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Density estimation of the globally threatened fishing cat *Prionailurus viverrinus* through a participatory science approach in the Chilika lagoon, eastern India

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ABSTRACT: The fishing cat *Prionailurus viverrinus* is an Indo-Malayan wetland-dependent felid which is listed as Vulnerable on the IUCN Red List. Its main prey, fish, has low energetic demands and is abundant in productive aquatic habitats. This facilitates high piscivore densities and potentially alters expected scaling patterns that link population density to the body mass of small cats. With local community participation, we estimated the density of the fishing cat in Chilika, Asia's largest brackish water lagoon, located in the state of Odisha, eastern India, with community participation. The study was carried out in 2 phases in different habitats during 2021 and 2022: a homogeneous marshy habitat and its buffer (Northern Block), and a heterogeneous matrix of different land-use types (Southern Block). We deployed a total of 144 camera traps across 4380 trap nights. Using spatially explicit capture—recapture (SECR), we estimated mean (±SE) fishing cat density to be 0.69 ± 0.1 ind. km^{-2} in the Northern Block and 0.67 ± 0.33 ind. km^{-2} in the Southern Block. The population abundance estimates for the Northern and the Southern Blocks were 159 ± 23 and 185 ± 91 respectively. In the former, SECR modelling indicated an effect of anthropogenic habitat modification upon the species' home range extent. Our density estimates are amongst the highest reported for the species outside protected areas. The results imply that Chilika holds an abundant population of the fishing cat, the continued persistence of which requires mitigation of local and external threats to fish populations. Furthermore, our study, with its inclusive approach, sets a precedent for the use of camera trapping for obtaining robust density estimates of species with uniquely marked individuals in wetland habitats.

KEY WORDS: Fishing cat · Fish · Camera trap · Chilika · SECR · Participatory science · Semi-aquatic niche

1. INTRODUCTION

The acquisition and consumption of prey are central to a carnivore's ecology, making prey density a key determinant of carnivore density (Carbone & Gittleman 2002). Ectotherms such as fish have low energetic demands and can reach high levels of abundance in productive aquatic habitats. Therefore, they tend to facilitate the occurrence of high densities of predators with smaller individual home ranges (Pough 1980, Newsome et al. 2013). High salmon *Oncorhyncus* spp. abundance, for instance, is known

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to facilitate social tolerance among brown bears *Ursus arctos*, leading to higher concentrations of these fish-eating carnivores (Egbert & Stokes 1974, Hilderbrand et al. 1999). Similarly, high fish abundance in a seasonally flooded protected area in the Brazilian Pantanal was found to support the highest jaguar *Panthera onca* population densities (Eriksson et al. 2022). Giant otters *Pteronura brasiliensis* were also found in high densities in the Orinoco, which is known for its fish productivity (Garrote et al. 2021). Therefore, the rich concentration of fish could alter expected scaling patterns that link the population density of mammalian carnivores to their mass (Carbone & Gittleman 2002), resulting in high densities of piscivorous carnivores.

Freshwater ecosystems are hotspots of biodiversity since these support ~10% of all known species and around one-third of all vertebrates, despite occupying <1% of the Earth's surface (Strayer & Dudgeon 2010). However, freshwater ecosystems and biodiversity populations are facing declines, rendering one in 3 freshwater fish species and 42% of the 70 wetland-dependent mammals vulnerable to extinction (Balian et al. 2008, Tickner et al. 2020). Over 70% of all natural wetlands have been lost in the past century (Davidson 2014). This makes it difficult to test ecological hypotheses on such systems.

The fishing cat *Prionailurus viverrinus* is a medium-sized wild cat found in the Indo-Malayan region and is classified as Vulnerable in the IUCN Red List (Veron et al. 2008, Mukherjee et al. 2016). It thrives in warm climates with moderate annual precipitation and moderate seasonal variation in both temperature and precipitation. This species is primarily found in low-altitude wet landscapes, such as the emergent coastal floodplains and deltas of major river basins in South and Southeast Asia, including the Indus, Ganga, Brahmaputra, Mahanadi, Godavari, Krishna, Irrawaddy, Salween, Chao Phraya and Mekong, as well as in island countries like Sri Lanka and Java (Petersen et al. 2022). It has been reported from a number of countries in South and Southeast Asia, such as India, Sri Lanka, Bangladesh, Nepal, Pakistan, Thailand and Cambodia. The majority of fishing cat populations reside outside protected areas (Mukherjee et al. 2016). Therefore, conservation efforts that rely solely on protected areas are inadequate to ensure the long-term survival of fishing cat populations. Moreover, wetlands, which are crucial habitats for this species, are rapidly disappearing due to conversion to agriculture and intensive commercial aquaculture. Almost all the Asian river basins are heavily disturbed and fragmented, further threatening the persistence of these wetlands (Grill et al. 2019).

The fishing cat's diet is primarily composed of fish but also includes small mammals such as rodents, birds, reptiles, crustaceans and molluscs (Haque & Vijayan 1993, Cutter 2015, Mukherjee et al. 2016). This felid is adapted to hunting in a semi-aquatic niche and has evolved a unique hunting strategy to catch fish (Macdonald & Loveridge 2010, Ganguly & Adhya 2022). Morphologically, the fishing cat has adaptations such as water-resistant fur, half-sheathed claws and partially webbed feet. The latter 2 adaptations facilitate movement in muddy terrain and gripping of slippery prey such as fish (Kitchener 1991, Sunquist & Sunquist 2014, Hunter 2019). Additionally, the fishing cat has modified hunting techniques from its small cat lineage, such as a sit-and-wait strategy to ambush unsuspecting prey and actively flushing prey out from their refuges, to efficiently hunt fish in the water (Ganguly & Adhya 2022). Due to its unique ecology within the recently evolved and rapidly diversified Felidae family and its globally threatened status, the fishing cat is considered an evolutionarily distinct and globally endangered (EDGE) species, yet it remains understudied (Johnson et al. 2006, Tensen 2018).

