogs. Human disturbances have shown negative influences on the fishing cat (Shankar et al. 2020). Likewise, free-ranging dogs are increasingly reported to be a significant concern for the survival of threatened species, especially in human-dominated landscapes (Young et al. 2011; Home et al. 2018).

CONCLUSIONS

Habitat restoration will be meaningful if the dependent fauna and the top carnivores are present in sufficient abundance. The research revealed the temporal occupancy of lesser felids in this ecosystem, and their activity pattern indicated sustainable resource sharing. The jackals can thrive in a highly disturbed habitat, but the lesser felids can locally go extinct in such environments. If avoided, the high human interference from this habitat can revamp the region as a significant conservation unit of threatened fishing cats. The restoration of mangroves will further provide more cover for these species and would create connectivity with the EGREE, ensuring gene flow between patchy meta-populations. Such an effort to restore the continuous stretch of mangroves may form a constant mangrove cover throughout the east coast. This continuity would ensure the connection between populations and the inbreeding or genetic drifts may be avoided, thereby strengthening a viable, healthy fishing cat population. The effort can be possible only by the involvement of local communities, by conducting awareness activities, and finding alternative livelihood options.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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