There are 5 known density estimates for the fishing cat: 4 from South Asia and one from South East Asia. Only 2 of these estimates are considered methodologically robust. For example, Das et al. (2017) estimated a density of 44 individuals per 100 km^2 in the Sundarbans Biosphere Reserve, but the sampled area was small (25 km^2), which could have resulted in inflated estimates. Phosri et al. (2021) estimated a density of 18 individuals per 100 km^2 in a protected landscape and its outskirts (~336 km^2) in Thailand. However, fishing cat mortality due to retaliatory killings for perceived depredation of farmed fish and small livestock is widespread in Thailand (Cutter 2015, Phosri et al. 2021). Therefore, it is vital to obtain robust density estimates of the fishing cat and to model its spatial ecology in relation to environmental conditions, such as wetland habitat features, prey abundance and anthropogenic disturbance. This can allow for the poorly explained trends in variability in small cat population densities to be adequately captured (Anile & Devillard 2020). Non-pantherine felids have received relatively little scientific and conservation attention, with baseline estimates of density and abundance lacking for most (Mugerwa et al. 2020, Srivathsa et al. 2022). With respect to the study of fishing cat populations, it is vital to determine whether fishing cats reach higher densities in productive landscapes with high prey abundance and whether anthropogenic persecution results in population suppression. With this context in mind, we conducted a study of fishing cat ecology in Chilika, the largest brackish water lagoon in Asia, located along the eastern coast of India in the state of Odisha. This macrophyte-dominated ecosystem is known for its high diversity and productivity of fish, with over 300 species having been recorded (Mohanty & Panda 2020). Annually, more than 12 000 tonnes of fish are caught in this ecosystem, providing livelihoods to approximately 0.2 million fishing families (Mohanty et al. 2015, Raman et al. 2018). Additionally, this ecosystem serves as a food resource for several fish-eating mammals, including the fishing cat, smooth-coated otter *Lutrogale perspicillata*, the recently discovered Eurasian otter *Lutra lutra* and the Irrawaddy dolphin *Orcaella brevirostris* (Pattnaik & Kumar 2016, Adhya & Dey 2020). Moreover, we observed no evidence of sustained negative interactions between the fishing cat and the fishermen or local residents in this area, making it an appropriate study site to test the hypothesis that high fish abundance could result in high fishing cat densities.

In our previous research, we found that fishing cats were primarily present in the northeastern and southern parts of Chilika lagoon where marshes and swamps have been formed. They were not detected in the northwestern section of the lagoon, where the shoreline acked hydrophytic vegetation. We conducted the current study in the areas with established fishing cat presence (Adhya et al. 2023).

The primary objective of this study was to estimate the density of the fishing cat in Chilika. We hypothesized that fishing cat densities would be higher in Chilika relative to other parts of the species' range, owing to the high abundance of fish. We tested this hypothesis as the second objective of our study. Additionally, humans tend to modify certain parts of Chilika's marshland, concentrating fish resources in certain areas. For example, fishermen create small mud embankments in water channels to temporarily modify portions of marshy habitat, increasing fish catch. Other parts of the marshland have been converted into aquaculture ponds, which have high prey density. We hypothesized that these human-mediated resource concentration patches would positively influence the extent of the fishing cat's range by serving as sites of local resource abundance to which individuals are likely to be attracted, and we tested this hypothesis as the third objective of the study. Finally, we conducted density estimation in 2 phases in Chilika because the study area could be stratified into 2 distinctly different habitat types: a section with contiguous habitat and another with habitat patchiness. We expected to obtain a higher estimate in the former habitat type owing to habitat contiguity, as fragmentation is known to suppress carnivore populations (e.g. Murphy et al. 2017, Anile et al. 2019). Thus, the fourth objective of the study was to compare population density estimates from both study areas.

2. MATERIALS AND METHODS

2.1. Study site

Chilika (19.8450° N, 85.4788° E) is Asia's largest brackish water lagoon (1065 km^2) and India's first Ramsar site (Pattnaik & Kumar 2016). Located in the eastern state of Odisha, it is drained by river Mahanadi's tributaries and small rivulets in the north and northeast and meets the Bay of Bengal to the south. Freshwater from these sources dilutes the seawater coming into Chilika and creates hydrological regimes of varying depths and salinity. Therefore, the lagoon was divided into 4 ecological sectors: the freshwater-dominated northern sector, the brackish central sector, the more saline southern sector and the saline outer channel sector (Figs. 1 & 2). The lagoon is rich in macrophytes, is home to 317 fish species and is also

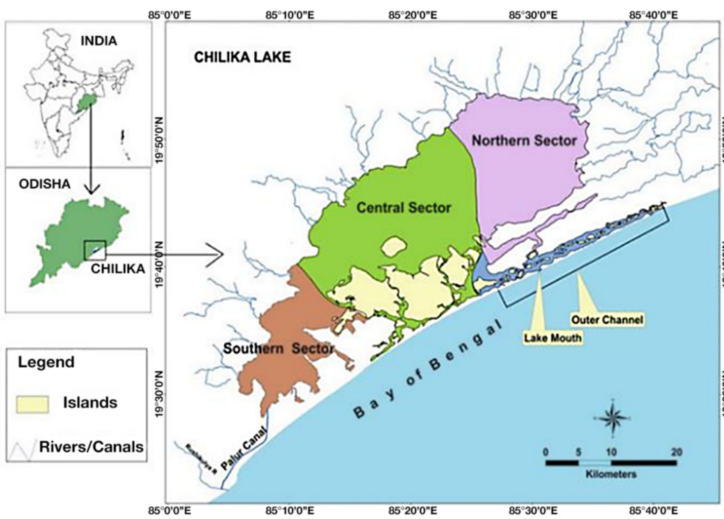

Fig. 1. Location of Chilika on the Indian eastern coast, showing the 4 ecological sectors: Northern Sector, Central Sector, Southern Sector and Outer Channel (Pattnaik & Kumar 2016)

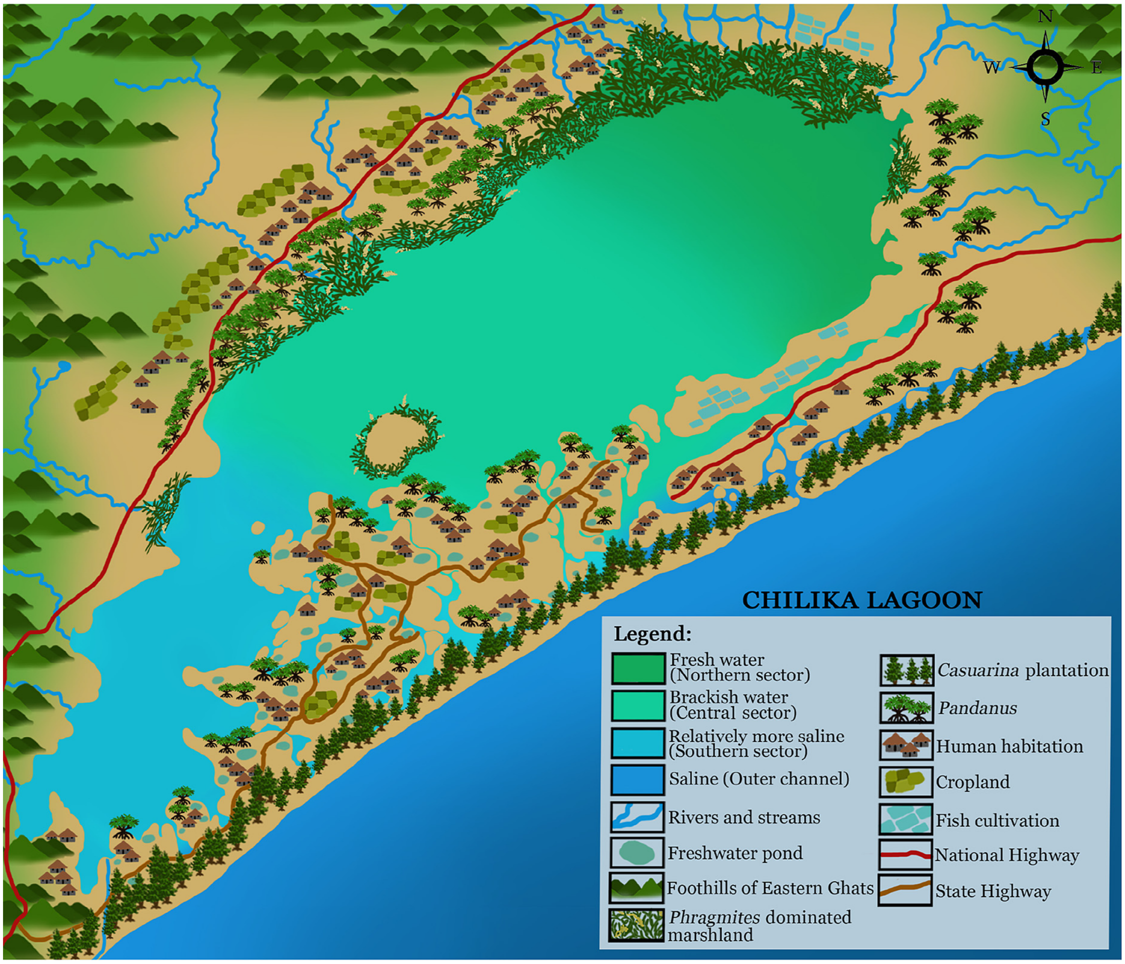

Fig. 2. Various land-use and land-cover types in and around Chilika lake in Odisha, eastern India. Principal land-use and land-cover types include stretches of open water in the lagoon and the Bay of Bengal, aquaculture ponds, *Phragmites*-dominated marshland and cropland

the largest wintering ground for birds in Asia (Pattnaik & Kumar 2016). Chilika is home to 4 species of piscivorous mammals: the fishing cat, smooth-coated otter, Eurasian otter and Irrawaddy dolphin. Some of the other mammals found in the terrestrial buffer of the lagoon include the golden jackal *Canis aureus*, Asian palm civet *Paradoxurus hermaphrodites*, small Indian civet *Viverricula indica*, striped hyena *Hyaena hyaena* and honey badger *Mellivora capensis* (Pattnaik & Kumar 2016, Adhya & Dey 2020, 2022).

We conducted our study in the (1) north and north-eastern section of Chilika (consisting of the northern sector and parts of the central sector), hereafter referred to as the Northern Block, and (2) coastal strip of islands in the south which encompasses the southern part of the central sector, hereafter referred to as the Southern Block. The vegetation in the Northern Block is more homogeneous than the Southern Block and is situated in the freshwater-dominated sections of the lagoon. It comprises a contiguous marshland (~115 km^2) dominated by *Phragmites karka*, a known refuge of the fishing cat (Adhya 2011), that is traversed by water channels. Regular fishing is conducted in these channels, and people often create mud embankments to concentrate fish in pockets of the marsh and catch them. Moreover, some portions of the marshland were also recently converted into aquaculture ponds to cultivate freshwater carps (Family Cyprinidae). There are no human settlements inside the marshland but it is heavily used for fishing. The Southern Block is composed of a multi-use matrix of different land-cover types including wetland complexes with mangrove-associated species such as *Pandanus* sp., cashew *Anacardium occidentale* plantations, aquaculture ponds, crop fields, human settlements and *Casuarina equisetifolia* forests.

2.2. Participatory data collection

In both the Northern and Southern Block, we held meetings with members of the rural community to make them aware of the density estimation exercise and convince them to become a part of the process by taking ownership of camera traps deployed in or near their villages. Local fishermen and farmers were trained in carrying out camera trapping surveys and recruited into the field survey and monitoring teams. Each team consisted of 2 local people: one student volunteer and one representative from the government departments (Chilika Wildlife Division/Chilika Development Authority). Optimal locations for camera trap placements were identified by the teams on the basis of the presence of fishing cat scat and tracks. Land—water edges consisting of riparian vegetation such as *Phragmites* or *Pandanus* lining shallow water channels or embankments of aquaculture ponds were found to have a relatively higher prevalence of fishing cat signs, in accordance with the findings of Adhya et al. (2023).

2.3. Study design for density estimation

We overlaid maps of both blocks with 1.5 × 1.5 km grids. It was felt that such a grid size would enable adequate exposure of an individual fishing cat to camera traps, taking into account published estimates of home range sizes of the species (Cutter 2015). The first part of the density estimation exercise was conducted in the Northern Block from 1 March to 15 April 2021. A total of 49 camera trap pairs were placed for 30 d, with the cameras in each pair stationed to capture both flanks of the fishing cat. The second session of the population estimation was conducted in the Southern Block from 26 March to 11 May. A total of 23 camera trap pairs were deployed here for 30 d each. This relatively dry period of the year allows for maximal access to the marshlands and the easy detection of fishing cat signs. All camera trap pairs were set at the land—water edge, i.e. in the mud flats within 10 m but maximally right next to the water channels or along embankments next to aquaculture ponds, where we found maximum evidence of foraging. Each camera was fixed at 30—45 cm from the ground and tied to a stick that was embedded into the mud. Cuddeback IR, Cuddeback White Flash and Browning IR camera traps were deployed, and the traps were set to capture pictures continuously for 24 h with no delay. Camera trap data was retrieved each day by the field team to prevent loss of data in case the traps were stolen. A map of camera trap sites is presented in Fig. 3.

2.4. Data analysis

Fishing cat individuals were distinguished on the basis of unique coat patterns (Phosri et al. 2021), which were found to be especially striking in the shoulder area, cheek, limbs and tail (Fig. 4). Individuals were identified using a 2-step process, the first of which involved 3 team members working separately on identifying individual fishing cats by segregating images of the right and left flanks into separate folders. Thereafter, the results were compared to arrive at a consensus regarding the identities assigned in the first stage. Individuals were also sexed if the images included the genital region.

Density estimation was conducted by using spatially explicit capture—recapture (SECR), as implemented in the package 'secr' v.4.4.5 of the R programming environment using a maximum likelihood approach (Efford 2022). In comparison to conventional mark—recapture approaches, SECR explicitly models density while accounting for individual heterogeneity in detection probabilities owing to the variation in the location of home ranges relative to the camera trapping array (Borchers & Efford 2008). Formally, the detection probability of each individual is modelled at each detector by a detection function, and it is the general form of this function and the parameters associated with it that are estimated. The principal detection parameters are the detection probability of the individual at the home range centre (denoted by '$g0$' or '$\lambda 0$') and the standard deviation of the detection function or the ranging scale parameter or the movement parameter (denoted by 'σ'), which is analogous to the home range radius of individuals, assuming a uniformly circular home range (Efford 2004, Borchers & Efford 2008). The spatial arrangement of home range centres of individuals is referred to as the 'state space' in SECR literature (Royle et al. 2014).

Spatio-temporal information regarding individual captures and the geographic coordinates of trap locations were created in the format mandated by 'secr' (Efford 2022). A habitat mask representing the underlying spatial distribution of home range centres was also prepared. In both blocks (Northern and Southern), a buffer of 10 km was drawn around the trap array, and areas deemed not to consist of fishing cat habitat were removed as per Phosri et al. (2021) in QGIS v.3.20.3 (QGIS Development Team 2021) in

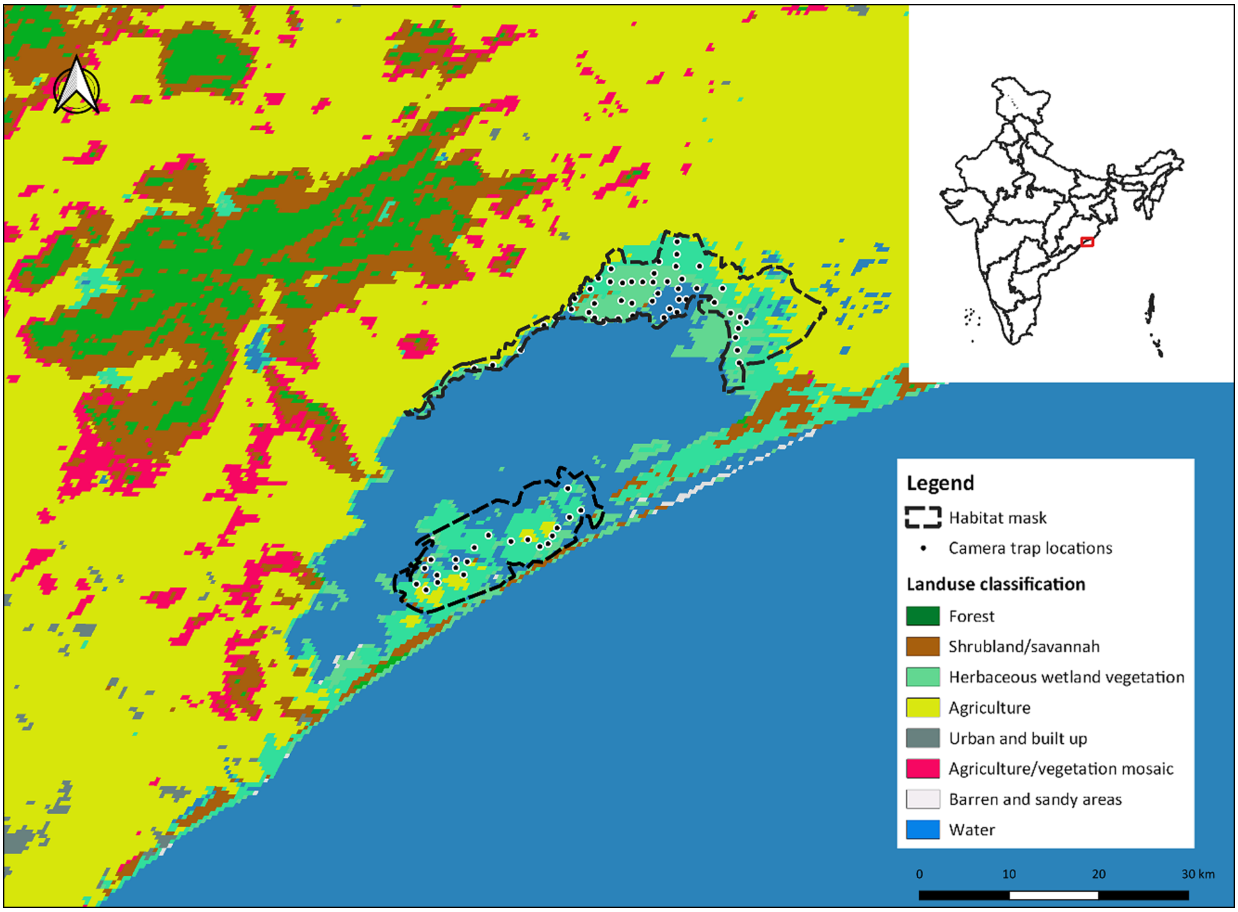

Fig. 3. Camera trap locations and habitat masks used for estimating fishing cat densities in Chilika lake in relation to land-use and land-cover types

order to generate the final habitat mask. Areas of non-habitat within the buffer consisted of stretches of open water forming the Chilika lake proper or the Bay of Bengal, large human settlements and zones of extensive paddy cultivation. The resultant habitat masks representing the underlying state space had an area of 230 km^2 for the Northern Block and 276 km^2 for the Southern Block. The 'esa.plot' function in R was used to check for positive bias in density estimates resulting from too small a trap buffer. The widely used half-normal detection function was incorporated with a set of constraints on g0 and σ. The SECR models developed were of the following broad types: (1) behavioural, (2) sex-specific and (3) habitat-based.

In the Northern Block, 4 types of behavioural effects on g0 were examined: (1) a general 'persistent' behavioural response expressed across all sampling occasions following initial detection (g0~b), (2) a trap-specific persistent behavioural response expressed across all sampling occasions following initial detection (g0~bk), (3) a Markovian behavioural response, manifested in the sampling occasion immediately after detection (g0~B) and (4) a trap-specific Markovian behavioural response (g0~Bk). In addition, it was hypothesized that the larger home ranges of male fishing cats (Cutter 2015), as in other felids (Figueira Machado et al. 2017, Ray-Brambach et al. 2018), would affect detection parameters. Sex-specific effects on g0 and σ were incorporated using hybrid mixture models, which allowed for the commonplace inability to unambiguously assign sex to all detected individuals (Efford 2022, Samarasinghe et al. 2022). We also tested the effect of sites of human-mediated resource concentration (HMRC) on g0 and σ.

A total of 18 models were formulated for the Northern Block using additive effects, with no more than 2 effects being incorporated per model in order to prevent overfitting. In the Southern Block, only the behavioural models were tested, as there was little habitat heterogeneity across camera trap locations.

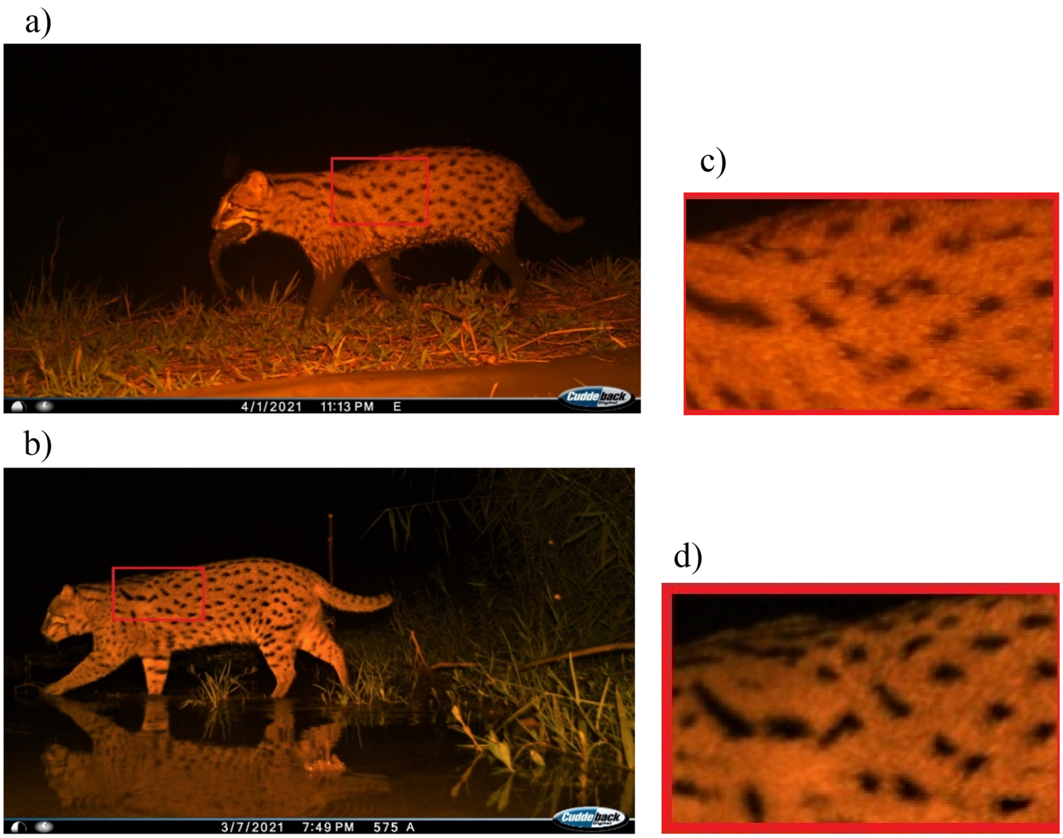

Fig. 4. (a,b) Example of 2 separate images used to distinguish individual fishing cats using their unique pelage patterns. (c,d) Portion of the images in (a) and (b) within the red box used for identification

Furthermore, given the small number of individuals (6 out of 30) whose sex could be unambiguously determined, we did not include sex as a parameter in the analytical framework for the Southern Block. Parameter estimates were obtained by the maximization of the unconditional likelihood in 'secr'. Model testing was carried out in 'secr' using Akaike's information criterion corrected for small sample sizes (AIC_c) (Akaike 1973, Burnham & Anderson 2002). Model averaging was conducted to obtain estimates for density and the detection parameters.

3. RESULTS

In the Northern Block, 98 camera traps were functional across 2940 trap nights, yielding a total of 472 fishing cat images, from which 73 individuals could be identified. In the Southern Block, 48 camera traps that were operational across 1440 trap nights yielded 57 individual fishing cat captures, from which 30 individuals were obtained. The relative abundance index (RAI) of the Northern and Southern blocks was 16.05 and 3.95 respectively, where RAI = (number of independent fishing cat captures / number of trap nights) × 100.

Among the models run on g0 and σ in the Northern Block, only one was found to have non-negligible AIC_c weight (Table 1). This model incorporated the additive effects of sex and trap-specific behavioural response on g0 (g0~h2+bk) and the additive effects of sex and HMRC on the movement parameter σ (σ~h2+HMRC). Covariate effects on beta coefficients for this model are presented in Table 2. Only 4 models had a ΔAICc value less than 20, and all of these incorporated the effect of HMRC on σ and a trap-specific behavioural response on g0. Based on the most parsimonious model for the Northern Block, the effects of the modelled covariates on g0 and σ are presented in Table 2.

The confidence intervals for the beta coefficients corresponding to the respective modelled effects did not overlap 0 in any of the cases, adding to the validity of the model receiving the most support.

We estimated a density of 0.69 (0.51–0.92) fishing cats km^{-2} and an overall abundance (±SE) of 156 ± 23 individuals across 230 km^2 of the Northern Block. Furthermore, the sex ratio estimated by the hybrid

Table 1. Model selection process for fishing cats in the Northern Block. Model descriptions highlight the effects of various covariates on g0 and σ (see Section 2.4). All models were developed using the half-normal detection function and under the assumption of constant density across the state-space

Model description ('+' signifies additive effect)	Notation	No. of parameters	AICc	Delta AICc	AICc weight
g0: Trap-specific behavioural response+ sex σ: Sex+HMRC	D~1, g0~h2+bk, σ~h2+HMRC	8	2221.619	0	1
g0: Trap-specific behavioural response+ sex σ: HMRC	D~1, g0~h2+bk, σ~HMRC	7	2241.356	19.737	0
g0: Trap-specific behavioural response+HMRC σ: Sex+ HMRC	D~1, g0~h2+HMRC, σ~h2+HMRC	8	2250.715	29.096	0
g0: Trap-specific behavioural response+HMRC σ: HMRC	D~1, g0~h2+HMRC, σ~HMRC	7	2252.013	30.394	0
g0: Trap-specific behavioural response σ: HMRC	D~1, g0~bk, σ~HMRC	6	2252.346	30.727	0
g0: Trap-specific behavioural response σ: Constant	D~1, g0~bk, σ~1	5	2269.009	47.390	0
g0: Trap-specific behavioural response+HMRC σ: Sex	D~1, g0~bk+HMRC, σ~h2	7	2270.205	48.586	0
g0: Trap-specific behavioural response σ: Sex	D~1, g0~bk, σ~h2	6	2270.974	49.355	0
g0: Sex σ: HMRC	D~1, g0~h2, σ~HMRC	6	2341.125	119.506	0
g0: Trap-specific Markovian behavioural response σ: Constant	D~1, g0~Bk, σ~1	5	2391.705	170.086	0
g0: Markovian behavioural response σ: Constant	D~1, g0~B, σ~1	5	2425.959	204.340	0
g0: HMRC σ: Sex	D~1, g0~HMRC, σ~h2	6	2428.919	207.300	0
g0: HMRC σ: Constant	D~1, g0~HMRC, σ~1	5	2435.142	213.523	0
g0: Sex σ: Constant	D~1, g0~h2, σ~1	5	2435.790	214.171	0
g0: General behavioural response σ: Constant	D~1, g0~b, σ~1	5	2445.281	223.662	0
g0: Constant σ: Sex	D~1, g0~1, σ~h2	5	2454.101	232.482	0
g0: Constant σ: Constant	D~1, g0~1, σ~1	4	2459.002	237.383	0

Table 2. Effect of modelled covariates on the detection probability parameters (g0 and σ) for fishing cats in the Northern Block. The beta coefficient estimates are on the logit scale for parameter g0 and on the log scale for parameter σ. The term bk=TRUE represents a site-level learned response, and HMRC=1 represents those habitats where human-mediated resource concentration was observed

Parameter	$\beta_{intercept}$ (SE)	β_{h2M} (SE)	$\beta_{bk=TRUE}$ (SE)	$\beta_{HMRC=1}$ (SE)
g0	−3.21 (0.33)	−1.46 (0.26)	1.98 (0.26)	–
σ	6.33 (0.11)	0.71 (0.13)	–	0.68 (0.09)

mixture model was found to be male-biased, with 1.54 males for every female. The coefficient of variation (CV) for the density estimate was found to be 14.49 ± 0.1% (for an estimated density of 0.69 km^{-1}).

In the Southern Block, only the model accounting for a trap-specific 'persistent' behavioural response on g0 (g0~bk) was found to have non-zero AICc weight (Table 3). The 3 best-supported models all accounted for behavioural effects. The results of the model selection process are presented in Table 2. The density was estimated to be 0.67 ± 0.33 (0.27–1.69) km^{-2}, and a CV of 49.25%. A total of 185 ± 91 individuals were estimated to occur over the 276 km^2 of the Southern Block of the study area. An increase in g0

Table 3. Outcome of the model selection process for fishing cats in the Southern Block. All models were constructed under the assumption of constant density across the state space and with a half-normal detection function

Model description	Notation	No. of parameters	AICc	Delta AICc	AICc weight
g0: Trap-specific persistent behavioural response σ: Constant	D~1, g0~bk, σ~1	4	732.080	0	1
g0: Trap-specific Markovian behavioural response σ: Constant	D~1, g0~Bk, σ~1	4	763.191	31.111	0
g0: Markovian behavioural response σ: Constant	D~1, g0~B, σ~1	4	774.625	42.545	0
g0: Constant σ: Constant	D~1, g0~1, σ~1	3	783.507	51.427	0
g0: General persistent behavioural response σ: Constant	D~1, g0~b, σ~1	4	786.173	54.093	0

Table 4. Effect of modelled covariates on fishing cat detection probability parameters in the Southern Block. Note that the β-coefficient estimates are on the logit scale for parameter g0 and on the log scale for parameter σ. bk=TRUE represents a site-level learned response

Parameter	$\beta_{intercept}$	$\beta_{bk=TRUE}$ (SE)
g0	−5.66 (0.65)	3.94 (0.64)
σ	7.61 (0.29)	–

was estimated to occur in the immediate aftermath of trap-specific detection ($\beta_{g0bk=TRUE}$ = 3.94, 95% CI = 2.68−5.19). The estimated values of g0 prior to detection and immediately afterwards were 0.0035 and 0.15 respectively. Covariate effects on beta coefficients for this model are presented in Table 4.

It was found that a buffer width of 10 km around the camera trap array eliminated bias in density estimates (Fig. 5).

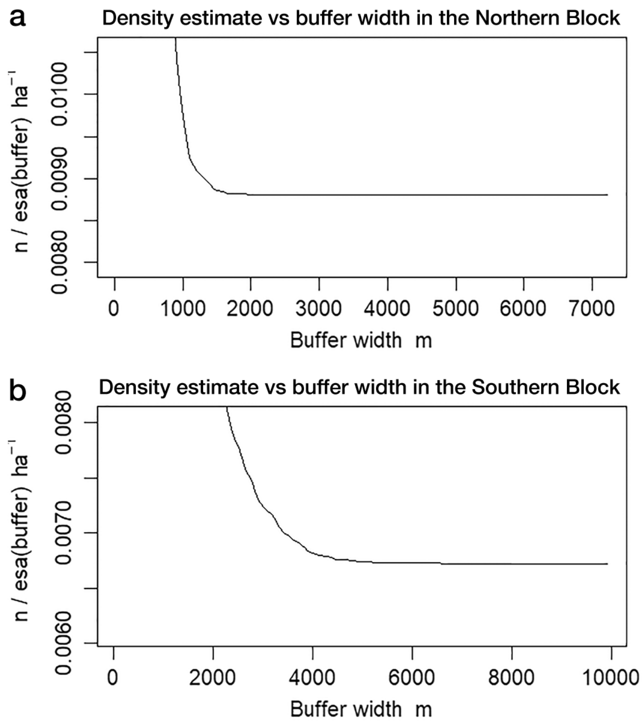

Fig. 5. Variation in fishing cat density estimate with increasing buffer width in the (a) Northern and (b) Southern blocks. Increasing the width of the buffer used for delineating the habitat mask typically results in an increase in the estimated density, up to a point. The buffer width should be greater than the minimum value that results in the density estimate forming an asymptote. Our selection of 10 km as the buffer width eliminates bias in density estimation. 'esa(buffer) ha^{-1}' refers to the effective sampling area as incorporated by the buffer surrounding the camera trap locations

4. DISCUSSION

The objectives of our study revolved around estimating the density of fishing cats in the productive wet landscape of Chilika lagoon and the examination of the effect of fine-scale habitat features on the movement of individual fishing cats. We found that the Chilika lake landscape had a high-density fishing cat population. The Northern Block, which consisted of contiguous marshy habitat, yielded an estimate of 0.69 ind. km^{-2}, while the Southern Block, comprising a mixture of land-use types with patchy wetland habitat, had an estimate of 0.67 ind. km^{-2}. These estimates are the highest reported for the species to date and more than twice what is predicted for carnivores of similar body mass by Carbone & Gittleman (2002). Chilika has a rich abundance and diversity of fish (Mohanty et al. 2015), which sustains a high density of fishing cats.

The CV associated with the Northern Block estimate, at 14.49%, is among the lowest reported in studies of fishing cats and falls below the 20% threshold suggested by Pollock et al. (1990) for population monitoring. As hypothesized, we also found a strong positive effect of camera trap sites with fish concentrations, referred to here as HMRC patches, on the ranging behaviour of fishing cats in the Northern Block. Resource patches were likely serving as attractants for fishing cat individuals, with individuals having a higher home range radius in the vicinity of anthropogenic habitat modifications. Fishing cats may be preferentially visiting such locations due to increased chances of catching their primary prey. Prey distribution and catchability are amongst the principal factors influencing carnivore habitat selection (e.g. Palomares et al. 2001, Davidson et al. 2012), and fishing cats have been known to extensively visit aquacultural ponds and other anthropogenic sources of fish concentration (Adhya 2011, Mukherjee et al. 2012).

However, we caution against the idea that increasing aquaculture ponds would be beneficial for the fishing cat. In landscapes with extensive aquaculture and minimal availability of natural fish, fishing cats could be killed in retaliation for fish predation in cultured ponds (Adhya 2011). Furthermore, HMRC sites did not significantly influence g0, implying that many of the hypothesized home ranges did not have such resource concentration sites. More broadly, the underlying orientation of home ranges may facilitate overlap by influencing the range parameter 'σ' but not 'g0' as much relative to sex-specific and behavioural effects.

In the Northern Block, males exhibited a lower probability of detection at the centre of their home ranges and a greater value of the movement parameter (σ). It is widely recognized that male felids, across various body sizes, have larger home ranges than females (Avenant & Nel 1998, Dillon & Kelly 2008), which can be reflected in sex-specific differences in detection probabilities and associated parameters, including for fishing cats (Phosri et al. 2021). In both blocks, the behavioural response exhibited by fishing cats was trap-specific, indicating that the same level of response was not observed at all traps and that the behavioural effect was persistent across all sampling occasions after the initial detection. The positive nature of the behavioural response suggests the prevalence of patch-focused foraging, possibly highlighting the significance of fish as their primary prey. Similar findings were reported in Thailand, where a persistence trap-specific behavioural response with an increase in g0 was observed (Phosri et al. 2021). Moreover, individual fishing cats were observed to repeatedly visit multiple camera trap stations, with several captures occurring over brief periods of time.

Our findings thus underscore the importance of linking the detection probability parameters used in mark–recapture methods with meaningful environmental variables based on species ecology, as these parameters are related to underlying individual space use (Royle et al. 2014).

In contrast to our initial hypotheses, we found similar density estimates for the Northern and Southern Blocks, despite their differences in habitat structure. The unexpected similarity in density estimates suggests that fishing cats may be able to adapt to patchy refuge patches as long as prey is abundant and rates of persecution remain low. However, further investigation is recommended to study the impact of habitat fragmentation on fishing cat space use at multiple scales, using a combination of radio-collaring and camera trap methods.

With respect to threats to the fishing cat, the Chilika landscape is not as heavily impacted by road infrastructure as is the case in many other parts of the species' range. Roadkill is a significant source of fishing cat mortality in fragmented landscapes (Ganguly 2020). Furthermore, if natural fish populations are scarce, fishing cats may rely more on pisciculture ponds, which could potentially expose them to negative human interactions. Such interactions have been reported from many regions across the species' global distribution range (Mukherjee et al. 2012, Cutter 2015).

Few density estimates are available for the fishing cat across its range. Density estimates from a variety of sites in South and Southeast Asia ranged from 6.06–53 per 100 km^2 (Nair 2012, Malla 2016, Mishra 2016, Das et al. 2017, Phosri et al. 2021). However, the majority of these studies suffered from several drawbacks, such as very large CVs (e.g. Malla 2016) or the restriction of sampling to a very small portion of the suitable habitat (e.g. Das et al. 2017). We did not observe any visible or sustained negative interaction between fishing cats and local residents, which could be attributed to Chilika being more of a common property resource which is accessible to all but owned by none. Thus, perception of loss associated with the fishing cat's fish preying tendency may not be prominent in this landscape.

Population estimates that are robust, and an understanding of drivers of distribution and persistence are crucial for the effective conservation of threatened carnivores (Karanth et al. 2002, Ripple et al. 2014). Although freshwater wet landscapes are known to shape the fundamental niche of the fishing cat (Petersen et al. 2022), this scarce resource has become the world's most threatened due to socio-economic development driving habitat conversion. These threats are particularly high in developing Asian economies (Hettiarachchi et al. 2015, Darwall et al. 2018). The current development regime in Asian countries has further exacerbated threats to wetland habitats by treating them as 'wastelands' and promoting their conversion through policy changes (Mukherjee et al. 2012, Phosri et al. 2021). Such a policy is especially concerning for fishing cat conservation, as 80% of the felid's distribution overlaps with human-dominated landscapes (Petersen et al. 2022) where such conversion is likely to be rampant. Therefore, deriving density estimates over a range of modified landscapes and human uses and understanding landscape-level gene flow between populations will be critical for understanding important stepping-stone populations within a metapopulation structure. India contains almost 40% of the global fishing cat population, with the eastern coast probably retaining important clusters of functional habitat (Rana et al. 2022). Among these, Chilika appears to be a promising area given its expanse, fish abundance, relatively less intensive production landscapes, low levels of negative interactions between humans and fishing cats and a viable population of this threatened feline.

Although Chilika has a large population of fishing cats, the wetland habitat is under threat due to the growth of intensive aquaculture, especially shrimp farming, the proliferation of invasive species, pollution, sedimentation and recurrent marsh fires. The mitigation of threats such as the expansion of aquaculture requires holistic conservation measures involving the resuscitation of traditional resource management programmes and the implementation of laws aimed at curbing illegal shrimp farming (Mishra & Griffin 2010). We suggest that the population of fishing cats and other threatened species be monitored on a regular basis. The current study relied heavily upon the participation of the local community, which can serve as a focal point for the implementation of programmes aimed at monitoring fishing cats and other biodiversity and the mitigation of threats.

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